

German Federal Government's National Electromobility Development Plan

August 2009

1	Executive summary	2
2	Introduction	3
3	Potential, challenges and goals	5
3.1	Definition of electromobility under the Development Plan	5
3.2	Potential of electromobility	8
3.3	Challenges posed by electromobility	9
3.4	Strengths, weaknesses, opportunities and threats in German electromobility	15
3.5	Goals of Development Plan	16
4	Activities by the German Federal Government	18
5	Proposed measures	22
5.1	Initial implementation steps - electromobility as part of the German Federal Government's Economic Stimulus Package	22
5.2	Developing Germany into the lead market for electromobility	25
5.2.1	Research and development	25
5.2.2	Enabling framework	33
5.3	National and international cooperation	39
6	Outlook	40
Annex:	Glossary	45

1 Executive summary

After far more than 100 years of developments in the internal combustion engine, electromobility heralds the dawn of a new technological era in road transport. The electrification of drives is crucial to the future of mobility. It affords the opportunity to lessen dependence on oil, minimise emissions and facilitate the integration of vehicles into a multimodal transport system.

Even though the internal combustion engine will remain important for transport in the foreseeable future and we need to keep additional efficiency improvements and biogenic fuel use on the transport policy agenda, we must begin today to make the necessary gradual transition to new efficient technologies. To keep up with international competition, Germany must become the lead market in electromobility and maintain the leading role of its scientific capabilities and its motor-vehicle manufacturing and parts supply industry.

The aim of the National Electromobility Development Plan is to speed up research and development in battery electric vehicles and their market preparation and introduction in Germany. The measures adopted in the German Federal Government's Economic Stimulus Package II will act as catalysts. They must be continued over time and respond to technological progress.

The essential technologies for electric drives, energy storage and grid infrastructure have already been developed. There is, however, still need for research, improvement and networking at many points in the supply chain. Greater efforts must above all be made in the key technology of storage batteries to maintain and strengthen the global competitiveness of the German motor-vehicle industry.

In the short term, we can begin the shift towards electromobility through demonstration projects and field tests. The first plug-in hybrid and battery electric vehicles can reach market maturity in a few years. The battery charging infrastructure will have to be built up gradually, starting at local or regional level. For broad market introduction, the cost structures of the vehicles need to be improved along with their suitability for everyday use. Due to the technological and economic challenges we still face today, it will probably take more than a decade for electric vehicles to glean a significant market share. The German Federal Government is looking to have one million electric vehicles on the road by 2020.

With its National Electromobility Development Plan, Germany has laid out a sound and broad starting grid. To travel faster on the road to the future, government, but especially industry, will have to step up their efforts. The German Association of Energy and Water Industries (BDEW), the German Association of the Automotive Industry (VDA) and the German Electrical and Electronic Manufacturers' Association (ZVEI) have only recently begun to shoulder responsibility here. To prepare the way for a broad introduction of electric vehicles in the coming years we shall need to take a number of policy, regulatory, technical and infrastructure measures. Open European standards will need to be set, for example, to ensure interoperability, safety and acceptance at a high global level. The German Federal Government will make its contribution in the next 10 years under the National Electromobility Development Plan. Besides regulatory measures to support progress in battery technology, grid integration as well as market preparation and introduction, consideration will be given to a market incentives programme and the best way of implementing it. Any further government activities will be subject to budget appropriations and policy decisions in the next legislature.

Ultimately, electric vehicles will only come into general use if total costs, including infrastructure, reach the point where no permanent subsidies are required in competition.

From the outset, then, the implementation of the National Electromobility Development Plan will require close consultation among all stakeholders. To do this, we need to set up a National Electromobility Platform made up of policymakers, industrialists and scientists, local government officials and consumers and able to appoint working groups for specific tasks.

Electromobility is another step by the German Federal Government in its strategy of lessening dependence on oil. In combination with renewable energies, it will make an important contribution to implementing government climate protection goals, as already set out in the Integrated Energy and Climate Programme (IECP). Electromobility is also important for the Federal Government's Fuel Strategy and High-Tech Strategy (HTS). It can also help pave the way towards a new culture of mobility and modern urban and regional development planning.

Electromobility means a paradigm shift for the transport and energy sector. Today, we can map out the best route towards future mobility, negotiate the questions and challenges and head for our destination on a journey of ongoing development.

2 Introduction

The German Federal Government's Integrated Energy and Climate Programme cites electromobility as a major component and its implementation report calls for drafting a National Electromobility Development Plan.

Ensuring long-term mobility calls for highly efficient vehicles that can be driven with alternative energies. Electric drives (hybrid, battery and fuel cell vehicles) afford great scope for lessening dependence on petroleum as a fuel and reducing CO₂ and local harmful emissions. Plug-in and battery electric vehicles, which are included in the Development Plan, are the first choice for energy efficiency. European neighbours and other countries, such as the USA, Japan and China, have already grasped this and support their industries with extensive programmes on the way to electromobility. Germany aims to take the lead.

Electromobility is therefore an issue of major strategic importance for the German Federal Government, as stipulated in the Integrated Energy and Climate Programme in combination with energy supply from renewable sources. The responsible ministries, the Federal Ministry of Economics and Technology (BMW_i), the Federal Ministry of Transport, Building and Urban Affairs (BMVBS), the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Federal Ministry of Education and Research (BMBF) entered into intensive joint dialogue with the business and science community to discuss the challenges and opportunities and draft guidelines for implementing the ten-year plan to achieve its electromobility goals. The outcomes of these discussions have been included in the National Electromobility Development Plan, which sets out the framework for future research, technological developments and market entry in Germany.

In the government's updated Fuel Strategy, electromobility is seen as a major means for the faster reduction of dependence on petroleum as a fuel. Alternative drive concepts and new transport technologies also play a major role in its High-Tech Strategy. Finally,

electromobility will also afford opportunities to introduce new categories of vehicle and modern transport schemes.

Overall, in terms of energy transport efficiency - from production via transport to the wheel - electrical energy is superior to fossil fuels. It also affords broad scope in the choice of primary energy source. The use of renewable energies, such as sun and wind, in particular can curb the emission of greenhouse gases in road traffic by a large margin. The vehicle batteries can be integrated into the power supply to increase grid stability in the medium and longer term, which will play an increasing role with larger ratios of variable energy inputs.

The German Federal Government's Integrated Energy and Climate Programme of 5 December 2007 has set out major parameters for an ultramodern, secure and climate-friendly energy supply system in Germany, primarily based on enhanced energy efficiency and renewables. It has also defined measures for ambitious and efficient climate protection. Government goals in electromobility are specified in Chapter 26.

The National Electromobility Development Plan envisages the development and promotion of a concerted strategy with the collaboration of science, industry and government, from basic research to market entry. It encompasses the whole supply chain from materials, components, cells and batteries to the entire system and its application. It also provides for devising a scheme to integrate the additional power demand generated by electromobility into the grid, link this demand with renewable energy sources and use electromobility to contribute to grid load management. This will ultimately position Germany as a lead market for electromobility and enhance the long-term competitiveness of the motor-vehicle manufacturing and parts supply sector as one of the major pillars of national industry.

In the next ten years, we can expect to see rapid technological and economic development in electromobility, which will call for a 'learning programme'.

To facilitate the implementation of the National Electromobility Development Plan through concerted action by all national stakeholders, the German Federal Government has taken initiatives in information exchange, networking and knowledge transfer. It held a strategy conference on 25 and 26 November 2008 to discuss key points for the plan. The conference underscored the importance of electromobility as a central field of innovation and demonstrated that industry is prepared to engage in multisectoral cooperation to advance Germany on the way to becoming the lead market. It also highlighted the need for government action in cooperation with science and industry in research and development, market preparation and introduction as well as in establishing the requisite enabling framework. The government goals pursued in the Development Plan also met with broad endorsement.

The measures provided for in the Pact for Employment and Stability in Germany to Safeguard Jobs, Strengthen the Forces for Growth and Modernize the Country (Economic Stimulus Package II) will act as a catalyst to enable the German motor-vehicle manufacturing and parts supply industry in the present economic crisis to build up its own research and development activities and gain technological and market leadership in electromobility, as it has succeeded in doing elsewhere. Other economic sectors, such as energy suppliers, public utilities, ICT service providers and research institutions will also benefit from these measures.

STARTING POINT

Electromobility has been identified as a major element and accorded a strategic role in the German Federal Government's policy agenda.

GOAL

The German Federal Government's Economic Stimulus Package II aims at combining near-term economic impacts with strengthening Germany's long-term future viability.

In the next ten years, we can expect to see rapid technological and economic development in electromobility worldwide. Electromobility poses a complex organisational challenge that goes beyond the technical issues as such (vehicles, system and infrastructure).

Electromobility

- will develop in phases;
- needs active management - also by policymakers;
- must be developed and achieved in interaction among global actors and regional implementing agencies.

Proceeding from the policy goals set and a realistic assessment of the initial conditions in technology, infrastructure, etc., the necessary development priorities have been defined based on the draft National Electromobility Development Plan, which will be continually updated.

3. Potential, challenges and goals

3.1 Definition of electromobility under the Development Plan

The electrification of drives is the key to a viable future transport system. In the assessment of the German Federal Government, battery and fuel cell technologies are mutually complementary paths that need to be pursued together. Besides the National Hydrogen and Fuel Cell Technology Innovation Programme (NIP) already successfully underway, the National Electromobility Development Plan will now step up efforts in battery and all-electric drive technologies.

Besides road transport, electric drives also play a role in rail and shipping. At present, no relevant approaches are being pursued for electric drive technologies in air traffic. Subsystems in ships and airplanes are, however, being electrified using fuel cells to reduce fossil fuel consumption.

In the National Development Plan, the electromobility vision is confined to road transport. The particular concern here is with cars, light commercial and two-wheeled vehicles (scooters, electric bicycles) and light vehicles. The electromobility strategy can also include city buses and other vehicles. Hybrid designs also afford scope for substantial CO₂ and energy savings in the short and medium term.

The demarcation criterion for the different drive technologies is the main source of energy used by the vehicles (petrol and diesel, gas, hydrogen, electric current). In pursuance of the IECP, the National Electromobility Development Plan is concerned with battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV), including range-extended electric vehicles (REEV). Both types of vehicle can be driven with electricity alone and charged at the power mains. Using renewable energies here affords scope for a substantial reduction in these vehicles' CO₂ emissions.

Plug-in hybrid drives have a greater fuel reduction potential than the present hybrid vehicles. The key feature in these is the electromotor that supplements the conventional internal combustion engine, enabling electrical operation for a short time. Based on these energy-saving vehicle concepts already available on the market, the present National Electromobility Development Plan aims at speeding up market preparation for plug-in hybrid drives and electric vehicles.

Comparison of electric vehicles with other vehicle types

Vehicle type	Acronym	Ratio of power grid use for battery supply	Included in National Electromobility Development Plan	Typical features
Electric vehicle	BEV (battery electric vehicle)	100%	Yes	<ul style="list-style-type: none"> • Electromotor with grid chargeable battery • Cars but also two-wheeled vehicles • High potential for CO₂ reduction through use of renewable energies
Electric vehicle with range extension	REEV (range-extended electric vehicle)	Partial, depending on battery range and use	Yes	<ul style="list-style-type: none"> • Electromotor with grid chargeable battery • Modified low-performance internal combustion engine or fuel cell
Plug-in hybrid vehicle	PHEV (plug-in hybrid electric vehicle)	Partial, depending on battery range and use	Yes	<ul style="list-style-type: none"> • Electromotor with grid chargeable battery • Combination of classical internal combustion engine and electromotor • Cars as well as commercial vehicles (e.g. delivery vehicles)
Hybrid vehicle	HEV (hybrid electric vehicle)	No grid connection	No, but important for the development of PHEV and BEV	<ul style="list-style-type: none"> • Conventional internal combustion engine plus electromotor • Battery charging through braking energy recovery • Cars and commercial vehicles
Fuel cell vehicle	FCHEV (fuel-cell hybrid electric vehicle)	No grid connection	No (use of synergies through exchange with NIP)	<ul style="list-style-type: none"> • Electromotor with fuel cell for energy supply

3.2 Potential of electromobility

1. Protecting the climate:

Electromobility can make a major contribution to reducing CO₂ emissions in the transport sector.

Car traffic causes approx. 14% of CO₂ emissions responsible for the greenhouse effect in Germany. On energy balance (well-to-wheel), electric drives are already more efficient compared with the internal combustion engine under today's power station mix and can thus contribute to a reduction in CO₂ emissions. Substantial climate benefits can, however, only be gained when electricity is generated from other sources than fossil fuels.

2. Safeguarding energy supply:

Driving with electric current can reduce our dependence on oil.

Electromobility will enable a broader diversification of the primary energy sources used for mobility. Besides reducing dependence on petroleum, this will also enable access above all to the whole gamut of renewable energies.

3. Developing Germany as a location for technology and industry:

Germany can become a lead market for electromobility, which will give fresh innovatory impetus to the national economy.

The motor-vehicle manufacturing industry is one of the major export sectors in the German economy. Vehicles made by German manufacturers are held in high regard worldwide for their innovative design, safety and reliability. Strategic alliances in power train electrification with the traditionally well-placed German parts suppliers could provide substantial innovatory impetus to the German motor-vehicle manufacturing industry, thus strengthening the entire economy.

4. Reducing local emissions (environmental protection):

Electric vehicles can free towns of pollutants, fine dust and noise to raise the quality of life.

Microclimates in urban centres and conurbations today are heavily impaired by exhaust, fine-dust and noise emissions from traffic. The need to reduce these emissions here and keener competition among municipalities and regions as sustainable places to live and work are conducive to advancing acceptance for zero-emission mobility in urban areas. Electric vehicles do not emit any local pollutants and are also very quiet. Electrifying commercial fleet and distribution traffic (e.g. refuse collection, town cleaning services) will afford additional scope for reducing local emissions.

5. Integrating vehicles into the mains system:

Battery electric vehicles will help improve grid efficiency and promote the development of renewable energies.

The intelligent use of electric vehicle batteries for storage affords the opportunity of raising overall power supply efficiency, by smoothing out production peaks, aligning production and load curves more closely and supplying balancing energy in future. The ability for storage in a variety of vehicle batteries mitigates adverse fluctuation effects and will facilitate the continued expansion of renewable energies in the whole system. The future grid integration of electric vehicles as suppliers of balancing energy will also raise the efficiency of conventional power stations, which will not need to be started up and shut down as frequently to deliver this energy. This will contribute to reducing the demand for fossil fuels, but will also result in shorter battery service life.

6. Paving the way for new mobility:

Electric vehicles can contribute to future intelligent and multimodal mobility schemes.

The modes of mobility we know today will change in future. They will be more diverse, more individual and better suited to modern urban landscapes and progressive mobility strategies. Electric vehicles will contribute to making a considerable improvement in the quality of life, especially in conurbations. Emotional associations with driving will also help gain acceptance for electromobility.

3.3 Challenges posed by electromobility

Harnessing the prospects of electromobility poses many challenges that call for multisectoral measures, the involvement of new actors and new modes of cooperation. Prime emphasis will be placed on multiple issues in research, a suitable enabling framework and market preparation and entry.

Due to the complexity of electromobility and its strategic locational significance for Germany, we cannot afford to confine attention to single components or subsectors; we need to incorporate the whole supply chain for designing and promoting the lead market.

Supply chain

Raw materials	Components	Vehicles	Electricity	Infrastructure	Mobility providers
Procurement/ processing	Development/ production/ recycling/training and competency development	Development/ manufacture/ sale/competency development	from renewable energies/grid management	Installation and operation of charging stations, grid infrastructure	Business models

This ranges from materials and raw materials for lithium-ion batteries and electromotors, to new components for electric drives to overall energy management. Devising new vehicle concepts, modernising energy supply systems, building new infrastructure (e.g. battery

charging stations) and developing specific supply capacity and business models are all equally necessary. Another challenge is to identify possible ways that electromobility can contribute to smart grid management. Harnessing the potential of this technology can help increase the share of renewable energies in the German electricity mix (e.g. by compensating for variable windpower).

Research and development - energy storage:

Electromobility requires efficient, safe and affordable battery systems.

The motor-vehicle manufacturing industry makes the following chief demands on battery systems for future electric vehicles:

- **Battery costs:** Lower battery costs are essential for broader market introduction. Today's costs of EUR 1,000 – EUR 1,200 per kWh of storage capacity still exceed the international targets by a multiple (typical, small electric cars with a range of 100 km presently incur battery costs of EUR 10,000 to EUR 15,000). The target cost amounts to EUR 300 to EUR 500 per kilowatt hour. This must be met to be able to generate a mass market for electric vehicles.
- **Higher energy and/or power density:** The energy density of 200 Wh/kg for battery systems generally demanded by 2015 means almost doubling that of present lithium-ion batteries. High energy density permits longer ranges, while high power density enables rapid power output, e.g. for acceleration and fast storage of braking energy (recuperation). At present, no available batteries meet both requirements in equal measure.
- **To match a comparable range with today's cars in the long term, batteries will need a drastic rise in specific energy density.** Brand new types of battery, such as chargeable metal-air batteries, are a possibility, with prospective energy densities of up to 1,000 Wh/kg. Long-term basic research will need to be conducted to explore these new approaches.
- **Longer service life and higher cycle stability:** Due to high battery costs, the demand is for battery service life to equal that of the vehicle. Requiring a service life of 10 - 15 years also means the ability to cope with 3,000 – 5,000 charging cycles without major detriment to the parameters. Another task here is to improve the quick-charge capacity for plug-in and electric vehicle batteries (for shorter charging times and, with that, increased mobility).
- **Improved safety features:** In normal operation, a battery management system ensures the necessary safety. This must also be assured for accidents or misuse that could cause fires or explosions.
- **High-power double-layer capacitors** are particularly effective for high and rapid performance requirements and can therefore provide a useful addition to batteries with high energy densities. The prime concerns in the future development of supercapacitors must be higher energy efficiency, a considerable improvement in manufacturing quality, reliability and the sustainable reduction of production costs.
- **Reductions must be made in weight, volume, charging times, the heavy dependence on operating temperature and in the use of toxic components.**

Research and development - vehicle technology:

Electromobility requires new concepts for vehicles, drives and components.

Electrically-powered vehicles will be developed to meet user needs, as a car for short trips in town, as a delivery van for the last mile in stop-and-go traffic or as a thrifty hybrid car with a long range. To improve the cost-effectiveness and acceptance of plug-in hybrid and electric vehicles, the electrical and mechanical components need to be developed, optimised and assimilated into a vehicle.

Since the electromotor in a hybrid vehicle functions both as motor and generator, solutions will have to be found for the diversity of motor designs and materials used. Another way of maximising performance when combining internal combustion engines with electric machines can be found in the engine itself. A systematic analysis must be made of the different layouts, depending on mode of operation, control and vehicle size.

Power electronics for motor control as well as other electronic controllers for drive and stability control systems need developing for the respective current performance category in tandem with the electrification of (auxiliary) power units, in industrial vehicles, for example. The necessary cooling for power electronics and batteries calls for new applications in on-board technology, catering for installation space, passenger protection, weight, reliability and electromagnetic compatibility.

Initial research on power train management in hybrid vehicles shows that knowing the route profile ahead of the vehicle can be relevant for rationalising consumption. Coupling vehicle navigation with driver assistance systems could help here.

Research and development - grid integration:

Electromobility requires new methods for integrating vehicles into power grids.

The first phase of grid integration for electric vehicles will focus on battery charging. Battery states of charge will be monitored on the vehicle side at first. Capacity bottlenecks due to additional power demand from the power grid could be largely avoided through intelligent control of charging outside peak load periods.

Besides traction functions, the vehicle battery in the second phase of electric vehicle grid integration will also function as a mains storage component with feedback capability. Feedback will be supervised, regulated and controlled on the grid side. Due to the increasing number of electric vehicles in this phase, the requisite additional power supply capacities will be enlarged by developing renewable energies. A promising synergy impact of electromobility will be the resulting ability to buffer variable electricity inputs for improved availability. As a storage element, vehicle batteries, particularly from larger fleets of vehicles, could be linked into combined renewable power plants (ICT-based interconnection of wind, biomass and photovoltaic systems, for example) and thus contribute to the continuity, cost reduction and improved marketability of electricity from renewable energies.

Another advantage of using additional storage components could be gained through improved load management strategies and the rapid provision of reserve power, to the benefit of power supply efficiency overall.

- Charging energy storage units: Advanced solutions based on information and communication technologies (ICT) are needed here to avoid charging bottlenecks. Control and billing systems must also include micro users.
- Charging and discharging storage units: Compensating for the fluctuation effects of renewable energies through intermediate storage requires regulatory and control mechanisms at medium and low voltages.
- Advanced information and communication technologies need to be applied to ensure the continuity of load supply, avoid adverse operating states in power station and grid components and reduce balancing and reserve capacities.

Enabling framework:

Training

Recycling sector

Standardisation

Regulatory legislation

- The shortage of scientists, engineers and technicians threatens to pose the largest growth constraint on electromobility.
- To secure the availability of important raw materials for the traction batteries, such as lithium or cobalt, also when electric vehicles have gained a larger market stake, it is very important to develop economical recycling procedures and guarantee high return rates. Setting up appropriate return systems and recycling capacities will make for an important competition factor.
- To ensure that electromobility is not hindered by national boundaries and products can be distributed worldwide, international norms and standards need to be set (e.g. for plugs, power ratings or safety measures). As a leading export nation, Germany must take initiatives early on here.
- New mobility concepts can have a positive effect on the urban landscape. Preparations already need to be made today for the requisite amendments to urban planning law and changes in future land use (e.g. location of and access to charging stations in public spaces) to ensure the rapid development of electromobility.
- An enabling framework needs to be established in the near term for the use of hybrid, plug-in, hybrid and battery electric vehicles to cater above all for the potential battery hazards, especially from lithium-ion batteries. These must specifically include provisions on transport, storage, return, disposal and extinguishing battery fires, etc.

Markets:

Market preparation (developing business models)

Involving users, diversifying applications

Organising market entry

- First of all, electromobility will link two industries that have hardly had anything to do with each other in the past: motor-vehicle manufacturing and power supply. The ability to harness potential synergies in this new constellation will heavily depend on how the interface is defined between electric vehicles and the power grid. Companies and research institutions in information and communication technologies will have to make major contributions. The parts supply industry can also be expected to play an increasingly important role as an innovation driver.
- As to the question of who should finance the currently high additional costs for the vehicle battery and the implications of its grid integration, it is too early to decide on the underlying business models and which industry should apply them.
- Except for niche products, electromobility is still in the market preparation phase. Electric vehicles and schemes for grid integration still need to gain consumer acceptance. Users of new products must be involved early on in the emerging applications to make the findings gained in demonstrations and field tests available to all stakeholders for the purposive development of vehicles for specific uses. Fleets of vehicles in the public sector should also play a leading part here.
- Market development as envisaged in initial forecasts would proceed too slowly and at an inadequate level to make marketing electric vehicles commercially attractive to manufacturers at present. German battery makers already expect the market introduction of plug-in and battery electric vehicles by 2010/2011, but most studies only predict a higher prevalence of electric vehicles over the medium term, because the service life, temperature tolerance and production costs of the storage media and electric power converters do not currently meet the requirements for more widespread use. Hybrid or electric vehicles are only expected to make up about 50% of all vehicles sold in 20 years time, for example. Electrically powered vehicles will already begin to play an increasing role in the medium term. To harness the potential afforded by electromobility, there is a need for faster and deeper market penetration than forecast. Industry in particular will also have to develop strategies here to accelerate market entry.

International comparison:

Other leading industrialised nations are devising strategies for electromobility.

The German Federal Government recognised the importance of electromobility early on and has taken up the challenge by drawing up its National Development Plan. In view of the scale of the forthcoming challenges, an international comparison can furnish additional pointers for a discussion of the measures that need to be taken by industry, science and government. The cases cited below date from the beginning of 2009:

- In its regulation setting emission performance standards for passenger cars, the European Union has limited average CO₂ emission for new cars. By 2015, the emissions of all new vehicles will be gradually lowered to 130 grams CO₂ per kilometre on Europe-wide average with another 10 grams per kilometre to be saved by means of other technical improvements and the increased use of sustainable biofuels.

The regulation, which also provides for higher target accounting of electric vehicles in the first years, also sets incentives for the introduction of alternative drives, including electric vehicles.

- The European Economic Recovery Plan issued by the European Commission at the end of November 2008 contains a Green Cars Initiative to promote research and development activities in safe and energy-efficient mobility - particularly electromobility. The Initiative includes both a lending programme by the European Investment Bank and the provision of subsidies through additional calls to tender pending publication in 2009 and 2010 under the 7th Research Framework Programme. It will be implemented as a public-private partnership between the European Commission and industry and dovetailed with relevant programmes in the member states. The Directorates General for Research, the Information Society and Media, Transport, and Energy are engaged on the European Commission side along with private enterprises.
- France intends to promote research and development for hybrid and electric vehicles with an overall budget of EUR 400 million over the next four years. Under a bonus-malus arrangement, purchase subsidies of EUR 5,000 are to be granted for vehicles with low CO₂ emissions below 60 g of CO₂/km. Under its Low Carbon Vehicle Programme in 2009, the United Kingdom is to promote research and development in subcomponents for electric and hybrid vehicles and grant purchase subsidies for the first electric and plug-in hybrid vehicles.

Other countries, such as the USA, Japan and China, support their industries and research institutes with extensive programmes on the way to electromobility.

- With a fund totalling approx. EUR 1 billion, China promotes technological innovations in more efficient drive technologies. Moreover, the Chinese Ministry of Science and Technology is supporting the development of over 10 pilot regions with more than 10,000 vehicles and approx. EUR 2 billion between 2009 and 2011.
- The US Government plans to invest US\$ 150 billion dollars in energy technology over the next 10 years and another US\$ 2 billion to promote advanced battery technology and components for electric vehicles. Demonstration projects will also be promoted with a total of US\$ 400 million dollars in infrastructure for electromobility. US\$ 25 billion has been earmarked as loans for motor-vehicle manufacturers and parts suppliers to equip or extend production centres for fuel-saving vehicles (Advanced Technology Vehicles Manufacturing Loan Programme - ATVM). It will also introduce fuel economy regulations for passenger cars and some other types of vehicle for domestic sale in the model years 2012 - 2016 with a target average CO₂ emission by 2016 of approx. 155 g/km.
- Japan supports the development of improved traction batteries with US\$ 200 million over five years, aimed at halving cell costs by 2010.

3.4 Strengths, weaknesses, opportunities and threats in German electromobility

The best starting point for devising a strategy is to review the current position. The standard tool for this is the SWOT analysis, the American acronym for strengths, weaknesses, opportunities and threats, also known as potentials analysis. Strengths and weaknesses are internal factors that are subject to active influence, while opportunities and threats are external factors amenable to limited influence only.

SWOT analysis: Electromobility in Germany	
Strengths	Weaknesses
<ul style="list-style-type: none"> • Global leader in motor-vehicle manufacture, drive technology and power electronics • Leader in energy technology (particularly renewable energies) • Leading position in industrial information and communication technology (ICT) • Rapid development of renewable energies in electricity mix • Modern infrastructure and high technical standard in energy supply grids • Good research infrastructure in major high-tech sectors • Germany well positioned for developing and constructing complex system technologies • Established and efficient recycling systems • Generally good infrastructure for testing and certification of technical products • High innovativeness and advanced environmental awareness 	<ul style="list-style-type: none"> ■ Very few production facilities for cells and battery systems • Battery research and training of junior scientists in need of expansion • Multisectoral cooperation among motor-vehicle manufacturing industry, electric power industry and battery manufacturers still in infancy • Lack of serial production experience with hybrid drives • High battery costs worldwide • Lack of norms and standards, e.g. for interfaces between vehicle and charging infrastructure, for safety aspects or testing and measurement procedures • European and global standards and norms still unspecified

Opportunities	Risks
<ul style="list-style-type: none"> • Germany established as lead market for electromobility • Reduction of import dependence on petroleum; securing long-term mobility • Contribution to climate protection and reduction of local emissions • Additional impetus for renewable energies and strengthening supply security • Improved grid integration of variable renewable energies and efficiency of electricity generation overall through mobile storage units • Innovative impetus for German motor-vehicle manufacturers, parts suppliers and ICT industries • Multisectoral cooperation • Creation of new jobs for highly skilled personnel 	<ul style="list-style-type: none"> • High investment needs • Insufficient access to key technologies in cell and battery systems • Progressive economies of scale for battery systems not assured • Isolated technical applications could impede market penetration • Danger of raw materials dependence and availability curbing growth • Reticence towards electric vehicles (e.g. costs, safety, range) • Unrealistic public expectations causing possible disappointment • Faster progress made by competitors

3.5 Goals of Development Plan

Electromobility will contribute to implementing energy and climate policy goals.

1. Electromobility will make a significant contribution to meeting climate protection targets.
2. Using renewable sources to meet the energy demands of electric vehicles will also contribute to implementing the development targets for renewable energies and improving grid integration of variable producers, thus helping to raise supply security in the long term.
3. The use of modern information technologies and the integration of electric vehicles will raise power grid efficiency in Germany.
4. The additional electrical energy requirements in this sector will be met with electricity from renewable energies. The prime source for electromobility will be current from variable renewable energies that cannot be used elsewhere as part of load management. Additional scope for renewable energies must be harnessed to meet the electricity needs of electromobility in excess of this.

Germany will become a lead market for electromobility.

5. The leading role of the German motor-vehicle manufacturing and parts supply

industry will be secured and extended.

6. Use will be made of innovative procurement management in the public sector.
7. Building production capacities for cell and battery systems in Germany and related recycling facilities will secure the strategic capabilities of German industry.
8. Establishing new business models in electromobility will afford opportunities for more growth through new products and services.
9. Supporting standardisation (e.g. for plugs, power inputs or safety precautions) will enable the internationalisation of electromobility and help German industry to position itself.

Innovations are the key for maintaining and developing competitiveness.

10. The aim in research is to interlink industry and science as closely as possible. Networking the motor-vehicle manufacturing, energy and information technology sectors along new supply chains will then set an innovatory momentum in motion for electromobility.
11. To do this, measures will be taken to step up research in all areas, network and extend research infrastructures and promote mutual exchange between researchers from industry and science.
12. Another concern is to ensure long-term excellence and innovative drive in electromobility. An initiative will therefore be launched to train junior technical-scientific personnel.

New mobility

13. Electromobility is another step in the strategy of lessening dependence on oil.
14. Electromobility will help pave the way for a new culture of mobility and modern urban and development planning.
15. Measures will be taken to speed up the market introduction of electric vehicles, particularly for short-distance traffic: The German Federal Government has set itself the ambitious target of putting one million electric vehicles on the road by 2020, possibly reaching over five million by 2030. By 2050, most urban traffic will be able to do without fossil fuels. This will also entail installing suitable infrastructure for charging the vehicles. The German Federal Government will support this with an appropriate enabling framework.
16. Besides private transport, support will also be given to schemes for introducing electromobility for commercial vehicles (e.g. urban delivery vehicles, local public transport) and two-wheeled vehicles.

Fostering social acceptance

17. To implement climate and economic policy goals, the forthcoming changes must gain social approval.
18. This is why the German Federal Government aims to ensure transparency and provide information on the implementation of the Development Plan and engage in

broad dialogue. The opportunities, challenges and goals will be subjected to continual reappraisal in line with developments.

19. The acceptance and market development of electromobility will be supported with a suitable regulatory framework and appropriate systems of incentives.

Hence:

Germany must gain a strong position in international competition.

- In the short term, the shift towards electromobility can be effected by means of hybrid and electric vehicles. Many basic technologies for electric drives, energy storage and network infrastructure have already been developed, although there is considerable need for innovation and rationalisation in batteries. Plug-in hybrid vehicles and small electric vehicles with an urban traffic range will therefore reach market maturity in a few years. In view of the current technological and economic challenges, however, it will take well over a decade until electric vehicles account for a significant percentage of the market.
- Germany can launch its efforts under the National Electromobility Development Plan from a strong and broad-based starting position, but it faces great future challenges. Government and industry will need to do more to proceed faster along the charted course, which calls in particular for a multisectoral, concerted approach on the part of all stakeholders.

4. Activities by the German Federal Government - review

The activities and measures of the German Federal Government are based on a variety of ongoing programmes and activities, which are outlined here. Assistance to date has concentrated on the following priorities:

- Research and development
- Enabling framework
- Markets

Research and development:

Energy storage

Vehicle technology

System and grid integration

The German Federal Government's 5th Energy Research Programme on Innovation and New Energy Technologies is part of the Integrated Energy and Climate Programme (lead ministry BMWi). Due to its major contribution to the total energy balance in Germany, energy research flanks R+D activities in transport. Ongoing consultation and alignment with the 3rd Transport Research Programme on Mobility and Transport Technologies, the government's High-Tech Strategy and energy research activities (see below) bundles competencies and harnesses major synergies. The object of the National Hydrogen and Fuel Cell Technology

Innovation Programme is to develop alternative drive concepts based on hydrogen and fuel cell technologies (led by BMVBS).

1. Energy storage

- State-of-art technology in electrochemical energy storage is not advanced enough for broad use in electromobility. New concepts are needed to meet the requirements of a real fleet of vehicles both in terms of electrochemical functional parameters and safety and economy. This calls for considerable research and development efforts and the convergence of major competencies in science and industry. As a new development instrument, innovation alliances take special account of this need. Here, the participating industry pledges to make additional investments in R+D well in excess of public aid. The Lithium-ion Battery Alliance (LIB 2015 - BMBF) was initiated under the government's High-Tech Strategy. R+D activities under LIB 2015 began at the end of 2008. The German Federal Government provides a budget of EUR 60 million in support of the LIB 2015 initiative (BMBF) with industry contributing another EUR 360 million. The LIB 2015 initiative is the purposive continuation of development activities in lithium-ion batteries. Of particular current note here are the joint projects LISA (EUR 1.7 million), REALIBATT (EUR 2.1 million) and LIHEBE (EUR 2.2 million). LIB 2015 involves the massive upscaling of R+D efforts in efficient energy storage.
- In components development for energy storage, the outcomes of an expert workshop held in October 2007 provided the basis for the BMWi Research and Development Concept for Mobile and Stationary Storage Batteries published in 2008. The aim is build capacities in Germany for implementation throughout the whole supply chain in the production of storage batteries. The projects aim to raise specific energy and capacity as well as cycle stability, improve safety features and sound out and harness potential cost savings. The assistance scheme also includes conducting important additional studies and rapid response to new storage methods, based on superconductive materials, for example. Under the Storage Battery Programme from 2009 to 2012, the German Federal Government will provide EUR 35 million to promote new developments in electric storage batteries (BMWi).

2. Vehicle technology

- The German Federal Government's 3rd Transport Research Programme on Mobility and Transport Technologies (led by BMWi) sets out the goals for assistance to research in drive technology. Special importance is attached to developing new vehicle concepts and technologies for reducing energy consumption and pollution in road transport.
- With the publication of the Position Paper on Alternative Drives/Hybrid Concepts in 2005, assistance in drive technologies was concentrated on developing hybrid drives (BMWi) and ongoing finance has since been provided for projects here. The aim of current research is upgrading core components of the hybrid power train and the applied development and integration of new functional modules. The R+D need for cars and commercial vehicles identified for assistance concentrates on electric traction drive motors, on transmissions and drive variants, electric energy storage for mobile use,

controllers and energy converters as well as energy and drive management. Developments are aimed at the broad standardisation and modularisation of the whole system. This will prepare the way for particularly efficient, reliable and - thanks to larger quantities - economically viable applications. For this purpose, the German Federal Government has made about EUR 30 million available to research institutions and industrial enterprises (BMWi). In 10 joint projects with 35 partners, work is being done on solutions for practical demonstration to meet the fuel consumption reduction target of 30%. These efforts are based on the results of the large-scale electric vehicle experiment on the island of Rügen at the beginning of the nineties and the funding priority, Minimum Emissions in 1999.

- Under the BMBF ICT 2020 Research for Innovation Programme, support is given to the Innovation Alliance Automotive Electronics (EENOVA) among leading manufacturers and suppliers from the German motor-vehicle manufacturing industry. One of the key activities of EENOVA is also energy management in the vehicle. Altogether, BMBF will provide up to EUR 100 million for this in the coming years. In return, the industry has pledged to invest about EUR 500 million in this area of research. Other activities are supported besides this in motor-vehicle electronics, via the funding announcement, Power Electronics for Energy Efficiency Enhancement, for example.

3. System and grid integration

- Intelligent power supply and network infrastructures, but also efficient ways of integrating electromobility into these future energy systems are essential to be able to harness its potential to the full. Modern information and communication technologies (ICT) can make a decisive contribution to this. The German Federal Government (BMW, BMU) launched the research programme, E-Energy - ICT control and optimisation of the energy supply system, at the end of 2008. Its aim in six pilot regions is to develop new schemes for digital networking and intelligent control of technical systems and market relations in electricity supply and conduct broad trials (Internet of Energy). This will provide solutions that make electricity production, grids, storage and consumption more intelligent, advance the integration of renewable energies and enable communication across all the links in the supply chain. E-Energy was declared a beacon project by the Federal Chancellor at the IT summit in December 2007. Up to EUR 60 million has been earmarked to support the technology programme that runs till 2012 (BMW, BMU). With contributions from the industrial partners themselves, the E-Energy programme will mobilise a total of about EUR 140 million in project funds.
- Advanced grid integration, which in addition to supplying the vehicles will also enable them to feed electricity back into the grid, was the subject of an expert workshop in April 2008 (BMW). Together with components manufacturers and scientists, representatives of the motor-vehicle manufacturing and energy supply industry discussed the necessary steps for a 'full-scale' electromobility scenario and strongly advocated including a new BMWi funding priority, Grids of the Future, as part of the German Federal Government's Energy Research Programme. Two new project networks aim to develop strategies, also with a view to the research policy treatment of the topic. The basic concern is to understand the complex technical and economic interdependencies of the transport and electric power sectors.

- The main instrument for developing renewable energies in Germany, which are needed for the low-CO₂ energy supply of electric vehicles, is the Renewable Energy Sources Act (EEG). As a result, their share in electricity generation has more than tripled to about 15% over the last ten years. The ratio is to be raised to at least 30% by 2020 and continuously increased after that. In addition, the German Federal Government promotes applied research, particularly for developments needed to ensure a large share of renewable electricity, e.g. virtual power stations, energy storage and load management as well as the improvement of forecasting methods for wind and solar electricity generation (BMU).
- By means of intermediate storage in electric vehicles, electricity produced from renewable sources could be fed in at peak load periods and contribute to meeting load demand better through renewable energies and raising the total amount of renewable electricity available. Work on this can be included in ongoing projects exploring the potential of stationary lithium-ion battery storage (BMU).

Enabling framework

- The challenges of reducing energy consumption and CO₂ emissions in road transport and finding economically and ecologically efficient ways to meet these were outlined in the German Federal Government's Fuel Strategy in 2004 (BMVBS). This provides a clear, long-term guideline for assessing the viability and special funding eligibility of avenues in fuel development and alternative drives. The Fuel Strategy is in ongoing development under the German Federal Government's National Sustainability Strategy. The National Hydrogen and Fuel Cell Technology Innovation Programme (led by BMVBS) already addresses an important technology priority. With the measures specified for electromobility in its Economic Stimulus Package II, the German Federal Government provides a substantial impetus to supporting efforts on the part of industry and strengthening Germany's international competitiveness in this new technology. The long-term goal is the development and market introduction of competitive electric drives with energy supply via fuel cells or traction batteries integrated into on-board power supply. The National Electromobility Development Plan will therefore support drive technologies and developments in plug-in hybrid and electric vehicles parallel to NIP, which has not attached priority to these so far.
- In energy storage, the innovation and employment impetus will come both from large-scale industry and small and medium-sized or highly innovative start-up enterprises. This is why these kinds of start-ups are particularly needed to follow up on project promotion (BMBF, BMWi), especially with a view to closing supply chains. The German Federal Government's High-Tech Start-up Fund provides support here.
- The introduction of an electromobility strategy will also affect regional and urban planning activities. Modern concepts, as explored in the funding initiative and promotional competition, Energy-Efficient City (BMW, BMBF, BMVBS), for example, are an effective way of catering for this planning factor.
- There is a backlog in promoting junior personnel. To catch up here, initial groups of young people are being promoted in the LIB 2015 Innovation Alliance (BMBF), for example, especially in energy storage. These groups will not, however, suffice to meet

future needs, so that intensive and wide-ranging support must be provided for young researchers to ensure and sustain German competitiveness in this vital technology sector.

Market development

The German Federal Government has already started market preparation for electromobility with individual initiatives. Practical questions will be settled in a four-year field test with government funding of EUR 15 million under the Climate Protection Initiative (BMU). The funds are earmarked for the implementation and evaluation of a fleet test with plug-in hybrid vehicles to try out the use and intermediate storage of electricity from renewable energies in motor vehicles under everyday conditions. Via their traction batteries, the vehicles can contribute to improving power supply systems with a growing share of variable renewable energy. This will make for substantial CO₂ savings thanks to the high efficiency and the substitution of fossil fuels. Ecological research is also conducted concurrent with the fleet test to assess the environmental benefits of electric vehicles (BMU). As part of the priority, Electric Vehicles and Plug-in Hybrids in the Context of Renewable Energy, a specific comparative ecological assessment of electromobility is being carried out. This will take account of vehicle energy consumption and emissions, as well as energy delivery, vehicle manufacture and disposal, and compare these with conventional vehicles. The project is being monitored by several scientific institutes.

5. Proposed measures

5.1 Initial implementation steps - electromobility as part of the German Federal Government's Economic Stimulus Package

The government activities underway (see Chapter 4) already provide an important impetus for the development of electromobility in individual fields, such as research in energy storage, vehicle technology or in initial measures for market preparation. Under the Economic Stimulus Package II, the German Federal Government has made an additional EUR 500 million available largely for the general benefit of electromobility. With the measures and projects assisted under Package II, individual activities can be extended and complemented with others. The Economic Stimulus Package II thus affords an excellent opportunity to speed up Germany's progress as an industrial location in the globally important innovation field of electromobility with a bundle of purposive measures and prepare for the anticipated commercialisation. The contents of the mobility priority in the Economic Stimulus Package concentrate on the R&D topics (cell and battery development, components and their standardisation for electric vehicles, power grids, grid integration, battery recycling, ICT research, training, competency development) as well as market and technology preparation and pays special attention to the regional priorities (pilot regions).

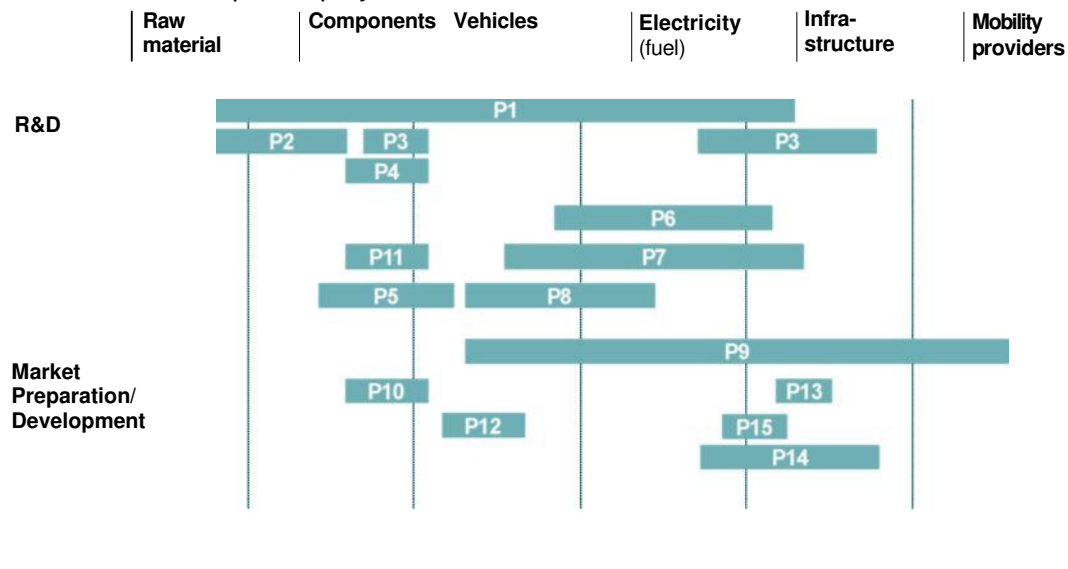
To bring German industry up to the top world technological standards in electromobility and advance market development as speedily as possible, a number of projects and programmes will be promoted in addition to the activities already planned in the Economic Stimulus Package II, which will take economic effect in 2010 and 2011.

These projects are necessary to enable Germany to gradually develop a market for various applications in electromobility and make a significant long-term contribution to low-emission mobility. To attain the government’s ambitious goals in energy and climate policy, the additional electrical energy requirements in this sector will have to be met with electricity from renewable energies. As a prime source, electromobility will use electricity from variable renewable energies that cannot be used elsewhere as part of load management. Additional scope for renewable energies must be harnessed to meet electricity demand from electromobility in excess of this.

For effective support, account must be taken of the different stages of the innovation process, with emphasis on research & development, market preparation/demonstration and an enabling framework. All project activities of the ministries involved are aligned with this approach.

The following figure and the table provide an overall picture of the range of additional activities for promotion under the Economic Stimulus Package II and the interministerial priorities in all innovative drive technologies with the focus on electromobility.

Overview of development projects



Measure or project

1	Setting up a competency network for electromobility systems research aimed at bundling the Fraunhofer Society's competencies in electromobility and making this available to the motor-vehicle manufacturing industry
2	Establishing applied research priorities in electrochemistry with the focus on electromobility and battery technology at universities and non-academic research institutions; developing joint curricula for the specific promotion of junior scientists; priorities in content to concentrate on key multisectoral electrochemical topics in electromobility; electrochemistry as the technological focus for mobile energy converters and storage units (especially batteries)
3	Energy research: new funding initiative, Key Elements in the Electricity Industry for Electromobility: storage, grids, integration, with the focus on electricity storage units, future electricity supply grids, concepts for grid integration and fuel cells
4	Developing production technologies for Li-ion cells/battery systems; suitable production or process technologies and the requisite plant and machine technology to be developed for the competitive, automated serial production of large Li-ion cells and batteries equipped with these
5	Transport research: prompt implementation of current project proposals (e.g. components and systems for braking energy recovery, optimising power train, on-board electricity generation for range extension, use of waste motor heat for producing electric energy, relevant aspects of standardisation), scientific preparations and monitoring of field tests (electric car, hybrid refuse collection vehicle)
6	Expansion of projects in E-Energy: new research and funding priorities - ICT for Electromobility and Smart Grids, Renewable Energies and Electromobility; ICT-based charging, control and billing infrastructure, electronic market places and ICT-based technical operation of e-mobility concepts and their integration into electronic supply grids, services, business models, norms and standards
7	Field tests on electromobility in car traffic; research topics to include alternative charging methods, further development of grid integration for renewable energies, testing and acceptance of upgraded propulsion systems
8	Fleet test on electromobility in commercial traffic; research topics to include development of a method for grid integration of renewable energies applying use profiles in commercial traffic, testing vehicles under everyday conditions, ascertaining energy requirements and user acceptance
9	Electromobility in the public domain - integrated mobility schemes in a limited number of selected pilot regions with the priority elements: city buses with battery storage for electric-powered stretches, medium-duty commercial vehicles with diesel hybrid drive, electromobility in distribution traffic, use of electric cars, motorbikes and bicycles, hybrid rail vehicles, installation of public charging stations, project coordination in the pilot regions
10	Battery testing centre (cells, batteries, systems, crash behaviour) for cells, batteries, systems
11	Research and development for a pilot plant to recycle lithium-ion traction batteries

12	Hybrid buses for ecological local public passenger transport (via KfW); small fleets of at least 10 buses in municipal transport services
13	Installing 25 pilot hydrogen fuel stations
14	Pilot project, Mobile with Biomethane (demonstration of the entire supply chain for the production and use of biomethane as fuel, including systems-analysis action research)
15	Erecting a pilot synthesis plant for the production of high-quality synthetic fuels (Bioliq at the Karlsruhe Research Centre)

5.2 Developing Germany into the lead market for electromobility

The goals of the Economic Stimulus Package II also set major milestones for Germany's progress towards becoming the lead market in electromobility. The aim now must be to develop these activities further and implement them under the National Electromobility Development Plan. As an innovation field which will trigger profound changes in vehicle technology, mobility and the power industry, electromobility requires far-reaching efforts by industry, science and government beyond the Economic Stimulus Package II. The National Electromobility Development Plan is therefore also conceived as a long-term undertaking that will last ten years.

Considering the present state-of-the-art, support for developing electromobility will have to be extended beyond the activities already underway. Any additional measures by the German Federal Government will be subject to budget appropriations and policy decisions in the next legislature.

5.2.1 Research and development

During the term of the Development Plan, research and development will have to address the following challenges:

Batteries, energy storage

Developing new, economical, efficient and reliable energy storage is a realistic proposition. The technological and economic demands placed on energy storage for mobile use are exceptionally high and their development will, however, require considerable additional efforts in the coming years. The German Federal Government is already on the right track with its ongoing funding programmes (Chapter 4). These assistance measures will be supplemented by the German Research Foundation's research initiative on lithium high-power batteries and new priorities set by the Helmholtz Association of German Research Centres.

The investment measures under the Economic Stimulus Package II (Chapter 5.1) provide the necessary basis for the proposed measures below so that an enabling environment can be created for their rapid translation into technical and marketable applications in close cooperation with German industry.

There is a backlog in promoting junior personnel. In the LIB 2015 Innovation Alliance (BMBF), initial groups of young people are being promoted, but these will not suffice to meet

future needs, so that intensive and wide-ranging support must be provided for young scientists to ensure and sustain German competitiveness in this vital technology sector.

In the short to medium term, rechargeable electrochemical energy storage is the most promising option for mobile use (all-electric vehicles and plug-in hybrid vehicles). Of particular note here are lithium-ion batteries, but ZEBRA (high temperature), redox-flow and magnesium batteries can also play an important role in future. Metal-air batteries can be expected to meet the modern requirements for high-energy and high-power batteries in the long term as well.

To achieve the goals listed in Chapter 3.3, the speedy and successful implementation of the R+D measures detailed in the following is essential to be able to ensure the low-loss and economical storage of electrical energy for mobile applications. Proceeding from the results of the above-mentioned initiatives, additional promotion activities will be needed to make decisive progress in developing fourth-generation high-power lithium batteries to the serial production stage, under a LIB 2020 Initiative or other specialist programmes in energy research, for example (see below).

Developing new materials or technologies

A central task on the way to high-energy and high-power batteries of the 2nd to 4th generation is to develop new electrodes, electrolytes and separators, which will require considerable R+D efforts due to the large number of possible combinations of materials. These are detailed below:

Lithium-ion batteries can be subdivided into different generations. In today's 1st generation, lithium cobalt oxide is used as cathode material, the anode consisting of lithium/graphite. Organic electrolytes and polyethylene are used as separators. This battery is applied in consumer products (laptop computers, mobile telephones). The low energy density and the safety deficits pose problems, though. Examples of the 2nd generation are the first batteries with lithium iron phosphates as cathodes and lithium/carbon as anodes, with the same electrolyte. Polymers or ceramic foils function as separators. In future, flexible, ceramic, nano-structured and particularly thin separators will be needed as alternatives to the constructions already available on the market. This also includes the development of separators with higher melting points for safety reasons. Batteries of the 3rd generation will have to contain high-voltage cathodes with different lithium metal oxides or lithium iron phosphates, possibly doped with other metals. The anodes could, for example, consist of a lithium/carbon/silicon/tin system, of lithium titanates or of silicon nanotubes, a problem with the former system in particular being the drastic changes in volume for charging/discharging. New developments are also needed in electrolytes (improved polymer electrolytes, inorganic electrolytes and ionic liquids to raise cell voltage to up to 6 volts). In the long term, 4th generation batteries should have the requisite properties of modern high-power batteries. Quite different electrode systems are under discussion here, metal-air and/or lithium-air and lithium-sulphur or magnesium-based batteries, for example.

General approaches include suppressing surface passivation (examination of the solid electrolyte interface - SEI, where present), improving electrode architecture (higher performance through specific electrode architectures with nano-composites), replacing cobalt (toxic, little available, costly) and coating individual components to increase conductivity.

Efficient battery and thermal management

This is imperative for the operation of modern high-power batteries. Every single cell of a battery must be permanently monitored and controlled (voltage, amperage, temperature, charge state). Specific charging/discharging strategies must be developed and optimal temperature conditions ensured, which may require additional cooling measures (increased performance, safety and service life).

Safety measures

Besides technical and economic aspects, safety requirements are of special importance for energy storage in the vehicle. As a rule, the requisite high energy densities detract from the high safety requirements. The danger of fire and explosion needs to be minimised with suitable separators, for example. Also crucial is the use of non-critical and well-matched electrodes and electrolyte materials. The necessary security measures must be supplemented with suitable overcharging protection.

Computer simulations

These can help in understanding the chemical, electronic and electrochemical processes in various battery systems (particularly passivation and degradation processes). This involves modelling and simulating cell and battery behaviour under operating conditions, e.g. for the analysis of structural changes in the components in prolonged operation as well as hysteresis effects of repeated charge/discharge cycles. Also desirable are reliable service life forecasts to be able, for example, to substantially reduce development times for new battery systems and thus save costs.

Measuring and testing equipment

This will make a substantial contribution to developing components and subsystems for energy storage. Uniform measurement procedures to determine the state of charge and durability tests are required for developing new charging and discharging strategies. The serial production of batteries also calls for reliable and extensive methods of testing for safety requirements.

Developing precise and mature process technology

This is needed to meet quality standards required of modern high-power batteries. It must conform with the technological state-of-the-art. Reliable production processes are needed for packing electrode, electrolyte and separator materials and optimising the interfaces between the individual battery components, for example.

Standardised packaging methods

Standardised packaging methods need to be developed for producing and packing cells.

Recycling

Of particular interest is the marketable recovery of the metals used at the highest purity grade possible, such as lithium, cobalt, manganese, nickel, titanium etc. as well as the marketable recovery of electrolytes (organic, ionic, conducting salts). Due to the limited

availability of certain elements, needs analyses must be conducted and actual raw material resources ascertained. The aim here in particular must be to identify strategic metals (such as cobalt). Account must also be taken of regulatory aspects, such as compliance with legal specifications (e.g. the EU Battery Directive: quantitative recycling efficiency of at least fifty per cent for lithium-ion batteries). There is a growing need for specific and appropriate recycling schemes, as different component parts and electrode designs are used with various combinations of materials, depending on application. A solution is to have intelligent, combined recycling schemes for the recovery of metals and electrolytes with a view to efficiency and sustainability. Besides this, there is a need to promote the development and use of cleaner or less hazardous and more economical raw material extraction and production methods. Further development is also needed on suitability for different materials combinations, raising recovery rates and efficiency as well as building up appropriate recycling capacities in Germany. Altogether, a high recycling rate will play a major role.

Developing double-layer capacitors

Besides batteries, these are another major option for use in electric vehicles. Double-layer capacitors are particularly effective for high and rapid performance requirements and therefore provide a useful addition to batteries with high energy densities. The aim of research is bring the specific effective storage contents up to the standard of today's lithium-ion batteries and extend the temperature range at marketable costs. R+D is needed on components, a scalable process for serial production, reproducible quality, including, for example, materials, process parameters, environmental safety and reliability.

Vehicle technology for electromobility

Under the National Electromobility Development Plan, support will be provided for the development of energy-efficient electric vehicle technology along two lines: Based on available vehicle concepts in the short term, electric drives and energy storage will be integrated for plug-in hybrids and electric vehicles. These vehicles will be built and tested in small lots. They will be used in field tests for gathering user experience and assessing technical components. The development work entailed and the construction of initial smaller test fleets will be financed to the end of 2011 from previous measures and the funds available under the Economic Stimulus Package II.

There is consensus that the transition to electromobility will be made by way of various vehicle categories with different electric power classes. The present intention is to enter the market with small town vehicles. Higher performance categories will follow.

Depending on vehicle and performance category, the future requirements made of electric systems cannot be met by simply scaling components with current and foreseeable technology. Long-term R+D will therefore be necessary on materials, components, circuit designs and their system integration to meet requirements in energy storage, and electric drive and electronic control systems. The work already started on this (Chapter 4) and under the Economic Stimulus Package II (Chapter 5.1) will provide the urgently needed initial basis.

Field tests will then be carried out and completely new vehicle concepts designed for the application of electric energy storage and drives under the National Development Plan. The vehicle concept depends on its primary purpose. On the way to particularly energy-efficient electric vehicles, this will probably be a larger determinant than for vehicles with conventional

drive units. The challenge will be to optimise the new vehicle concept for distance range and handling features also under the limitations of an electric drive. A minimum amount of versatility is a major criterion for acceptance by prospective car purchasers.

To improve the cost-effectiveness and acceptance of plug-in hybrid and electric vehicles, the electrical, electronic and mechanical components need to be developed and upgraded for vehicle use. Examples of thematic priorities for research are listed below:

Motors and components

Since the electromotor in hybrid and electric vehicles functions both as a motor and generator, both efficiencies are important. Solutions have to be found for the problems entailed in the different machine designs and materials used. A systematic analysis must be made of the different layout, depending on mode of operation, control and vehicle size:

- a) Development and selection of suitable electromotor concepts (e.g. synchronous motor with permanent magnets, asynchronous motors, possibly also transverse flux machines, connected reluctance machine) with optimum performance, size and weight as well as safety and economy (also for wheel hub motors)
- b) Development and optimisation of electric components or systems for braking energy recovery as well as their electronic controls
- c) Use of fuel cells to supply additional electrical energy in all-electric vehicles (range extender)
- d) Development of specifically adapted and special internal combustion engines for use in electrically powered vehicles (e.g. range extender)

Another way of maximising performance when combining internal combustion engines with electric motors can also be found in the engine itself. A possibility here, for example, is the so-called downsizing option of compensating for the additional weight of the hybrid unit without any loss in previous total performance (without hybrid unit). The transition from today's characteristic-mapping drive control to the more effective real-time control will allow emissions reductions and fuel savings in the two-digit percentage range. This will require control and on-board power supply technologies with substantially higher computing power and reliability than available now and in the foreseeable future.

The term range extender denotes a small internal combustion engine or a fuel cell as an ancillary energy source for electric vehicles. The dimensions of these components differ from those in a hybrid concept as do their operational characteristics and management.

System integration of drives

The concern here is to optimise the whole system or individual components in terms of efficiency, weight, installation space, safety, costs, quality, reliability, power density and materials used as well as their integration into the vehicle concept. Ways will have to be found to maximise the efficiency of components for hybrid or electric drives and above all their interoperation with the other vehicle systems, such as handling and safety systems, depending on vehicle size and range of application.

Transmission

A major component for combining drives and designing various drive versions is the transmission. The need for component and strategy maximisation is particularly apparent in

this unit. To combine the performances of drives and/or motors (internal combustion engine and electric motor), suitable mechanical couplings and/or transmissions are needed, in the form of planet-wheel gears, for example. Operating strategies can entail numerous switch combinations with sometimes suboptimal efficiencies. Efficiencies of 98% are quite feasible for a mechanical gear stage, but this configuration does not allow for a differentiated strategy. Electromagnetic transducers could be an area to explore for improvements in the medium term. To combine the power capacities of the two drives (internal combustion engine and electric motor), planetary gear sets are needed in transmission, for example.

Optimising power electronics

The interfaces between the different components are controllers and converters. These electronic components control the electrical components (storage units, drive motors, auxiliary power units, etc.) and are essential for energy supply to the motors. The adjustment of current and voltage during the drive or recuperation phase incurs losses in the converters. Power electronics need optimising in terms of the electronic assemblies used and new semiconductor materials are needed to meet the requirements for drive components in an electric vehicle, service life and the reduction of installation space as well as the technology input (including cooling). The technology applied can be expected to depend heavily on the electric power class and hence the vehicle category, which will call for long-term R&D on materials, components, circuit designs and their system integration to meet requirements.

Retrofitting

Possibilities need exploring for the economical retrofitting of a hybrid drive and/or plug-in hybrid vehicle.

Safety and electromagnetic compatibility

Electromobility poses a variety of new challenges in vehicle safety: Besides battery safety, the electric components require special attention for layout in the event of an accident. The vehicle design must ensure the protection of passengers and rescue workers after a crash. The high voltage of the electric drive requires suitable insulation, identification and defeat devices.

Moreover, electrical components in the vehicle have to meet electromagnetic compatibility requirements: on the one hand, protecting against overload in the components and on the other, minimising potential interference by electrical components in an electric drive with other components and their impact on the environment and health.

There is also a need to protect less able road users: The soundless motor in an electric machine requires new approaches in traffic safety. Responsive, active safety systems based on sensors and vehicle communication could play a key role here.

In the long term, the assurance that electric vehicles offer at least the same measure of safety as their conventionally-powered counterparts could prove to be a distinctive feature of German production as compared with competitors from the Far East.

Reliability

Besides assured technological feasibility, a crucial future issue will be the reliability of the electric/electronic systems.

Projections based on today's vehicles (2009) show that despite the extremely low fault

probability of an individual electronic component approximately one in 200 of luxury-class and middle-class vehicles contains a built-in electronic fault ex-works due to the large number of installed components. Their rapid increase and possible fault propagation may countervail almost fault-free individual electronic components. The progressive electrification of vehicles therefore calls for completely new concepts to avoid faults and enhance the reliability of electric and electronic components. The ongoing measures (Chapter 5.1) will provide initial basic findings on this.

Cooling

The thermal requirements of drives and batteries must be accounted for in the overall vehicle concept. Unavoidable waste heat should be used for vehicle air conditioning and/or recovering electrical energy through thermoelectric systems.

On-board technology

Further scope for improving the whole system is afforded by optimal integration of the new drive technologies into on-board technology and electronics. In commercial vehicles and cars, the electrification of components can yield additional efficiency gains, which are necessary to make electric drives an attractive option overall. Components such as door-openers in city buses and auxiliary power systems in industrial vehicles must be integrated into overall energy management. Particularly in heating and air conditioning (also battery air-conditioning), there is a need to adopt approaches to find innovative solutions (e.g. waste heat utilisation, solar energy).

Initial research on power train management in hybrid vehicles shows that knowing the route profile ahead of the vehicle can be relevant for rationalising consumption. The parameters need to be examined for putting this potential to use or extending it. One approach here could be coupling with vehicle navigation and on-board devices for driver information and assistance systems. Accounting for all known parameters (e.g. topology, traffic conditions, speeds), consideration could be given to specifying energy-efficient routes and speeds as an option. Additional scope for optimisation is available in connection with Car2Car communications or navigation services, but this also depends on the willingness of mapmakers to keep a record of and update the relevant information.

Technology for infrastructure/system and grid integration

In grid infrastructure, the use of electric vehicles in the introductory phase will place demands on charging and billing procedures. The application of modern communication technologies is a key element here. Advanced electromobility schemes, where electricity supply to the vehicles accounts for a considerable share of power demand, a larger number of vehicle batteries are used as balancing components in the power grid and a much higher contribution is also made by renewable energies to energy supply, however, call for more advanced technologies. In this phase, future infrastructure will comprise interactive storage charging and discharging devices, comprehensive grid management strategies, new grid components and a different grid architecture.

Major steps for developing, testing and implementing the electromobility strategy will be taken with funding under the German Federal Government's Economic Stimulus Package II from the BMWi initiative, Key Elements in the Electricity Industry: storage, grids, integration. Providing testing facilities, but also testing advanced network components will lay the

technical foundation for the speedy development of an efficient grid infrastructure. Future assistance measures in energy research will follow on directly here. These will comprise conceptual studies on the gradual effects of increasing mass mobility with electric and hybrid vehicles. The aim is to depict electricity generation and distribution with high dispersement over space and time taking special account of renewable energies. Account must be taken of the obligations under the international UCTE network (now part of ENTSO-E). Based on this, the effects on power stations, electricity grids and energy demand will be ascertained and subjected to a climate-policy assessment. Supplementary cost-efficiency, feasibility and constraints analyses will identify technical-economic parameters and restrictions.

Electricity generation and grid infrastructures

Due to the long periods of capital commitment, changes in electricity generation and grid infrastructure take a long time. In the long term, however, new grid strategies are required to increase power supply efficiency. Research and development work must aim at improving capacity utilisation in power stations and distribution grids, but also individual grid components, so as to ensure load continuity, minimise reserves and increase the contribution of renewable energies. For this purpose, energy research must develop components and systems for control and test these in combination with decentralised power/heat cogeneration plant-based supply capacity, including stationary energy storage units on a pilot scale. Involving energy suppliers as well as urban planners, municipalities and consumers plays an essential role here. The technical requirements for various operator models will be developed together with energy supply companies, grid operators, car park owners and motor-vehicle and battery manufacturers.

Grid - vehicle interface

Suitable infrastructure and equipment need to be developed for the grid - vehicle interface. These include charging and grid stations, controllers, meters and measuring devices. Coordinated production, distribution and storage also require the development and testing of innovative communications facilities (smart metering). Grid restrictions must be brought into line with the state of charge of traction batteries and the individual operating parameters of a variety of vehicles. Load-dependent rates, billing modes and data protection provisions also need to be developed and tested with a view to cost effectiveness and the competition framework.

At the international EU level in future, aid priorities should account for trans-systemic interactions between electric vehicles and power grids in smart grid management. The aim is to improve the integration of renewable energies in decentralised electricity generation and input. International cooperation under the auspices of the International Energy Agency (IEA) in grid integration of electric and hybrid vehicles is currently being monitored by Germany.

Information and communications technology for electromobility

Under two complementary funding priorities of BMWi (ICT for Electromobility) and BMU (Smart Grids, Renewable Energies and Electromobility), research will be conducted on the essentials for interaction between electric vehicles and grid and transport infrastructure. Altogether EUR 57 million has been earmarked for this between 2009 and 2011. The aim of the two E-Energy funding priorities is to develop and test key technologies and services for

integrating electric and hybrid vehicles into existing energy and transport grids with the help of modern information and communication technology. The focus is on ICT-based charging, control and billing infrastructures and related business models, services, norms and standards. Research will also look into the potential of electric vehicles as mobile energy storage devices and their integration into electronic marketplaces for optimal grid management. The needed integration and optimisation of vehicles, transport and energy, largely separate sectors till now, will require the pervasive application of ICT. Integrated data transfer systems and smart control systems with intercommunicating charging and battery change stations will be installed and tested. Investigations will also be made into ICT-controlled charging and discharging of vehicle batteries depending on electricity supply and demand and the potential of electric vehicles to provide storage and grid services for power supply to private households in peak load periods (smart home). To ensure the acceptance of future electromobility strategies, customer-friendly billing and roaming models will also be developed and tested. The inclusion of local public passenger transport also plays an important role here (e.g. charging stations at public park + ride car parks).

5.2.2 Enabling framework

In developing a suitable enabling framework for electromobility, the German Federal Government will pursue two primary objectives: first, maximising the ratio of electric vehicles to total new registrations and, second, promoting the use of power from regenerative energy sources in electromobility.

For the successful market introduction and dissemination of electric vehicles, it is particularly important for charging facilities to be organised for simplicity and cost-efficiency. The aim should therefore be to set up an infrastructure that allows for charging electric vehicles at home and en route. All-electric vehicles will only be attractive for the consumer if adequate charging facilities are available at a reasonable price.

Renewable energies

The use of renewable energies will allow electric vehicles to develop their ecological innovation potential to the full. While in well-to-wheel terms, electric vehicles afford few CO₂-emission advantages over efficient internal combustion vehicles when using the average electricity mix, as CO₂ is emitted in electricity generation, renewable energies can transform them into virtual zero-emission vehicles. Moreover, increased growth in renewable energies together with further progress in energy efficiency will also contribute to avoiding increasingly costly energy imports and thus to improving supply security in Germany.

For these reasons, the German Federal Government is looking to meet the additional power demand generated by electric vehicles with renewable energy. Electric vehicles will account for a relatively small share of total electricity demand in Germany. One million all-electric cars, for example, would take up approx. 0.3% of total power demand. This order of magnitude will certainly not be exceeded in the medium term (till 2020), but a considerably larger share of electrical cars is envisaged in the long run. Replacing a third of today's total car traffic with electric operation (not significantly before 2020) will only require about 5% of present gross electricity demand.

Despite this relatively small additional power demand, account must be taken of the effects on power and industrial sectors included under emissions trading. This has to do with the fact

that instead of the transport sector the electricity needed for electric vehicles falls under the emissions trading sector, for which maximum CO₂ emission limits apply.

Care also has to be taken to avoid market access for electric vehicles being hampered by a misleading perception on the part of the public, as they could associate them with new emissions in electricity generation. This is why stress should be placed on the environment-friendly aspects of electric vehicles, especially because they are generally energy-efficient, will cause only a small increase in power demand in the medium term and operate at low emission rates due to coupling with renewable energies, as specified in the IECF.

Appropriate measures could also contribute to meeting the minimum percentage target in transport specified in Directive 2001/77/EC of the European Parliament and of the Council on the promotion of electricity produced from renewable energy sources in the internal electricity market (EU Directive on the promotion of renewable energies), that is, providing ten per cent of the energy in the transport sector from renewable energies by 2020. At present, target accounting is based on the share of renewable energies in the national or EU electricity mix.

Moreover, an economically relevant prospect of electromobility is the contribution electric vehicles can make to smart power grid management and to feeding in needed current from renewable energies. Only when advantage is taken of these, can the potential of this technology be harnessed to the full and help increase the share of renewable energies in the German electricity mix (e.g. by compensating for variable windpower). If the timing for charging electric vehicle batteries under load and storage management is properly adjusted to remaining current demand and the availability of electricity especially from solar radiation and wind energy, this can considerably improve the integration of renewable energies into the German power system.

By adding information and communication technology capabilities (smart grid) to the power grids, electric vehicle batteries can be actively integrated into them in the medium and longer term for balancing and storage purposes (including load management) with a stabilising effect. A smart meter installed in the vehicle, for example, can receive a signal via the power grid on the best or cheapest time to charge the battery. Charging can also be adapted to the current individual needs of the consumer: rapid charging to be able to continue the journey quickly or slow charging to save costs when there is no hurry overnight or at the weekend. Instruments for employment here are incentives to optimise charging in line with partly variable inputs of renewable energies, individual charging needs and vehicle states, by introducing time-variable tariffs, for example.

Even more important than energy storage in electric vehicle batteries as part of load management in the long term is the ability to feed back current into the grid and contribute to providing more balancing power. With decentralised systems for generating renewable energy, a larger number of electric vehicles could be connected into a virtual power station. They could therefore perform an important function for regional energy and capacity autonomy. In principle, about a million electric vehicles could already double the storage capacity of all pump storage power stations installed today. This will enable the greatest possible use of current from renewable energies not required at particular times. To make strides in coupling renewable energies with electromobility, the following measures need to be taken:

- Account must be taken of electric vehicles in measures for system integration of electricity from renewable energies under the Renewable Energy Sources Act (power to

issue statutes according to Section 64(1) 6 for the improved integration of electricity from renewable energies).

- In the negotiations following the pending review of specific emission targets in Section 13(5) of the CO₂ Car Regulation in 2013, the aim must be for electric vehicles using renewable energy to be credited by a multiple of the fleet limit. This will ensure that the targets of the CO₂ Car Regulation can be met with even better cost-efficiency.
- It must be ensured that full national target accounting for the transport sector is made for electricity from renewable energies used by electric vehicles in Germany under the EU Directive for the promotion of renewable energies.

Mobility schemes, demonstrations and field tests for market preparation

For all the differences in segments (small car, van, etc.), car concepts to date have more or less proceeded from a universal use profile, i.e. using the same vehicle for both individual urban short-distance mobility and long distances with the whole family in holiday traffic. Both the ongoing technical restrictions on all-electric vehicles and the quest for particularly energy-efficient vehicles will mean a departure from this universal use profile. The challenge therefore consists in finding the best mobility approach for the respective purpose at hand. Attention should not be confined to hybrid, plug-in hybrid or all-electric, but should also take the mobility needs of the individual road user or enterprise into consideration. New concepts are needed, both for passenger and commercial vehicles, which afford large scope for energy savings due to their tailor-made adjustment to needs. For delivery vans and city buses, the typical driving cycles are suitable for hybrid and electric options; in refuse collection vehicles, the auxiliary power units must be included in the drive layout to maximise efficiency for adaptable urban use.

Theoretical estimates and practical demonstrations of specific, new solutions under realistic traffic conditions are crucial for assessing effectiveness, user acceptance and technical and logistical feasibility. Urban planning schemes and the combination of electromobility with new approaches in public transport will play an important role here.

Precisely when previous paradigms for application scenarios, use profiles and acceptance have become defunct, there is a need to amass new information from demonstrations and field tests, with the following specific aims:

- Verifying the functionality, reliability and suitability for everyday use of new vehicles and energy supply schemes (especially a customer-friendly, secure, non-discriminatory, interoperable charging infrastructure)
- Obtaining relevant information for future mobility concepts, also examining issues such as customer acceptance or possible business models
- Obtaining key data on user behaviour, energy requirements and their development over time as well as on ways for grid stabilisation through adaptable charging and feedback times
- Ascertaining kilometre costs from such factors as electricity demand, additional vehicle outlay, infrastructure costs, load-dependent cost of electricity, taxation, etc., with suitable costing models and detailed invoices from studies of real scenarios
- Clarifying regulatory issues, such as reviewing the highway code or regulations on driving

licences, safety standards in rescue and salvage (crash behaviour or high-voltage problem in vehicles)

Applied scenarios for fleet tests ought not to be confined to logistics chains in commercial traffic or the operations of a public transport company or commercial fleet operator; they must also include above all vehicles in private use.

Demonstrations and field tests are therefore a major step in market preparation for Germany as a location. Field test operators must also plan specific steps for the phase after demonstrations and field tests and provide information on the use of national supply chains. Establishing pilot regions also paves the way for future demonstrations and field tests that can meet comparability requirements and other criteria for substantive results and analyses.

The findings from field tests and related studies are also needed to prepare decisions as an added flank for electromobility.

Standardisation

The German Federal Government promotes private-sector standardisation activities in electromobility. For the successful positioning of German industry, it is important to place more emphasis on normative measures and open standards when developing technical solutions in electromobility. The early introduction of technical rules at international level can help sustainable development in this direction.

To ensure that electromobility is not hindered by national boundaries and products can be distributed worldwide, there is a need to set international norms and standards (e.g. for plugs, power inputs or safety measures). As a leading export nation, Germany must take initiatives early on here. It must seek to set long-term international norms to facilitate the exchange of goods. With this in view, Germany must exert influence on this work early on for the benefit of its industry. Use must be made here of national standardisation for rapid effects to promote innovation (preparing so-called specifications). Besides technical interfaces, cross-sectoral aspects also need taking into account, such as quality, safety and environmental impact.

Foremost challenges in standardisation activities include:

- The key element for the success of electromobility is the energy storage unit. Relevant for norms and standards are the requisite safety requirements, capacity and wear resistance, for example. The resulting information on available energy storage units will ensure market transparency.
- Standardised components and interfaces, in the future high-voltage network in the vehicle, for example, make for an open market and reduce dependencies among market players. Standards with specifications and performance features for systems and components facilitate the efficient and cheaper introduction of new technologies.
- Materials requirements, measurement methods as well as quality and quality assurance also need to be examined. Finally, standards are required for a suitable human-machine interface (HMI) for the new drive technologies.
- The charging stations should be standardised. This also includes suitable metering technologies and corresponding billing systems that still need developing. Future public

charging points in particular should be available for non-discriminatory use by all electricity suppliers and every vehicle model. It would be inexpedient for every supplier to install a separate charging station infrastructure for its clients. Electricity from electric vehicles must be delivered in competition, just like electricity supply to households.

- Another major challenge is the integration of the standardised charging interface into the vehicle hardware and software architecture. The interface between charging station and energy storage unit is just as decisive here as aspects of smart load management and grid use/support.
- Standardised safety requirements need to be developed for the electric vehicle (crash test behaviour; rescue and salvage).

Suitable business models also need to be subjected to norms and standards to reduce subsequent transaction costs in contracts, for example. To allocate and invoice services rendered, suitable arrangements must be standardised, while catering for data protection and customer privacy.

Working conditions and qualification

Electromobility will bring about changes in the activities of many employees now working in the motor-vehicle manufacturing and parts supply industry. These workplaces must be analysed in close consultation with the competent business associations and labour representatives. An essential prerequisite for Germany to attain its goal of becoming the lead market in electromobility is the qualification and further training of personnel in the motor-vehicle manufacturing industry but also in motor-vehicle workshops, car-sales showrooms and other parts of the motor-vehicle sector.

As a proactive measure, a training initiative together with industry and trade unions will strengthen all areas of relevance to electromobility:

- Engineering courses of study
- Post-graduate programmes
- Endowed professorships
- Research priorities in universities and institutes
- Commercial training up to technician and master craftsman

Another priority must be attached to further training of skilled personnel already engaged in the industry. By doing this and by concentrating the central components of the supply chain in Germany, the forthcoming structural adjustments can be made in a socially responsible way and jobs can be secured and created.

Raw materials availability

One of the most important raw materials for traction batteries is lithium, for which estimates on reserves vary widely. Total reserves of lithium alone cannot, however, suffice as an indicator of its future availability for vehicle batteries; other time factors must also be taken into specific account:

- Speed of possible expansion in annual production capacities for lithium carbonate

(approximately 80,000 tonnes in 2007)

- Access to proven or prospective resources
- Lithium demand trends for non-motor-vehicle applications, particularly for energy supply to mobile communications terminals
- Market penetration rates of hybrid, plug-in and electric vehicles
- Future return and recycling rates (see Chapter 5.2.1)

Due to expected demand in non-automotive applications alone, long-term bottlenecks in raw materials availability cannot be ruled out. This will be exacerbated if electric vehicles gain a larger market stake worldwide. This does not just apply for lithium; it also holds for other strategically important metals, such as copper, cobalt and rare earth elements as well. Raw materials availability must be safeguarded in future. The German Federal Government will support industry with a coherent raw materials policy. High recycling rates can also contribute to securing raw materials availability.

Additional measures

To develop electromobility into a lead market in Germany, the following specific measures need to be taken:

- Market success of electric vehicles can change actual consumer behaviour on the part of grid users as a whole. This applies in particular for peak loads in the grid and their shifts over time. If electromobility causes grid bottlenecks in individual segments due to a tangible load increase, appropriate market steering mechanisms will need to be considered.
- For low-cost electricity delivery, standardising mechanisms are needed to regulate power input. One way to do this would be to adapt the load profiles used today for supplying households to specific consumer behaviour. Via suitable (time-variable or load-dependent) rates, price signals could be set to encourage the consumer to adopt a certain charging behaviour to maximise the energy-efficient benefit of electric vehicles. Consumers will, however, demand sufficient flexibility to be able to charge at any time. Denying them this facility would impede market introduction of these vehicles.
- User benefits such as special lanes, special parking lots and other preferential use rights for electric vehicles could provide an additional incentive for both private users and commercial goods transport. Electric vehicles will therefore need to carry a clear identification mark.
- Procurement guidelines for public authorities could help enable government to set a good example in the use of electric vehicles.
- To promote market entry for electric vehicles under the National Development Plan, the German Federal Government is sounding out a market incentives programme to stimulate the sale of 100,000 electric cars. The programme will seek to encourage investment decisions, give manufacturers planning certainty and support vehicle sales.

Ultimately, electric vehicles will only come into general use if total costs, including infrastructure, develop to the point where no permanent subsidies are required in competition.

5.3 National and international cooperation

Cooperation among government, science and industry

With the measures under Number 9 of the Economic Stimulus Package II, the German Federal Government combines short-term economic stimulus with the medium-term and long-term industrial policy goal of developing Germany into the lead market for electromobility. It is prepared to launch funding programmes, set up incentives systems and take regulatory measures over the next ten years to support this development. At the same time, it expects industry to pledge its commitment to furthering electromobility market preparation and entry well beyond 2010. From the outset, then, the implementation of the National Electromobility Development Plan will require close consultation among government, industry and research. The following measures are envisaged:

- Updating and supporting the implementation of the National Electromobility Development Plan is the task of the Interministerial Working Group on Electromobility (BMW, BMVBS, BMU, BMBF).
- To ensure the efficient implementation of the National Electromobility Development Plan, close consultation is needed among all stakeholders involved. A National Electromobility Platform will be set up consisting of policymakers, industrialists and scientists, local government officials and consumers and able to appoint working groups for specific tasks.
- A coordinating body will be appointed to support the German Federal Government with the initial task of facilitating cooperation among the project executing agencies.
- Evaluation processes: After completion of the promotion measures, the German Federal Government will reassess goals in 2011 based on the outcomes of the projects under the Economic Stimulus Package II. Another evaluation can be made about half-way through the term, i.e. in 2015.
- International Electromobility Conference: To reaffirm the determination on the part of government, industry and research to achieving the goal of making Germany the international leader in electromobility and take full advantage of its international competitiveness, the German Federal Government will hold a conference on electromobility in 2010. Another aim will be to bring the implementation steps in the National Development Plan into line with global developments.

Cooperation in Europe

In pursuit of its goals in the National Electromobility Development Plan, the German Federal Government sees the need to take measures for the coherent development of roadmaps, technologies, infrastructure facilities, markets, norms and standards as well as an enabling framework for electromobility. This is why the measures in Germany must be interlinked with the programmes in the neighbouring European states and the European Commission as early as possible. With a view to efficiency, the European Commission is also seeking harmonisation and envisions its Green Cars Initiative as a public-private partnership with industry and the member states. With a view to implementing its National Development Plan, the German Federal Government will need to do the following in this connection:

- Monitor the activities of the neighbouring European states and the European Union in promoting and developing technologies, infrastructure, norms and standards and a general framework for electromobility and assess these against the goals and measures of the National Development Plan
- Coordinate European roadmaps, measures and programmes in electromobility by making strategic use of its influence in the European Commission and in other consultative bodies, e.g. the European technology platforms
- Coordinate assistance programmes in Germany with those of the European Commission
- Coordinate policy positions bilaterally with individual neighbouring states and launch joint programmes on electromobility
- Inform actors from industry and science about aid facilities of the European Commission and lending programmes by the European Investment Bank, reply to requests and provide advice for applications

In implementing the National Electromobility Development Plan, new instruments will be created or existing ones used (e.g. ERA networks) for the one-stop execution of these tasks in interministerial agreement.

6. Outlook

A new era of individual mobility has begun. Today, we still stand at the beginning of the road to electromobility. The measures adopted under the Economic Stimulus Programme II in research, development and market preparation will function as the ignition. The package of purposive assistance measures will provide business and industry with know-how and excellence in the innovation field of electromobility and prepare Germany as a location for worldwide competition in the commercialisation phase.

This start-up phase will be followed by the market escalation phase, culminating in the development of Germany as a lead market in electromobility.

To accomplish this goal, vigorous efforts will have to be made in research and development parallel to the three phases of market preparation, market escalation and mass market (see Table) to help Germany gain a durable technological lead and, with that, pass a major milestone on the way to establishing a lead market. R+D measures are especially necessary in energy storage (batteries), vehicle technology, system and grid integration as well as raw

materials availability.

To do this, activities will have to be stepped up in the coming years to provide policy support to the later phase of market escalation, subject to current financial planning to 2012 and policy decisions in the next legislative period. There will of course be shifts in implementation priorities, but it is important from the outset to plan the development of the electromobility lead market for the long term (see Table) to afford the stakeholders planning certainty.

While the plan of action and milestones for the market preparation phase have been defined through the measures in the Economic Stimulus Package II, specifying measures and drawing up new plans for market escalation will call for ongoing consultation among government, industry and research, which is what the National Electromobility Platform is for. This is the only way to plan the phase of market escalation together with all stakeholders and to secure Germany the leading role in electromobility. Starting with market preparation, the following table sets out the milestones on Germany's progress to becoming the lead electromobility market.

Pathway to the lead electromobility market

	Phase 1 (2009 - 2011) Market preparation	Phase 2 (2011 - 2016) Market escalation	Phase 3 (2017 - 2020) Mass market (aim: lead market in electromobility)
Research and development	R&D is of special importance in batteries/double layer capacitors, vehicle technology and infrastructure/grid integration in all phases.		
Batteries and double layer capacitors	<ul style="list-style-type: none"> • Research and development as well as start-up of production of 1st generation Li-ion batteries • Research and development on 2nd generation Li-ion batteries and double layer capacitors 	<ul style="list-style-type: none"> • Demonstration and field tests of Li-ion batteries and double layer capacitors • Mass production of 1st generation Li-ion batteries • Production start-up of 2nd generation Li-ion batteries and double layer capacitors • R+D on 3rd + 4th generation Li-ion batteries 	<ul style="list-style-type: none"> • Mass production of 2nd generation Li-ion batteries and double layer capacitors • Production start-up of 3rd generation Li-ion batteries • Continuation of R+D on Li-ion batteries and alternative storage technologies
Vehicle technology	<ul style="list-style-type: none"> • Production of PHEV and BEV based on existing vehicle platforms as prototypes • Drive technologies (engines/converters) adapted to performance category, installation space, safety and reliability • R+D for electrical, electronic and mechanical vehicle components for PHEV and BEV 	<ul style="list-style-type: none"> • Production of PHEV and BEV based on existing platforms by all OEMs in small lots • Serial production maturity of 2nd generation PHEV /BEV platform • R+D for economical drive technologies and vehicle components for 2nd generation platforms 	<ul style="list-style-type: none"> • Mass production of 2nd generation PHEV/BEV • Production of higher performance BEV/PHEV

Infrastructure	<ul style="list-style-type: none"> • Research and development of new components • Testing and simulation facilities for grid integration trials • First public charging stations • Studies and demonstrations for coupling with renewable energies 	<ul style="list-style-type: none"> • Charging infrastructure in many towns and regions • Research, development and initial trials for grid integration (load management) • Coupling with renewable energies • Development of advanced charging and energy transmission systems 	<ul style="list-style-type: none"> • Field tests on complete systems under realistic conditions • Full-coverage charging infrastructure • Grid integration and feedback • Initial trials of fast loading, contactless energy transfer
Enabling framework	<ul style="list-style-type: none"> • Safety standards • Regulatory framework • Standardisation of interfaces 	<ul style="list-style-type: none"> • Use of procurement guidelines for the public sector • Appraising systems of incentives 	
Market development	<ul style="list-style-type: none"> • Application in fleet tests 	<ul style="list-style-type: none"> • First private users • Business models for charging, feedback and batteries 	<ul style="list-style-type: none"> • 1 million electric vehicles on Germany's roads in 2020 • Germany is the lead market for electromobility

Electromobility must be assimilated into integrated mobility concepts. From the beginning, users will have to be familiarised with new mobility options. Owing to the obvious potential applications of all-electric vehicles (cars, transporters, two-wheeled vehicles), it is best to deploy them initially in conurbations or certain clusters. Also with a view to long-term strategy, the largest volume of traffic and prospective customers are located in conurbations. Only an integral approach, including planning the enabling framework, will ensure that electromobility gains customer acceptance in the long run.

To keep up with international competition, Germany must become the lead market in electromobility and maintain the leading role of its scientific capabilities and its motor-vehicle manufacturing and parts supply industry. The German Federal Government has therefore set itself the ambitious target of putting one million electric vehicles on the road by 2020 and installing a charging infrastructure throughout major conurbations. A million vehicles are just the beginning but they will already lay the foundation for a self-sustaining system. This will already make important contributions to climate protection, improved grid integration of

renewable energies and to reducing local emissions. The figure could reach over five million vehicles by 2030. By 2050, most urban traffic will be able to do without fossil fuels.

We must continue our firm commitment to virtual CO₂-free mobility. The German Federal Government will do everything necessary under the National Electromobility Development Plan and beyond.

Annex: Glossary

Advanced driver assistance systems (ADAS) are ancillary electronic facilities in motor vehicles to assist the driver in certain handling situations. A frequent focus here is on security aspects, but also enhancing driving comfort or ecology (e.g. as part of central energy management).

An **anode** is an electrode that attracts electrons from an electrolyte or a vacuum (and where oxidation processes therefore take place). As a component of a battery it is of negative polarity. The positive counter electrode is called the cathode.

The **asynchronous motor** is the electromotor in most frequent use today. Consisting of a stator and 'passive' rotor, it requires no brushes and sliding contacts and is therefore very low-wear. Frequency converters are used for speed regulation. For construction reasons, this is always a few percentage points lower (the difference is the so-called slip) than that of the rotating field located at the stator, or below the related synchronous speed (hence the name asynchronous motor). It can also be used as a generator.

Battery air-conditioning keeps the temperature difference between individual cells within certain limits (usually under 5 K). This is needed in batteries that are built of many individual cells (per packaging), because the cells on the inside heat up more (due to less heat removal). The air is usually conditioned by a ventilator. The individual cells are equipped with temperature sensors for measured value logging.

The task of a **battery management system** is to equalise the temperature among the individual modules, maintain cell voltage within permissible limits, keep the charging and discharging process to the specified range and provide deep discharge protection through current limitation. The physical values need to be measured in specified intervals.

BEV stands for battery electric vehicle, that is a battery-powered electric vehicle. This term denotes a vehicle with electric drive powered only by a battery (i.e. that only uses the battery as an energy source), as opposed to hybrid drive technologies, where an internal combustion engine is also used, for example (for drive purposes or for charging the battery).

A **business model** generally consists of the three main components - value proposition, value chain structure and revenue generation model. In energy supply to electric vehicles, there are numerous degrees of freedom when designing these models, depending on whether the vehicle owner buys or only leases the battery or the energy provider grants battery purchase subsidies under electricity purchase commitment agreements at set rates, etc.

A **cathode** is an electrode that releases electrons to an electrolyte or vacuum (and where reduction processes therefore take place). As a battery component it is of positive polarity. The negative counter electrode is called the anode.

CCS is the abbreviation for carbon-dioxide capture and storage, that is, for the separation of CO₂ in a power-station process and its subsequent storage in geological structures.

A **combined renewable power station** combines several systems based on various renewable sources of energy, such as wind, sun, biomass, etc., for electricity generation. Added to this are suitable energy storage units and ICT-based control. The aim of this combination is to match the efficiency and reliability of conventional large power plants.

Cycle stability denotes the number of charging and discharging cycles a battery can undergo before its capacity decreases below a certain percentage of initial capacity.

Double layer capacitors fill the gap between classic condensers and accumulators. They can be used as energy storage units (electrostatic instead of electrochemical). Their storage capacity is considerably lower than that of batteries or accumulators but they charge and discharge the respective amounts of energy in a much shorter time.

Downsizing means reducing the size of physical equipment while retaining the previous performance. The latter is often facilitated through higher efficiencies from synergies generated through the reduction of single components within a system, as other components can frequently be reduced as well, thus lowering total weight, etc.

The **electricity mix** indicates the ratios of current generated from the individual primary energy sources, i.e. from the individual fossil fuels (coal, petroleum and natural gas), from nuclear energy and from renewable energies.

Electrochemistry is a branch of physical chemistry that deals with the connection between electrical and chemical processes. Electrochemical reactions take place in galvanic cells, in accumulators or fuel cells, for example.

An **electrolyte** is a (mostly liquid) substance which when under electric charge conducts electric current in an electric field. Its electric conductivity and the charge transport are based on the directional movement of ions.

The European EMC Directive defines **electromagnetic compatibility** as the ability of a vehicle or component(s) or separate technical unit(s) to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

Energy conversion efficiency is a measure of how effectively one energy is converted into another. It is usually designated with the Greek character 'eta'. Mathematically, it is defined as the ratio between input and useful output (in per cent).

Energy density denotes the amount of energy that can be stored per unit of mass or volume of a battery (measured in the first case in kJ per kg or kWh per kg).

Energy transport efficiency from well-to-wheel means overall efficiency from energy production from the respective primary energy sources (fossil or renewable, in stationary systems or the internal combustion engine in a vehicle) up to its conversion into mechanical energy at the driving wheels of a motor vehicle. This perspective thus accounts for all conversion losses and provides information on the overall energy efficiency of a motor-vehicle propulsion concept.

The **EU Battery Directive** (September 2006) regulates the production and disposal of batteries in the European Union. Upper limits are set for particularly hazardous contents (where they are not completely banned) and requirements for suitable disposal methods and specifications are made for ensuing legislation, on marking and identification, for example.

The **European CO₂ fleet targets** (Regulation no. 443/2009 of 23 April 2009) require that the average CO₂ emissions for new vehicles in the EU must be lowered to 130 grams CO₂ per kilometre by 2015. This reduction is phased (65 per cent of new vehicles must meet the Regulation specifications by 2012, for example). Another 10 grams per kilometre are to be

saved by means of other technical improvements and the increased use of sustainable biofuels.

A **fuel cell** is a galvanic cell that transforms the chemical reaction energy of a continuously supplied fuel and an oxidant into electrical energy. This transformation is direct, not via the intermediate step of generating thermal energy. Efficiencies achieved so far exceed those of petrol and diesel engines and match (or slightly exceed) those of modern gas turbines. A frequent design is the hydrogen/oxygen fuel cell.

Grid integration means the process of feeding in electrical energy from external sources into the power mains without impairing their stability (voltage, frequency etc.). Variable energy inputs in particular (as is the case with many renewable energies) call for special facilities.

Grid parity is achieved when electricity from alternative energy sources can be produced at the same costs or provided at the same prices as ordinary mains power (from conventional sources).

Heat-power cogeneration denotes the simultaneous production of mechanical energy for electricity generation and useful heat (for heating purposes or production processes) as occurs centrally in thermal power stations or locally in block-type thermal power stations. This results in considerably higher efficiency (up to 90%) in relation to the primary energy input and a substantial reduction of waste heat released to the atmosphere.

HEV means hybrid electric vehicle, a vehicle that combines a conventional internal combustion engine drive with an electromotive drive powered by a rechargeable battery. If the electric component only makes up a small ratio of the propulsion concept, the term mild hybrid is used.

A **high-temperature battery** is one whose required operating temperature considerably exceeds normal ambient temperatures. The best known example is the ZEBRA battery, a rechargeable sodium nickel chloride battery, whose working temperature is approx. 300 degrees centigrade.

Hysteresis generally designates a state whose effect persists after energy supply has stopped. These lagging effects can also be observed in magnetic reversal of ferromagnetic materials (magnetic hysteresis) or during battery charging/discharging. The energy required to overcome this usually counts as a loss.

The **large-scale electric vehicle trial** on the island of Rügen was carried out from 1992 to 1996 on behalf of BMBF to test the potential of electromobility. It comprised 60 vehicles with a conventional layout (only converted for electric propulsion). Due to this approach and particularly the low efficiency of the electric energy storage units available at that time, the outcome was disappointing both in terms of practical suitability and ecological impact.

Lead market is a market that serves future demand trends at an early stage - it performs a leadership function by translating innovative concepts earlier than elsewhere into marketable products and services (which are accepted by customers). This enables the branches of industry involved to gain competitive advantages, particularly on international or global markets.

A characteristic feature of the **lithium-ion battery** (Li-ion for short) is its very high energy density. It is thermally stable, delivers largely constant voltage during discharge and is prone

to virtually no memory effect. Energy storage is based on depositing lithium ions (Li⁺) in the layer lattices of the cathode (made of graphite, for example). Other main components include the anode (e.g. made of lithium metal oxides), the electrolyte (anhydrous) and separator (made of polymer or ceramic). All components are currently in the process of intensive development.

In the **magnesium battery**, a special magnesium alloy is used as the anode, the cathode consists of a molybdenum sulphide compound and the electrolyte has a jelly-like consistency. The battery was developed to replace toxic metals such as lead or cadmium. Its energy density is much lower than in Li-ion batteries.

In **metal-air batteries**, the anode metal (e.g. iron, aluminium or zinc) is oxidised in an alkaline electrolyte while atmospheric oxygen is converted with water to hydroxide ions at the catalytic cathode. Current technical problems in producing a suitable cathode still hamper a broad industrial production of rechargeable systems. A particularly promising future option is the zinc air battery (with zinc as anode material).

A **multimodal transport system** is based on the complementary use of individual means of transport, such as rail, sea and road. The aim is to make use of their specific advantages and sustainability aspects and integrate them into an overall system.

By **power density** is meant power output per unit of mass or volume. It is a major parameter for electric energy storage. It describes the energy throughput per time unit related to mass or volume (unlike energy density which denotes the corresponding amount of energy). In electric vehicles, it therefore has a major influence on acceleration performance.

Power electronics is the name given to the branch of electrical engineering concerned with transforming electrical energy with electronic devices.

Primary energy comprises energy forms available in nature, particularly in the form of fossil fuels (coal, petroleum and natural gas) and renewable energies (solar radiation, wind etc.). Secondary energy, in contrast, is produced by converting primary energy (entailing losses).

Production peak is defined as above average production of electricity by energy producers whose output generally fluctuates. Examples of this are photovoltaic systems under high solar radiation or electricity generation by windpower stations during gusts of wind.

A **smart grid** is an intelligent power grid that applies modern information and communication technology to integrate locally produced energy, for example, improve load management or possibly for client energy management.

A **smart meter** is an intelligent, electronically-run electricity meter equipped with additional functions, such as controlling energy demand or coupling it with related transmitted information, the present availability of windpower, for example (enabling specific recharging of electric vehicles with current from renewable energies).

PHEV stands for plug-in hybrid electric vehicle, a vehicle that combines propulsion powered by an internal combustion engine and an electric motor whose battery can be charged from the power mains (plug-in with a plug as opposed to a normal HEV, whose battery is charged from the internal combustion engine or by means of recuperation).

Range extenders are subunits that can extend the range of electric vehicles beyond the capacity of the built-in battery. Internal combustion engines and fuel cells are major options here.

By **recuperation** is meant the recovery of braking energy. In electric vehicles, this is usually done by switching the drive motor to generator operation, feeding the energy back into the vehicle battery. Only part of the braking energy can be recovered due to conversion losses.

Recycling is the general processing of waste so that it can re-enter the production process as a secondary raw material. Of particular relevance for electromobility is recycling raw materials with limited availability or high extraction costs. These include, for example, numerous metals used in energy storage units (lithium, cobalt etc.), but also conducting salts in electrolytes.

Redox flow batteries consist of two liquid electrolytes separated by a membrane and stored in external tanks, which facilitates a decoupling of power (membrane) and capacity (contents of tank). Energy is actually stored in chemical compounds (through reduction and oxidation), similar to classic accumulators. One advantage is fast charging through liquid exchange (tanking). Due to its present power density, however, it is considered to be more suitable for stationary than mobile applications.

Renewable energy sources are sources of sustainable, permanently regenerative energies. These include in particular solar thermal energy and photovoltaics, hydropower, windpower, geothermal energy and bioenergy.

The **separator** in lithium-ion batteries is the separating layer between anode and cathode. It is constructed as a membrane which is only permeable for certain substances, such as ions (Li⁺). It is usually made of polymers or ceramic materials.

The **synchronous motor** consists of a constantly magnetised rotor and a surrounding stator to which a rotating field is applied. Frequency converters are used to regulate its speed, which is synchronised with the rotating field applied (hence the name synchronous motor). It is therefore suitable for applications requiring a steady speed. Disadvantages, however, include difficulties with auto restart and the frequent occurrence of unwanted rotational oscillations. It can also operate as a generator.

System integration describes the process of combining individual technical components into a functional overall system.

UCTE is the acronym for the Union for the Coordination of Transmission of Electricity, which coordinates the integrated grid. UCTE also deals with defining and updating rules on the secure operation of grids and power stations. As of July 2009, it has been taken over by the European Network of Transmission System Operators for Electricity (ENTSO-E).

Variable energy inputs denote energy feed-in that is subject to marked fluctuation over time. This is the case for windpower (dependent on climatic zone) and solar energy, for example.

V2G (vehicle to grid) schemes aim to use batteries in electric vehicles as grid buffers, i.e. to feed energy from electric vehicle fleets back into the grid when needed. This can help improve load and storage management, to compensate for fluctuations in inputs from renewable energies, for example.

Well-to-wheel stands for the entire fuel supply chain from production to use in vehicles. 'Well' means the drill hole, referring to the classic supply chain for fossil fuel. 'Wheel' means the use of the fuel in the vehicle, including the rotation of the tyres.

The **ZEBRA battery** is a rechargeable high-temperature battery (named after the favourite animal of the developer). It is based on sodium nickel chloride with the reactants sodium

chloride (common salt) and nickel. The various ions are separated by a semi-permeable ceramic wall. It has some favourable properties for mobile application (energy density, cycle stability), but its use is hampered by the requisite high operating temperature (approx. 300°centigrade).