Federal Ministry of Education and Research

IDEAS INNOVATION PROSPERITY
The High-Tech Strategy for Germany

Electric Mobility – Rethinking the Car

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Preface

The move from conventional mobility to electric mobility with motors and batteries is revolutionising vehicles and, with them, the entire automotive industry. As a result, we need completely new ideas and technologies if we are to make electric mobility an attractive prospect. The programmes launched by Germany's Federal Ministry of Education and Research (BMBF) back in 2008 to award financial assistance for research and development and initial and continuing training in the field of electric mobility are a significant contribution to efforts to shape the changes and give them a solid basis. The core areas on which the programmes focus are batteries, energy efficiency and training in the form of academic education and vocational training (initial and continuing). A particularly important aspect is the need to closely dovetail the activities of academia and industry so that everyone – consumers included – can benefit from the good ideas yielded by research.

Internal combustion engines have been constantly fine-tuned in a process lasting a hundred years so it is bound to take more than a mere half-decade for electric mobility to be able to compete with them. The BMBF has provided the impetus for many promising developments over the past five years but rethinking the car will not happen overnight. The research and development required will take quite some time yet.

The success achieved in recent years has been encouraging and points to greater things to come and we are certain all the hard work will pay off. Why? Partly because electric vehicles (EVs) are clean, quiet, effective mobility providers and a bridge to new mobility strategies for a future in which the focus will not be solely on the car. But also because they present an opportunity for Germany's automotive industry to maintain pole position on the global market.

It will, after all, be the market that decides which technologies are successful in the medium and long term. All the BMBF can do is help lay the foundations for an automotive future that benefits the environment and the economy.

Aiming to make electric mobility a common feature of our roads. (Robert Bosch GmbH)

This brochure outlines the challenges posed by electric mobility. It also presents selected research projects as an insight into the wide range of solutions being developed in close cooperation at German universities, research establishments and in industry.

Contents

	Page
Introduction	2
Strategy and activities of the BMBF	8
Batteries – no electricity, no electric mobility	10
The lithium-ion battery	14
Alliance for the Battery of the Future (LIB2015)	16
Pooling expertise	18
Manufacturing tomorrow's batteries in Germany	19
Spotlight on: Fraunhofer System Research for Electromobility	20
Energy efficiency – How can we make EVs go further?	24
The electric motor	26
Efficient drivetrain technologies	28
Intelligent power electronics for energy management	30
Reliability	32
Lightweight construction	33
Comfort	34
Vehicle concepts	36
Spotlight on: The South-West Leading Edge Cluster	38
Training for electric mobility – technology powered by people	40
National Education Conference	41
Driving the next generation of research talent	42
Experiment kits	44
Electric car racing	44
Electric mobility up close	45
Spotlight on: e performance	46
Summary	48
Further information	52

Introduction

One only needs to take a quick look at the headlines in Germany to see electric mobility is a hotly debated issue. Hopes and expectations abound as to what it can offer consumers and the opportunities it presents for German industry. But there are still major scientific, technical and design challenges to be overcome before EVs can really take the market by storm. Current solutions do not yet provide the large range, acceptable cost, rapid charging and long battery life that customers want. Infrastructure availability is also an issue.

In response, the BMBF is concentrating on ensuring initial and continuing training for bright minds, systematic accumulation of expertise and fruitful collaboration between academia and industry to gear up for future EV generations. However, despite all the hopeful developments of the past five years, one thing is quite clear: the technology race to optimise the EV is a marathon, not a sprint, so stamina is called for. But that is no surprise; after all, the struggle to find an EV solution that can satisfy future needs and the market has only just begun.

"We've always said it's a marathon. We're aware of that and we started it with the aim of finishing it successfully. You can't start complaining about stitch just 100 metres into the race."

Professor Henning Kagermann, Chairman of the National Platform for Electric Mobility (NPE) and President of acatech – the National Academy of Science and Engineering

Combustion engines – setting the pace for 100 years

For more than 100 years, the internal combustion engine defined the development of a technical feat that was a success story for engineering and for Germany. In fact, however, the car's rise to widespread popularity began with electric vehicles. In 1881, five years before the legendary Benz, Gustave Trouvé could be seen steering his electrically powered, low-noise tricycle through the streets of Paris. And in 1899 it was "La Jamais Contente" ("The Never Satisfied"), designed by Belgian engineer Camille Jenatzy, which became the first car in the world to go faster than 100 kilometres "per hour" and it did so by completely electrical means. In the United States, there were actually more EVs on the roads in 1900 than there were internal combustion engine vehicles. Ultimately, however, vehicles fuelled by petrol or diesel became the more popular choice. The reasons back then were similar to today – they had a larger range and battery technology could not evolve fast enough to keep up with the rising popularity of petroleum and the rapid proliferation of petrol stations.

The 1899 "La Jamais Contente" was ahead of its time with its fully electric drive system. (Museum Autovision)

It was the start of a revolution in individual mobility. Instead of "boneshakers" or horsepower of the oat-eating variety, people could harness much more horsepower to get from A to B – more quickly and more comfortably. And that gradually made the world "smaller". When cars became generally affordable after the Second World War, many people fulfilled their dream of four-wheeled freedom with a vehicle standing ready outside the front door to take them on short shopping sprees or even to the other end of Europe on holiday. Reliable, fast, safe, comfortable, good-looking mobility had arrived.

Driving the economy

Cars became a major economic driving force, especially in Germany. According to Germany's Federal Statistical Office, more than one fifth (in excess of 317 billion euros) of Germany's total industrial turnover in 2010 was generated by the automotive industry. Almost one in seven jobs are directly or indirectly linked to vehicle making, be it in planning, component supply, production or service provision. Around 1,000 companies work in the area of vehicle construction and they are not all big name car makers. There are also countless small and medium-sized enterprises (SMEs) whose components are key to making cars successful products. The work of the SMEs is vital to ensuring the high quality, reliability and safety of German cars, so highly valued by customers the world over. Indeed, German manufacturers sell the lion's share of their products (more than 60%) abroad. In 2011, the industry reported international sales revenues of approximately 223 billion euros.

"125 years ago the automobile was invented here in Germany and it's reinvented here every day too. There is no other sector with such rapid innovation and such a global outlook."

Matthias Wissman, President of the German Association of the Automotive Industry (VDA)

More than a third of all industrial expenditure on research and development takes place in the automotive sector. It is one of the top investors, making it one of the top drivers of innovation in Germany. And it will need to maintain that high level of commitment if it is to master the challenges ahead.

EVs are both an opportunity and a challenge for the German automotive industry.

Petroleum – an economic and an ecological challenge

Though the challenges for EVs are similar to those of 100 years ago, one crucial factor has changed completely: the availability of petroleum. Once the turbo drive of an entire industry, it is now a braking force. The Earth's petroleum reserves will not last forever. That is a fact that cannot be changed by tapping new deposits using complex, costly and environmentally controversial methods such as fracking from shale rock or oil sands. There is also a general consensus that prices for this coveted commodity are more likely to rise than fall, which means it will become considerably more expensive to drive a conventional vehicle.

But it is not just economic uncertainties that are forcing the automotive industry to rethink things. The new mentality has also been brought about by the ecological problems caused by the meteoric spread of cars powered by petroleum-based fuels across the globe. After all, 13% of worldwide carbon dioxide emissions are attributable to the transport sector and the figure looks likely to climb further. In Germany, it is approximately 20%, a whole two thirds of which comes from passenger cars.

EVs can help cut carbon emissions and protect fossil resources.

Number of cars continuing to rise

Policymakers have taken steps to counter these problems. The EU Commission, for instance, has issued stricter environmental targets for car makers. They are being asked to cut per kilometre carbon emissions from the 2007 level of 157 grams to 95 grams by 2020 – a reduction of 40%. Germany's Federal Government has also set its own climate protection targets, aimed at decreasing carbon emissions in Germany by a total of 40% (compared to the 1990 figure) by 2020, putting the onus on all stakeholders to take action.

"Cheap oil is a thing of the past. Even if there were enough easily extractable oil, vehicles have to move away from combusting liquid hydrocarbons. Traffic's contribution to climate risk is increasing."

Professor Andreas Knie, Managing Director of InnoZ (Innovation Centre for Mobility and Societal Change), Professor at Technische Universität Berlin

The number of cars, however, will continue to rise. That is particularly true in newly industrialising countries, especially China. Estimates suggest that 50% more passenger cars will be sold worldwide in 2020 than today. With regard to the EU, studies claim people will travel roughly 30% more kilometres than now in 2030 and that 75% of that will still be by car.

These are the challenges (stricter climate protection requirements combined with growing demand for cars and scarcer resources) that the German automotive industry will have to tackle if it is to continue to be Germany's main export engine. But they also offer our automotive industry a prime opportunity.

What makes EVs appealing?

True, cars that run on natural gas or organic fuel can help cut emissions too. But it is the excellent energy efficiency and good controllability that make electric motors particularly appealing. Their efficiency rating is higher than 90%, compared with approximately 35% for internal combustion engines. In other words, 90% of the electrical power used can be converted into mechanical power and hence into driving force. Unlike with combustion engines, electric motors can run at full power from the very first revolution or "rev". Furthermore, electric motors are low-maintenance, versatile and exceptionally quiet. And they have another very special advantage too: braking energy can be fed back into the vehicle's energy supply whereas it just dissipates as heat in conventional vehicles.

EVs are efficient, quiet and fast with it.

When run on electricity from renewable sources, electric motors are a particularly environmentally friendly option as they help reduce carbon emissions both at the local and the global level. According to "Fraunhofer System Research", studies show that supplying the required electrical energy will not be an issue. They claim it will take less than a 5% rise in electricity supply to operate 15% of vehicles electrically. They also point out that, once there are one or two million EVs on the roads, the battery charging process will have to be coordinated to prevent evening load peaks and overloading of local transformers as well as to avoid new peak load power stations having to be built.

Electric mobility is more than just electric vehicles

More and more people are moving to urban regions, only to be greeted by permanent traffic congestion, inadequate parking and a radical intensification of exposure to air pollution and noise. These problems will not be solved, especially not in large urban areas, simply by switching to electric or hybrid vehicles. New mobility strategies are needed. EVs will be integrated into a good

> *"Electric cars can only make a real contribution to protecting the climate if they're charged with renewable energy that would otherwise not have been used. In that respect, the emergence of electric mobility can only be considered a positive trend if it is part of the energy revolution that aims to establish a renewable electricity system."*
>
> *Dr Karl-Otto Schallaböck, Wuppertal Institute for Climate, Environment and Energy, Project Manager for research activities supporting work undertaken as part of the BMBF's "Key technologies for electric mobility" (STROM) funding programme*

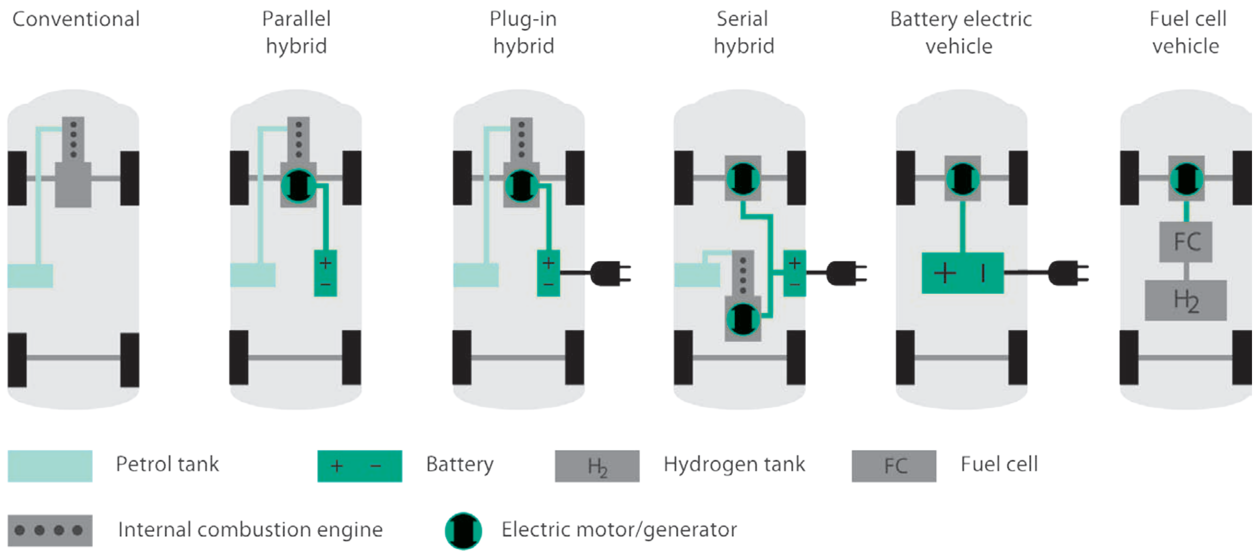
local public transport structure and there will be a wide selection of electrically powered vehicles. They will include two-wheeled vehicles and commercial vehicles such as waste collection lorries or vans for city deliveries. The principle of borrowing instead of owning, which is already making car sharing clubs popular in German cities, may well become even more widespread. EVs would be a good way of meeting that need and they would also be suitable for corporate fleets, for example. The fact is that cars are actually only used for an average of two hours per day. Most of the time, they are idle. Range is often not a problem either. According to a study by the Institute for Transport Studies at the Karlsruhe Institute of Technology , around 80% of passenger cars in Germany do not travel more than 60 kilometres per day anyway.

Nonetheless, many people will continue to see the car as a status symbol and there will still be a need for individual mobility. On top of that, people are accustomed to a certain level of comfort and safety, which new EVs must at least equal if they are to conquer the market.

EVs are part of tomorrow's multi-faceted mobility system.

National and international development

Despite the technological issues yet to be overcome, car makers and governments around the globe are putting their money on electric mobility. In a wide-ranging programme, the US is providing 2.4 billion dollars for EV development. China plans to have five million EVs on its roads by 2020 and France and Japan have already launched their first completely battery-operated EVs. So the technological race to create the best EV has long since started and it offers tremendous opportunities for Germany.



Various electric drivetrains already exist. This diagram shows how they compare to conventional drivetrain systems .(Fraunhofer IAO)

In its 2009 National Development Plan for Electric Mobility, the Federal Government set out its objective to make Germany a leading provider of electric mobility. Since 2010, a prestigious group of experts from academia, industry, trade unions, environmental organisations and other interest groups from society has been pursuing that goal, at the invitation of Chancellor Merkel, in the National Platform for Electric Mobility (NPE). Their in-depth consultations serve as the basis for an electric mobility roadmap as well as proposals for concrete action.

“Manufacturers in other countries already have production models on the market. However, the very high prices indicate they haven’t found the right approach yet either to be able to offer EVs at competitive prices. But that’s the key, that’s where the true innovation lies. German manufacturers are seeking to deliver perfect, safe quality but they don’t want EVs to be the ruin of their businesses. The current strategy certainly makes sense.”

Professor Markus Lienkamp, Head of Institute of Automotive Technology and co-head of the Science Center for Electromobility at the Technical University of Munich

The NPE’s recommendations have been incorporated into the government’s electric mobility programme. The main point the programme makes is that the focus in the coming years needs to be on promoting research and development. Accordingly, the four ministries responsible for economics, transport, the environment and education and research have coordinated their research programmes with the aim of translating engineers’ ideas into marketable innovations as effectively and swiftly as possible. After all, ultimately it will be buyers who decide who wins the race for the best EV.

Electric mobility is gaining significance across the globe.

“Germany has to play a leading role in e-mobility because it is definitely coming. And jobs and prosperity in Germany depend on it. So, though we mustn’t just start doing things for the sake of it, we should take intelligent steps, early on, to secure progress in this area. That’s why it was certainly right to set up the NPE. After all, the intention behind it is not only to build a lead market but also to continue to develop Germany into a leading provider.”

Professor Henning Kagermann, Chairman of the National Platform for Electric Mobility (NPE) and President of acatech – the National Academy of Science and Engineering

Solid foundations

Germany is extremely well placed to become a world leader in electric mobility. It has a strong tradition of car and component making – two sectors that have demonstrated an impressive capacity for constant innovation and market leadership for more than a century. But Germany also has a diverse landscape of universities and non-university research establishments, giving it solid foundations in the realms of science and research too.

The BMBF has also signposted the way forward, both in terms of structure and issues to be dealt with, in the form of its “high-tech strategy”. It places the research focus on the five global challenges of our times, i.e. climate/energy, health/nutrition, mobility, security and communication.

Germany’s excellence in engineering, particularly mechanical and electrical engineering, provides a further springboard for electric mobility. Interdisciplinary fields, such as mechatronics, have also been emerging for some years now. We also have a good basis in IT and the natural sciences but we lag way behind when it comes to electrochemistry, which is, however, crucial to battery research.

A number of segments are already working around the clock on electric mobility research and the first vehicles are already on the market. (RWE)

Outside the academic segment, the sound vocational training provided by Germany's "dual system" (a combination of on the job and school-based training) plays a significant part in equipping the industry with an excellently trained technical workforce. But there is still much to do in the area of training and research if we are to remain successful and master the huge technological challenges posed by electric mobility. That is precisely the purpose of the BMBF's electric mobility strategy, which is described in the following section.

EVs are a technological challenge but one that Germany can master.

Strategy and activities of the BMBF

Turning Germany into a lead provider of electric mobility is an ambitious objective. Indeed, for the German automotive industry, electric mobility is nothing less than a complete shift in paradigm. It will need to continue developing vehicles that are reliable and offer high quality, making them attractive and competitive, but it will have to do so using entirely new technology.

Customers want optimum safety and an optimum driving experience. On top of that, the electric mobility "package" will have to include outstanding service solutions and a charging infrastructure with user-friendly billing methods. Electric mobility is a huge technical challenge cross-cutting a variety of disciplines and sectors. The BMBF has therefore decided to focus its strategy on interdisciplinary research into new technologies, particularly energy storage and more economical use of energy. In addition, initial and continuing training are vital since Germany can only become a leading electric mobility provider if it has well-trained professionals.

Strategic focus on batteries and energy efficiency – we have to completely rethink the car!

"I know from personal experience how long true innovations take to make it onto the market. Sadly, it's not rare for 15 to 20 years to pass before they go into line production. That in itself is reason enough for us in "Autoland" to rev things up with whole-vehicle designs, infrastructure system solutions and networked mobility systems tailored to electric mobility. They need to be sustainable, work in terms of engineering and cost efficiency and appeal to people's emotions as well as their ecological conscience!"

Professor Johann H. Tomforde, owner of the Competence & Design Center for Mobility Innovations and inventor of the SMART

The greatest technical challenge involved in electric mobility is the range that the new vehicles can cover. To ensure a good range, it will be essential to develop high power, extremely safe, long life batteries. But it takes more to create an EV than simply swapping the tank for a battery and the combustion engine for an electric motor. The entire car has to be rethought because the new form of energy supply and the different drivetrain require a different control system and totally new components to match. As a result, the entire automotive value chain will change.

"We won't really get anywhere if we just fit electric drivetrains in existing combustion engine vehicles. We have to go right back to the drawing board."

Professor Markus Lienkamp, Head of Institute of Automotive Technology and co-head of the Science Center for Electromobility at the Technical University of Munich

In particular, research now needs to focus more on the energy efficiency of the entire vehicle as a way of compensating for the limited amount of energy available. Lightweight construction is a must, as are components that work in perfect combination and intelligent energy management (for requirements such as interior air conditioning) that does not detract from comfort.

The energy distribution and data transfer between the vehicle's various components will have to be managed by electronic and software-based vehicle control systems, reflecting the general trend. Information and communications technology (ICT) will therefore play a key role in the car of the future too – not only inside the vehicle but also at the interface with the charging infrastructure and, consequently, the electricity grid. ICT will also feature strongly in new service models and transport solutions involving EVs, such as payment systems or automated traffic management based on the current traffic situation and battery status.

Today, the ability to innovate is crucial for growth and employment. But innovation can only bear fruit if technological developments can be combined with service and work processes to create added value. So new technologies, such as electric mobility, require innovation-seeking research in other areas, in parallel with technological research, to meet that need.

Strategic focus on initial and continuing training – technology powered by people

Highly motivated and qualified professionals are essential if electric mobility is to enjoy long-term success. As well as the new initial and continuing training programmes, especially those delivered at "inter-company vocational training centres", the research projects supported by the BMBF also help ensure excellence in training. One example is the "e performance" research project, in which a modular EV was developed, providing more than 70 young researchers from universities with input for their dissertations and theses.

As a direct result of the first National Education Conference for Electric Mobility, funded by the BMBF, we are seeking to work with universities to identify ways in which the various existing programmes can be consolidated and better dovetailed. Existing methods and structures, both in higher education and vocational training, need to be brought together so that the electric mobility challenge can be tackled with interdisciplinary solutions.

Electric mobility – an interdisciplinary task

Any attempt to rethink the car has to consider the entire value chain – from the raw materials to development, production, the various possible uses and, at the end of the road, recycling. All of these points are covered by the activities of the governmental departments involved, which now provide over 900 million euros of financial support to far more than 100 collaborative research projects. That money comes on top of the 500 million euros already spent up to 2011 as part of the Second Economic Stimulus Package. At over 480 million euros, the BMBF's share of that financial assistance is the largest.

In view of the interdisciplinary nature of electric mobility, the BMBF provides support for efforts to form research alliances. The aim is to improve cooperation between the fields of basic research and application, between academia and industry, thus reducing the time to market for brilliant new ideas. These alliances also enable the various fields, e.g. mechanical and plant engineering, chemistry, power electronics and IT, and companies themselves (from SMEs to car makers) to be better integrated. A major prerequisite for receiving financial assistance is that the companies have to put up at least 50% of the project costs. However, SMEs can access special grants to help them do this.

The following sections present selected projects as an example of the activities funded by the BMBF in its priority areas of batteries, energy efficiency and initial and continuing training.

Batteries – no electricity, no electric mobility

The battery supplies the energy that keeps an EV's heart beating. Battery performance is a make or break factor for EVs' user friendliness and for the success of electric mobility. Battery research therefore has a pivotal role in the BMBF's strategy.

The goal is to develop Germany into one of the leading centres of EV battery production technology while at the same time pushing ahead research for the next generation of batteries.

Batteries are a significant source of added value and, if we want to create that value in Germany, they need to be produced here too. To date, battery production in Germany has been minimal. In the consumer electronics segment (laptops, cameras and mobile phones, for instance), Asia is the world leader, which is why EV battery production has become established there too.

"The lion's share of the added value offered by EVs comes from batteries. Battery cell production is currently firmly in the hands of Asian industrialised and newly industrialising countries; German businesses play a minor role on the international market. It remains to be seen whether and when we can catch up and eliminate that competitive edge. In the medium to long term, Germany does have a good chance of tapping into this market through its already well-positioned chemical and materials research."

Professor Martin Wietschel, Deputy Head of the Competence Center for Energy Technology and Energy Systems (CCE) at the Fraunhofer ISI institute and member of the NPE

Germany has a very strong manufacturing tradition. Mechanical and plant engineering are cornerstones of the country's economy, as is the chemical industry. These capabilities mean we are well-placed to embark on drivetrain battery production. Only if we produce them here in Germany can we guarantee valuable synergies in conjunction with the advances being made in the plant and production sectors.

For many years, battery research tended to be neglected in Germany. Thanks to the funding schemes it introduced in 2008, the BMBF has managed to revive this important research and technology segment and create incentives to establish new research groups and university departments and to secure new generations of researchers.

The biggest problem with batteries is that their energy density is almost one hundred times lower than that of petrol. This factor restricts the travel range significantly and even the highly efficient electric motors cannot compensate for it.

"The energy density of batteries is one of the key parameters in electric mobility in that it still limits range and therefore has consequences for the design and potential uses of EVs. Although lightweight construction and specially tailored vehicle design can solve the limitation problem, energy densities must be much higher if EVs are to achieve ranges comparable to those of internal combustion engines. High-voltage batteries and the post-lithium-ion batteries (e.g. lithium-sulphur and metal air batteries) that will be developed in the future are expected to help ensure that electric mobility becomes a permanent fixture in transport systems in years and decades to come."

Dr Axel Thielmann, Deputy Head of the Competence Center for Emerging Technologies (CCT) at the Fraunhofer ISI institute and Project Manager LIB2015 Roadmapping

As a result, the EVs currently available on the market only have a range of somewhere between 100 and 150 kilometres.

Consequently, in addition to production technologies, cell chemistry is a research priority. The aim is to optimise good existing materials and develop new ones to enable more energy to be stored while keeping weight to a minimum. Another objective is to lengthen battery life and increase power density in order to speed up the charging process. The plan is to bring the battery life into line with the service life of the other vehicle

Analysis of raw materials for battery cell production (Li-Tec Battery GmbH) components by ensuring 3,000 to 5,000 charge cycles over ten to fifteen years. In addition, the batteries need to be safe not only during normal operation but also in the event of an accident. That poses quite a challenge, bearing in mind the high levels of energy, voltage and, in some cases, combustible chemicals. The battery management system, which manages the charge status in the battery system, therefore plays a crucial role.

Last but not least, there is the cost factor. At the moment, the battery accounts for around half of the overall vehicle cost. This figure has to be slashed; the initial target set is to have twice as much energy density at half the cost by 2015.

So far, interest has focused on lithium-ion batteries. In principle, their relatively high energy and power densities, coupled with high cycle stability, make them suitable for use in EVs. However, they need to be made larger and provide more energy. But there is a whole range of requirements involved in increasing the energy levels, primarily with regard to safety. Battery research in Germany, which is constantly picking up momentum, is concentrating on future generations of this battery technology and the development of new battery types such as lithium-sulphur or metal-air cells based on totally new cell chemistry. The following sections describe some of the BMBF research projects in this area.

Researchers create electrodes with new battery materials using the coating facility at the University of Münster battery research centre – Münster Electrochemical Energy Technology (MEET). (WWU/MEET)

The lithium-ion battery

A lithium-ion battery is a rechargeable, electrochemical energy storage unit, based on a battery cell. It is possible to combine several battery cells to form modules, which are then coordinated and controlled by the battery management system.

"Lithium-ion battery" is the generic term for various different battery types. They use different electrode materials but they are all based on the idea that lithium ions, dissolved in the electrolyte, migrate between the electrodes during charging and discharge.

The cell elements

Cathode

The cathode is the positive electrode (terminal). It is made of an aluminium foil, which is coated in different materials (known as "active materials") depending on the battery type. The active materials can be made, for example, of lithium metal oxides ($LiMeO_4$) or lithium metal phosphates ($LiMePO_4$).

Anode

The anode is the negative electrode. It is made of a copper foil, usually coated in graphite.

Electrolyte

The electrolyte is the substance in which the lithium ions are dissolved and migrate back and forth from the cathode to the anode. It is normally a liquid, organic solvent but it can also be made of (synthetic) polymer or ceramic material.

Separator

The separator is made of a porous material, often a plastic or fine ceramic material, which only allows the positive lithium ions to pass and blocks the electrons' path. By doing this, it separates the electrodes mechanically and electrically, thus preventing short circuiting.

How the cell works

Voltage is applied to the electrodes in order to charge the battery (Fig. 1). In the cathode, positive lithium ions and negative electrons break free from the lithium metal oxides. The electrons flow to the anode via the outer circuit. The lithium ions migrate through the electrolyte to the anode, where they become embedded in the gaps in the graphite layer (in a process known as "intercalation"). The lithium ions pick up the electron again and remain in the interlayer in the form of metal.

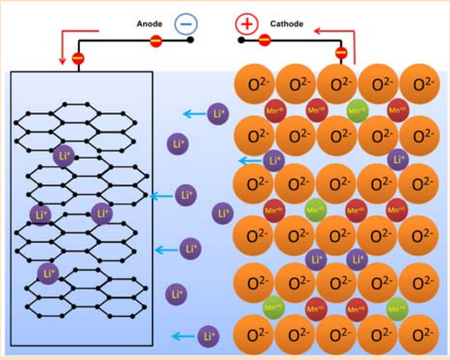


Fig. 1: Charging process for an $LiMnO_2$ battery; left: graphite anode, into which the lithium ions are inserted (or "intercalated", from the Latin "intercalare"); right: $LiMnO_2$ cathode, from which lithium ions migrate (Professor Marco Oetken and Martin Hasselman, Department of Chemistry, Freiburg University of Education)

During discharge (Fig. 2), a load is connected. The lithium releases the electron, dissolves and migrates back to the cathode in the form of an ion. There, it bonds with the metal oxide and an electron in the crystal structure of the lithium metal oxide.

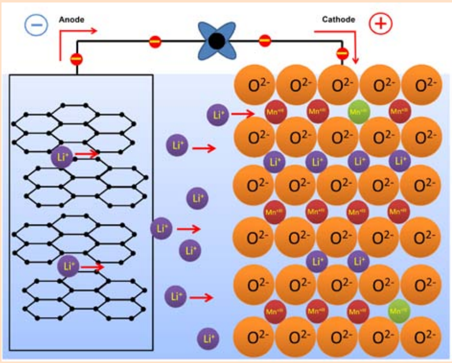
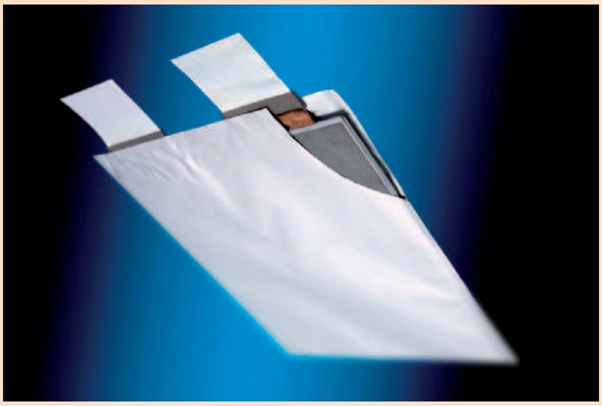


Fig. 2: Discharge process for an $LiMnO_2$ battery; left: graphite anode, from which lithium ions migrate; right: $LiMnO_2$ cathode, into which the lithium ions are intercalated (Professor Marco Oetken and Martin Hasselman, Department of Chemistry, Freiburg University of Education)



Inside of a high-power cell; the two electrodes can be seen at the top. (Fraunhofer ISIT)

Research aspects

Increasing energy density
Here, the aim is to store more ions in the electrodes while keeping volume and weight to a minimum. One way to do this is to use more or more absorbent active material, e.g. nanoparticles or nanocomposite materials. Another possibility would be to switch to materials that allow a higher voltage level (5 volts instead of the present level of, for example, 3.6 volts).

“A composite is a material composed of two or more joined materials. In battery production, an example would be electrodes made of a combination of silicon and carbon. If a material can absorb more lithium, the battery charge can be increased, thus increasing the amount of energy stored in the battery. Nanoparticles are particles no bigger than approximately 100 nm. They are particularly interesting in battery research as possible cathode and anode materials. Their surface is larger compared to their volume and they have short diffusion paths, making higher charge and discharge rates possible.”

Professor Martin Winter, Project Manager LIB2015 and Co-Head of Münster Electrochemical Energy Technology (MEET), University of Münster

Increasing power density
To achieve this, the ions in the various materials must be made more mobile so that they are transferred faster. This could be done, for example, by increasing the reactive surface area between the electrode and electrolyte.

Increasing battery life
This can be done by minimising the materials’ reactivity, thereby slowing down the ageing process. The cycle stability, i.e. the possible number of charge and discharge cycles, would also need to be increased.

Increasing safety
Attempts to improve safety cover a wide range of aspects. Crash safety, for instance, can be improved through new designs and more stable or more flexible materials. In the cell field, researchers are endeavouring to remove toxic, highly flammable and explosive chemicals from the equation. Flexible separators with a high melting point can prevent short circuiting, and reliable monitoring of temperature and charge status provides protection against overheating and overcharging.

Battery production
The first step is to mix the chemical components used to coat the electrode foils. The electrode sheets are then cut out of the film and dried. Next, the anode, separator and cathode are assembled in stacks, after which the cells can be wound, folded or stacked themselves. Then the cell stack is filled with the electrolyte and sealed. Finally, the battery is “formed”, i.e. charged for the first time, by hooking it up to a power source. Research is required on all of these production steps.

Alliance for the Battery of the Future (LIB2015)

Founded back in 2008, the Lithium-Ion Battery Alliance (LIB2015) now has some 60 partners from the academic and industrial spheres. With an industrial consortium comprising BASF, Bosch, Evonik, Li-Tec and Volkswagen at the helm, the aim is to develop future generations of high power, affordable lithium-ion batteries by 2015. With its mix of several joint industry projects, inter-institutional alliances and young researcher groups, the alliance covers all aspects of research and development on lithium-ion batteries.

LIB2015 Innovation Alliance

- Time frame: 2008 – 2015
- BMBF funding: approx. € 60 million
- Partners: approx. 60 companies, universities and research establishments

One of the alliance's activities is the development of new materials for the electrodes and electrolyte, with the aim of improving energy and power density plus safety. The work on electrodes is intended to increase their ability to absorb lithium. One strategy being pursued is to make the electrodes out of composite materials with nanoparticles.

Introducing nanostructures means the lithium ions can be transported through the material more quickly, resulting in faster charging and discharging. Another advantage is the higher mechanical flexibility of nanostructured electrodes and their ability to absorb more lithium, which increases the available energy. In addition, by using a combination of different nanoparticles, the properties of the electrode materials can be adjusted as required.

In the following, we present details of some of the research projects being carried out by the LIB2015 Innovation Alliance. For more information, please visit www.lib2015.de.

The **LIB-NANO** and **LiVe** projects are carrying out fundamental research work to determine which particle sizes and make-ups are suitable and how they interact with the electrolytes. A further aim is to prevent high reactivity as it speeds up the battery ageing process. One possible option is to use polymer electrolytes to avoid the risk of short circuiting and potential leakage of liquid electrolyte.

The **KoLiWin** project is looking at the properties of such electrolytes and how they interact with nanostructured electrodes. There is also a BMBF group of young researchers examining new types of gel polymer electrolytes, which offer exceptionally high conductivity and good mechanical stability.

The **HE-Lion** project, the largest and most comprehensive in the alliance, is also working on lithium-ion batteries with high energy densities (>300 Wh/kg). Other objectives are a high level of safety, long battery life and environmental friendliness.

One trend intended to boost the amount of stored energy is to raise voltage levels. The **LiFive** project is developing new materials for cathodes and electrolytes so that lithium-ion cells can be built with a voltage level of 5 volts instead of the present 3.6 volts. In addition, the team is devising models with which battery life can be predicted when the batteries are actually still in development.

As vehicle batteries become bigger, there will be new tasks for the battery management system. Where there are lots of cells interacting electrically, they need to be balanced out. The most important job for the battery management system is controlling the charge and discharge processes. The cells do not have any overcharge protection of their own so their charge status has to be monitored constantly. Another important aspect is thermal management. Depending on the ambient conditions, the cells have to be cooled or heated to optimise the electrical properties (which are very temperature-sensitive) and to slow down ageing. New battery management systems are being developed on the **BatMan** and **Li-Mobility** projects.

Utmost priority is being given to battery safety. The shift to systems with high quantities of energy entails significant risks, especially in terms of temperature and charge stability. The mandate of the **Li-Redox** project is to improve the cells' overcharge protection. The idea

A chemistry lab technician assembling a lithium-ion test battery inside a glove box. The battery will be used to examine various new cathode materials. (BASF)

is to add components to the electrolyte to enable it to absorb any excess charge and essentially carry it in the circuit so that it does not destroy the electrodes. And on the **SLIB** project the team is drawing up standardised methods and rules for testing battery and component safety.

The LIB2015 Alliance is being given direction by a road map prepared by the Fraunhofer Institute for Systems and Innovation Research (ISI), which takes into account the ecological, economic and political parameters. The road mapping process places the latest project developments in context with the other activities being carried out in this field around the world. It also identifies new technology pathways and compiles forecasts and scenarios for future developments.

“The approximately 60 project partners in LIB2015 actively collaborate on interdisciplinary projects, to which they contribute their specific expertise. Thanks to this set-up, we have been able to successfully link up and pool knowledge.”

Professor Martin Winter, Project Manager LIB2015 and Co-Head of Münster Electrochemical Energy Technology (MEET), University of Münster

Pooling expertise

Expanding university research

"Electrochemistry for electric mobility" competence networks

Time frame: 2009 – 2011
BMBF funding: North: approx. € 13 million
South: approx. € 22 million

Project partners
- North: four universities and two research establishments
- South: four universities and five research establishments

One of the first steps the BMBF took to systematically revive battery research in Germany was to launch two large competence networks in 2009 using funds from the Second Economic Stimulus Package. The "Competence Network North" is centred around the Forschungszentrum Jülich research centre and the "Competence Network South" has what is now the Karlsruhe Institute of Technology (KIT) at its hub. Both networks have played a key role in helping to link up and expand the existing expertise in battery research at universities and research establishments. This is reflected in such things as the joint research projects that have been initiated, equipment and plant that has been installed and is used jointly and concerted efforts to provide initial and continuing training for the new generation of researchers.

"The equipment available at the various establishments has been hugely improved with the help of the funding from the Second Economic Stimulus Package. That really kick-started electrochemistry, awakening it from its long slumber and rapidly spawning a whole range of high-intensity activities generating high awareness. Now we have to keep the momentum going – scientific success can only be attained through years of painstaking research. Ten years is nothing when it comes to developing new scientific expertise."

Professor Werner Tillmetz, member of the Board of Directors of the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) and spokesman for the Competence Network South

Enhancing battery excellence

Excellence and technological implementation of battery research (ExcellentBattery)

Time frame: 2012 – 2016
BMBF funding: approx. € 28 million

The ExcellentBattery call for proposals is a continuation of the strategy started with the competence networks, the objective being to fund excellent battery research activities. Battery research centres are to be set up at establishments with the relevant expertise and a number of research groups will collaborate within those centres. What makes this approach special is that the groups will be headed by internationally renowned researchers and bring together expertise from the worlds of chemistry, materials research and engineering. A core interest of ExcellentBattery is transferring research findings to industrial application. To achieve this, industry projects are running alongside the research project and there is an emphasis on patent applications and licensing agreements for commercial use of research outcomes. Creation of spin-off businesses is another explicit aim.

The first project to get off the ground, in 2012, was the Center of Excellence for Battery Cells at the Technical University of Munich (ExZellTUM). Its primary goal is to design new material systems that will help increase batteries' energy density. ExZellTUM is a joint project by the institutes for Electrical Energy Storage Technology, Technical Electrochemistry and Machine Tools and Industrial Management plus the Heinz Maier-Leibnitz research neutron source (FRMII). The Fraunhofer-Gesellschaft, BMW, Manz Tübingen and TÜV SÜD Battery Testing are also involved.

Dry room for battery cells (Li-Tec Battery GmbH)

Manufacturing tomorrow's batteries in Germany

Prerequisites in place for series production of lithium-ion batteries

Production research for high power lithium-ion batteries for electro mobility (ProLiEMo)

Time frame: 2009 – 2011
BMBF funding: approx. € 20 million

Project partners:
- Daimler AG
- DeutscheACCUmotive GmbH & Co. KG
- Evonik Litarion GmbH
- Li-Tec Battery GmbH

In 2012, the first German series production line for large-format lithium-ion batteries began operation in Kamenz, in the East German state of Saxony. Since then, the batteries for the smart fortwo electric drive have been produced there using a ceramic separator developed by Evonik – testimony to the success of the ProLiEMo project, which was coordinated by Daimler AG. In a team that also included cell and battery specialists from Evonik Litarion, Li-Tec Battery and Deutsche ACCUmotive, the project successfully conducted research into and optimised the prerequisites for industrial series production of high power lithium-ion batteries. The four project partners cover key parts of the value chain in Kamenz, from cell component (electrode and separator) production to cell manufacturing to the finished batteries ready for use in vehicles. Thanks to the cells' modular structure, the process steps have been considerably streamlined and throughput is up. Energy requirements and material wastage have been significantly reduced, resulting in a major decrease in production costs too.

Testing platform for production technologies

KliB – Ulm research production line

Time frame: 2012 – 2014
BMBF funding: approx. € 24 million

Project partner:
- Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW)

Battery technologies are constantly evolving and giving rise to new challenges for production. With this in mind, the BMBF is supporting the installation of a research pilot production line for large, vehicle-ready lithium-ion cells at the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) in Ulm. The aim is to systematically cultivate expertise to gain a better understanding of process control and parameters so as to improve cell quality, minimise wastage and cut production costs. The team will pilot new ideas for materials, explore technical production issues and collect information about production times, quality management and safety. The research production line is intended as a platform upon which companies can test and evolve materials and components in conditions akin to those of mass production. The ZSW is being advised by the Competence Network for Lithium-Ion Batteries (KliB), which brings together around 50 companies from across the value chain plus a number of research establishments. The work is scheduled for completion in 2014.

The calender, a system composed of several rollers, and the roller cutting machine for electrode production on the research production line in Ulm. (ZSW/M. Duckek)

Spotlight on: Fraunhofer System Research for Electromobility

Electric mobility in Germany needs to be promoted in a systematic, comprehensive approach. To this end, the Fraunhofer-Gesellschaft has harnessed the expertise of 33 institutes, pooling it in what it has called "Fraunhofer System Research for Electromobility". Supported by BMBF funding from the Second Economic Stimulus Package, researchers worked together on an interdisciplinary basis from 2009 to 2011. This enabled all of the parts in the electric mobility value chain to be assessed and researched in a coordinated manner. In addition to the "FreccO" and "AutoTram" demonstration vehicles created on the project, it also led to a unique knowledge and expertise platform for product development undertaken with industry partners based on projects past and future. The BMBF awarded around 34 million euros in financial assistance for Fraunhofer System Research for Electromobility.

The five core areas of Fraunhofer System Research for Electromobility

1 –Power generation, energy distribution and conversion
With EVs, electricity (ideally from renewable sources) can be used extremely efficiently. For that to happen, charging has to be easy, flexible and quick and the energy has to be able to be distributed within the vehicle as required.

Core research areas:
- Connection to the electricity grid
- Hardware and software components for stationary and mobile charging devices
- Analyses of the load on electricity grids
- Modular power electronics
- Integrated independent axle drive for twin motor control

2 –Energy storage technology
Demonstrator cells based on new materials since vehicle performance and range will be key to ensuring widespread uptake of EVs. Storage and supply of electrical energy are pivotal.

Core research areas:
- New active materials such as a core shell silicon carbon composite for the anode
- New cathodes for next-generation lithium-sulphur cells based on carbon nanotubes
- Sensors and electronics for monitoring pressure and temperature in the cell
- Development of modular and flexibly scalable battery systems

3 –Vehicle design
The switch from internal combustion engines to electric motors paves the way for a revolution in vehicle design. With distributed engines, there is no longer any need for mechanical transmission elements, which means extra space.

Core research areas:
- Wheel hub motors with integrated power electronics and cooling
- Lightweight multi-material systems and manufacturing methods using fibre composites
- System for battery replacement by motor workshops/garages
- Whole-vehicle testing using four complementary test rigs

4 –Technical system integration and socio-political aspects
Development of two demonstration vehicles, in which the components developed on the project were tested to establish how they worked as part of the overall system and how they dealt with real conditions.

Core research areas:
- “Frecc0” demonstration vehicle, based on a sports car
- “AutoTram” demonstration vehicle – a type of tram that does not depend on the track network
- Investigation of vehicle designs and potential uses

5 –Function, reliability, testing and production
When it comes to reliability, safety and comfort, EVs have to meet the same high requirements that apply to today’s conventional vehicles. And they have to be economical to produce.

Core research areas:
- Recommendations for evolving test methods and standards
- Assessment of component reliability and safety
- Studies on the availability of raw materials and resource efficient production
- Ecological footprints, especially for batteries
- Development of a precision casting method for motor windings

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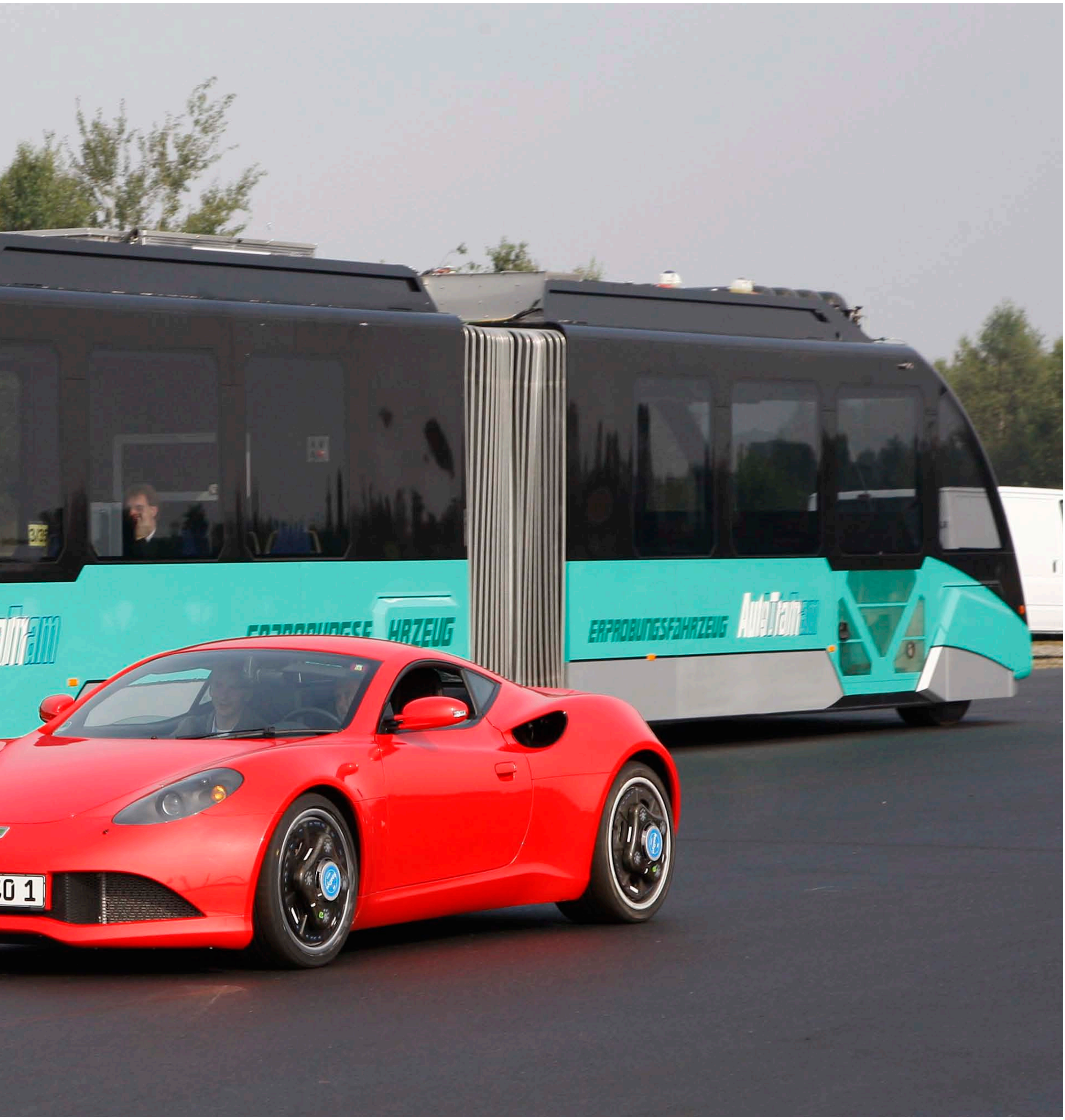
“The results achieved in the space of just two years were pioneering in many ways. Technically acclaimed studies and demonstration vehicles were created around the topic of electric mobility, and the system research model proved so successful that it has been continued since the beginning of 2013 under the new president of the Fraunhofer-Gesellschaft.”

Professor Holger Hanselka, Chief Coordinator, Fraunhofer System Research and Director of the Fraunhofer Institute for Structural Durability and System Reliability (LBF)

Finishing the project on a high note: wheel hub motors, battery systems, charging points – these and other important components for the EVs of the future were developed by Fraunhofer scientists during two years of painstaking research. The two demonstration vehicles, AutoTram and Frecc0, were test-driven on 2 September 2011. (Ingo Daute)


ERPROBUNGSFAHRZEUG

Energy efficiency – How can we make EVs go further?

If the energy in a vehicle is to be used efficiently, it is crucial that all of the components work in perfect unison. That goes for the energy storage and supply in the batteries and equally for the main consumer of energy, the drive motor, as well as the secondary consumers such as the air conditioning, multimedia applications and any other extras.

Electric motors are much more efficient than internal combustion engines but that edge could be bettered through improved control systems, new materials and advances in production.

Power electronics have a vital part to play when it comes to distributing energy in the vehicle. New circuitry, innovative materials and increasingly ingenious assembly and connection techniques will make further miniaturisation of the electronic components, lower energy loss during operation and more precise control possible.

Electronic components and controls already have an ever more significant role in conventional vehicles. However, since the electrical energy in an EV is also needed to drive the wheels, much higher levels of electrical power are required. One issue to be dealt with is electromagnetic compatibility (EMC). In other words, steps have to be taken to ensure the electronic components do not have a negative effect on each other despite the electromagnetic fields that are generated within them and surround them.

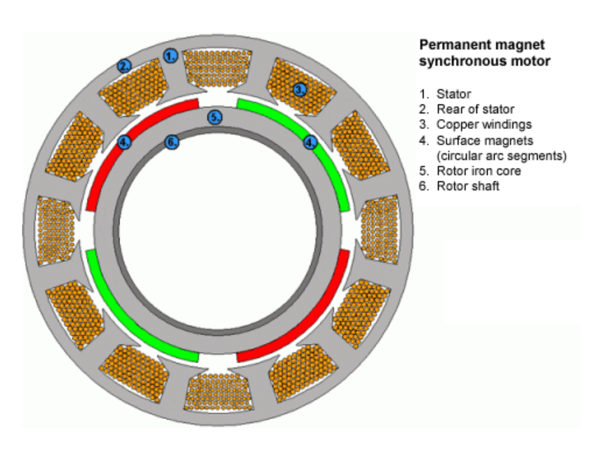
Last but not least, new materials and increasingly sophisticated lightweight designs provide an opportunity to save weight in all parts of the car and thus to expand range.

But it is of fundamental importance that all these efforts to ensure energy efficiency do not lose sight of the comfort, reliability and safety to which car drivers have become accustomed. The work being done on completely new vehicle designs unites all of these points.

The prototype EV from the BMBF Visio.M project passes its test drive with flying colours. (A. Heddergott/S. Rauchbart/Technical University of Munich)


M EV 2012

The electric motor



Schematic diagram of a permanently excited internal rotor synchronous motor. (www.hybrid-autos.info)

An electric motor converts electrical energy into mechanical energy. It consists of a stationary component (the stator) and a rotating component (the rotor). There are various types of electric motor but asynchronous and synchronous are currently the most popular for EVs.

Stator and rotor
The stator is a metal body with conductive windings (e.g. copper wire), which are the same irrespective of whether the motor is synchronous or asynchronous. A three-phase alternating current flows through the stator's windings.

The varying alternating current and the positioning of the windings create a magnetic field, which "wanders" around in a circle inside the stator. This magnetic field "pushes" or "pulls" the pivoted rotor, resulting in a circular motion.

What happens in a synchronous motor?
The rotor has a static, fixed magnetic field, which is generated either by a permanent magnet or by a winding through which a direct current flows. The rotary field now "pulls along" the magnet, which then rotates with the same number of revolutions as the rotary field.

What happens in an asynchronous motor?
The rotor in this type of motor is essentially a cage made of metal bars (in fact, it is referred to as a "squirrel cage rotor") and does not usually have any other electrical connection. The cage is picked up by the rotating magnetic field, which causes a current to be generated in the cage's bars too. This in turn generates a magnetic field, which sets the rotor turning. The rotor always lags slightly behind the stator's magnetic field, hence the "asynchronous".

Motor control
The motor's control system ensures that the direct current from the battery is converted into the three-phase alternating current required by the stator.

The motor's torque and number of revolutions (and therefore the drive power) are controlled via the amplitude and frequency of the current. In addition, the shape of the rotor and stator influences the motor's characteristics because it affects the magnetic field.

Asynchronous motors versus synchronous motors
The permanent magnet synchronous motor is compact and highly efficient. On the downside, however, the magnets are expensive and the motor relatively difficult to control. The asynchronous motor scores on cost and controllability but it takes up more space. The ideal motor and control system have not yet been found.

Many of the technologies currently available were designed for stationary operation. The need for an electric drivetrain that can cope with varying speed and loads, frequent switching between motor and generator operation and maximum efficiency means new solutions have to be devised. Numerous research and development projects are therefore working on new ideas for motors and control systems.

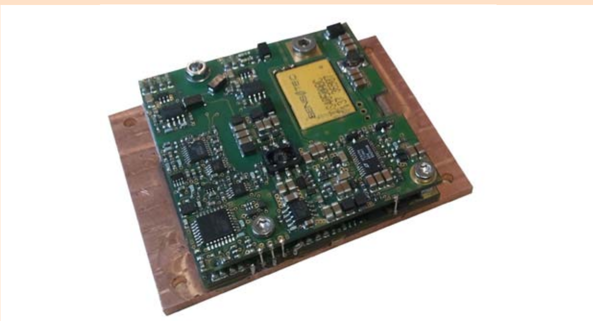
"Twin motor"/"twin drive"
Occasionally, twin motors are used as the electric drive, i.e. two electric motors drive one axle together. "Twin drive" is when two motors drive a unit or vehicle or when an electric motor and an internal combustion engine are combined in a hybrid vehicle.

Power electronics

Without state of the art power electronics, wind turbines would not be able to feed their electricity into the grid, trams would not go anywhere and refrigerators would not work efficiently. Power electronics serve as the "energy control room" in almost all spheres of everyday life. In EVs, they are responsible for distributing the correct amount of energy to the various electronic components. The focus is not only on the nominal power but also, increasingly, on ensuring high power levels using a minimum of space and weight.

"One of the challenges is maximising energy efficiency. By increasing the efficiency of the power electronics, you also reduce power loss and, as a result, the amount of heat that has to be removed from the system by means of cooling. The power electronics have to be robust, reliable, safe and compact so as to cut down on volume and weight. These are particularly important points in mobile applications. Another key aspect is what is known as "system integration", in other words locating the power electronics precisely where they have their effect, e.g. on the motor. Long cables between encased electronics and mechanical parts would just make the vehicle more prone to failure, heavier and more copper intensive. And one fundamental issue, which is obviously especially interesting for our industry customers, is cost efficiency."

Dr Martin März, Deputy Director of the Fraunhofer Institute for Integrated Systems and Device Technology (IISB)



Latest-generation voltage converter – small and efficient. (Fraunhofer IISB)

Recuperation of braking energy (regenerative braking)

Electric motors can also operate as generators. When the rotor turns, electricity is generated in the stator's windings and that electricity can be fed back into the battery (once it has been converted into a direct current). During the electric braking process, the vehicle switches from motor to generator operation, thus converting rotation energy into electricity. The braking force can be adjusted by controlling the outflowing current.

Electric motor assembly. (Robert Bosch GmbH)

Efficient drivetrain technologies

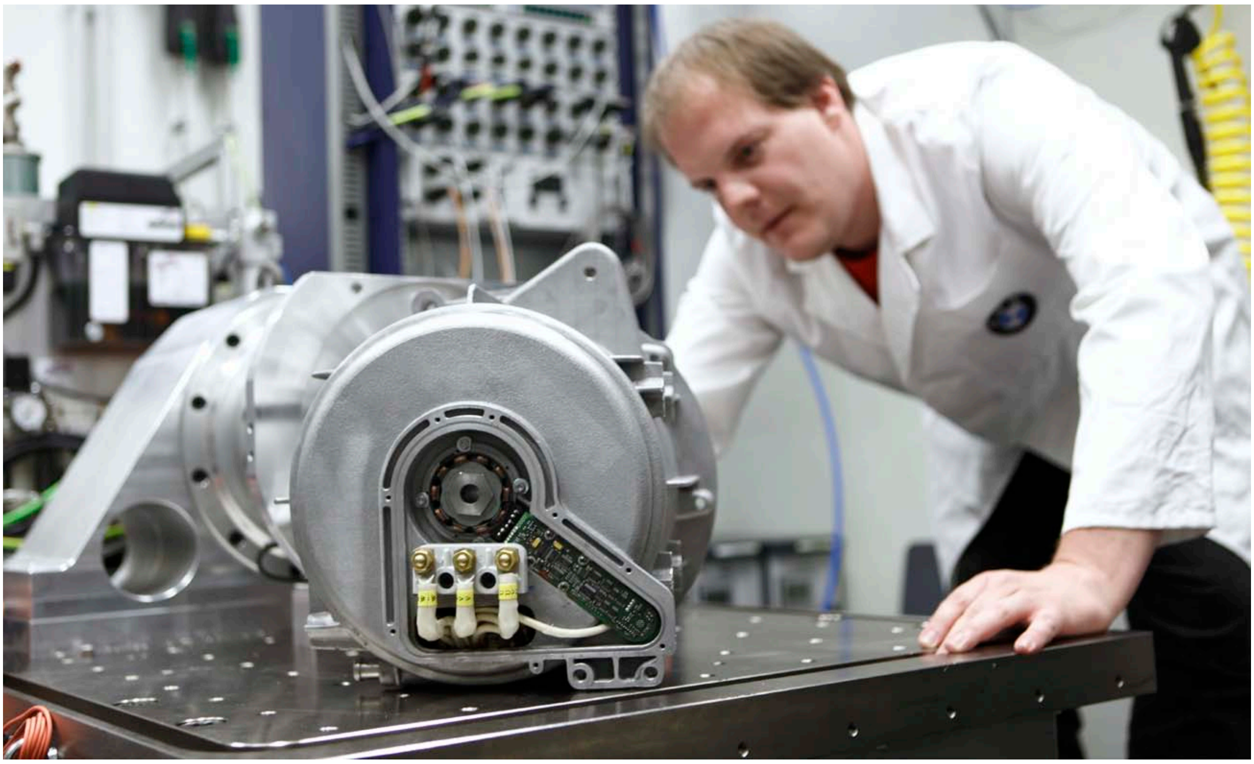
With their far higher efficiency rating (over 90%), electric motors are superior, in principle, to internal combustion engines. And, fitted with the right power electronics, they can be controlled more quickly and precisely, which means, for instance, they can accelerate faster.

Electric motors are very robust, long lasting, inexpensive to maintain, can easily be adjusted to provide the required level of power and are very quiet. They have been in use in many shapes and forms in all areas of industry and as rail transport drive systems for quite some time.

To be used in cars, they need to be even more efficient and the different types of motor – asynchronous and synchronous, the latter with and without permanent magnets – need to undergo further development. These are the points on which the research agenda is concentrating.

As electric motors are relatively small and flexible, there are a number of places in which they can be located in the vehicle. This has a major impact on the vehicle's overall architecture. As well as the option of having one central motor unit, as with the single engine block in conventional vehicles, the drive system can be divided between two smaller motors on each axle or each wheel can have its own drive. This can greatly improve handling and, consequently, safety – as long as the driver knows how to use an active, reliable control system.

Indeed, drivetrain control is one of the main priorities for optimisation. In terms of hardware, researchers are interested in, for instance, new materials that could be used to make stronger magnets or to reduce weight. Research is also needed on combining electric motors and internal combustion engines/fuel cells to form hybrid motors or range extenders. The following sections outline some of the research projects covering these topics.



Electric drivetrain on a test rig. (BMW AG)

Innovative windings

Highly flexible production systems for higher efficiency traction drives (HeP-E)

Time frame: 2012 – 2015
BMBF funding: approx. € 4 million

Project partners:
- BMW AG
- ESSEX Germany GmbH
- Friedrich-Alexander-Universität Erlangen-Nürnberg (Institute for Factory Automation and Production Systems (FAPS))
- Otto Rist GmbH & Co. KG
- Scansonic MI GmbH
- Technical University of Munich (Laboratory for High Voltage Technology and Power Transmission (HAS) and Institute of Metal Forming and Casting (utg))
- Weinmayr GmbH

Copper windings are core components in any electric motor. When electricity flows through them, these wound conductors enable the magnetic field to be generated that sets the rotor in motion. The strength and shape of the magnetic field are key factors in the motor's performance, i.e. its power density and efficiency, which is why the quality of the copper windings determines the quality of the motor. On the HeP-E project, four companies and three university institutes, headed by BMW, are developing innovative production methods for the copper windings. Their approach uses robot technology, with which the copper wire can be wound more tightly and evenly. This also results in the windings being better insulated against each other. The project is also seeking to improve the bonding of the conducting wires in the electric motor by means of robot-aided laser welding. These automated production methods will bring about a reproducible increase in the quality of the windings and, with them, the motors.

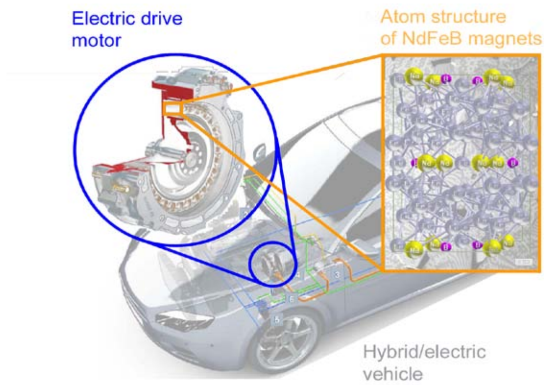
New magnets for motors

Quest for new hard magnetic phases with high energy density (REIeaMag)

Time frame: 2011 – 2014
BMBF funding: approx. € 2 million

Project partners:
- Aalen University
- Magnetfabrik Bonn GmbH
- Max Planck Institut Stuttgart
- Robert Bosch GmbH

Magnets are key features in electric motors and they need to be manufactured from materials that are as magnetic as possible so that they can be made compact and light. The strongest, industrial-purpose permanent magnets currently available are based on neodymium iron boron (NdFeB). The problem is, however, that neodymium is one of a number of rare earth metals that, while they are not as rare as the name suggests, are mainly produced in China. In fact, 97% of these metals come from there. Consequently, supply is heavily dependent on China and there is a high risk of price fluctuation for materials that are already very expensive anyway. The intention of the REIeaMag research project, being conducted jointly by Robert Bosch, Magnetfabrik Bonn, the Max Planck Institute Stuttgart and Aalen University, is to develop alternative magnetic materials with a lower rare earth metal content and, potentially, better magnetic properties. To this end, the research team is devising efficient, systematic search methods.



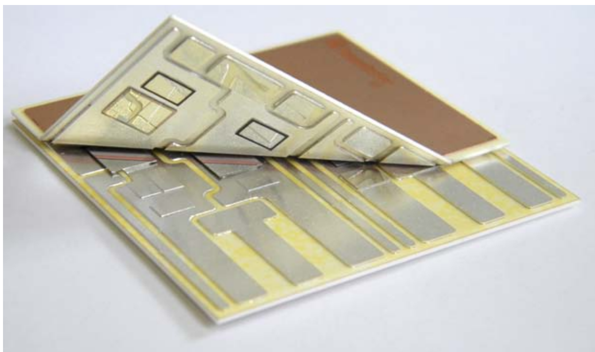
Rare earth compounds in electric motors. (Robert Bosch GmbH)

Intelligent power electronics for energy management

Power electronic control units and energy converters make sure all of a vehicle's compnents are supplied with the required electrical energy. They convert direct current into alternating current and vice versa, transform the voltage to the necessary level and assign the energy for the drivetrain and other electronic components. Consequently, they also serve as a link between the battery and the motor.

As elsewhere, the trend in power electronic components is constant miniaturisation coupled with enhanced performance. This has been made possible by new (semiconductor) materials, new assembly and connection techniques for the electronic components plus circuitry and component innovation.

A major challenge to any further miniaturisation is the fact that the components are subject to varying thermal loads. This is partly due to the ambient conditions in the vehicle and partly the heat loss caused in the power semiconductors themselves during the electrical conducting and switching processes. The heat has to be dissipated, by means of complex cool sinks, water cooling or fans, to ensure it does not damage or prematurely age the materials. Research activities are not only looking to optimise the cooling but also to reduce the energy loss in the first place. Without these improvements, it will not be possible to meet the high reliability, cost and service life requirements.



Part of an ultracompact power electronic module, developed for experimental purposes on the UltiMo project. (Fraunhofer IISB)

Efficient control

Ultracompact, maximum reliability power module (UltiMo)

Time frame: 2010 – 2013
BMBF funding: approx. € 4 million

Project partners:
- ANCeram Aluminium Nitride Ceramics GmbH & Co. KG
- BLZ Bayerisches Laserzentrum Gemeinnützige Forschungsgesellschaft mbH
- Conti Temic microelectronic GmbH
- curamik electronics GmbH
- Daimler AG
- Danfoss Silicon Power GmbH
- Fraunhofer Institute for Integrated Systems and Device Technology (IISB)
- Fraunhofer Institute for Silicon Technology (ISIT)
- Fraunhofer Institute for Reliability and Microintegration (IZM)
- Volkswagen AG
- W.C. Heraeus GmbH

Electric motors are controlled via a power electronic module, which can be integrated, for example, in the drive axle. These devices need to be as small and light as possible and able to work reliably even in the tough ambient conditions inside a vehicle (temperature range of -40° to +125° Celsius and strong vibrations). The researchers on the UltiMo project, coordinated by Continental and involving several Fraunhofer institutes, Daimler, Volkswagen and other companies, are developing a demonstrator with a revolutionary, highly efficient module. The ingenious thing about it is that the power semiconductors, which are subject to a high thermal load, are cooled on both sides.

Previously, the components could only be cooled on one side because the other had to be used for the aluminium wire bonding. Now, a new, large area connection technique has been developed, which also facilitates cooling so that heat can be dissipated on both sides and thus very efficiently.

This approach provides other advantages too: the semiconductor components can withstand higher loads, which means fewer are needed. This in turn significantly reduces the amount of material needed, the costs and the size of the modules.

Robust and less loss

Compact electronic modules with high power for e-mobility, drive technology and lighting (ProPower)

Time frame: 2012 – 2014
BMBF funding: approx. € 17 million

Project partners:
- ANDUS ELECTRONIC GmbH LEITERPLATTEN TECHNIK
- Audi AG
- Danfoss Silicon Power GmbH
- eesy-id GmbH
- F & K DELVOTEC Bondtechnik GmbH
- Forschungs- und Entwicklungszentrum Fachhochschule Kiel GmbH
- Fraunhofer Institute for Integrated Systems and Device Technology (IISB)
- Friedrich-Alexander-Universität Erlangen-Nürnberg
- GÖPEL electronic GmbH
- Heraeus Materials Technology GmbH & Co. KG
- Heraeus Precious Metals GmbH & Co. KG
- Hofmann Leiterplatten GmbH
- Infineon Technologies AG
- OSRAM AG
- Siemens AG
- SEHO Systems GmbH
- Sondervermögen Großforschung (special large-scale research fund) at the Karlsruhe Institute of Technology (KIT)
- Technische Universität Berlin
- Technische Universität Dresden
- VIA electronic GmbH

Testing process for power electronic components. (BMW AG)

Power electronic components for batteries and motors are not yet up to the standards required by manufacturers in terms of installation space and reliability. The ProPower project aims to tackle these challenges at each stage of the value chain. 21 partners from industry (from component suppliers to car makers) and academia are working together on this large project, headed by Siemens.

The ultimate goal is to do away with active cooling for the power modules as far as possible. To achieve this, the researchers are pursuing a dual strategy of bringing heat loss down by enhancing component efficiency and making the actual power electronics more robust so they can survive the high temperatures in miniaturised modules without sustaining any damage.

Reliability

Not all electronic systems are the same. EV motors use currents in excess of 250 amperes (much higher than in conventional vehicles) plus voltages of more than 400 volts, and they require fast current switching. These factors lead to relatively strong electromagnetic fields.

Electromagnetic fields can spread (either through wires or space) to nearby electronic components and have a negative effect on them. This can be particularly detrimental to the on-board electronics, which run on very low voltages and milliampere currents and are therefore sensitive even to minor interference. This problem is also being addressed by projects funded by the BMBF.

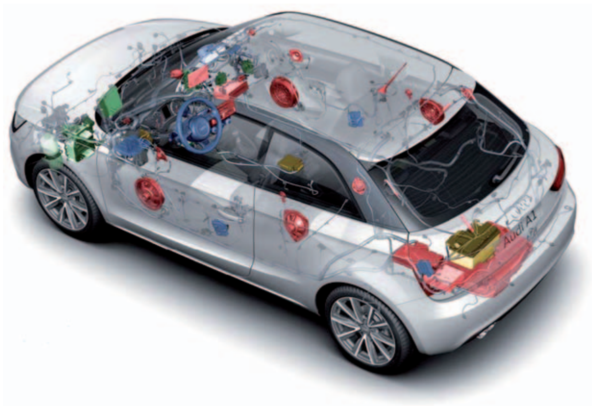
Electromagnetic reliability and electronic systems for electric mobility (EM4EM)

Time frame: 2011 - 2014
BMBF funding: approx. € 7 million
Implemented within the Eureka CATRENE cluster programme

Project partners:
- Audi AG
- Conti-Temic microelectronic GmbH
- Daimler AG
- ELMOS Semiconductor AG
- Friedrich-Alexander-Universität Erlangen-Nürnberg
- Infineon Technologies AG
- Leibniz Universität Hannover
- NXP-Semiconductors Germany GmbH
- Robert Bosch GmbH
- TU Dortmund University
- Zuken EMC Technology Center

Though baffles and electronic filters have proved popular ways of shielding electronics from interference fields, they make cars more expensive and heavier and that added weight impacts on range. Coordinated by Audi, car makers, component suppliers, circuit manufacturers and universities from eight European countries have joined forces in a project christened "EM4EM" to come up with alternative strategies to solve these problems. Their initial aim is to determine and model the potential electromagnetic interference in order to develop a simulation platform for electromagnetic reliability. The idea is to use the platform to analyse the problem at all levels and to find solutions, from the smallest element, the circuit, to the circuit board, the components, control devices, cables and, finally, the vehicle as a whole.

The shape of the body and the material of which it is made are also likely to be affected. Positive effects can be achieved, for instance, by adjusting the positioning of the components in the vehicle. But the researchers have also set out to draw up design guidelines for electronics to ensure they generate less interference and are less interference-prone. The project is also looking to roll out a Europe-wide master´s programme on the subject of electromagnetic reliability.



System architecture of the on-board electronics in the Audi e-tron. The components being examined on the project are shown in colour. (Audi AG)

Lightweight construction

By making cars lighter, energy consumption can be slashed especially since the battery itself is no light weight. With this in mind, work on EVs is seeking to assimilate the principles of lightweight construction already applied in some automotive components.

The primary goal in attempts to reduce weight is to take lightweight materials such as magnesium alloys, special steels or carbon fibre composites and improve their suitability for automotive production. Each material has to be optimised in line with its specific function in the vehicle. They have to meet different requirements, with regard to safety for example, depending on whether they are used for the body or the chassis. And, finally, it must be possible to mass-produce them inexpensively in the required form. This is still very problematic and solutions will have to be found in areas such as machining and bonding but also mechanical handling of materials, especially carbon fibre composites.

Handling of hollow parts

Method for producing large-volume, functionalised, highly resilient hollow composite parts (TwinOSheet)

Time frame: 2011 - 2014
BMBF funding: approx. € 2 million

Project partners:
- Audi AG
- bielomatik Leuze GmbH + Co. KG
- Friedrich-Alexander-Universität Erlangen-Nürnberg
- Jacob Plastics GmbH
- LANXESS
- Neue Materialien Fürth GmbH
- Schaumform GmbH
- Siebenwurst Modell- und Formenbau GmbH

One reason why fibre composites are not used very widely in mass applications is their high price, which is chiefly due to fibre composite components being complex to produce. The components are based on extremely resilient, woven mats, made, for example, of carbon fibres. They are placed in a mould, covered with epoxy resin and hardened. It is still very difficult to automate this process because the fibre mats slip easily and are extraordinarily difficult to grip. However, it is crucial that they are precisely positioned if the material is to be of good quality.

The eight project partners working with plant and mechanical engineering firm bielomatik Leuze are aiming to develop a method that could be used to mass-produce hollow fibre composite parts. These parts can be used for a variety of applications, including hollow seat shells, motor housing or hollow body support structures.

A component produced using the TwinOSheet method. (bielomatik Leuze GmbH + Co. KG)

The project work involves designing and simulating suitable moulds and the component structure. For production purposes, it is imperative that good systems for handling and gripping the composites are developed and two or more shells can be produced and welded together to create the hollow part. Here too, the project team are employing simulation techniques. Temperature and pressure are key factors for processing, and a method for checking the quality of the joins is essential. The project is also evaluating the energy and materials used in a bid to maximise production efficiency.

Comfort

A pleasant in-car climate makes for a much more comfortable ride. So EVs need to match the comfort provided by conventional cars and keep drivers from dissolving in the heat and passengers from perishing with cold.

All of the extras that add comfort to the travelling experience, be it the air conditioning, automatic controls, hi fi or other media, have to be supplied with energy from the battery's (limited) resources. Alternative, economical solutions and technologies are therefore needed to make sure range can be maximised without minimising comfort.

Just the right temperature

Innovative air conditioning solutions and thermal comfort solutions aimed at optimising EV range (E-Komfort)

Time frame: 2011 - 2014
BMBF funding: approx. € 1 million

Project partners:
- Fraunhofer Institute for Building Physics
- P+Z Engineering GmbH
- Volkswagen AG

The idea behind the E-Komfort project is to provide passengers with warm or cold air where they need and want it instead of throughout the whole of the vehicle's interior. At floor level or around the arms are possibilities, for instance. The project team, comprising developers from Volkswagen, the Fraunhofer Institute for Building Physics and P+Z Engineering, has set out to cut down on energy consumption without detracting from comfort. The air conditioning for the occupant cell is, after all, the second biggest consumer of energy in a car and EVs do not have the heat that a combustion engine loses to use for heating. The researchers are working with computer models to simulate human perception of temperature and comfort. The results will be used to determine the best locations for the various parts of the air conditioning system and the most efficient means of controlling those parts. This research has to consider the energy management for the entire vehicle too. Trials using real test persons will then seek to verify the theory, the ultimate goal being to develop a comfort model and ISO standards for the new methods.

EV users want the same level of comfort they are accustomed to from conventional vehicles. (Fotolia)

Vehicle concepts

Two, three or four wheels; one, two or four seats – EVs come in various guises for a variety of uses and customer requirements. From speedy sports cars to nimble city cars, there is no end to the possibilities.

The one thing that always holds true is that a vehicle can only have any appeal if it ticks all the boxes, from performance to comfort to design. So the research being carried out into new vehicle concepts will be instrumental in bringing EVs to market.

A city car small in size and big on appeal

Research assistants from the Technical University of Munich prepare the Visio.M project's prototype EV for testing. (BMBF/Leo Seidel)

Visionary vehicle concept for urban electric mobility (Visio.M)

Time frame: 2012 - 2014
BMBF funding: approx. € 7 million

Project partners:
- Autoliv B.V. & Co. KG
- BMW AG
- Daimler AG
- Finepower GmbH
- Hyve GmbH
- IAV GmbH Ingenieurgesellschaft Auto und Verkehr
- LION Smart GmbH
- Neumayer Tekfor Holding GmbH
- Technical University of Munich

The Visio.M research project has been set up to demonstrate that EVs can be both extremely light and safe. Scientists and engineers from leading German technology firms and the Technical University of Munich are working in a team coordinated by BMW, and supported by various associated partners, to invent a new type of microcar. Most types currently available are retrofitted combustion vehicles but the car being developed on this project will be completely new and specifically tailored to customers' requirements and electric mobility. The aim is to ensure a level of safety and price that will make it mass-marketable. Although there are no strict safety requirements in place for these types of microcar, the researchers are particularly keen to achieve a safety level in line with that offered by conventional cars.

The developers have opted for a design in which large parts of the body are produced from one piece, thus creating a stable structure. They are also using particularly light and sturdy carbon fibre plastics and solutions that save weight in the motor and gearbox.

"Our project is specifically aimed at the second car market, which is why we have optimised the range (>100 km), maximum speed (120 km/h) and number of passengers (two) for the requirements of those customers. These are limitations that second car customers are willing to accept. By making clever choices about the technical innovations we've used, we are able to cut back on weight and bring costs down to a level that enables our vehicle to compete with similar, combustion engine vehicles. Small EVs such as the one developed on the Visio.M project are already performing better in Germany in terms of carbon emissions than similar vehicles with internal combustion engines. That puts Germany well on track to reducing carbon emissions."

Professor Markus Lienkamp, Head of Institute of Automotive Technology and co-head of the Science Center for Electromobility at the Technical University of Munich

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But safety comes first elsewhere too, in the form of anti-lock braking and a torque vectoring system. The latter applies different levels of power to each wheel to control the vehicle. Teleoperated driving is also being explored. A trial vehicle has already passed the first

Narrow roads, difficult parking, short trips door to door – all no problem for the battery-run, electric one seater, Colibri. (BMBF/Leo Seidel)

drivetrain and chassis tests. Now the project will move on to evolving the new technologies so that they can be used in mass production.

On the road in a one seater

Implementation of a new one-person electric light vehicle using a system-wide approach (1PeFZ)

Time frame: 2011 - 2013
BMBF funding: € 3 million

Project partners:
- Altair Engineering GmbH
- B&W Fahrzeugentwicklung GmbH
- CPM Compact Power Motors GmbH
- Innovative Mobility Automobile GmbH
- Lätzsch GmbH
- Stolfig GmbH
- Chemnitz University of Technology

"Colibri" is the name of the one-person light vehicle being developed by Innovative Mobility Automobile GmbH along with six other partners. It is targeted at customers in large urban areas. A new seating solution and a magnesium frame safety cell afford maximum safety and comfort despite the limited space. Simulations are planned to guarantee crash safety. And for the drive system, the developers have opted for twin electric motors, which offer particularly efficient control. In addition, the one seater will be fitted with an innovative steering and operating solution, including a smartphone interface that will enable it to be linked up to future mobility services.

Spotlight on: The South-West Leading Edge Cluster

The South-West Leading Edge Cluster is one of the largest regional alliances for electric mobility. Founded in 2012, it now brings together some 80 representatives of industry, universities and research establishments from the Karlsruhe/Mannheim/Stuttgart/Ulm region. They include world famous large, medium-sized and small enterprises. The BMBF is providing 40 million euros of funding for the cluster.

The purpose of the cluster's research is to provide highly efficient, low emission, marketable mobility. To achieve that, its members are pursuing a joint strategy of cutting costs, improving handling and comfort and integrating the various transport modes and the energy supply system in an intelligent manner. They are therefore pooling their expertise in a number of areas of innovation, those being vehicle technology, energy and supply technology, information and communication technologies (ICT) and services and the cross-cutting area of production technology. And they are collaborating in interdisciplinary research projects to devise solutions with which to reach their strategic targets.

The South-West Leading Edge Cluster for Electric Mobility is one of five leading edge clusters on a range of topics that an independent jury recommended for funding in the third round of the BMBF's competition for leading edge clusters. The cluster is managed by the e-mobil BW GmbH state agency for electric mobility and fuel cell technology.

Vehicle technology

A good in-vehicle climate is an absolute must when it comes to comfort. The **GaTE** project is therefore conducting research on a new mode of thermal management with an inexpensive heat pump and a higher level of recirculated air. The aim is to minimise the battery energy needed for the vehicle's air conditioning systems.

Another aspect of EVs is that they need to be repaired quickly in the event of a fault, without putting garage staff at risk. In response to that need, the **DINA** project is analysing faults and identifying the complex circumstances behind them in order to devise new methods for fast, conclusive troubleshooting.

The South-West Leading Edge Cluster comprises the regions around Karlsruhe, Mannheim, Stuttgart and Ulm. (e-mobil BW GmbH)

The **ELISE** project is developing a telematics platform to serve as an interface between the vehicle, operator and other services. This facility will enable the latest data concerning the vehicle and its surroundings, such as the charge status and location, to be captured and linked up.

Energy technology

In a bid to make the battery charging process as user friendly as possible, the **BIPoLplus** project is exploring the possibility of a touch-free, rapid charge system with which energy can be transferred between the charging point and the EV. The experts are considering both the vehicle itself and how the charging system is integrated into the energy supply grid.

To reduce the drain on the energy storage unit caused by secondary electronic systems such as the air conditioning, the **InnoROBE** project is developing small on-board charging systems that can deliver additional electrical energy and heat for them, without using the battery, and thus increase the vehicle's range.

Another aspect of user friendliness is the need for a convenient-to-use infrastructure for charging batteries quickly. In an attempt to meet that need, the **AUTO-PLES** research project is working on an innovative parking and charging system. The aim is an automatic process for manoeuvring EVs into and out of the parking spaces at charging points and charging them.

Information and communication technology

ICT supplies a platform for connectivity between vehicles and systems for traffic data, fleet management, public transport, energy and charging infrastructure.

The **Smart Grid Integration** project is looking for ways to overcome the challenges electric mobility poses for the energy industry. The team is working on ICT-based technical solutions and billing methods for organising and optimising the charging processes, one of the aims being to prevent bottlenecks in the energy supply.

On the **GreenNavigation** project, a driver assistance system is being developed that supports energy efficient driving and plans routes so as to optimise consumption. It does this by taking into account traffic data, charging point locations and vehicle characteristics.

The researchers on the **eFlotte** project are developing methods and computer systems with which to manage EV fleets and charging systems. The goal is optimum coordination of EV deployment (and of petrol or diesel cars in mixed fleets) based on (range) requirements, vehicle availability and charging infrastructure.

EVs will be embedded in new mobility set-ups, comprising both local public transport and car sharing clubs. The aim of the **I-eMM** research project is therefore to draw up a strategy for this type of integrated mobility service, using the Rhine-Neckar region as an example.

Production technology

When it comes to manufacturing EVs, there are still a number of challenges – particularly for makers of batteries and drivetrains – surrounding costs, quality assurance and scalability. The keys to solving these issues are automation, modularisation and plant planning.

Automation is the focus of the **AutoSpEM** project, where specialists are developing automated grippers and handling systems for the various stages of battery production.

On the **Epromo** project, plant and mechanical engineers are framing a new, modular approach for production, assembly and testing of electrical drives. The **ProBat** project is aimed at equipping plant engineers and battery manufacturers with software-based tools for planning safe, efficient and scalable plant layouts.

“Future-proof mobility solutions will create intermodal transport chains for people and goods. The South-West Leading Edge Cluster for Electric Mobility is making a significant contribution to that mobility revolution and thereby supporting the high-tech strategy defined by the BMBF and the Federal Government. The aim is to develop new technologies for highly efficient, low emission, market-driven e-mobility and to set up the industry to manufacture them in Germany. What makes the South-West Leading Edge Cluster for Electric Mobility special is the collaboration between 80 partners from academia and large world market leaders, along with small and medium-sized enterprises, in the key sectors of automotive, energy and ICT plus the cross-cutting area of production. The joint work being performed within the cluster, with financial assistance from the BMBF and the federal state of Baden-Württemberg, means the partners can come together to shape the technological revolution right from the beginning of the road to electric mobility.”

Franz Loogen, Cluster Manager and Managing Director of e-mobil BW GmbH

Training for electric mobility – technology powered by people

EVs will never become part of everyday life without daring, creative ideas from researchers, engineers and service providers. To establish that skill set and become a leading provider of electric mobility, Germany needs excellently trained professionals.

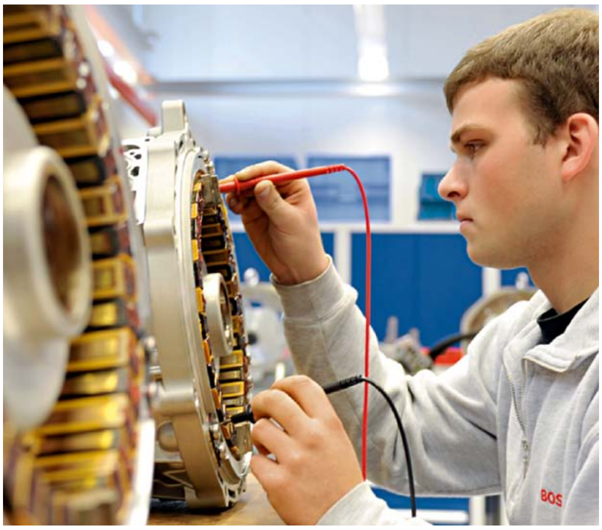
The BMBF's strategy is to install new working groups as part of research projects at universities and research establishments to give students (undergraduates and Ph.D. students alike) hands on experience of the fascinating field of electric mobility. All of the funding programmes for electric mobility explicitly include training. By working together, academia and industry can equip young engineers with the skills they need for the world of work and introduce them to companies at an early stage.

"Research and development consortia, such as the LIB2015 research alliance, with its more than 60 partners from industry and universities, have spawned a wide range of collaborative activities. By sharing knowledge and ideas, they generate valuable synergies for both sides. Industry and the academic partners benefit from the theoretical expertise and the students get thorough, practical training."

Professor Martin Winter, Project Manager LIB2015 and Co-Head of Münster Electrochemical Energy Technology (MEET), University of Münster

The new, interdisciplinary requirements of electric mobility have to be catered for in the vocational training system too. Though it will not be necessary to add new profiles to the existing profiles for state-recognised occupations compiled by the Federal Institute for Vocational Education and Training (BIBB), the current training syllabi will need to be updated. As many people who will be involved in making and developing EVs in the future already work, continuing training programmes will have to be designed to equip them for the new tasks ahead. This will need to be done in cooperation with universities, chambers of commerce and businesses. The BIBB is particularly active in this field and conducts numerous research and development projects concerning training in the automotive and electrical trades, with the BMBF's support. The "QuEle" project, for example, examined existing training programmes in the automotive sector to identify which areas of continuing training for electric mobility need to be bolstered. A further core aspect of the BIBB's work is the modernisation and expansion of inter-company vocational training centres, which are particularly helpful in supporting SMEs' vocational training efforts.

The seed for a career connected to electric mobility will be sown in schools and homes. The BMBF therefore supports various programmes designed to inspire young people as early as possible to embark on a career in the technical sphere. They include schemes to promote uptake of mathematics, IT, natural science and technology. There is also a "Girls' Day" event, with activities specifically geared to giving girls and young women the opportunity to spend a day gaining real-life experience of a range of occupations, especially in the technical segment.



Helping shape the future – training in the field of electric mobility opens the door to exciting job opportunities. (Robert Bosch GmbH)

National Education Conference

28 June 2011 saw electric mobility trainers convene for the first time, at Congress Centrum Ulm. (University of Ulm/E. Eberhardt)

Initiated by the NPE's Training and Qualifications Working Group and supported by the BMBF, the National Education Conference for Electric Mobility took place in Ulm in June 2011. Stakeholders in academic and vocational training (representatives of companies, chambers of commerce, universities, research establishments and technical colleges) met to discuss what requirements electric mobility places on education and training.

They considered whether new state-recognised occupations needed to be defined for electric mobility, whether universities were prepared for the subject and what industry could contribute. The conference looked at all aspects of electric mobility, from material development to vehicle engineering, electrical and IT trades through to customer service.

There is already a clear need for new skills for electric mobility. In general, more interdisciplinarity, an understanding of the overall system and the ability to think across sectors are necessary. On the technical side, knowledge of power electronics, electrochemistry, battery technology, electrical machines and handling of high voltage systems are important. The delegates at the conference concluded, however, that there was no need for completely new state-recognised occupation profiles or higher education courses.

Instead, the required content can be integrated as new modules in existing training courses. Universities will also have to ensure more effective dovetailing of existing syllabus content. One of the reasons for this decision was that the majority of vehicles on the roads will still have conventional drive systems.

“The National Education Conference addressed electric mobility as a significant challenge for our society, identified where there might be a lack of skilled people and specified recommendations for future vocational training and higher education courses. The wide-ranging debate, from battery technology through to social acceptance of modern mobility strategies, left the delegates inspired and pleasantly optimistic about the future of Germany's automotive industry.”

Professor Karl Joachim Ebeling, President of the University of Ulm (which hosted the Education Conference) and Deputy Chair of NPE Working Group 6 – Training and Qualifications

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Professor Gunther Olesch (far right), Member of the Board at Phoenix Contact, explains his company's training strategies. (University of Ulm/R. Grass)

Driving the next generation of research talent

DRIVE-E programme

Each spring, the DRIVE-E Academy opens its doors to some 50 students from engineering or natural science programmes at German universities. They get to hear fascinating presentations by prestigious experts, demonstrate their own creative skills in workshops, visit big name car makers or small and medium-sized enterprises and experience for themselves the dynamic driving sensation offered by an EV. To qualify for a place at the DRIVE-E Academy, set up in 2010, students have to submit an application and a jury chooses the winners.

The Academy is part of the first programme designed to foster young talent in the area of electric mobility research. Christened "DRIVE-E", it was established by the BMBF and the Fraunhofer-Gesellschaft. The organisers select venues close to appropriate companies and to labs at which research is being carried out on the topic and the students can have a go themselves. Of course, the week-long event also provides ample opportunity to network with other students and representatives of the research and industry sectors. Indeed, the Academy has already been the launch pad for quite a few business ideas and careers.

The highlight each year is the DRIVE-E prize ceremony. Two prizes each are awarded in Category I (coursework, project work and bachelor's dissertations) and Category II ("Diplom" dissertations and "Magister" or master's theses). Abstracts can be submitted on topics such as electric drivetrains, energy storage systems and energy management, grid integration or vehicle concepts and driving strategies. Students may put their work forward for the prize irrespective of whether they attend the Academy.

"If German industry is to assume a leading role in the future global market that is electric mobility, it's essential that it has highly qualified professionals at its disposal. The DRIVE-E programme therefore aims to reach talented young people while they are still studying and encourage them to choose a career in this exciting, multi-faceted field. The Fraunhofer-Gesellschaft feels it is important to nurture the new generation of researchers in application-oriented areas; and its commitment to DRIVE-E, in partnership with the BMBF, is paying off. We organisers are amazed every year by the quality of the applications and the students' enthusiasm. The participants share ideas and network with each other, a process that's invaluable in spurring their professional development. In fact, it often results in a career in electric mobility or even joint projects. Over the next few years, we will be looking to expand this employee base to help ensure long-term success for Germany in the field of electric mobility."

Professor Lothar Frey, Director of the Fraunhofer Institute for Integrated Systems and Device Technology (IISB) and co-initiator of DRIVE-E

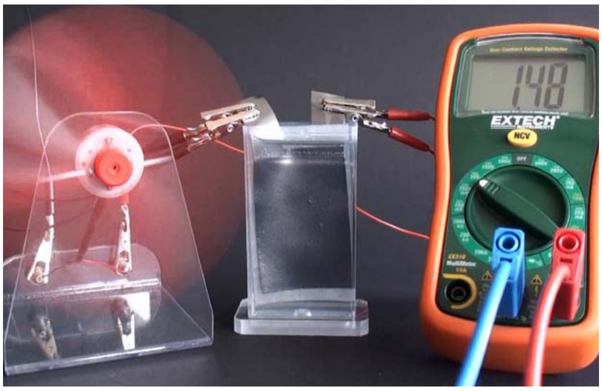
The DRIVE-E Academy: one week completely dedicated to electric mobility. (BMBF/Jörg Carstensen)

DRIVE-E-E 2013 in Dresden – students get their careers rolling. (BMBF/Jörg Carstensen)

Experiment kits

Putting theory into practice

Electric mobility belongs on the curriculum at school and university and the livelier and more accessible it is, the better. That is why Freiburg University of Education and Aug. Hedinger GmbH, with support from the BMBF, have developed a make-your-own lithium-ion battery kit. As these batteries have a complex make-up, the project partners have used a slightly modified method. The result is a robust experiment kit that is quick and easy to use, does not require any toxic substances and provides a clear visual demonstration of how such batteries function.



The battery experiment kit gives pupils a simple tool for making a lithium-ion battery. (Professor Marco Oetken and Martin Hasselman, Department of Chemistry, Freiburg University of Education)

“Although universities are generally strong in electrochemistry and electrical engineering, there is a lack of experienced experts to head up institutes and departments dedicated to electric mobility. The shortage can only be resolved by means of long-term, systematic measures. The crucial thing is to convey the thrill of natural science and electrical engineering to young people – ideally while they are still in school.”

Professor Werner Tillmetz, member of the Board of Directors of the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) and head of the Electrochemical Energy Technologies Division

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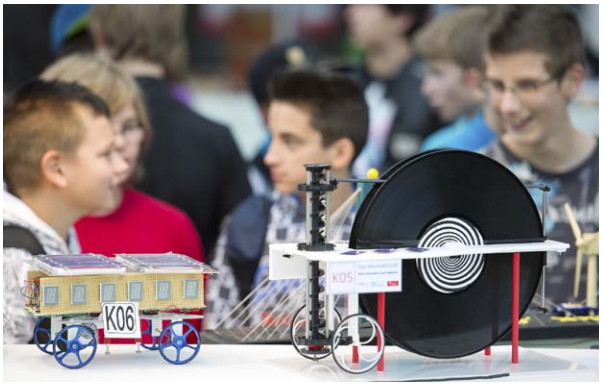
Electric car racing

SolarMobil Deutschland

The cars are at the starting line, ready to battle it out on the ten metre long track. But this is no ordinary race – the cars are solar-powered, ultra light models and the winner will be the one that makes most efficient use of the sun’s energy. The mini racers have been designed by teams of pupils aged eight to 14 and 15 to 18. The older pupils have an extra challenge to deal with – a tunnel. So they have to ensure energy is stored if they want to be in with a chance of winning.

There is also an exhibition of particularly quirky cars that have been awarded prizes for creativity. The jury has chosen them for their imaginative design (combined with operability).



The SolarMobil Deutschland competition is all about creative ideas and technical expertise. (BMBF/VDE)

This is all part of the SolarMobil Deutschland school competition, which the BMBF and the German Association for Electrical, Electronic and Information Technologies (VDE) have been running since 2010. It puts the spotlight on mobility, renewable energies, energy efficiency and teamwork and has proved a successful way of getting young researchers hooked on solar energy and electric mobility. The competition comprises regional rounds, followed by a national final, and also includes a prize category for particularly good posters.

Electric mobility up close

Electric mobility showcase projects

In a Germany-wide competition, four regions qualified as "showcases" aimed at giving people hands on experience of electric mobility. Projects in Berlin-Brandenburg, Bavaria-Saxony, Baden-Württemberg and Lower Saxony will set out to test and demonstrate to the public how EVs fit into everyday traffic scenarios. Rather than focusing on the actual vehicle, these activities will move forward to concentrate on integrating EVs into the electricity grid and existing traffic systems, incorporating customer requirements and developing business models and services.

One of the priority areas of the showcases is education and training. In the academic segment, work is underway to set up cross-university teaching content for existing courses in an effort to ensure consistency. For instance, the "Bavaria-Saxony Electric Mobility Showcase Academic Education Initiative" is a collaborative project by six universities in the federal states of Bavaria and Saxony. They have joined forces to develop new teaching formats for full-time programmes, part-time bachelor's and master's programmes, summer schools and (part-time) CPD programmes. Once they are ready, the plan is to make the formats and materials available to any German educational institutions that would like to have them.

At the end of 2012, the Baden-Württemberg "Living Lab BWe mobil" showcase launched the "Mobile Training Centre for Electric Mobility (MSE)" and "Electric Mobility Showcase – Take-a-Look Workshop" projects. The "MSE" project, which will run for two years, visits different types of school in a mobile info unit and uses specially developed materials to teach pupils and teachers alike about electric mobility. The objective is to present various aspects of electric mobility in a lively way and to inspire children and young people to find out more about the subject. The goal is to reach more than 5,000 pupils and to improve the teaching materials on an ongoing basis and make them accessible to the general public. The subject is also to be integrated into teacher training.

Initial and continuing training in the field of electric mobility is one of the focuses of the showcase initiative. (BMBF/Stefan Rauh)

The "Take-a-Look Workshop" has been designed for employees in companies working in the field of electric mobility. The project involves the development of a hands on, try-it-out-for-yourself pilot workshop for training and events. It is intended to inform employees about potential effects on their workplaces and draw their attention to possibilities for continuing training and potential career opportunities. In addition, modules for continuing training are to be developed based on the various topics covered by the workshop.

In the next few years, the BMBF will provide up to 20 million euros in financial assistance for the initial and continuing training projects as part of the government's showcase initiative.

"Electric mobility requires training strategies that go far beyond the actual EV. From the charging infrastructure to energy supply to transport systems, there is a mesh between the different areas, which means that initial and continuing training have to be delivered on several levels if they are to serve their purpose properly. The Bavaria-Saxony ELEKTROMOBILITÄT VERBINDET showcase specifically deals with the three pillars of school, vocational and academic training in all aspects of electric mobility."

Steffen Thie, Coordinator, Bavaria/Saxony Electric Mobility Showcase

Spotlight on: e performance

e performance was a research and development project that ran for three years and led to the creation of a fully electric demonstration vehicle. Partnering with Audi on the project were Bosch, several institutes at RWTH Aachen University as well as other German universities and research establishments. The researchers and engineers came up with a modular system, the modules of which can be used for various EV types and classes. The e performance project received around 22 million euros in financial assistance from the BMBF.

Actually, it would be more accurate to say the engineers developed lots of cars – not just one – in the form of a modular system. The idea behind this scalable architecture is that different modules can be used in different electrically propelled vehicles depending on the performance level required. So the system covers everything from sports cars to saloons to city cars and even plug-in hybrids.

A shining example of interdisciplinary collaboration: a vast team of industry and research professionals helped bring the e performance project to a successful conclusion in September 2012. (Audi AG)

Training

In particular, the project focused on bringing students and graduates together with experienced experts in companies to collaborate on solutions to the technical challenges. This creative blend yielded some impressive results: 20 Diplom dissertations, 50 doctoral theses and numerous bachelor's dissertations and other coursework were produced on the e performance project.

User interface

The car has an innovative user interface in the shape of an Apple iPad built into the centre console. The driver uses an app system to choose between the Eco, Comfort or Sport driving modes, control the interior heating, select the battery charging method (automatic or remote-controlled) and decide between front, rear or four wheel drive. All of the other infotainment functions, media players for instance, are also controlled via the iPad. The driver determines the direction of travel and chooses between neutral and park using just one button.

Instrument cluster

A customisable LCD panel below the windscreen displays all of the latest driving data. There is information on power input, regenerated braking energy, battery charging status, selected gear, energy used by the secondary electronic systems plus data on all of the other functions, which are selected via the iPad.

The cockpit is fitted with an iPad (on the right) that serves as the main control unit. (Audi AG)

Acoustics

An artificial driving sound is generated for the EV, which is a quiet vehicle per se, based on speed and other parameters. The idea is to raise the driver's and other road users' awareness of the vehicle, provide a positive feel in the car and give the acoustic feedback on the vehicle's operating status that drivers are used to.

Drivetrains

Three, separately controllable electric motors have been built into the car. There is a synchronous one on the front axle (for slow driving) and two asynchronous motors on the rear axle, which can be added in to provide quattro four wheel drive with a total horse power of 204.

The drivetrain solution devised on the e performance project, with a synchronous motor on the front axle, a twin motor on the rear axle and the battery in the middle. (Audi AG)

Battery system

The high voltage battery system is modular in structure and comprises two packs, each with 200 macrocells based on lithium-ion consumer cells. Safety in crash situations was a particular concern, which is why the macrocells have bevelled walls, enabling them to shift relative to each other in the event of a collision. Hollow aluminium sections between the macrocells can absorb the majority of the impact.

Charging device

The battery is charged via a cable. The on board charger speeds up the charging process considerably. Very small and light components can be used for the circuitry.

Power electronics

The team devised a scalable energy supply system for their modular design. Two direct current converters keep the battery current at a consistent level. The power module for the twin motor on the rear axle is attached to the motor's actual housing, which keeps things very compact. The front axle power module can be used for various types of motor.

Thermal management

The car's Makrolon® polycarbonate windows offer extremely good insulation and thus reduce the heating required inside the vehicle. Sensors monitor the air quality and help prevent condensation on the windows.

The volume flow rate in the cooling system can be adjusted. A heat pump has been added so that the lost heat can be recovered for heating purposes. The thermal manager controls the more than 40 sensors and 30 actuators. Settings can be adjusted to make optimum use of energy, taking into account the needs of the various components and parameters such as safety, driver requirements and vehicle dynamics.

“e performance has created a universal, modular system, with which a variety of vehicle platforms and drive types can be implemented. The lessons learned are invaluable for the vehicle projects currently underway at Audi. e performance yielded so many insights of such relevance that we have already decided there will be new projects to follow on from it.”

David Vergossen, Audi Electronics Venture GmbH

Summary

The automotive industry is facing radical change. After more than one hundred years of the internal combustion engine, alternative drive systems such as hybrid or fully electric motors are gaining in popularity. This trend is due in part to the knowledge that petroleum sources are limited, resulting in further price increases. But it also stems from an awareness of the risks of climate change and environmental pollution, to which car traffic and the emissions from it contribute.

Electric motors offer a promising alternative to petrol or diesel drivetrains, not least in view of the rapid spread of motor vehicles in the newly industrialising and developing countries, especially in Asia. Be it as hybrids or completely battery-powered vehicles, EVs supplied with electricity from renewable sources provide an opportunity for mobility that is kind to the environment and resources and appeals to users. And manufacturers in China, Japan, Korea and the US, plus our European competitors, have picked up on this.

Electric mobility is a technological challenge

If the German automotive industry wishes to maintain its position as a leading provider, it will have to deliver top performance at acceptable prices in the electric mobility segment too. That poses major challenges both for the car making industry and its suppliers because they need to do more than simply replace the internal combustion engine with an electric motor and the tank with a battery.

Since EVs are mainly controlled electronically, numerous new components will be required and they will have to work together in a smooth, safe and energy-efficient manner. Well-rounded solutions are called for in order for EVs to overcome the biggest challenge – ensuring an attractive travel range of a few hundred kilometres without detracting from comfort. At the same time, driving an EV needs to be as reliable, safe and comfortable an experience as driving a conventional car.

Other important prerequisites are convincing business models and an infrastructure that works properly and provides a fast, customer-friendly charging facility. All of that can only happen if new technologies are developed and professionals with the relevant skills are trained.

Pointing electric mobility in the right direction

The BMBF spotted the emerging trend and began investing heavily in electric mobility research and education as early as 2008. In keeping with the Federal Government's strategy, which is set out in the 2011 Electric Mobility Programme and which the National Platform for Electric Mobility is helping to implement, the BMBF is focusing on research into battery and energy efficiency technologies and on initial and continuing training. These aspects are key to getting EVs to market and moving. A primary goal is to strengthen cooperation between academia and industry by awarding financial assistance for networks and alliances. Support is specifically being given to joint activities across disciplines and sectors, in line with the interdisciplinary character of electric mobility. Germany has a solid basis upon which to build – both in terms of its rich university and research landscape and its system of dual vocational training and of its strong electrical engineering, mechanical engineering and chemical industries.

Strategic focus on batteries

Batteries will be the most expensive components in tomorrow's EVs and their efficiency will determine vehicle range. With range set to increase from the present level of 100-150 km to 250-300 km in the medium term, research on new battery technologies is one of the priorities. The batteries' energy and power density, their useful life and the number of charge cycles possible need to be increased but it is also essential that production costs decrease dramatically. BMBF-funded projects are therefore researching new materials for electrodes, separators and electrolytes but always without losing sight of the need for battery safety. That safety is ensured by choosing appropriate materials but also by means of mechanical stability and active control of the charge and discharge processes by the battery management system, including meticulous sensor-based monitoring.

A large number of the projects are dedicated to taking lithium-ion batteries, which already work well in the first generation of EVs, to the next stage. For the future, new battery solutions are being worked on with the aim of providing ranges in excess of 400 kilometres. The research projects supported by the BMBF are laying the foundations for other technologies such as lithium-sulphur or metal-air batteries. Efforts to install cell and battery production facilities for EVs in Germany are being stepped up so that the major added value that stems from the batteries can be created in Germany too. As a result, new production and processing techniques are being developed, as well as the machinery and plant needed to implement them, in line with the principle of improved resource efficiency. Key milestones that have already been achieved on this journey include the first production plant, which began operation in Kamenz in 2012, and the installation of a research production line in Ulm, where companies will be able to test and evolve materials, components or units from 2014 onwards. It is anticipated that the projects that end in 2015 will already help establish globally competitive, automated series production of large format lithium-ion cells, and batteries fitted with them, in Germany.

Strategic focus on energy efficiency
As the battery can only deliver a limited amount of power, the vehicle as a whole has to be extremely energy efficient. Though electric motors are already particularly efficient and easy to control, researchers are seeking to boost their efficiency and performance still further by, for example, inventing new materials for the magnets. Motor production is another area in which there is tremendous potential for enhancing performance. Improvements could be made, for instance, in the automated winding of the windings and the punching of the sheet metal used for the rotor and stator.

The power electronics, which convert and distribute the electrical energy as needed, perform a key function. New types of circuitry and assembly and connection techniques are opening up the possibility for ever smaller electronic components that, despite their compact size, can still cope with the tough conditions in EVs (be they due to immense fluctuations in temperature or high currents and voltages) and function reliably.

Lightweight construction methods will also help save energy. New, particularly light and hard-wearing materials such as magnesium alloys, high strength steels or carbon fibre composites are being developed for this purpose. However, another important aim is to devise inexpensive technologies for mass production.

All of these features will be implemented in comprehensive, new vehicle concepts. As well as catering for the need for conventional style cars with four wheels and four seats, they will include three-wheelers and one-seaters, which are particularly appealing for getting around cities and will therefore encourage market uptake. Researchers working on these ideas are, however, also committed to ensuring safety and comfort for drivers.

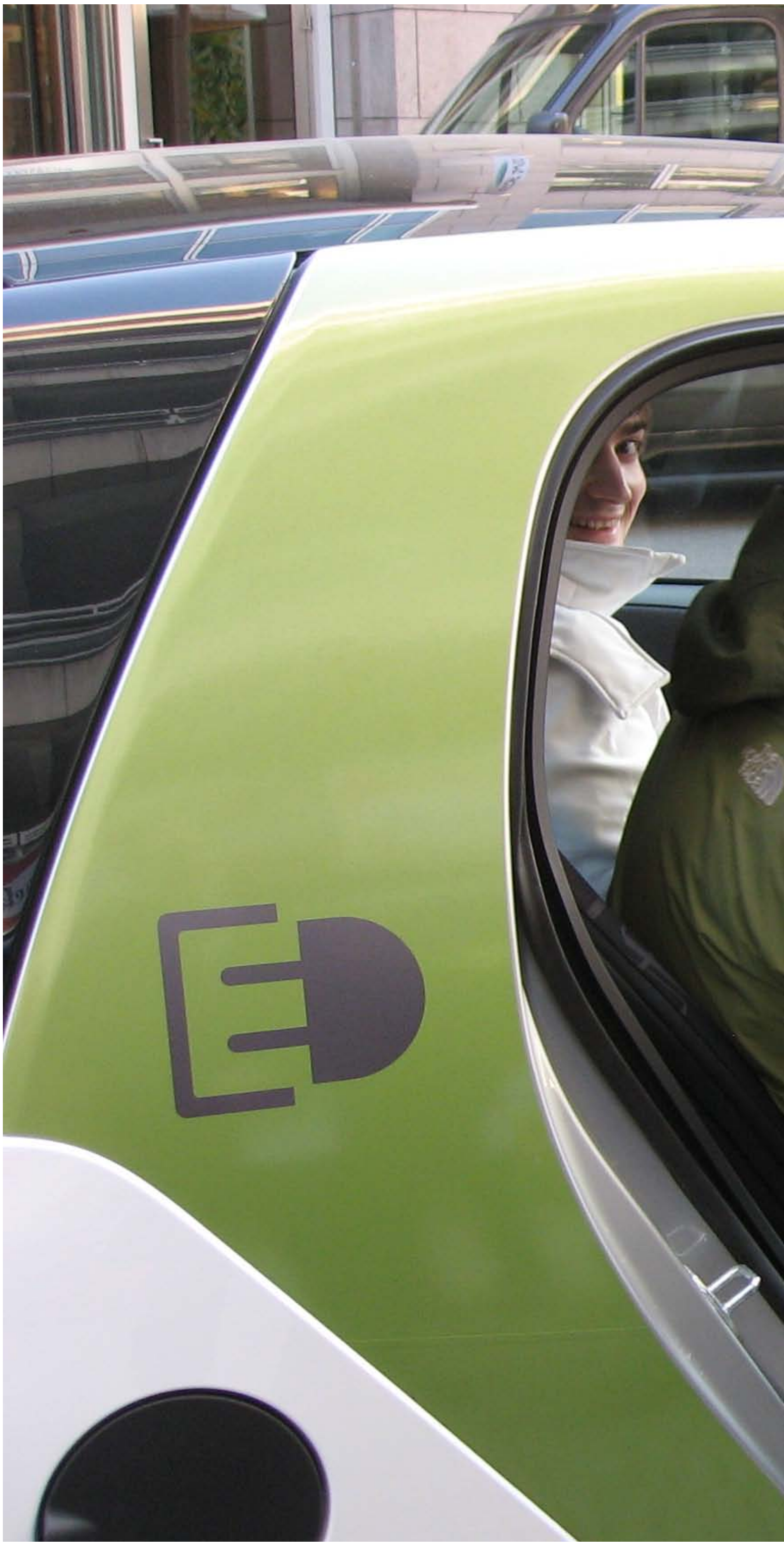
Strategic focus on initial and continuing training
Excellently trained professionals – for research, production and service delivery – are crucial if we are to master all of the technological challenges ahead and make electric mobility a success. New university courses and profiles for state-recognised occupations will not be necessary but the existing syllabi will have to be adapted to reflect the changing requirements. With this in mind, the BMBF awards funding for university networks and close collaboration between academia and industry. Jointly developed curricula and research projects help ensure training (both academic and vocational) is consistent and reflects real life, while also introducing young professionals to companies at an early stage.

An important tool in conveying the thrill of this field to young people is hands on experience. So the BMBF promotes creativity and teamwork in all areas of electric mobility – with the focus on the fun factor. Examples include experiment kits for schools and universities, design competitions such as SolarMobil Deutschland and holiday academies for students (e.g. DRIVE-E).

Establishing electric mobility requires staying power

Developing vehicles that combine excellence and good looks will not be enough to bring about an electric mobility breakthrough. With that in mind, the BMBF has launched a new programme to provide additional financial assistance for research into customer oriented services in all areas of electric mobility. Topics covered will include the establishment of an easy-to-use, nationwide charging infrastructure (including billing processes), new business and Build-Operate-Transfer (BOT) models, which will integrate EVs into existing transport structures in the form of, for example, car sharing, plus new IT infrastructures as the basis for such models.

It will take considerable staying power to turn Germany into a leading provider of electric mobility. After all, the internal combustion engine has been a success story for a hundred years so it will take more than a few years for the new technology to supersede it. Nonetheless, the goal is to make electric mobility competitive as soon as possible and the BMBF is putting the necessary mechanisms in place to achieve that through targeted funding of education and research. This approach will bear fruit in other areas too, not just for EVs. Many of the technologies invented for battery driven EVs can also be used in other vehicles. Hybrids and combustion engine vehicles, for example, can also benefit from better energy efficiency, lightweight construction and innovative electronics. And finally, as with any technology, many of the advances will have an effect beyond the mere car – in terms of stationary energy storage systems, more economical lighting, renewable energies and more efficient production plant.



Setting off on the road to electric mobility. (BMBF/Sabine Tomm)


Weltweite Dienstleistungen

Further information

Background information on funding for electric mobility

Federal Government Electric Mobility Programme (http://www.bmbf.de/pubRD/programm_elektromobilitaet.pdf)

Federal ministries

Federal Ministry of Education and Research (BMBF) (http://www.bmbf.de/en/14706.php)

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) (http://www.bmu.de/en/)

Federal Ministry of Transport, Building and Urban Development (BMVBS) (http://www.bmvbs.de/en/)

Federal Ministry of Economics and Technology (BMWi) (http://www.bmwi.de/EN/root.html)

Federal Funding Advisory Service

http://www.foerderinfo.bund.de/en/

Promotion of new talent

DRIVE-E programme (http://www.drive-e-org) (German only)

INVENT a CHIP (www.invent-a-chip.de) (German only)

SolarMobil Deutschland (www.solarmobil-deutschland.de) (German only)

Spotlights

South-West Leading Edge Cluster for Electric Mobility (http://www.emobilbw.de) (German only)

Fraunhofer System Research for Electro Mobility (http://www.elektromobilitaet.fraunhofer.de/en/)

e performance (http://www.audi-future-lab-mobility.de/en/)

Funding programmes

E-Energie (http://www.e-energie.info/)en/

ElektroMobil.NRW (http://www.ziel2-nrw.de/2_Wettbewerbe_und_weitere_Foerdermoeglichkeiten/1_Wettbewerbe_2009/ElektroMobil_NRW/index.php)

ICT 2020 (http://www.bmbf.de/en/9069.php)

Pilot Regions for Electric Mobility (http://www.bmvbs.de/SharedDocs/DE/Artikel/UI/modellregionen-elektromobilitaet.html)

National Development Plan for Electric Mobility (http://www.elektromobilitaet2008.de/)

Electric Mobility Showcases (http://www.schaufenster-elektromobilitaet.org/programm/)

WING – Materials Innovations for Industry and Society (http://www.bmbf.de/en/3780.php)

Initiatives and alliances

ARTEMIS – Embedded Computing Systems Initiative (http://www.artemis-ju.eu/)

AutoCluster NRW (http://www.autocluster.nrw.de /)

Bayern Innovativ – Cluster Automotive (http://www.bayern-innovativ.de/85a43b49-1610-104b-6c59-283cff086c92?Edition=en)

CATRENE – Cluster for Application and Technology Research in Europe on Nanoelectronics (http://www.catrene.org/)

DEUFRAKO – German-Franco Cooperation in Transport Research (http://deufrako.org/web/index.php) (German only)

ECPE European Center for Power Electronics e.V. (http://www.ecpe.org/)

edacentrum – (institute for electronic design automation) (https://www.edacentrum.de/en/)

ENIAC – European Nanoelectronics Initiative Advisory Council (http://www.eniac.eu/web/index.php)

eNOVA – Strategy Board for Electric Mobility (http://www.strategiekreis-elektromobilitaet.de/english)

EPOSS – European Technology Platform on Smart Systems Integration (http://www.smart-systems-integration.org/public)

ERTRAC – European Road Transport Research Advisory Council (http://www.ertrac.org/)

Federal Association for Electric Mobility (http://www.bem-ev.de/)

Federal Association for Solar Mobility (http://www.solarmobil.de/)

Forum Elektromobilität e.V. (http://www.forum-elektromobilitaet.de /)

Innovation Alliance for Green Carbody Technologies (http://www.bmbf.de/press/2590.php)

LIB2015 Innovation Alliance (http://www.lib2015.de/)

National Organisation Hydrogen and Fuel Cell Technology (http://www.now-gmbh.de/en/)

Associations and Organisations

VDA – Association of the Automotive Industry (http://www.vda.de/en/index.html)

VDI – Association of German Engineers (http://www.vdi.eu)

ZVEI – German Electrical and Electronic Manufacturers' Association (http://www.zvei.org/Seiten/Startseite.aspx)

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