e-mobil BW
State Agency for Electric Mobility and
Fuel Cell Technology Baden-Wuerttemberg GmbH

STRUCTURE STUDY BW^e MOBILE 2011

Baden-Württemberg on the way to electromobility

Baden-Württemberg

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e-mobil BW GmbH – State Agency for Electromobility and Fuel Cell Technology

Fraunhofer Institute for Industrial Engineering (IAO)

Ministry for Finance and Economics Baden-Württemberg

The Stuttgart Region Economic Development Corporation (WRS)

CONTENT

PREFACE

Baden-Württemberg is Europe's number 1 innovative region, with uniquely developed structures and a special enterprise landscape, as well as an excellent research and higher education landscape. In addition to major automobile manufacturers, in Baden-Württemberg it is primarily the medium-sized companies that make a decisive contribution to the value creation of the automobile industry. Innovative products, solutions and services from the state enjoy worldwide sales and recognition.

The coming years will be marked by stricter regulatory requirements, with regard to the necessary reduction of harmful CO_2 vehicle emissions. Simultaneously, fossil fuels will become increasingly scarce. Concepts for a sustainable mobility, in which electromobility constitutes an important component, form an essential prerequisite for mastering these ecological challenges and at the same time creating economic growth.

Electrification of the drivetrain means a huge change for the automobile industry: because some components will be dispensed with and new components will be added, the share of value creation between different participants, and possibly between economic regions, will be redistributed.

Baden-Württemberg is well positioned for this change. Today, there are already numerous activities and cluster initiatives in the state that promote the transfer of knowledge between research and industry, and that contribute to the development of common, cross-industry approaches to solutions. This study provides an overview of these activities, and identifies future potential and risks for the automobile industry, starting from the present position of the state.

Dr. Nils Schmid MdL
Deputy Minister-President and Minister for Finance and Economics of the State of Baden-Württemberg

Electromobility is the mobility of the future. Megatrends, such as increasing global warming, the finite nature of our resources, the growth of our cities, as well as an increasing standard of living and the associated stronger demands imposed on mobility for people and goods, make a revolution in our mobility an absolute necessity. The path to sustainable and intelligent mobility in our cities has only just begun. It requires new thinking, and for that reason in particular, presents both great opportunities and also risks for all participating stakeholders.

To bring electromobility to market maturity, electrification of the drivetrain must be considered from a systems context. In the future, mobility will primarily require the competencies of the automotive sector, the information and communication technology (ICT) sector and the energy sector. Crucial market synergies can only be developed, and industrialization of electromobility can only be driven, via a systemic and closely intermeshed collaboration of these three key sectors, with due consideration of the cross-disciplinary field of production. Baden-Württemberg, through its traditionally developed automobile industry and its combined competence in the ICT and energy sectors, has the very best qualifications for taking a leading global role in electromobility.

It is not just a networking of industries that will be the determining competitive factor. Small and medium-sized enterprises are the core of the economic strength in Baden-Württemberg and simultaneously provide its drive for innovation. The capabilities and active integration of small and medium-sized firms in the change to electromobility are essential prerequisites for the international competitiveness of Baden-Württemberg, and they are the guarantors for assuring value creation and jobs in the Baden-Württemberg automobile industry.

Franz Loogen
President e-mobil BW

CORE FINDINGS AND IMPLICATIONS

- Drivetrain electrification is in full swing and no longer just a vision of the future. Hence, over time, electrification will increase through the various forms of hybrid (mild hybrid, full hybrid, plug-in hybrid, range extender) to the pure electric vehicle.

- In 2020, approximately 50 percent more passenger vehicles will be sold worldwide than are currently being sold. In relative terms, the proportion of passenger vehicles with a pure combustion engine should drop from today's figure of approximately 98% to around 67% in 2020. The share of pure battery electric vehicle designs could be approximately 5 percent by the year 2020.

- Virtually half of worldwide market potential (growth) in the year 2020 is allotted to components of the electrified drivetrain (electric motor, power electronics, battery system, charger), this represents a value of approximately 100 billion EUR.

- Significant cost reduction potential is anticipated in the manufacturing of new components. Nevertheless, by 2020, pure battery electric vehicles will have significantly higher production costs as compared to conventional internal combustion vehicles. In a future buying decision, in addition to the purchase price, all of the operating costs of the vehicle (costs for fuel, electricity, taxes, insurance and maintenance) will also play an important role.

- As a cross-industry development, electromobility will not only have an influence on the automobile industry; it will also lead to a convergence of the automobile, ICT, and energy sectors. Innovative business models and evolving user behavior also come into focus.

- This change will also involve developments in the areas of production technology and qualification of employees. This is why, in addition to new competences in processing and manufacturing, training and education as well as continuing education content must also be extended and adapted.

- Baden-Württemberg is well-positioned as a technology location for electromobility. In research and development (R&D) of electrified drivetrain components and the associated charging infrastructure, due to the collaboration of higher education, research institutes and companies, a solid foundation exists that must be further extended in the future.

- In order to generate significant employment effects in the state, it is important to generate extensive depth in value creation for the „new drivetrain components". In this regard, R&D findings must be transferred to industrial manufacturing. Plant engineering and mechanical engineering, which is outstandingly positioned in the state, can and must accompany this process.

- Great potential for value creation and job creation in the state are offered by the conventional technologies (transmission, efficiency technologies and the exhaust systems combustion engines), as well as by the new components, such as power electronics, electric motors and particularly the battery system.

- In the year 2020 in Baden-Württemberg, with optimal exploitation of existing potential, approximately 10,000 new jobs could be generated through the „new drivetrain components". The relatively high value of the new components and the relatively high degree of automation in manufacturing offer good overall prerequisites for regional manufacturing.

- As essential stakeholders in the Baden-Württemberg automobile value creation landscape, small and medium-sized enterprises must be actively integrated into the knowledge transfer processes of large enterprises and research institutes. A competitive „electromobile" value creation structure can only be holistically established in the state through the competencies of medium-sized companies.

Chapter 1

STARTING POSITION AND OBJECTIVES

Looking back over the last two years, it is evident that the topic of „electromobility" is picking up speed. At IAA 2011 a separate exhibition hall was devoted to the theme of electromobility. All the major automotive manufacturers attended, presenting a broad palette of the most varied vehicle concepts for the coming years; there were also concept vehicles that enabled a more extended look into the future. The underlying technology shift away from motor vehicles with conventional propulsion toward alternative, and in this case electrified, propulsion concepts will lead to a number of changes.

Alongside the newly required materials and production processes, there will also be changes in the qualifications and education content required by prospective employees, for example. The structure of the previous value creation chain will be extended, with new participants. For example, an abundance of business models, ranging between those of „old" companies and those of entirely new companies, can be observed in the market, for example in the area of battery cell manufacturing. Moreover, aspects, such as information and communication technology for vehicles, infrastructural work content and the associated new market opportunities are becoming the centre of attention. Whereas previously such topics only received rudimentary consideration, now the resulting challenges facing electromobility in the course of the pending change must be solved and the solutions implemented.

For the „automobile state" of Baden-Württemberg in particular, this type of upheaval must be viewed as a major challenge - even though from the current perspective this upheaval is still quite slow in starting up. To maintain its leading position in the future, the anticipated effects of electromobility on automobile value creation must be detected and the associated opportunities and risks for the state must be identified. Consequently, within the framework of this Structure Study 2011, which is a revision of the preceding Study (2009/2010), the following questions will be the focus of consideration:

- What technological fundamentals and development paths exist?
- What contribution to competitive capacity can the production technology offer?
- What new fields of activity arise?
- How will the markets, as well as the production costs of „new drivetrain components" develop?
- What market potential will arise in the area of alternative propulsion concepts?
- How is the automobile industry structured in Baden-Württemberg?
- What effects does electromobility have on the value creation structure and employment structure?
- What participants, competences, clusters and initiatives exist in Baden-Württemberg in the area of electromobility?

In this regard, in addition to extensive secondary research, a large number of personal interviews and telephone interviews were conducted with industry and research experts. The statements and opinions of the persons interviewed are emphasized in these chapters and thus permit greater insight into the respective topics.

Chapter 2

THE AUTOMOBILE INDUSTRY ON THE WAY TO ELECTROMOBILITY

2.1 ELECTROMOBILITY PROPULSION AND VEHICLE CONCEPTS

»Electromobility propulsion concepts« are becoming increasingly significant. This term embraces all passenger motor vehicles and commercial vehicles, as well as two-wheelers (scooters and electric bicycles), used on the road, that can cover a least a portion of the route propelled purely by electricity, regardless of whether they get their energy from a battery or from a fuel cell. Moreover, vehicle concepts that have electrical components for optimization of the combustion engine are also considered. This chapter will also present the different vehicle concepts, technical fundamentals and possible development paths.

Vehicles can vary both in the type of propulsion concept applied, as well as by vehicle type. The propulsion concepts, in turn, can be classified as conventional and electromobile; conventional propulsion concepts, include vehicles with traditional, as well as consumption-optimized combustion engines. On the other hand, electromobility propulsion concepts include, as shown in Figure 1, hybrid vehicles (parallel hybrid, power-split hybrid) plug-in hybrid vehicles, electric vehicles with range extension (serial hybrid) as well as pure electric vehicles and fuel cell vehicles [German Federal Government (2009)].

- Hybrid vehicles (parallel hybrid, power-split hybrid)
  Characteristic features: Electric motor for support of the traction drive; battery can be charged through recuperation; combination of a conventional combustion engine with an electric engine; pure electric propulsion is possible in some cases over a short range. Depending on the degree of support from the electric motor, these concepts are also referred to as mild hybrids or full hybrids.
  Examples of current and planned models:
  Toyota Prius, Daimler S400 Hybrid, Daimler E300 Blue Tec Hybrid

- Plug-in-Hybrid Vehicle (PHEV)
  Characteristic features: Electric motor with grid-chargeable battery; combination of classic combustion engine with electric motor; pure electric propulsion possible, depending on battery size and use. The difference from the classic hybrid is the possibility of charging the battery via the grid.
  Examples of current and planned models:
  Fisker Karma, Prius Plugin, Daimler S500 Plug-In, BMW i8

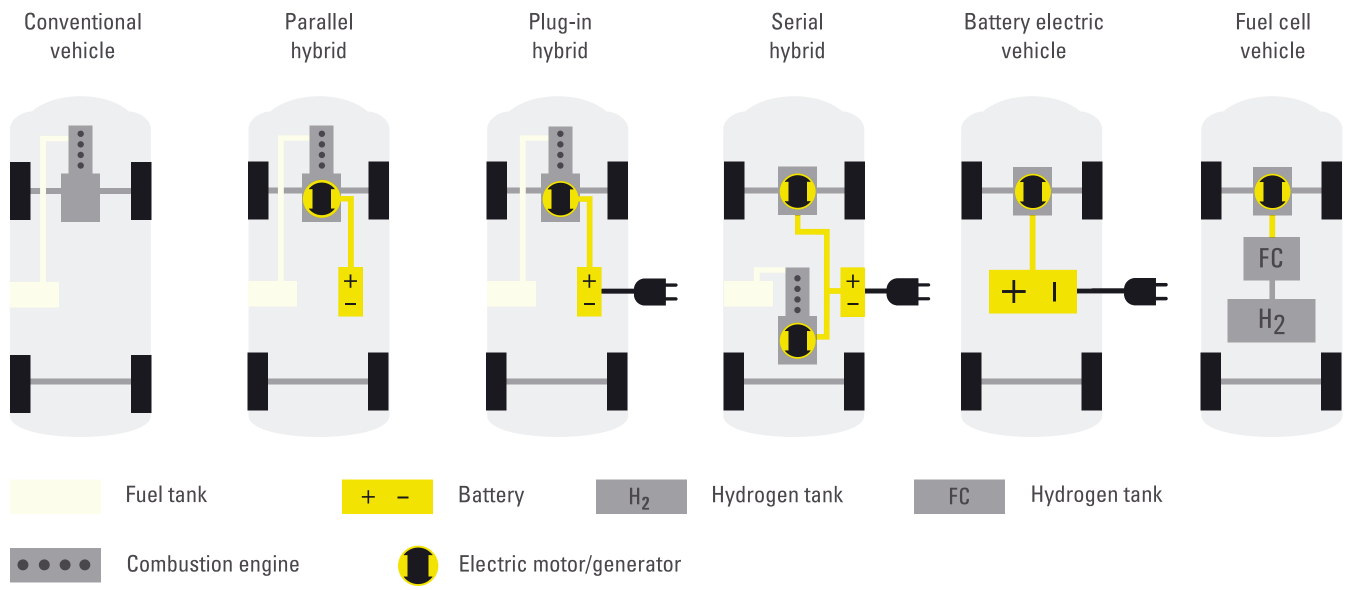
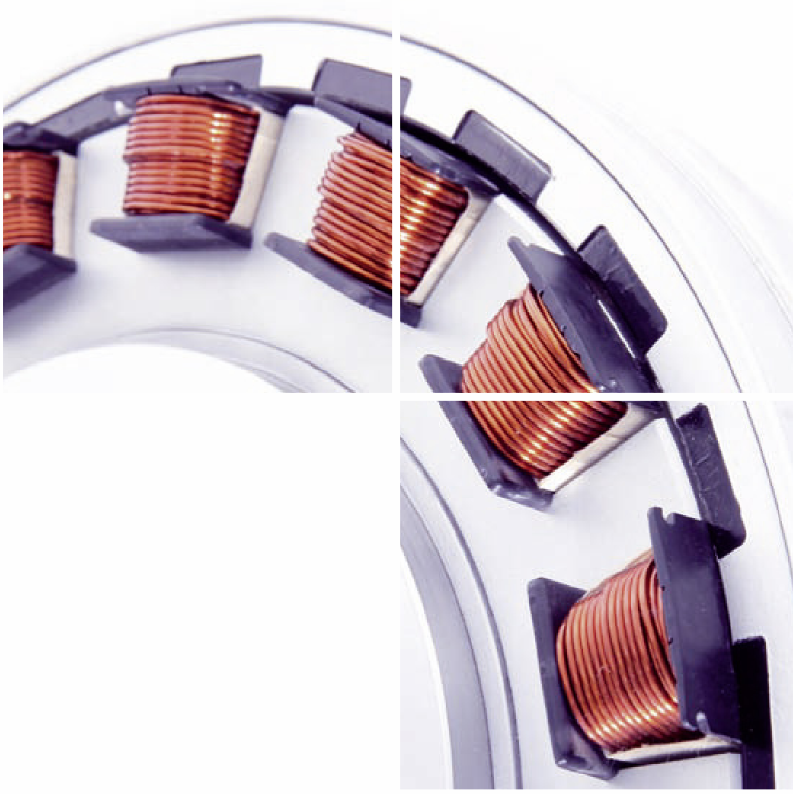


Fig. 1: The diversity of Electromobile concepts compared to conventional propulsion systems[1]

1. Authors' own illustration



- Range Extended Electric Vehicle (REEV)
  Characteristic features: Powerful electric motor with grid-chargeable battery; pure electric propulsion; modified combustion engine with restricted power for charging the battery, also referred to as serial hybrid.
  Examples of current and planned models: GM Volt, Opel Ampera, Audi A1 e-tron, Daimler Blue Zero E-Cell Plus

- Battery Electric Vehicle (BEV)
  Characteristic features: Powerful electric motor with grid-chargeable battery; no combustion engine, no fuel tank and no exhaust system; only the power grid and recuperation are used for battery charging.
  Examples of current and planned models: Mitsubishi i-MiEV, Nissan Leaf, Smart E-Drive, Tesla Roadster, Daimler A-Class E-Cell, Audi A2 e-tron, Renault Fluence Z.E.

- Fuel Cell Vehicle (FCEV)
  Characteristic features: Electric motor is supplied with electrical energy using hydrogen as the energy source and an energy converter fuel cell; also has a battery (recuperation).
  Examples of current and planned models:
  Honda Clarity, Daimler F-Cell (B-Class), Opel Hydrogen 4

In terms of vehicle concepts, there is a distinction between vehicles for personal transport (passenger vehicle, two-wheelers, commercial vehicles, work vehicles) and public transport vehicles (buses, rail-bound vehicles, boats). Figure 2 shows some examples of the various areas of application.

»In the area of electromobility the range extender will be the first to be accepted. The range deficit due to the required high energy density not yet being available represent a problem that will continue to exist for the next 10 years.«

Dr. Andreas Gutscth, Project Direction -
Competence E at the Karlsruhe Institute of Technology (KIT)

Pedelecs and electric small bicycles
Elmoto

Passenger vehicle individual transport
Smart E-Drive

Commercial vehicles
Vito E-Cell

Work machines
Atlas/Deutz
hybrid wheel loader

Public transport
Citaro G BlueTec Hybrid

Fig. 2: The various electric vehicle concepts[2]

2. Authors' own illustration

»In the future there will definitely be a great variety of propulsion technologies - certainly much to the regret of the automobile industry, since it must develop all the technologies in parallel, and not just the two classic technologies, Otto engine and diesel engine.«

Dr. Werner Tillmetz, Member of the Managing Board – Electrochemical Storage Technologies, Centre for Solar Energy and Hydrogen Research, Baden-Württemberg (ZSW)).

Although market availability of electromobility vehicles in years past was still quite low, a variety of different vehicle concepts from the manufacturers promises to crucially change the automobile landscape in coming years. In addition to other hybrid variants (HEV), automotive manufacturers are particularly announcing numerous models in the Plug-In Hybrid (PIHV) area, range extended vehicles (REEV) and pure battery electric vehicles (BEV). In the area of fuel cell vehicles (FCEV) still exhibits a very low level of market availability over the coming years. Fig. 3 shows a summary of some of the announcements made by vehicle manufacturers for modified individual passenger transport, from a temporal perspective.

»We are working concurrently on different propulsion concepts. Our goal is that the modules and components of the different propulsion concepts overlap, so that they become interchangeable and scalable. This is the only way to counter the uncertain market development.«

Peter Froeschle, Director - Strategic Energy Projects & Market Development for Fuel Cell and Battery Vehicles, Daimler AG

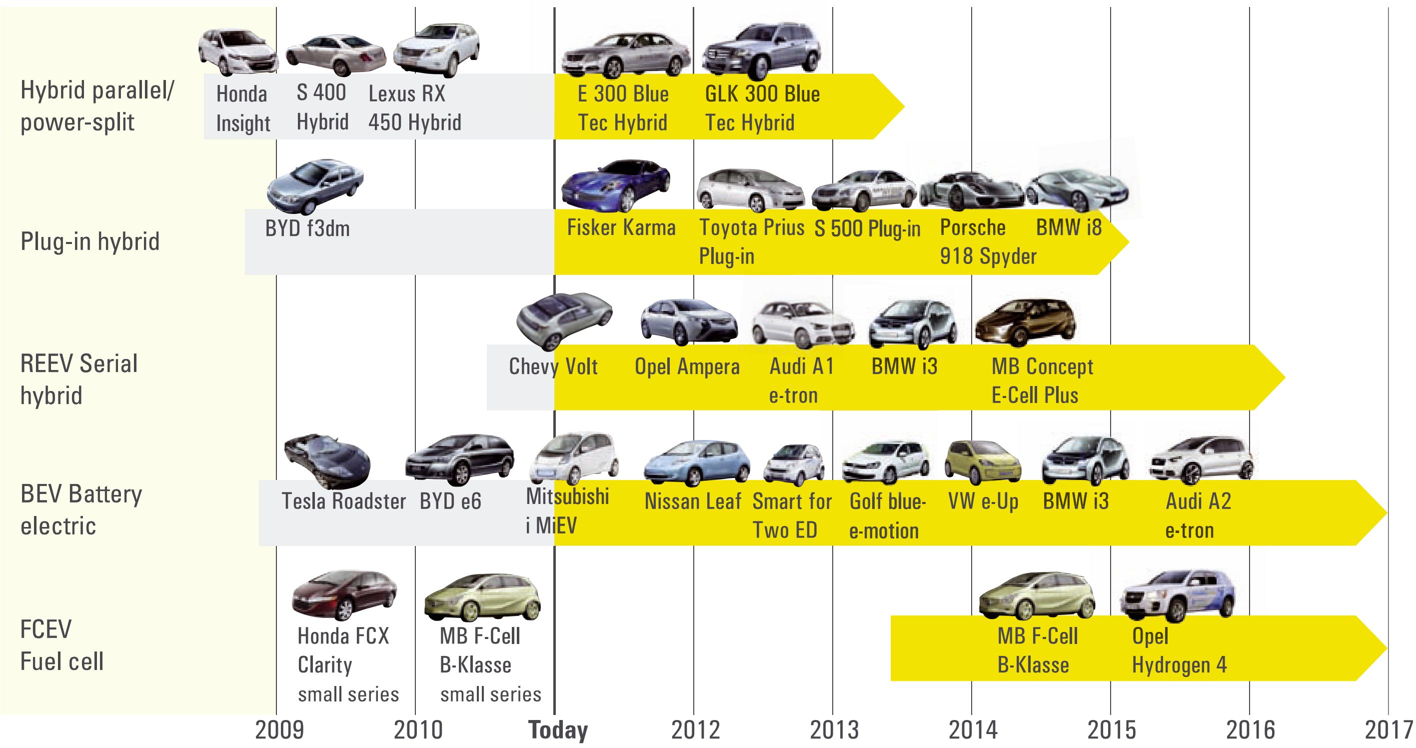


Fig. 3 A selection of current and planned electric vehicle concepts[3]

3 Authors' own illustration

2.2 COMPONENTS OF ELECTRIC VEHICLES AND CURRENT AREAS OF DEVELOPMENT FOCUS

2.2.1 ENERGY STORAGE DEVICES

Electric propulsion must always obtain the required energy from a suitable energy source - which it then converts into propulsion power with efficiency greater than 90 percent. Thus the energy storage device is the core component of electromobility, as it plays a significant role in determining both the performance and range of the vehicle.

2.2.1.1 ENERGY STORAGE DEVICES IN GENERAL

Based on the current state of the technology, various alternatives are available: In particular, it is necessary to consider the various types of rechargeable secondary batteries (lead-acid, NiMH, Li-Ion), hydrogen as an energy source together with the energy converter fuel cell, as well as capacitors. Gravimetric energy density [Wh/kg] as well as power density [W/kg] is an essential selection criteria. These are usually presented in a so-called Ragone plot (see Fig. 4).

If you compare the energy density of batteries with that of gasoline or hydrogen, then a serious disadvantage of the secondary cell becomes apparent (see Fig. 5). This relatively low energy density results in the requirement to install heavy battery packs in the vehicle in order to obtain acceptable ranges. On the other hand, the advantages relative to the combustion engine include the outstanding efficiency of the electric propulsion (max. combustion engine efficiency of 30 percent vs. electric motor efficiency of 90 percent), as well as local emission-free mobility.

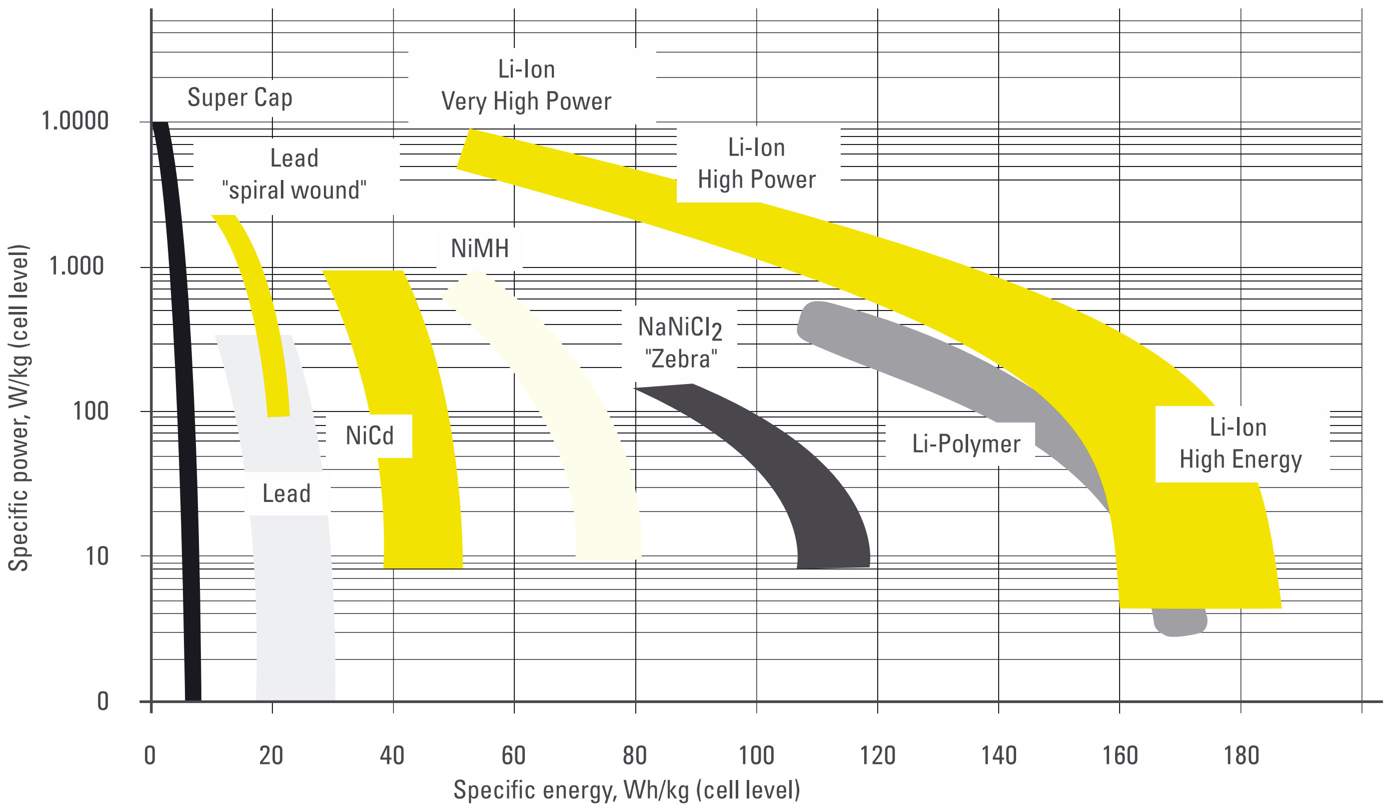
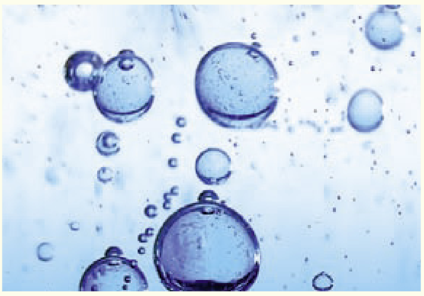


Fig. 4: Ragone plot[4]

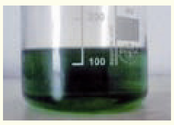
4 Sauer (2009)



Hydrogen 33.306 Wh/kg

Gasoline 11.944 Wh/kg

Lithium-ion 180 Wh/kg



NiMH 80 Wh/kg

Fig. 5 Comparison of gravimetric energy density of different sources[5]

In addition to energy density there are further factors that must be considered in the selection of a suitable energy source. These include: Power density, safety, service life, cyclic stability, usable capacity (Depth-of-Discharge, DoD), self-discharge rate and, naturally, the cost. Each type of energy storage device has specific advantages and disadvantages [Oertal (2008)]. Thus, it is clear that currently there is not just one energy storage device, but rather various storage devices that can exploit their respective advantages in different areas. Fig. 6 presents a summary of the essential advantages and disadvantages of different energy storage devices and their possibilities for further development. Due to its relevance in the automotive sector, lithium battery technology will be discussed in more detail, following the summary.

5 Authors' own illustration

	Hydrogen/in conjunction with fuel cell	Li-Ion	Supercaps	NiMH	Lead acid
Advantages	- Energy density three times as high as gasoline (33.3 kWh/kg)	- High specific energy - High cell voltage - Good cylindrical stability and service life with (thermal and battery management) possible - No »memory effect« - Low self-discharge	- Reliable and robust - Long service life, very high cycle count - Very high power density	- Reliable and robust capable of deep discharge - Long service life in discharged status - At low temperatures capable of deep discharge	- Low manufacturing costs (material price, technology) - Available in large quantities various dimensions
Disadvantages	- Low efficiency (48%), however still better than combustion engine - Storage of hydrogen is problematic. Infrastructure not yet available - High costs for fuel cell system - Heat dissipation of low temperature fuel cell is problematic	- High costs - Reactive with air and moisture - Complex battery management (electrical and thermal)	- High self-discharge (parasitic, internal currents) - Large voltage swings - Very low energy density - High monitoring effort - High danger potential in the case of abuse	- High self-discharge (particularly at increased temperature) - Poor cyclic efficiency - Only capable of fast charge - Relatively low energy density	- In general low cycle stability - Not capable of deep discharge - Low energy density - Poor charge retention - (Sulphatization) - Short service life
Possibilities for further development	- Use of new, more cost-effective catalytic converters - Further development of the high temperature fuel cell for the mobility sector - Use of new, storage possibilities for hydrogen - Cost effective and readily available procedures for production of hydrogen	- Short-term further developments on Li-Ion - Storage concerns the electrode materials for increasing the storage density, Electrolyte, separators, housing to improve performance and safety - Battery management for achieving long service-life and cycle count at concurrent high discharge depth	- EEStor Inc. (Austin/Texas): Capacitor with ferro electric ceramic layer (barium titanate) as dielectric (Estimated energy density up to 340 Wh/kg, no products yet)	- Reduction of self-discharge through improved separator materials	- Through the use of the lead anode through a carbon electrode (Axion) an inexpensive „battery supercap" can be implemented - Shorter charging times - Higher power density - Improved lifecycle duration
Summary	Good suitability for energy storage/conversion in the stationary sector - mobility area formerly limited to special applications - Cost reduction necessary for automobile use - Cost effective and environmentally friendly manufacturing of hydrogen must be implemented	- Highest potential, however still high costs for use in electrotraction: - Low quantity for low number of E-vehicles is initially problematic - Optimized production and series maturity for the consumer products	- The combination of Supercaps with saving of high energy density offers potential	- Due to the relatively low energy density the high self-discharge and the poor fast charge capacity NiMH rechargeable batteries have only limited suitability for PHEV and BEV - However the system is mature and extremely robust	- Lead-acid rechargeable batteries are not suitable for PHEV and BEV due to the low energy density and short service life

Fig. 6: Comparison of different energy storage devices[6]

6 Author's own illustration

2.2.1.2 LITHIUM-ION BATTERIES

STRUCTURE AND CHARACTERISTICS

The lithium-Ion battery has the highest potential for use in future hybrid and battery electric vehicles due, among other characteristics, to its relatively good energy density (50 to 200 Wh/kg) and power density (up to 5,000 W/kg). Moreover, the achievable high cyclic stability (approx. 3,000 cycles to 80 percent DoD), as well as a high cycle efficiency (approx. 96 percent at 80 percent DoD), are arguments for the use of this battery in the vehicle. However, lithium batteries are relatively expensive. The battery cells consist of 2 electrodes (negative anode and positive cathode) that are divided by a separator, and usually contain an electrolyte. Rechargeable lithium batteries can be classified depending on the selected electrode material, as well as the separator and electrolytes, as lithium-ion batteries (lithium-ion with liquid electrolyte, as well as lithium-ion polymer with gel electrolyte), and lithium-metal batteries (lithium-metal with liquid electrolyte, and lithium-polymer with polymer electrolyte). The different properties and characteristics of the cells depend on material selection.

CONSUMER AREA

In the area of consumer products, lithium-ion batteries have been used for some time. In this sector, a lithium-cobalt-oxide ($LiCoO_2$) cathode, a lithium-graphite anode, an organic electrolyte, and a polyethylene separator are usually used. Japan, Korea and China are driving this market in terms of technology and production. However, there are characteristics relating to safety, service life, and aging of the cells that are problematic for use of these consumer product cells in an automobile; these characteristics are not significant in the consumer sector due to short innovation cycles or low loads. Since new processes and procedures, as well as new challenges, are necessary for the new concepts and materials, for some time, the extent to which the previous manufacturers of consumer lithium batteries will be able to profit from their know-how in handling the component materials and production of small cells, has been an open question.

AUTOMOBILE APPLICATIONS

For electromobility, not only new cell chemicals are demanded, also new cell types are required. In this area the trend is toward larger cells. In addition to the round cell which has often been used up to this point in time, it is now mostly prismatic cells or pouch cells (so-called coffee bags) that are being developed for the vehicle sector.

The conflicting objectives between power density and energy density that are evident in Fig. 4, result in a differentiation of high energy and high power batteries depending on the selected cell chemistry and cell structure: While the former enables a long range of the vehicle (desirable for a battery electric vehicle), the latter permits strong power consumption and output, (required for recuperation or boost functions in the hybrid, for example).

In this regard, the different usable battery capacity of the different concepts must also be considered. For hybrids this is approximately 10 percent with an extremely high cycle count (i.e. only approximately 10 per cent of the nominal available capacity is used), for battery electric vehicles, the figure is up to 80 percent with a lower number of charge cycles.

DIFFERENT CELL CHEMICALS

In addition to the $LiCoO_2$ battery there are a number of approaches that have achieved significant improvements in the characteristics of the battery, particularly in terms of energy density, through the use of new materials for the cathode and electrode. The lithium iron phosphate cell is cited as an example; it is also characterized by the fact that „thermal runaway“ (uncontrolled temperature increase from an exothermal reaction due to released oxygen, that can cause the cell to explode) does not occur at increased cell temperature.
Fig. 7 provides an overview of four different Li-Ion battery types and their respective characteristics. High material costs of the aluminum and copper foil used for the anode and cathode, as well as electrolyte and separator costs and the complex production procedures and high machining costs, result in high prices for lithium-ion vehicle cells.

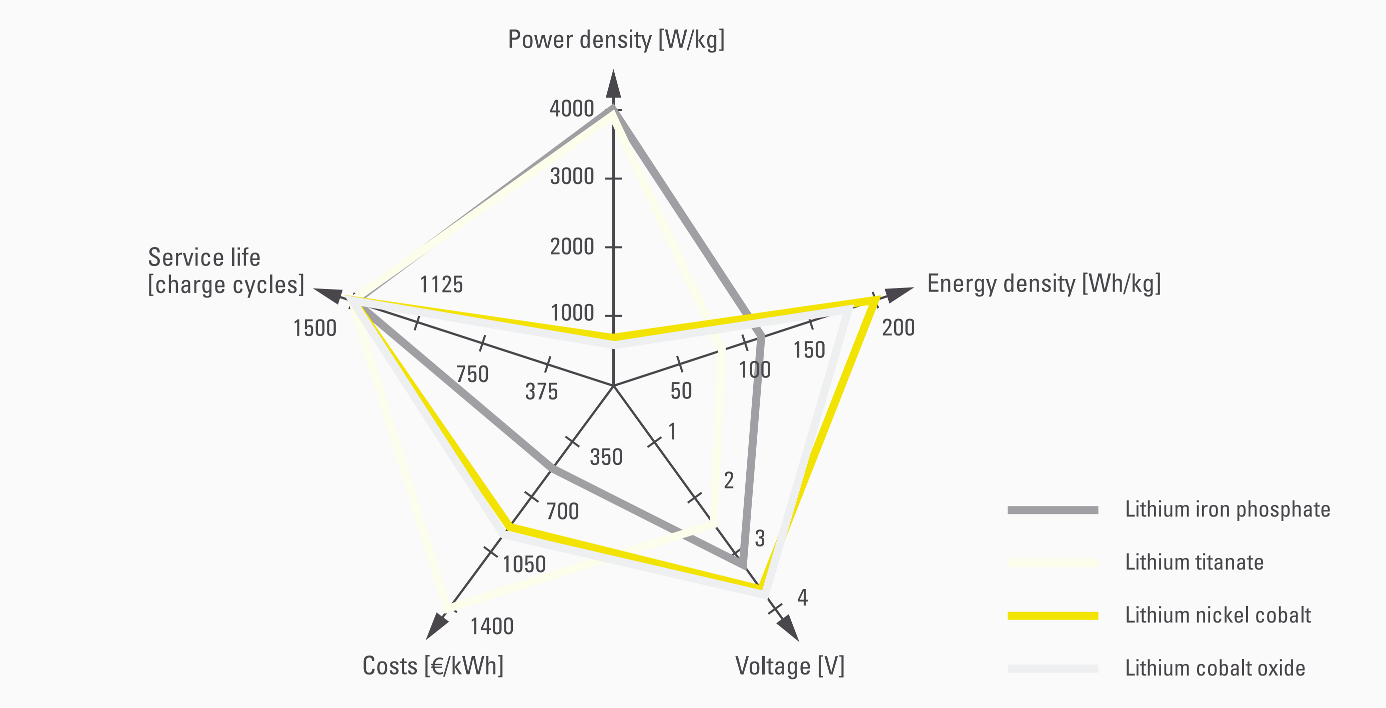


Fig. 7: Characteristics of lithium-ion battery types[7]

DEVELOPMENT TRENDS

Technological developments currently concentrate on the following points [Tube (2008b); Sauer (2009); Winter (2011)]:

- Increased safety, for example through new electrodes: Anode materials (TiO_2, metal alloys), cathode materials ($LiMn_2O_4$, $LiFePO_4$), separators (ceramics), electrolyte (polymer electrolyte, ionic liquids, ceramic electrolyte)
- Increased energy density of the anode by increasing the lithium proportion, for example through new anode materials such as silicon anode materials ($LiSi_5$) or tin
- Replacement of organic solvents and separators with inorganic and ceramic elements
- Alternative material structures: For example, through nanoparticle electrodes and nano-structured electrodes (for anode and cathode)
- High-energy accumulators (metal-air cells such as lithium-air or lithium sulfur cells
- Reduction of the hazard potential and effects through internal and external short circuits, overload, deep discharge and heat input
- Cost reduction, through new electrodes for example: Anode materials (TiO_2), cathode materials ($LiMn_2O_4$, $LiFePO_4$)
- Increased service life and cyclic stability: For example, through new cell chemicals ($LiNiCoMnO_2$, $LiNiCoAlO_2$)
- Optimization of performance even at low temperatures
- Activation of alternative concepts (redox flow)

7 Authors' own illustration based on Tübke (2008a)

2.2.1.3 FUTURE CELL CHEMICALS

New-generation battery technologies are frequently based on metallic anodes, for example, lithium-sulfur or lithium air. Significantly higher energy densities are achieved with these anodes. Currently, recharging is still a challenge in this regard: During the recharging process, non-uniform deposition of the lithium occurs. This causes so-called dendrites to form; the dendrites penetrate the separator after multiple charges and thus can cause an internal short circuit and failure of the cell. Currently lithium-sulfur, in particular, and lithium-oxygen are being discussed from the medium-term and long-term perspectives, respectively. However, alongside performance of the cells, safety and required service life are the highest priorities for the automotive manufacturers. These requirements must be fundamentally fulfilled before series production of the cells will become probable.

LITHIUM-SULFUR CELL

The Lithium-sulfur cell, in the charged state, consists of a metallic lithium anode that is connected to a sulfur bearing cathode. This offers a high proportion of active material, as well as a large surface area and good conductance. The result is a theoretical energy density of 1675 Wh/kg, as well as a power density of 3900 W/kg. Cell voltage is between approximately 2.2 and 2.5 Volts. As yet unresolved is a parasitic shuttle mechanism that occurs in addition to the desired chemical reaction. This results in a high self-discharge of the cell and poor efficiency.
Actual values currently achieved are 350 Wh/kg and 300 full cycles (Sion Power Corporation). Developments are particularly aimed at reducing the cost structure of the electrodes, increasing the actual energy density (approximately 600 Wh/kg is considered possible in this regard), increasing cycle stability (> 2000 cycles is the goal) and, in addition, solving the problem of the so-called „shuttle mechanism" [Tübke (2011); Hagen (2011)].

LITHIUM OXYGEN BATTERIES

Lithium-oxygen batteries currently hold out the promise of the greatest energy densities and thus the longest ranges for a given weight. The anode consists of a pure lithium metal, while the cathode consists of a porous Mn_3O_4-/C mixture, and is replaced by air supplied from the outside. The energy density that can theoretically be achieved is 5200 Wh/kg with consideration of the oxygen (11,140 Wh/kg without consideration of the oxygen). The cell voltage is approximately 2.9 Volts.
To date values of approximately 700 Wh/kg at 300 full cycles have been attained (PolyPlus Battery in Berkeley, CA) [Tübke (2011)]. It is expected that commercially implementable systems will require at least 20 more years of development time [Möller (2011)].

HIGH-VOLTAGE BATTERIES

Further developments are aimed at enabling higher voltages in the cells. This would mean that a lower number of cells would suffice. Here the target values are 4.5 to 5 Volts. High-voltage materials are already considered as advanced in terms of technical application (for example, $LiNiMnCoO_2$, $LiCoPO_4$ and $LiNiPO_4$), however, they still need to be integrated into the area of future technologies for automotive manufacturing [Hartnig (2011)].
The voltage range cannot be arbitrarily increased because current materials, in particular, become unstable at high voltages and, moreover, no electrolytes exist that are stable at high voltages [Möller (2011)].

LITHIUM METAL POLYMER BATTERIES

The separator/electrolyte consists of a polymer that prevents dendritic growth of the lithium during recharging and should also ensure the safety of the battery.
One advantage of the LMP battery is its high efficiency that can be as much as 99.7 percent. The lithium metal polymer battery (LMP) has been known for some time, however up to this point in time it has not been able to find an application in automotive manufacturing, due to unresolved problems. For example, one reason has been that current can only flow in the cells above a temperature of 60 degrees Celsius. The technology also became known when the company DMB advertised that they had solved the problems, with a 600 km drive from Munich to Berlin: Due to a special layer-like structure (using 4-layer technology) and a new type of material combination. The general safety and functionality was confirmed by the Federal Institute for Materials Research and Testing (Bundesanstalt für Materialforschung) and DEKRA8. However, scientists and research experts doubt the presentation of the record range [see Winter (2011) for example].

2.2.1.4 SUPERCAPS

Electrochemical double-layer capacitors (also referred to as ultracaps or supercaps) have a large surface area and a low thickness of the dielectric. Supercaps are particularly characterized by a significantly improved power consumption and power output (gravimetric power density to 20,000 W/kg), and high efficiency (cycle efficiency 98 percent at 80 percent DoD), as compared with batteries. Also they have a high level of cycle stability (approx. 500,000 cycles at 80 percent DoD). Disadvantages are high costs and a low energy density (gravimetric energy density of approx. 4 Wh/kg) [see Frost & Sullivan (2009); Tübke (2011), for example]. Supercaps could represent an interesting extension of existing Li-Ion energy storage devices and offer „stop-and-go" support, however, in general only for brief strong charge processes (recuperation) and discharge processes (boost function), that offload the battery. However the high power density could support implementation in mild hybrids. Due to the low energy density, systems to date are not suitable for providing energy storage for pure electric vehicles.

2.2.1.5 REDOX FLOW BATTERIES

The process in redox flow batteries is based on the principle of storing chemical energy in the form of dissolved redox pairs in external tanks. Power is generated in a separate power module. During discharge, the electrode is supplied continuously with the dissolved material from the storage tank that must be converted; the resulting product is routed into another storage tank. When charging, the pump direction of the electrolyte is reversed. A distinction is made between redox flow batteries, with two fluid electroactive components, and hybrid flow batteries with one fluid and one solid electroactive component. Vanadium, vanadium bromide and polysulfide bromide can be used as electrolytes for redox flow batteries. On the other hand, zinc-bromine or cerium-zinc is used for the hybrid-flow battery. The electrolytes are usually carbon-based or made of graphite, partly in the form of a felt. Usually a Nafion (112, 125) or polystyrene sulfonic acid membrane is used as the separator. Depending on the metal pairing of the electrolyte, different voltage levels are achieved, from approx. 1.0 to 2.2 V (graphite electrodes with aqueous electrolyte at max. 1.7 V) [Tübke (2011)].

Current development objectives include, in particular, new electrolyte systems for higher energy densities, but also electrode optimization for increased power, as well as reduction of system and maintenance costs, for example, through new membranes. The energy capacity is essentially determined by the tank size for the electrolyte solution and this can be easily scaled. Efficiency is as high as 80 percent. The system offers a flexible structure (separation of energy storage device and converter) and is characterized by a long service life and a high level of cycle stability (> 10,000). Likewise, low maintenance effort, fast response time (μs-ms), good overcharge and deep discharge tolerance, and no self-discharge, are exhibited. However, the aqueous electrolytes also result in a low energy density, as well as high costs in the high-energy range [Tübke (2011)]. Energy density depends on the solubility of the redox pairs and is currently at approx. 70 Wh per liter of electrolyte fluids for a vanadium bromide combination.

In the target power range, redox flow batteries offer promising development potential for better exploitation of grid capacities and avoiding bottlenecks through distributed, grid-integrated power storage. Thus they are particularly interesting for stationary applications.

8 The Federal Institute for Materials Research and Testing, has performed technical safety experiments on the basis of the UN Manual of Tests and Criteria for Transport of Dangerous Goods. The object of the experiments was to determine whether the technology is safe at extreme climate and air pressure fluctuations, electrical short circuits, overload or wrong polarity, and with strong mechanical influences, such as vibration, impact, and collision. Likewise, the range test performed by DEKRA was passed; DEKRA tested the charging and discharging of the battery, determination of tractive resistance and maximum speed, as well as the general technical safety of the vehicle [Pudenz (2011)].

2.2.2 COMPONENTS OF THE BATTERY-POWERED ELECTRIC DRIVETRAIN

2.2.21 BATTERY SYSTEM

For use in motor vehicles the secondary cells must be brought together in battery systems. For this, modules are formed from the individual cells. The cells can be coupled in a series circuit to increase voltage. The usual values for battery systems in vehicles can be as high as 400 V. These modules are then bundled together in an overall system to increase the capacity [Blazejak (2009)]. In addition to the cell modules, an overall battery system also includes components for electronic, electric, thermal, and mechanical integration (see Fig. 8).

Different requirements, such as cooling and packaging, imposed on the overall system are derived from the different cell types. This has a direct influence on the complexity and the overall cost of the system. Consequently, it is necessary to understand the battery as a total system and accordingly not only to improve individual components in order to achieve a system improvement, but also to pursue systemic optimization. This holistic consideration for the design and optimization of the system is necessary because it has a direct influence on the characteristics of the overall system.

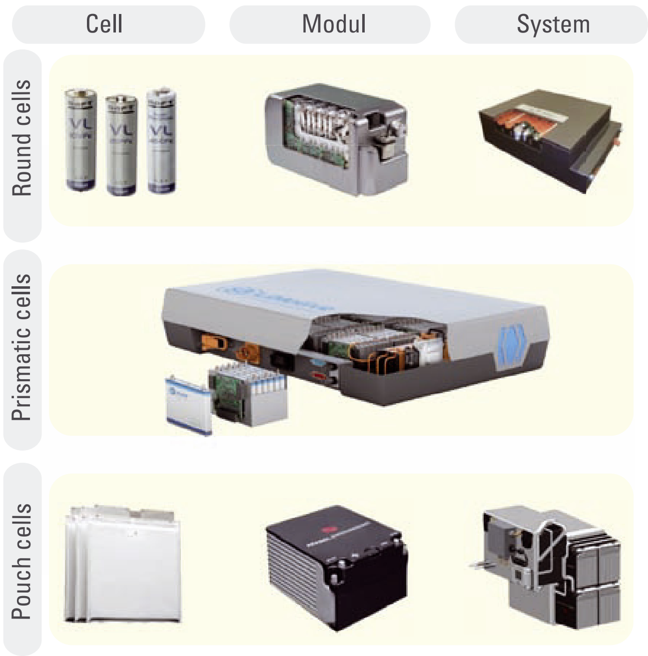


Fig. 8: The value creation stages of battery production[9]

BATTERY MANAGEMENT

Battery management monitors the charge status of the individual cells, regulates communication between the modules and the overall battery, analyses relevant sensor data and controls measures for eliminating undesired deviations, for example through activation of battery cooling, charge equalization between cells (cell balancing) and extends to safety switch-off at critical status.

The electrolyte system of the lithium-ion cell is not capable of being overloaded, and thus it is sensitive to overcharge or deep discharge. Production differences result in different cell characteristics, that drift farther apart over time. Battery management organizes these differences and consequently is viewed as the key component for sustainable use of Li-ion batteries in vehicles.

BATTERY THERMAL MANAGEMENT

In addition to battery management, lithium-ion high-performance batteries also require active thermal management to control the cooling and warming of the battery.

Aging of a lithium-Ion battery depends, in particular, on use (charge currents, discharge currents, deep discharges) and implementation conditions, and determines the useful service life. Automotive manufacturing requires an end-of-life (80 percent residual capacity/DoD) equal to the useful life of a vehicle (10 to 15 years) at operating temperatures of approx. 40°C [Brotz (2007); Fehrenbacher (2009)].

9 Authors' own illustration; image material: Saftbatteries (2011) I Battery module (2011) I Johnson Controls (2011) I SB LiMotive (2011) I ELAB 2011

Lower limit	Ideal range	Upper limit
-20°C	18°C	60°C
- Internal resistance of the electrolyte increases - Limited power output/consumption - Electrolyte can freeze		- Oxidation and decomposition of electrolyte (aging, reduced service life, cyclic stability, DoD) - Safety (overheating, short circuit, material-dependent thermal runaway above +130°C due to instability of the SEI surface passivation layer)

Fig. 9: The wellness temperature of battery cells[10]

2.2.2.2 ELECTRICAL MACHINE

The electrical machine can extend and improve the combustion engine as a propulsion source (improvement of the efficiency of combustion engine machines in partial load range for hybrids), or can also completely replace the combustion engine (for example, in the REEV, BEV, and FCEV concepts). Use of the term „electrical machine" is appropriate, as most of the electric propulsion systems can drive the engine, as well as the generator for energy recovery.

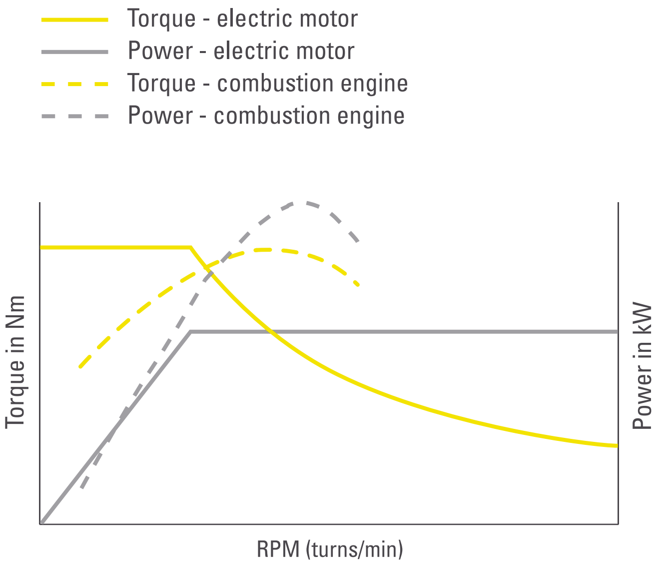


Fig. 10: Torque and power curves compared[11]

CHARACTERISTICS

Due to its torque characteristics the electric motor is outstandingly suited for use as the propulsion engine in vehicles: Maximum torque is available from 0 rpm, it remains constant up to a specific rpm and only drops thereafter (field weakening range). Consequently, a clutch can be dispensed with and only a transmission gearing unit is required. Additional advantages are high efficiency (as much as 95 percent), problem-free partial load range, torque from standstill, recuperation possibility, robustness, long service life, low maintenance costs, good scalability and a relatively low noise level. Moreover, the motor can also be operated for a specific period of time above the actual nominal power (overload range) without damage.

THREE-PHASE MOTORS

Three-phase machines are AC machines with 3-phase alternating current. The rotating-field windings are in the stator (also stationary armature) of the motor. The three alternating voltages are each offset by 120 degrees and feed the windings with the resultant currents. In the vehicle, to achieve this, the direct current from the battery must be converted into a 3-phase alternating current and then the electric motor can be activated appropriately for the situation. So-called inverters are required for this. This generates a rotary magnetic field inside the motor, which is followed by the rotor.

10 see Tübke (2008a)
11 Author's own illustration

MOTOR TOPOLOGY

In general, 3-phase current machines can be categorized as synchronous or asynchronous motors based on the operating behavior of the stator and rotor. For the latter, since there is a time lag between generation of the magnetic field in the rotor and in the stator, the rotor turns with a time delay, and thus runs asynchronously. However, the motor scores with good power density, a simple structure and simple regulation, and the fact that it does not require magnets. On the other hand, the synchronous motor has even higher efficiency and higher power density. The speed of the rotor synchronously follows the specified frequency and the rotating magnetic field in the stator. However it requires more complex regulation. The rotor can be designed with expensive permanent magnets (buried or surface magnets) or with external excitation in coils (building a magnetic field using current-carrying coils) at the expense of efficiency. There are specific rotor and stator constructions, depending on motor polarity; these are presented in Fig. 11 [Franke (2011a)].

DESIGN FORMS

The various design forms are shown below [for example see Freialdenhoven (2009); Mathoy (2010); Hofmann (2010)].

Asynchronous machine (ASM): One characteristic of the asynchronous machine, also referred to as an induction machine, is the cage winding in the rotor (inductor). The rotor, structured as

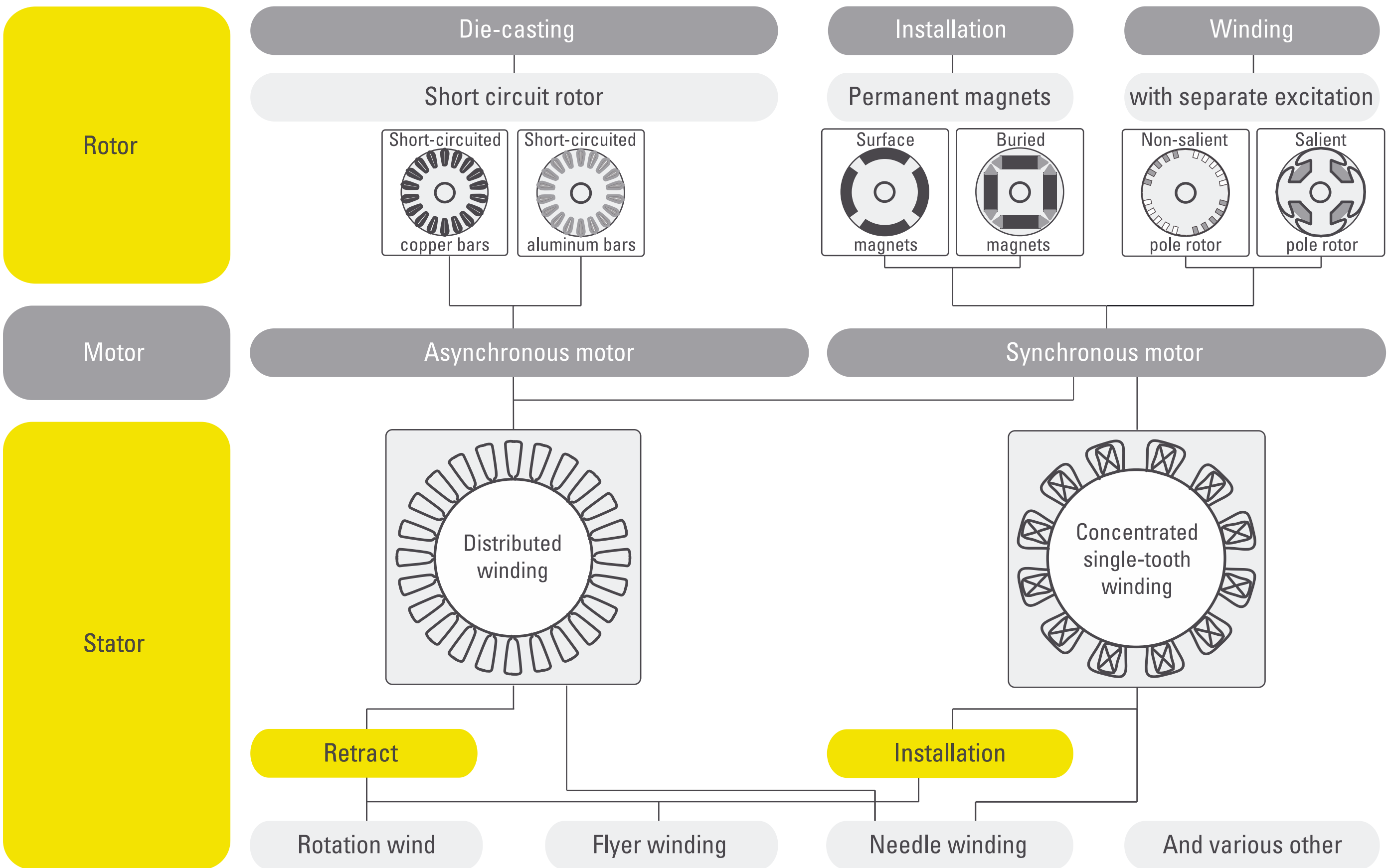


Fig. 11: Motor topologies[12]

12 The Authors' own illustration based on Franke (2011a)

sheet metal elements usually has a bar winding, in which the bars are connected by two short-circuiting rings. In some cases this results in extremely high currents in the rotor. The torque achieved is proportional to the difference (slip) of the circumferential speed to the grid frequency. The machine has a high rpm range, constant power output at uniform inverter load and high overall efficiency. In this way the ASM dispenses with sliding contacts to the rotor (as opposed to the direct current machine or the externally excited synchronous machine). The asynchronous machine has an extremely simple and cost-effective structure with low volume and weight. Further, only a relatively cost-effective controller and pulse generator are required. The ASM is a so-called high-speed machine, as opposed to a high-power machine) and thus requires a gearbox. However, at higher rpm the asynchronous machine exhibits a quadratically decreasing torque curve. Moreover, multi-pole motors require extremely precise and small air gaps for a good current phase angle. Also, rotor losses at low rpm and high torques cause high rotor temperatures. However, the efficiency is below the level for a synchronous machine. It is considered safe, economical and is suitable for urban applications. It has already been used in the Tesla Roadster, for example.

Permanently excited synchronous machine (PSM): The stator structure of a permanent-magnet excited synchronous machine is similar in structure to an asynchronous machine. In addition to distributed windings, concentrated windings can also be used here. Moreover, the rotor (also referred to as the inductor) is equipped with permanent magnets. These can be fixed in place on the surface (surface magnets) or they can be located in pockets within the rotor (buried magnets). It has a simple mechanical and electrical structure (no brushes, no sliding contacts, and no complicated windings). Multi-pole motor types can also be easily manufactured. With short-circuited windings, the machine develops a high braking torque (safety function, however this can also entail risks) and has an excellent efficiency level in the lower rpm range and partial load range. Thus it is considered to be one of the high-power machines. The PSM achieves an extremely high torque density and power density. Particularly with use of rare earths, (Nd-Fe-B magnets) an extremely compact design is possible - even more compact than it is the case for externally excited synchronous machines. The necessary use of rare earth metals however results in high material costs and dependence on imports. Likewise a cost-intensive rotor position encoder is also necessary. However, every permanent-magnet excited motor also has a limit torque that is defined by its magnet content. Moreover, at high rpm there are significant losses and only moderate power. The high rpm range (field weakening range) requires extremely high reactive current components for the inverter. Likewise extremely high short-circuit currents and idle voltages are possible if inverter defects arise. Further, a complex manufacturing process must be assumed for mass production. The permanent magnet excited synchronous machine is currently the most widely distributed machine for hybrids. However, it is being increasingly used as a traction motor, as well.

Current excited synchronous machine: Externally excited synchronous machines are employed to provide larger synchronous motors, in particular. Although the stator has the same structure as a PSM, the rotor is magnetized by current supplied from the outside (instead of magnets, for the PSM). To do this the rotor has salient poles that have windings or non-salient poles with retracted windings. The rotor (also referred to as an inductor) is magnetized via the current-excited poles. The exciter windings are supplied with current via slip rings (in some cases brushes). For larger machines (diameters greater than 400 mm) contactless transmission is also possible. However, as opposed to direct current motors, only a little current must be transmitted into the rotor. Current excited synchronous motors achieve 2.5x the nominal value for approximately 30 seconds, and up to 4x the nominal value for 5 seconds. A major advantage for them is the fact that magnets do not need to be used for this. Likewise, the machine does not have a power drop at higher rpm. It also has an extremely high efficiency level; however, it has lower power density than the PMS. In addition, there is a minor worsening of the efficiency level and a need for additional power electronics for provision of the exciter current in the rotor. A special design of the synchronous machine is the hybrid synchronous machine: Through the additional use of permanent magnets, an increase of the reluctance torque can be achieved. This is advantageous in enabling adequate torque in emergency operation even without current excitation.

Synchronous reluctance machine (SyR): Reluctance motors are based on the principle that a body that can be magnetized (but which itself is not magnetic) aligns itself in the direction of the external field. For the synchronous reluctance machine excitation is provided by a current component that lags behind the applied voltage. The stator has winding coils (distributed or concentrated). The rotor also consists of a number of laminated segments that are connected by non-magnetic elements. Rotor windings and magnets are not required. The synchronous reluctance machine has a simple design and is extremely robust. High torque yield, however, is associated with noise development, because the torque is achieved through pulse currents that also induce radially acting forces and thus induce noise development. This must be resolved in the design. A high level of intrinsic safety occurs due to the shape. To compensate for the lack of permanent magnetization, possibilities for combining the reluctance principle and permanent excitation are offered. In this regard, special forms, such as a pre-magnetized reluctance motor or hybrid reluctance motor, are possible. The hybrid-excited machine contains significantly fewer magnet materials than does the PSM. Nevertheless, an rpm range independent power is achieved as is the case with the asynchronous machine, however with higher efficiency in the lower rpm range. Peak overload does not approach the characteristics of a PMS. For a high quadrature reactance, extremely precise and small air gaps must be maintained, as is the case with ASM. Extremely high requirements are also imposed on the reduced material, and the motor topology has complex regulation.

REQUIREMENTS AND CHALLENGES

In the selection of an optimal propulsion concept for electric vehicles and hybrid vehicles, the emphasis is on system coordination of motor, power electronics and transmission, to achieve an optimum in terms of cost, weight, power density and efficiency, as well as safety and reliability.

It should be noted that widely varying requirements from the industry sector, as well as automotive manufacturing will be imposed on the production of electric machines. Examples that can be cited from automobile manufacturing are a higher delivery quality (100 parts per million, i.e. number of defective parts for 1 million produced units) and delivery reliability (100 percent), as well as a higher level of automation (wage fraction approximately 5 percent), and also a reduced service life (approx. 4,000 hours) [Franke (2011a)]. Through the different motor concepts, new requirements and new challenges are arising for the companies and new requirements for manufacturing processes that must now be developed for mass production of automobiles.

Currently, several automobile manufacturers are already active in developing and manufacturing electric motors on their own, (BMW is one example), or in collaboration with a supplier (Daimler and Bosch). Thus manufacturing of electric motors could become a core competence of automobile manufacturers. For example, automobile manufacturers could manufacture machine components, such as rotors and stators, on their own, buy-in the power electronics and take over assembly and integration in the vehicle [Schäfer (2010)].

NEW CONCEPTS

The small size and flexibility of connection enable a variety of new concepts for positioning the electric machine in the vehicle and thus enabling new vehicle architectures. For example, a central arrangement, comparable with today's combustion engines, is possible, as is distribution of the propulsion power between two smaller motors on the front and rear axles, or even four wheel-hub motors in the wheels of the vehicle (example: Active Wheel from Michelin, Fraunhofer or MIT, see Fig. below).

Wheel-hub motors offer numerous advantages, such as selective wheel activation for supplemental functions (e.g. torque vectoring or ESP without complex auxiliary systems), good weight distribution, extensive freedom for automobile designs and divided brake energy recovery on all four wheels. But there are still some challenges; e.g. relative to the issues of unsuspended mass, particularly in the high-speed range, that must be resolved. It is also expected that wheel hub motors will be more expensive overall and they require greater effort to ensure safety and service life. In addition, cabling is more complex if the power electronics remain situated in the vehicle chassis, and there is high mechanical stress for the machine.

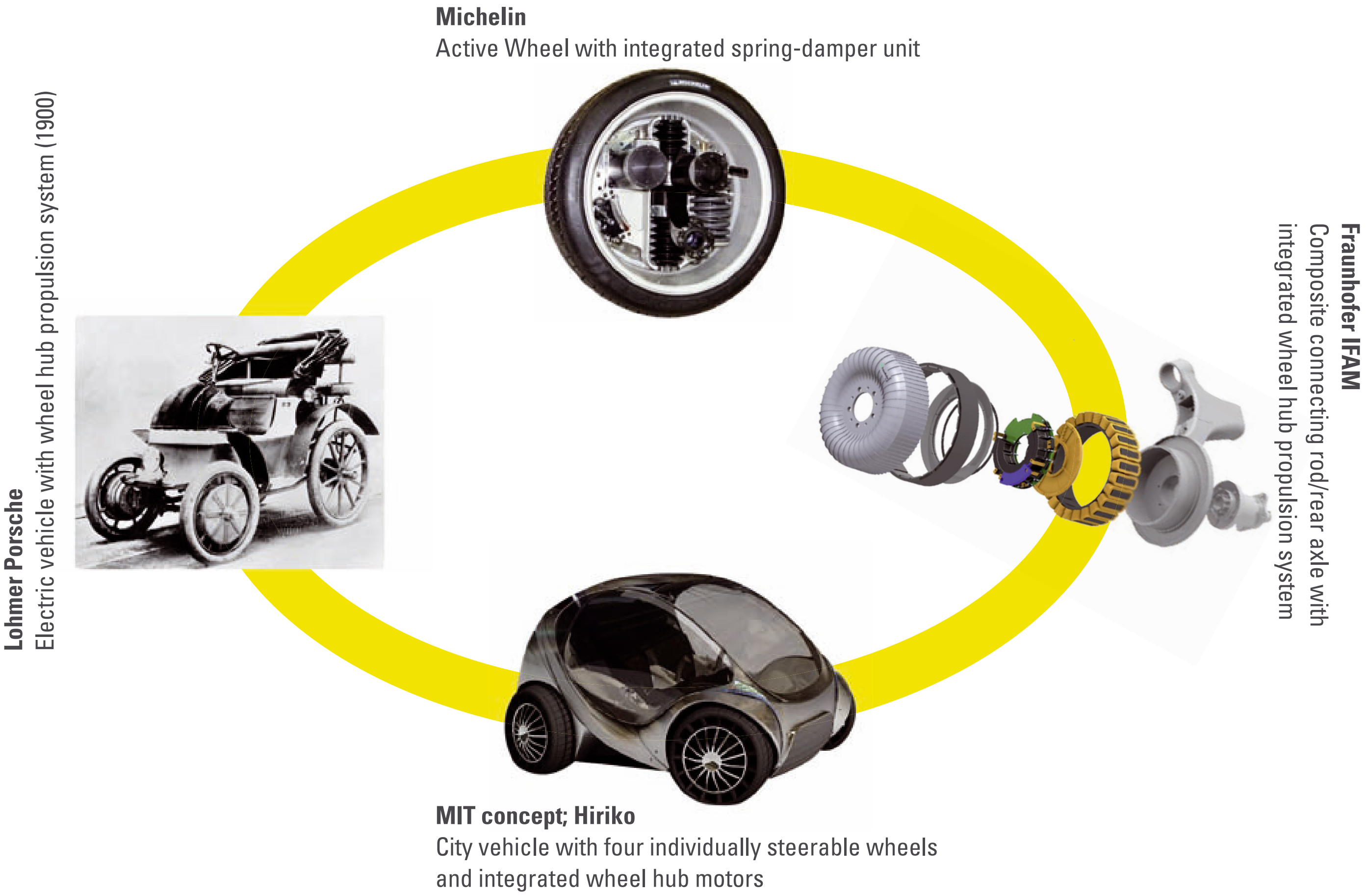


Fig. 12: Wheel hub drive: Historical look back and current concepts[13]

13 Authors' own illustration

In addition to two-wheelers, commercial vehicles with low speeds (such as construction machines, industrial trucks, city buses), in particular, could profit from a good cost/benefit ratio and package advantages [Schäfer (2010)].

2.2.2.3 POWER ELECTRONICS

The power electronics module has the task of enabling the flow of energy in the vehicle. In this regard, tasks include converting a voltage to a different level (stepping a voltage up or down), inverting a voltage (inverting AC voltage to DC voltage or vice versa) or a combination of both. In addition to regulating the propulsion, the power electronics is also used to provide the recuperation or the charging process, as well as voltage conversion within the on-board power supply. The power electronics thus are significant components that influence the economy and efficiency of hybrid and electric vehicles.

Although electric motors can be operated for a short time in the overload range without overheating, the power electronics must be configured to accommodate the maximum currents. This inevitably results in increased cost and greater effort. In the design of the power electronics, the costs, availability, performance, weight and packaging of the system must be optimized as far as possible, in order to achieve a result that is optimal for the respective requirements.

In the hybrid or electric vehicle, three-phase propulsion systems are used almost exclusively, as described in the preceding section. For this, the electrical energy from the energy storage device must be adapted to the requirements of the electric machine. Control of the energy between battery and electric machine requires an electronic adjustment device, the inverter. Here, the energy of the battery (direct current) is converted for operation of the electric motor (multi-phase AC voltage); activation of the motor requires a variable AC voltage and this needs to have a variable frequency for rotation speed adjustment.

The inverter consists of a power module (with high-power semiconductor circuits, e.g. IGBTs, SJ-MOSFET), capacitors, control electronics (controller, software), power connections, cooling and housing. The most frequently used circuit technology is the B6 bridge circuit with 6 power switches. To smooth the input voltage an intermediate circuit capacitor (usually a film capacitor) is required. Due to the high voltage and required capacitance, the capacitor can reach a considerable volume. Thus it has a significant influence on the power density of the entire inverter. The capacitor is also a critical component which, together with the power module, crucially determines the reliability of the inverter. Both components (power module and capacitor) are also responsible for a major share of the cost of the inverter [Cebulski (2011)].

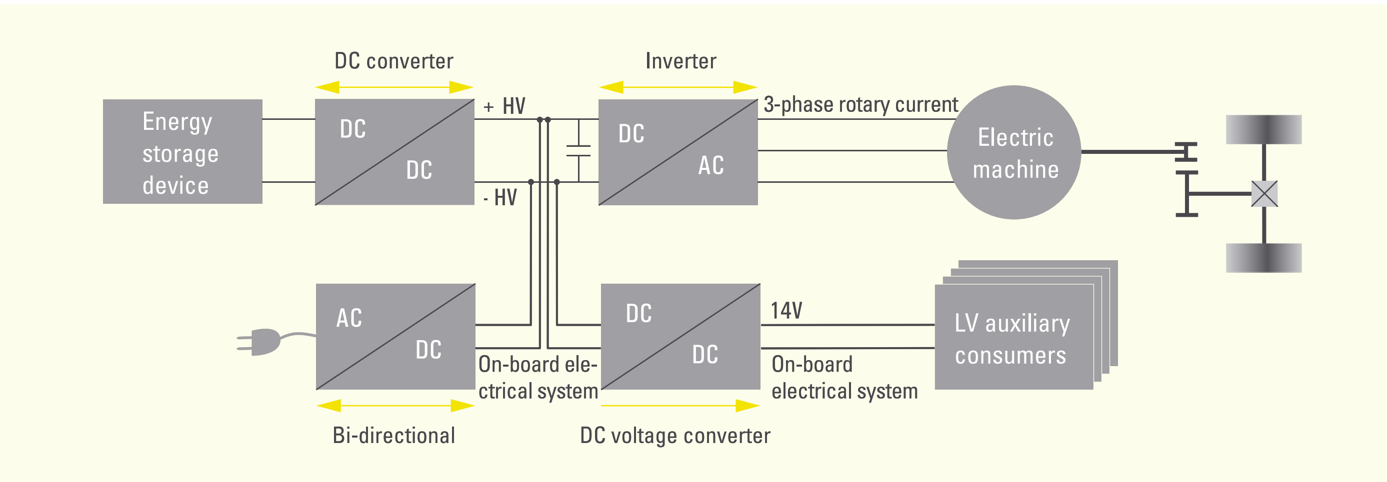


Fig. 13: Possible topology - power electronics with HV battery and LV on-board electrical system[14]

14 The authors' own illustration based on Hoffmann (2010)

Fig. 14 shows the pulse inverter and its essential components in schematic structure.

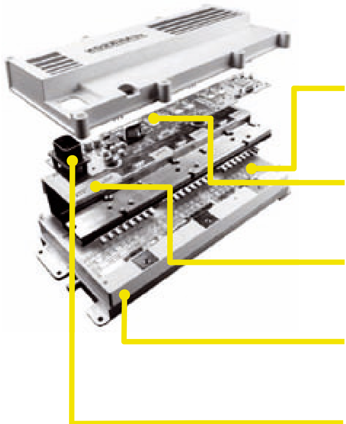


Fig. 14: Pulse inverter and its essential components[15]

Developments are aimed at significantly improving the durability of the power semiconductor module relative to the number of load cycles, even at higher chip temperatures, and achieving higher switching frequencies. For example, attempts are being made to achieve this through new manufacturing processes or new semiconductor material (SiC, GaN). Likewise, there are attempts to further increase power density (for example, through a three-dimensional structure). However, there are also attempts to achieve lower losses or to implement soft-switching topologies [De Donker (2011)].

Currently the inverter is usually located in a separate housing. This requires extensive effort for cabling and for the connections. High costs and high weight are incurred due to the high currents and the requirements imposed on insulation and shielding of the cable. The plug connections too must satisfy high requirements. Consequently, work is focused on adapting the inverter to the electric motor. This could also reduce the intermediate circuit capacitance and hence separate housing could be dispensed with; moreover it would be possible to employ a common cooling system for the inverter and the electric motor. However, in order to integrate the control electronics in the E-propulsion system, first the inverter components must reliably meet the requirements for robustness against vibration and the effects of heat [Cebulski (2011)].

DIRECT CURRENT CONVERTER

In addition to the inverter, direct current converters (DC/DC converters or converter modules) are also components for voltage adaptation. The DC/DC converter generates a changed output voltage from a variable input voltage with the aid of power electronics elements. The most important criteria in this regard are the values and the quality of the voltages and current used or that will be generated [Cebulski (2011)].

A direct current converter, for example, is used to supply the 14 V on-board electrical system from the high voltage on-board electrical system of an electric vehicle. In addition, although a high-voltage battery can be directly connected to the high-voltage on-board electrical system, for a low-voltage battery an appropriate voltage adaptation must be executed using a DC/DC converter, and the battery voltage must be set to a higher voltage level (example Toyota Prius from 202 V to 650 V) [Cebulski (2011); March (2011)].

CHARGER

In order to externally charge a battery electric vehicle - for example via, the national grid -, a charger is required. This unit adapts the external voltage level to the voltage necessary for charging the battery.

Fig. 15 shows a typical curve of the cell voltage [in volts], and the current [in amperes] for the charge process for a lithium-ion battery, versus time. A sample discharge process is also illustrated. The illustration also shows the state-of-charge (SOC) curve. It is clearly evident in this respect that within a short time approximately 70 percent SOC is achieved; however, reaching the 100 percent mark requires additional time and lower charge current intensity.

15 Authors' own illustration I Image material: SIKRON 2011

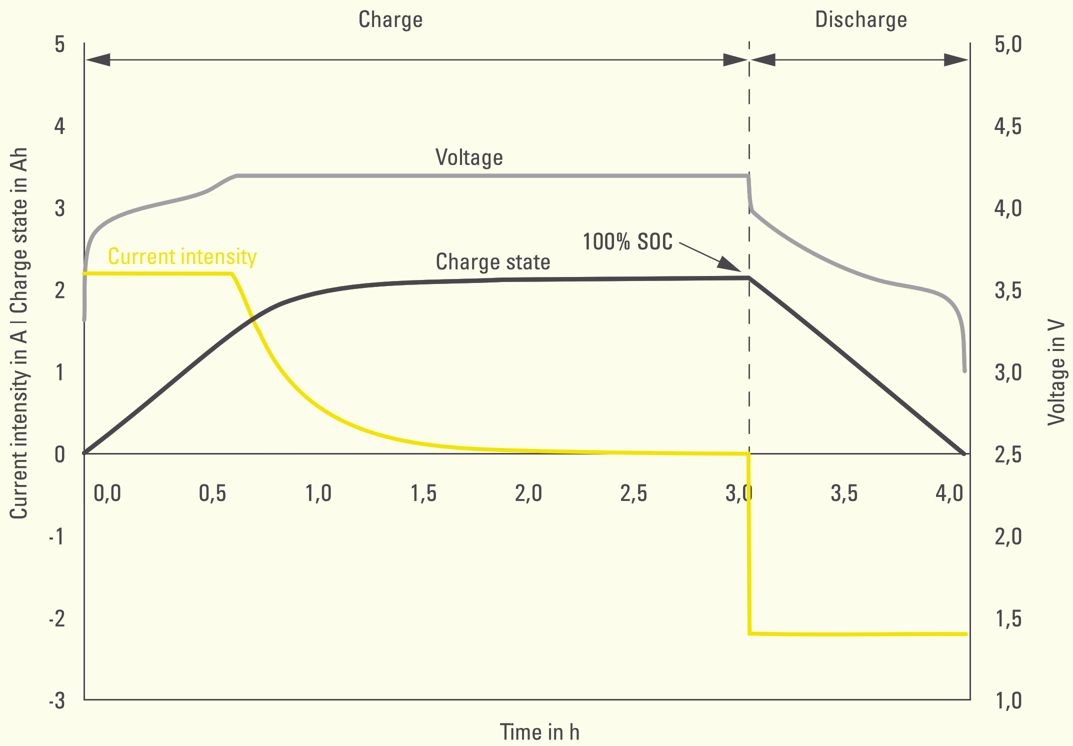


Fig. 15: Charge and discharge curves of a lithium-ion cell at fast charge[16]

The charger can either be installed in the vehicle (on-board-charging), which at this point in time is the prevalent design, or it can be installed in the charge column as an external device (off-board charging). Off-board-charging is usually used for fast charging. In this case, for example, direct current for the battery is already generated in the charge station. Depending on the concept implemented, the adaptation is executed as inversion or as voltage conversion; for which separate chargers are also necessary. The topologies required for this are currently the subject of intensive discussion and research, as is standardization of the charge processes and connector systems. So-called „integrated chargers" are an interesting development. These exploit the existing infrastructure of converters in the vehicle for the charge process and involve significantly lower costs.

2.2.2.4 TRANSMISSION

Due to the torque characteristics of a combustion engine, conventional vehicles require a clutch and transmission. Efficiency and optimization for comfort have allowed these to become extremely complex and expensive, the trade off is that current eight-gear automatic transmissions or dual-clutch transmissions no longer offer any comfort disadvantages over continuously variable transmissions (CVT).

HYBRID TRANSMISSION

Integration of an additional electric motor for power-split hybrids and parallel hybrids adds additional complexity in the drivetrain and the transmission. Different automotive manufacturers are employing different solution approaches to combine the electric propulsion system and combustion engine: Toyota uses a single

16 Lutz (2008)

planetary gear unit, BMW, Daimler and GM, on the other hand use two planetary gear units, clutches and brakes. VW, Audi and Porsche position the electric motor between the clutch and a conventional automatic transmission.

TRANSMISSIONS FOR ELECTRIC VEHICLES

Depending on the electric motor concept, a manual transmission is neither required for start up, nor for the maximum speed. Completely dispensing with a multistage transmission is only possible for high-torque machines. A simply built and inexpensive step-up gear unit suffices for these concepts. However some development directions have high-speed motors that require a stepped transmission. Multi-step transmissions are frequently designed simply as two-step transmissions. In general, dispensing with the complex transmission components contributes to reduced costs and an increase in efficiency of the entire propulsion system. Hybrid vehicles usually require a more complex and very sophisticated and expensive transmission unit, while battery electric vehicles usually have simple and thus inexpensive solutions.

2.2.3 OTHER COMPONENTS

2.2.3.1 AUXILIARY AGGREGATES

In today's combustion engines the auxiliary aggregates are almost exclusively operated with a constant ratio of transmission to the crankshaft. The supply of energy to these components must be ensured and taken into account in any overall consideration. They account for 20 to 25 percent of the mechanically executed work and thus approximately 7 percent of the total energy of a vehicle [see. A. Friedrich (2007) for example].

Currently a number of auxiliary aggregates are necessary to assure the functional capacity of a combustion engine (lubricating oil pump, coolant pump, fuel delivery system, radiator fan, mechanical charger) or implementation of exhaust cleaning (secondary air pump, catalytic converter preheater). These are not required for battery electric vehicles. However other aggregates that are powered by the combustion engine cannot or should not be dispensed with in battery electric vehicles such as the power steering pump, the vacuum pump for boosting the brake force, the ABS, the ASR, and the automatic leveling system. If the combustion engine is removed, these components must either be electrified or electric auxiliary motors must be installed, which can be used in a manner that fulfills the requirements and that can be operated in a manner that is optimized for consumption. For example, innovations are needed for steering systems (electro-mechanical solutions, „steer-by-wire" concepts) for combination recuperation via the generator and for friction brake systems or electromechanical brakes).

It must also be remembered that the entire energy required for the auxiliary aggregates needs to be provided by the main battery of the vehicle. This reduces the energy available for pure driving, and thus it reduces the range to a considerable extent. It must also be remembered that a new acoustic design will be required for the electric auxiliary aggregates. Previously this could be omitted because the combustion engine provided a permanent background noise, even in idle, and for the user it drowned out possibly unpleasant noises generated by the electric auxiliary aggregates. Due to the reduced noise emission of the electric drivetrain however, new requirements are now imposed on the construction of the auxiliary aggregates.

2.2.3.2 AIR CONDITIONING

Vehicles with a significant electric propulsion component constitute a major thermal management challenge from two perspectives: First, by omitting or minimizing the combustion engine a „no-cost" heat source and a drive unit for the air conditioner have been dispensed with. Second, for the battery electric vehicle in particular, the energy that must be used for air conditioning for the driver has a tangible impact on the range of the vehicle. Given the prerequisite of a certain battery size, if the air conditioning system of a battery electric vehicle is operated in accordance with today's procedures, the range that can be achieved with the vehicle is reduced. As illustrated in Fig. 6, this effect becomes more pronounced the higher the power consumption of the heating or cooling components is.

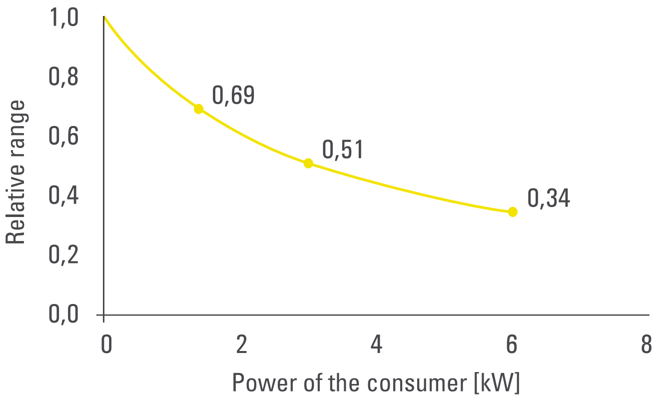


Fig. 16: Reduction in the achievable range of a battery electric vehicle with increasing power requirement of the air conditioning system[17]

In winter the energy required for heating constitutes a considerable proportion of total energy consumption and accordingly, shortens the range of the vehicles. Measurements of the AMS in accordance with TÜV Süd-E-Car-Cycle, showed the following values: Smart ED: 47 percent range loss, Mitsubishi i-MieV: -43 percent, Karabag Fiat 500: -20 percent [Bloch 2011)].

Since a combustion engine propulsion aggregate is not present for warming in battery electric vehicles, supplemental heating systems need to be fitted. These types of heating systems can be air or water PTC (positive-temperature coefficient) elements, heat pumps or fuel heaters. All heating elements are characterized by various advantages and disadvantages and must be evaluated differently in accordance with the respective requirements of the various concepts, from the hybrid to pure battery propulsion.

For efficiency increase of the air conditioning system it is also beneficial to adjust the temperature selectively near the bodies of the occupants with a distributed system, instead of warming the entire passenger compartment with a central system. The seat belt, head rest, and the side module of the seat, or the door trim are suitable locations for installation of air outlets for blowers near the individual occupants [Klassen (2011)]. An electric seat heater, as already used in conventional automobiles, a windshield heater or steering wheel heater can be used as additional components of a distributed air conditioning system for warming the vehicle interior [Frigge (2011)].

In addition to use of suitable components in the vehicle, preconditioning the vehicle cabin prior to starting a trip, using the power supply from the grid or a charge station at parking places, results in a lower power requirement during the trip.

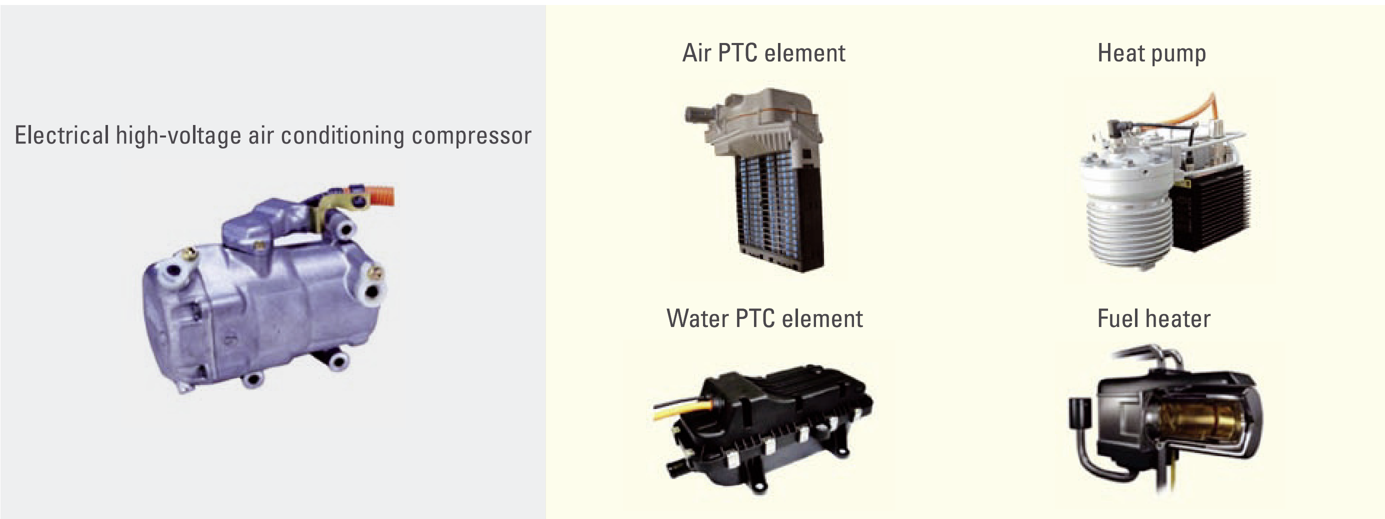


Fig. 17: Cooling (left) and heating elements (right) for battery electric vehicles and extended range vehicles[18]

17 Grossmann (2010) I Assumption: Average propulsion energy consumption of 16.7 kWh/100 km in the NEDC
18 Authors' own illustration based on Frigge (2011)

Through application of this measure the air conditioning system has a lesser influence on the achievable range because less energy from the traction batteries is required for heating or cooling the interior and thermal storage media can be used in the automobile at the desired temperature.

2.2.3.3 RANGE EXTENDERS

Most recently through the Opel Ampera, so-called serial hybrids (also referred to as range-extended electric vehicles) and the underlying technology have become well known. However, Audi, Mercedes-Benz, Fisker and Lotus are also working on implementation of the appropriate concepts. For these, the following requirements must be realized:

- Compact design
- Optimal NVH (Noise Vibration Harshness) behavior
- High power to weight ratio
- Reliability (even after longer periods of non-use)
- Optimal efficiency at (a few) defined load points
- Good integration possibility in the vehicle architecture
- Low costs, low consumption and low emissions

Currently the classic combustion engine dominates as the propulsion system of the generator for producing electricity. However, from the technical perspective a variety of concepts are possible as range extender machines. For example: Classic piston machines (Otto, diesel, LPG, CNG, Stirling, 2-stroke, boxer), rotary piston machine (Wankel engine), gas turbine, fuel cell, and also other exotic concepts, such as the free-piston linear motor, ball-piston engine and wave disk generator

2.2.3.4 HYDROGEN FUEL CELL

Due to its high energy density in combination with a fuel cell, hydrogen is an interesting energy alternative to the battery. This is particularly true for electric vehicles that will be used for long distances and/or have a particularly heavy weight. However, the prerequisite for a breakthrough of this technology on the market is an appropriate hydrogen infrastructure. For years, intensive research has been underway in this area, and significant progress has already been made. For example, prototypes in the vehicle sector have already been tested on the market for years. For various reasons, large production runs have not yet been started. In addition to the technical aspects, infrastructure and economic reasons are also involved. A number of manufacturers are already executing small production run trials (Daimler, Honda, Opel, etc.) and have announced mass production for 2014/15. Until then, the aim is to drive the expansion of the necessary infrastructure in Germany. On the industry side, alliances have been formed and the goal has been formulated to first equip the metropolitan regions with the necessary hydrogen infrastructure and then, by 2020, to establish 1000 H_2 gas stations throughout Germany.

The Clean Energy Partnership (CEP) must be particularly emphasized in this regard. Fifteen partners (BMW, Daimler, Ford, VW, Toyota, Linde, Shell, Statoil, and others) are testing the system capability of hydrogen in daily use. This includes the continuous operation of powerful hydrogen vehicles and their fast and safe refueling. However, the CEP is also concerned with clean and sustainable generation of hydrogen in order to enable hydrogen transport and storage of H_2 in the liquid and gaseous states. Resulting from the „Verkehrswirtschaftlichen Energiestrategie", in December 2002 the CEP was established with support from politicians and industry under the direction of the Federal Traffic Ministry [Clean Energy Partnership (2011)].

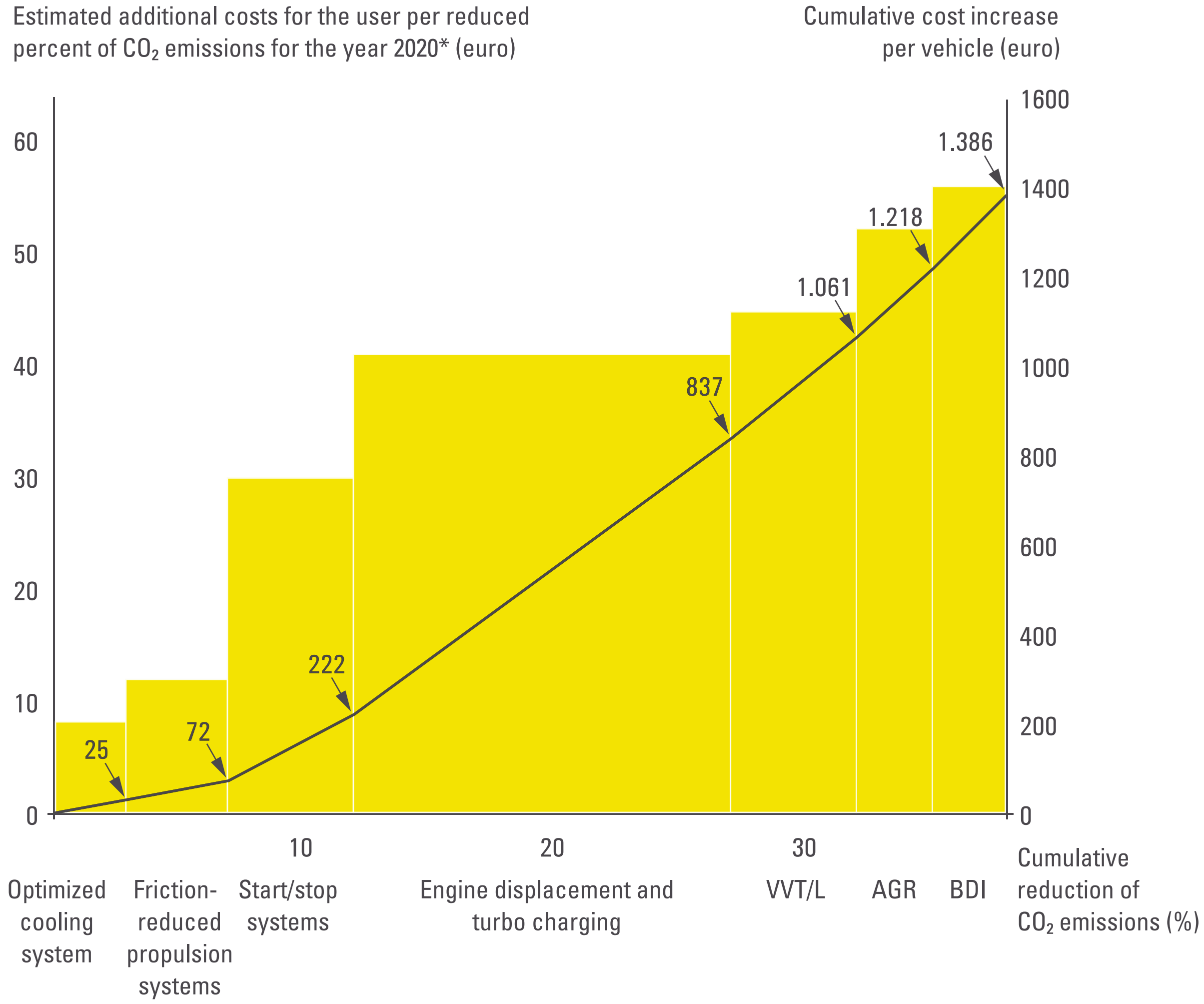
Baden-Württemberg - supported by its traditionally strong hydrogen and fuel cell sector - can take a leading role in this regard. In this area, since the beginning of 2012, five H_2 gas stations are already in operation across the state, some of these are subsidized by state funds.

2.2.3.5 OPTIMIZATION - COMBUSTION ENGINE

For the most part experts unanimously view the combustion engine as the dominating technology for the next decade(s). It is used in classic combustion engine vehicles and in hybrids. It is assumed that a large amount of money and development effort will continue to be invested in this technology. Developments in this area are currently aimed, in particular, at optimization of CO_2 emission and reduction of fuel consumption. Energy saving potential of up to 30 percent is assumed [see McKinsey (2011b); BCG (2011), for example].

Measures and approaches for realizing this potential are to be found in various industries. However, the complexity of the combustion systems and the costs for the modules will also increase. The influence of an efficiency technology on CO_2 reduction and on the associated costs is shown in Fig. 18.

Only by improvement to combustion engines emissions can be reduced by around 40 percent



Incremental average costs per reduced percent of CO_2 emissions	0% - 10% 17 euros	10% - 30% 33 euros	20% - 30% 43 euros	30% - 40% 52 euros

Fig. 18: Potential for reduction of consumption (cumulative costs over the cumulative CO_2 savings)[19]

19 Author's own illustration based on BCG (2011) I Comment: VVT/L = Variable control of the injection sequences and of the valve stroke I AGR = exhaust gas recirculation I BDI = gasoline direct injection I *The estimated net base price 2020 includes a one-percent reduction in manufacturing costs between 2010 and 2020 and a manufacturer's mark-up between 50 and 100 percent. The estimate is based on the North American D-segment vehicle . Consideration of vehicles from other segments will presumably show slight deviations.

The directions for technical development of the combustion engine can be summarized in the following points:

- Downsizing with, in some cases, multiple charging via turbocharger or mechanical charger (compressor)
- Downsizing via reduction in the number of cylinders
- Gasoline direct injection
- Reduction of engine friction
- Variable valve timing (VVTL: Variable Valve Timing and Lift)
- Cylinder deactivation
- Start/stop system
- Other processes: Combined combustion (Diesotto), HCCI, CAI
- Other CO_2 optimizations: Electronics, exhaust recirculation, optimized cooling circuit

In the coming years the combustion engine will be increasingly used as a range extender. For this special application, the important thing is for designers and researchers to develop engines that work reliably in spite of long interruptions in running and short-term high loads.

2.3. FACTORS INFLUENCING PRODUCTION

SYSTEM COMPONENTS

Electrification of the drivetrain results, as cited above, in a number of new propulsion concepts and vehicle models and thus has a direct influence on the complexity and diversity of the variants as well as on the number and type of new components or of components that are no longer required.
New components, such as battery system, electric machine, power electronics and charger, result in extended sales potential for companies if the required competences and production capacities can be built up in house. However, at the commencement of the current development of the electric drivetrain, the automobile industry had neither the background of technological experience, nor the production capacity to produce electric motors and battery systems for their requirement by themselves in the short term [Roland Berger (2011b)]. A number of factors influence the manufacturing of these system components:

- Quantity variability: The distribution of electric vehicle is still in the early stages and amounts to an extremely low quantity. However, after an (expected) slow ramp-up, there will be a need for high scalability of production in order to cover the high quantities required in automotive manufacturing.
- Technological maturity: The system components described are still at the beginning of their development for automobiles and consequently show a high level of further development possibilities. Extremely short innovation cycles must also be considered by the producing companies during the investment in plant technologies.
- Plants, processes, competences: These differ significantly from the requirements that previously predominated in automotive construction, accordingly time and financial resources are required for production ramp-up.

In this regard, the production technology and the build-up of important production competence can significantly contribute to lowering manufacturing costs in the future and thus contribute to the required reduction in the manufacturing costs of the entire vehicle. Competitive prices, in turn, form the basis for the build-up of a significant market (see chapter 3.4 in this regard).

PRODUCTION LOCATIONS

Based on the low quantities of (pure) electric propulsion systems sold to date, including 2011, there is only a low level of established production capacities existing at the worldwide locations of the automobile industry and its supplier industry. Currently, there is a strong focus on plants for automobile system components with high capacities, primarily in the Asian area - examples are Japan and Korea, but China should also be mentioned in the area of battery cell manufacturing [Roland Berger (2010)].
However, an increased build-up of production capacities in Europe and above all in the USA can be assumed - this is already shown by the developments of recent years. For example, a majority of the grants from the American Recovery Act are reserved for building up production capacity of the system components (particularly batteries, but also electric motors and power electronics) [see Roland Berger (2010)]. In 2015, in the area of lithium-ion battery production, significant over-capacity in production will predominate [Roland Berger (2011a)]. In general, it can be assumed that production capacity for system components will stay close to the market sales. This means that production capacity will ramp up in that country where electromobility experien-

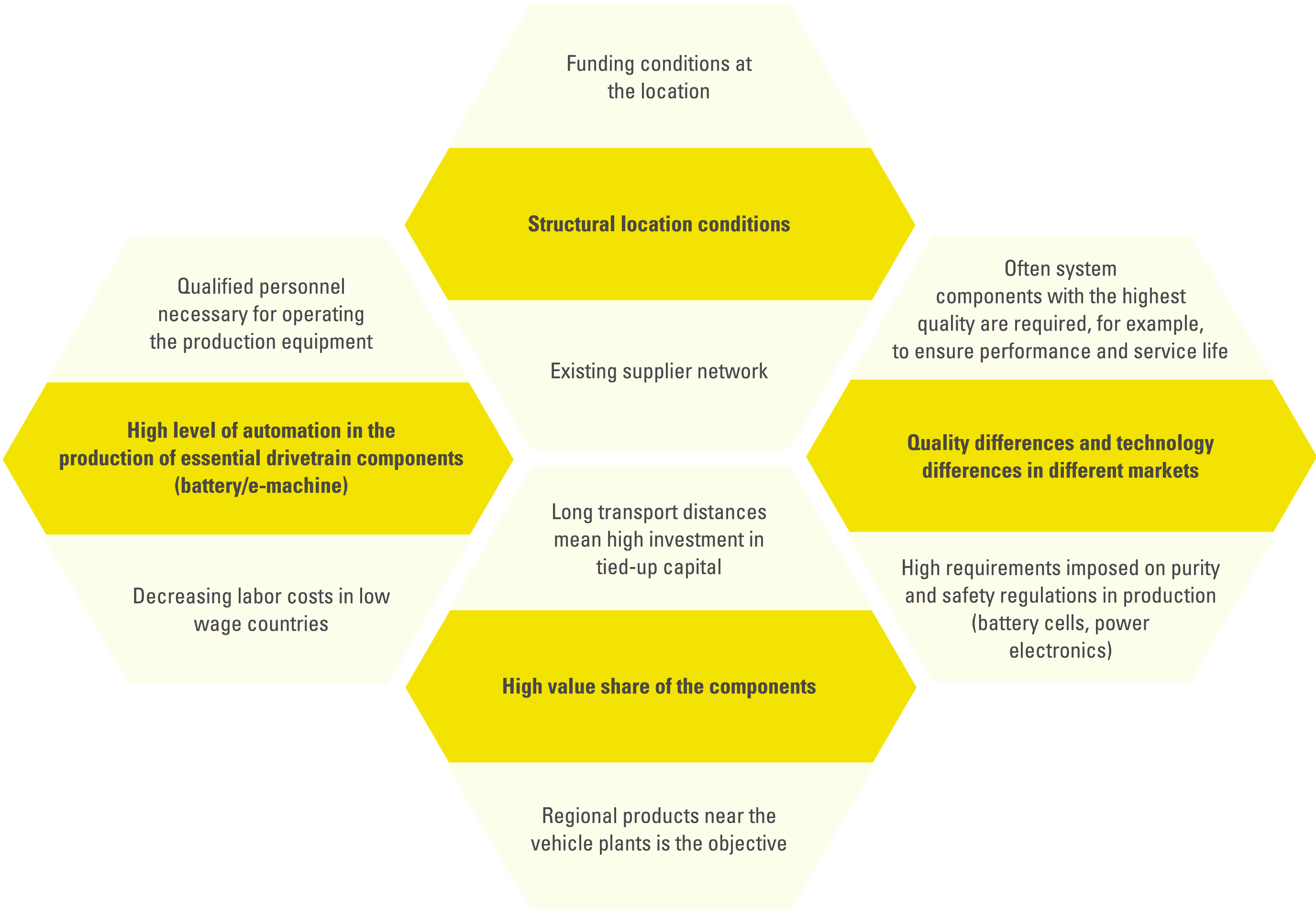


Fig. 19: Aspects for selection of a manufacturing location for components of the electric drivetrain[20]

20 Authors' own illustration based on Roland Berger (2011b)

ces a high demand (through state subsidies or regulation, but also customer requirements). Accordingly suppliers must also position themselves regionally. The prerequisite for the producing enterprises is not only a good understanding of the technological requirements of their customers (other suppliers or OEMs) locally, but rather a good understanding of the type of collaboration and the rules for dealing with the respective business partners, as well.

For a definitive decision on production locations, in the future, as shown in Fig. 19, several aspects will need to be considered. In addition to a qualified workforce, factors such as the proximity of resources and transport routes, as well as the potentially very high level of automation and the resulting increased reduction in labor costs of a manufacturer in low wage countries will play a role [Roland Berger (2011b)].

PRODUCTION TECHNOLOGY AND COMPETENCES

The production technology of the newly required system components differs in many aspects from the requirements that previously dominated in the automobile industry. Accordingly, companies that currently have a high ranking in the automobile industry are not automatically placed in this sector. Entirely new technology fields are arising that previously were not in the competence focus of the automobile companies, such as coating processes for the manufacturing of electrodes. In these areas, the possibility arises for new companies from other industry sectors to move into the automotive world.

»I am convinced that further technological developments of the product will only lead to economic success if the production technology for these developments is built-up in parallel.«

Dr.-Ing. Gisela Lanza, Management Board, Institute of Production Science, Karlsruhe Institute of Technology (KIT)

Here, an advantage due to production competences gained in an area outside of the automobile industry may have the potential to be transferred into the automotive world. One example of this could be the electric motor and a number of German producers could profit from their many years of experience in this area.
Naturally, in this case, production technologies must be adapted to the automotive requirements, which in terms of cost, install space size, as well as (malfunction) safety differ significantly from the previous requirements in other industry sectors.

Moreover, there is a shift in the weighting of previous production technologies. For example, if the production technologies of an OEM for the combustion engine are currently in the area of metal processing, it must be assumed that due to the move toward electric motors, installation activities will predominate for such an OEM [Franke (2011b)]. Whereas the manufacturing times of the production steps, turning, milling, drilling and grinding have increased by 1 to 26 percent for hybrid propulsion systems (starting from a conventional combustion system), the pure electric combustion system will result in a reduction of between 47 and 78 percent [Abele (2009)].

The ELAB research project „Effects of electrification of the drivetrain on employment and location environment" (see www.elab.iao.fraunhofer.de) examines these changes in an in-depth analysis of the changing processes, production technologies, competencies and resources. Within the framework of the research work the central question needs to be addressed, namely what are the effects on employment, in terms of quality and quantity, resulting from the trend towards alternative propulsion concepts in a typical ideal automotive drivetrain production? The project, funded by the Hans-Böckler Foundation, IG-Metall BW, and Daimler AG, will be executed by the Fraunhofer IAO in collaboration with the DLR and the IMU Institute. The results will be published in early 2012.

The trend towards electronic/electrical systems through increased substitution of electrical components for mechanical components, and a general reduction in the number of components (for example, replacement of the combustion engine and the transmission, with approximately 1400 parts, by an electric motor with approximately 200 parts [Bain (2010a)] will be extended. However, it is still unclear how the positioning of the OEMs and suppliers will be organized, and which main task areas and associated production technologies must be built up for the respective companies.

POSITIONING OF THE PRODUCTION COMPANIES

Overall, a far-reaching shift should be expected with newly required production competencies and technologies, as described above. The result will be a reorganization of the value-creation chain and, accordingly, a new alignment of participating companies relative to their strategy, competences, technologies and resources. This applies to existing suppliers and OEMs, but also particularly to new companies in the supplier industry, right up to plant engineering companies.

»Established suppliers to the automobile industry are pursuing diversification strategies and forming joint ventures for production of mechanical, as well as electrical propulsion components, to minimize risks and to participate in all market segments uniformly.«

Martin Kreuter, Corporate Development, New Business – Industry Innovation, Bayer MaterialScience

The extent to which a serious shift of the value creation chain between OEM and supplier can be assumed will certainly be highly dependent on the strategic alignment of the companies. Currently, the OEMs exhibit a very varied image with respect to the components that define their core competences; this can be illustrated using the example of the electric motor. In this case VW provides its own manufacturing, while Daimler has founded a joint venture with Bosch, and Ford relies completely on suppliers [Roland Berger (2011b)]. However, the practical implementation of a variety of cooperation agreements within a company must first be proven. In addition to founding the companies Li-Tec and Dt. Accumotive, Daimler has also announced collaborations in recent years (only in the battery cell and battery system sector) with the following companies: Continental, JohnsonControl Saft, Hitachi, Cobasys and BYD. Volkswagen is also involved in this type of complexity, through cooperation with Sanyo, Toshiba, BYD, Varta Microbatteries, as well as Bosch (likewise only battery).

A possible strategy for strong and independent positioning of an OEM, as well as cooperation with partner companies and supplies could be:

- Short-term: Setting up a joint venture with an established partner (also outside of the automobile industry) that has years of experience and a high level of know-how of the required core components, and that can also offer production capacity
- Medium-term: Build-up of the firm’s own „in-house“ competence, to remain independent from external companies, and build-up of the firm’s own production lines in order to produce high quantities, autonomously and in a manner that is cost-optimized and that offers effective capacity utilization.
- Long-term: Outsourcing the components or sub-components that have become commodities and no longer enable differentiation from the competition, to reduce the firm’s own costs and to take advantage of the competition between supplying companies.

2.4 TODAY'S MARKETS AND MARKET SCENARIOS

2.4.1 MARKET DEVELOPMENT SCENARIOS

In the National Electromobility Development plan the goal has been set to bring one million electric vehicles onto German roads by the year 2020 [German Federal Government (2009)]. This goal applies for the vehicle population and consequently is particularly relevant with regard to the charging infrastructure that will be necessary in the future. The development plan considers pure battery electric vehicles (BEV) and plug-in hybrid vehicles (PHEV), including range extended vehicles (REEV), that are primarily used as passenger vehicles but also as commercial vehicles [German Federal Government (2009)] (see Fig. 20).
In the second report of the National Platform Electromobility, published in May 2011, several incentive measures were introduced to achieve this goal. If these types of measures are not implemented, the analyses from the NPE assume only 450,000 electric vehicles in the year 2020 [NPE (2011a)]. To estimate market development, a metastudy was executed that analyses and combines the results of existing studies. These studies do not start with the vehicle population, but rather start with sales per year. Using a metastudy offers the advantage that potential incorrect estimates can be compensated for in the studies analyzed. Moreover, the data stock can be adjusted for extreme scenarios. As compared to the situation in 2009, the market scenarios differ fundamentally in the anticipated dynamic development of the automobile market. For the most part, this is attributed to the excellent fundamental economic data, such as worldwide economic growth and worldwide employment at the time this study was prepared. Development of the automobile market (or the scenario of diffusion of alternative propulsion concepts) depends on various factors according to the study analyzed.

Goal: 1 million electric vehicles by 2020 (in thousands)

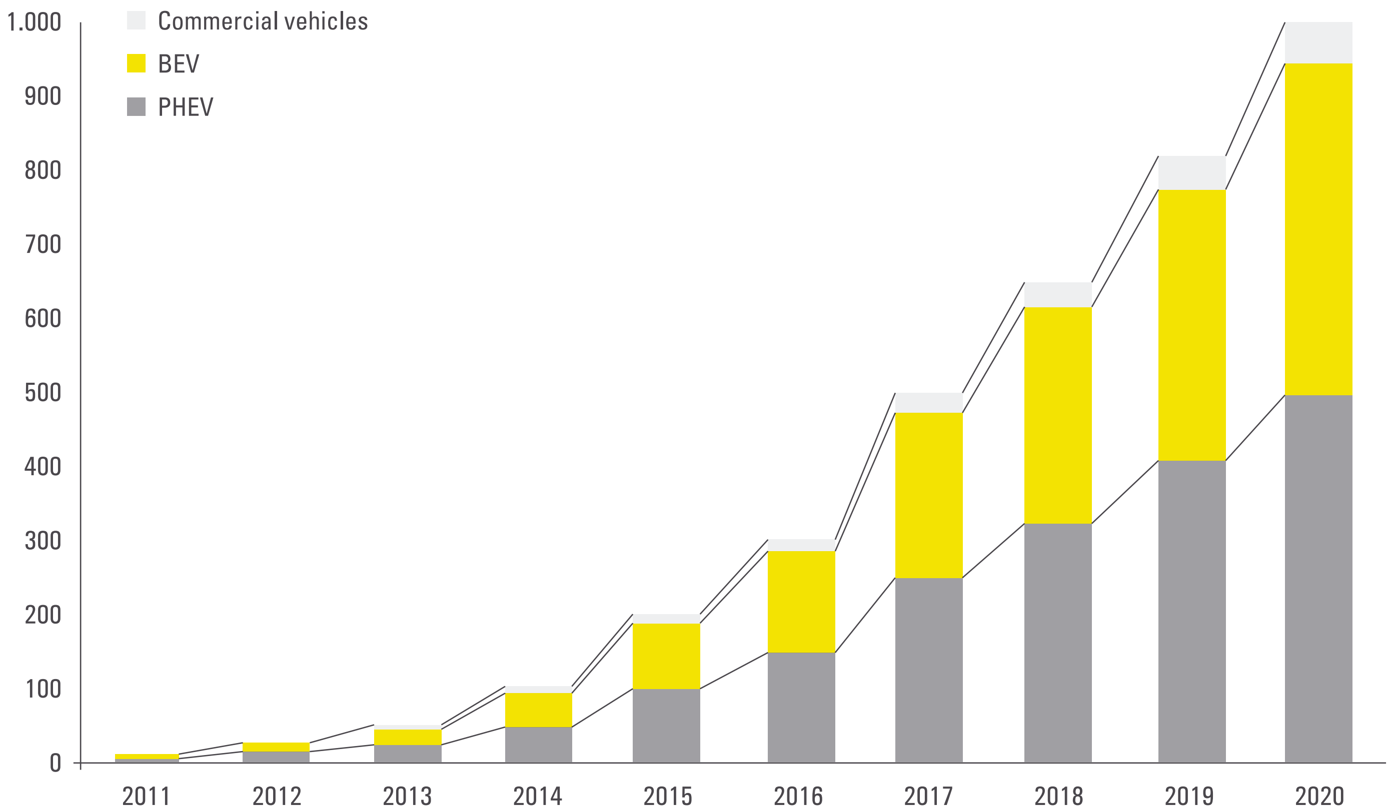


Fig. 20: Market ramp-up curve of the NPE[21]

21 NPE (2011a)

The oil price plays a major role in the studies from the Boston Consulting Group [BCG (2011)] and from Bain [Bain (2010b)]. Indeed, for the Boston Consulting Group, the price per barrel is the main differentiating factor relating to the development of electromobility. It should be noted here that changes in the oil price are not proportional to the price of gasoline (or diesel price [Welt online (2011)].

The CO_2 limit values are discussed in the studies from McKinsey [McKinsey (2011c)] and Bain [Bain (2010b)]. High regulatory dynamics are referred to. In the EU, for new cars, reduction of emissions to an average of 95 grams per kilometer has been demanded by the year 2020 [AISBL (2011)]. China has set lofty goals for itself [Chinese Embassy (2010)], even if these goals are internationally non-binding. Thus, measured by economic growth, CO_2 emissions should be reduced by 40-45 percent as compared to the year 2005 [Reuters (2011)]. In the USA the goal has been set to reduce greenhouse gases by 83 percent by the year 2050 [EERE (2009)]. According to the Roland Berger estimate, the reduction goals of the EU, in particular, are so strict that optimization of combustion technology will not be sufficient to achieve these goals [Roland Berger (2009)]. This holds additional potential for alternative propulsion technologies.

Subsidy and promotion policies also play a considerable role in the studies of Bain [Bain (2010b)] and PRTM [(PRTM (2011)]. See the chapter on the international subsidy situation for an in-depth discussion.

In addition, cost development of central components, particularly of the battery must be included in the scenario development. This was considered as a central point by PRTM [PRTM (2011)] and the International Energy Agency [IEA (2011)].
The newly-industrialized countries, such as China, India, and Brazil were emphasized in the studies that were analyzed. These countries are characterized by high growth and have great potential for market development.

The plans pushed through by the Chinese government, to make the domestic market one of the leading markets for electric vehicles, are reflected in extensive subsidies and incentives for consumers. Moreover, Chinese companies have been formed into an alliance over the entire value-creation chain and are working towards the common (government) goal [GTAI (2011)].
In India, it is expected that the subcontinent will become the third largest automobile market by the year 2020. Smaller passenger vehicles are expected to dominate the Indian market [JD Power (2011)].
In terms of the size of the automobile market, Brazil surpassed Germany in 2010. High growth rates are anticipated for this South American country in the coming years; at this point in time, only one in seven Brazilians owns a car. In addition, alternative propulsion technologies have had a special significance since the 1973 oil crisis and the focus is more on ethanol fuels than on cars with electrical components.

The changes, to which the forecasts concerning use of vehicles with electrical components are subject, are demonstrated by the variance in the estimates of the various consulting firms. Moreover, it is difficult to anticipate technological breakthroughs. Nevertheless the results of the metastudy executed here clearly reflect the change of the automobile market toward electromobility.

Overall in the metastudy, a worldwide increase of car sales, from approximately 60 million in 2010 to approximately 87 million in 2020, is expected. This would correspond to annual growth of 3.7 percent.

The share of vehicles with electric propulsion components grows at rate that is highly disproportionate. While in 2010 only hybrid vehicles showed sales figures worthy of note (approx. 1.2 m.), in 2020 the following sales figures are expected:

- REEV[22]: 4.2 m. units
- BEV: 4.6 m. units
- PHEV: 4.9 m. units
- HEV: 14.6 m. units

Considering the relative values, the metastudy suggests that the share of cars with a pure combustion engine will drop from the current approximately 90 percent to approximately 67 percent (see Fig. 21).

22 The numbers for REEV and PHEV were usually added to other vehicle classes in the studies considered and were only separated out when the metastudy was prepared.

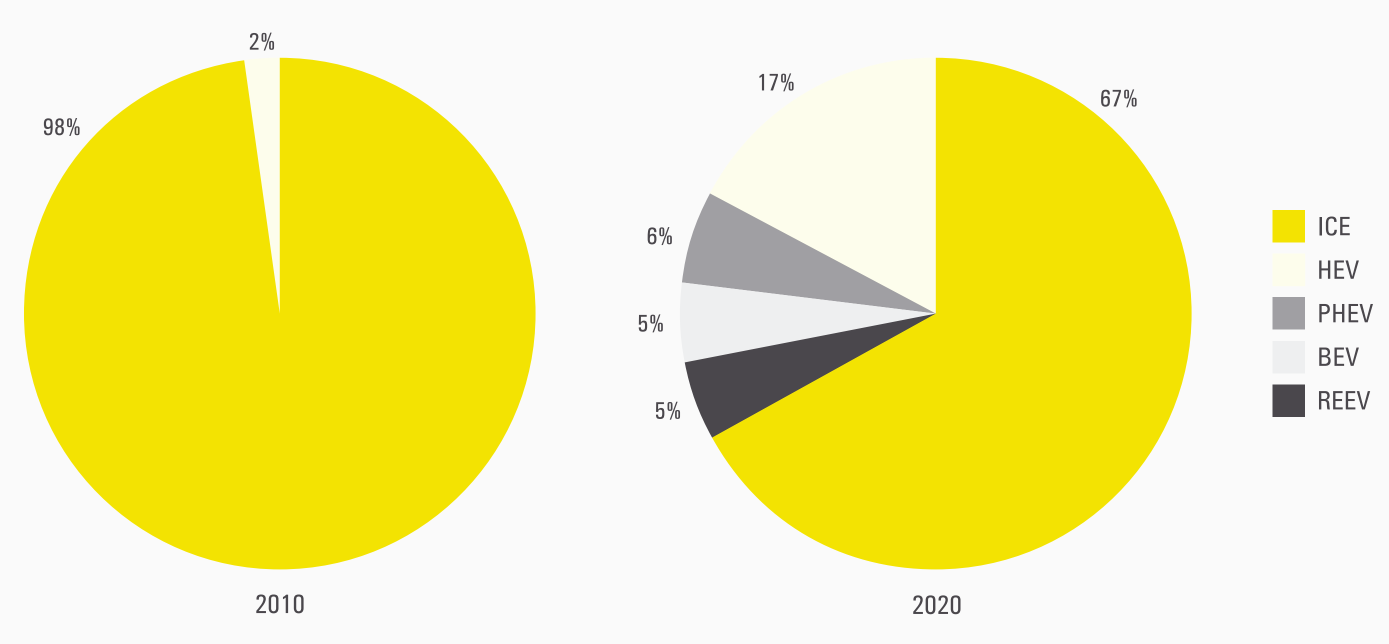


Fig. 21: Results of the metastudy »Market development - propulsion concepts«[23]

The Federal Government has also defined goals for the spread of electromobility in Germany after 2020: By the year 2030, six million electric vehicles should be running on Germany's roads. This is part of Germany's advanced climate protection strategy, which forecasts a reduction of greenhouse emissions by 80 percent, compared to 1990, by the year 2050 [German Federal Government (2010)]. The European Union goes even further and would like to achieve a reduction in emissions of up to 95 percent by the year 2050 [European Commission (2011)]. If the state environmental protection goals remain unchanged in Germany and the rest of the world, then at the very least a significant increase in the market share of alternative propulsion technologies must be considered.

2.4.2 LIFE CYCLE COST CONSIDERATIONS

The market penetration of electromobile propulsion concepts significantly depends on the profitability of these concepts for producers and owners. Relative to conventional vehicles based on combustion engines, electric vehicles have significant additional manufacturing costs. The reason is primarily the high cost of the batteries. At this point in time, a precise estimate of the development of these additional manufacturing costs is not really possible. Through increasing product volumes or other breakthroughs in battery technology, these additional costs could be drastically reduced, according to the assessment of the National Platform Electromobility (NPE) [NPE (2011a)].

For the year 2020, the NPE however expects purchase prices for electric vehicles to be significantly higher than the purchase prices for conventional vehicles [NPE (2011a)]. Due to the different cost structure of conventional and electric vehicles, for a breakthrough of electromobility it will be crucial to make users aware of the total costs of different propulsion technologies over the entire life cycle. While fleet operators are already making decisions today on the basis of total cost calculations, for the private user it is frequently still the purchase price that is the most important criterion for the purchase decision.

The so-called life cycle cost (Life Cycle Cost = LCC) or Total Cost of Ownership (TOC) include not only the actual purchase price but also all operating costs, such as:

23 Authors' own illustration I McKinsey (2011c) I BCG (2011) I Bain (2010) I IEA (2011) I JD Power (2010) I Scotiabank (2011) I PRTM (2011) I Authors' own calculations

costs for fuel, electricity, taxes, insurance, and maintenance. The main differences in the life cycle costs of conventional and battery-electric vehicles are illustrated in Fig. 22.

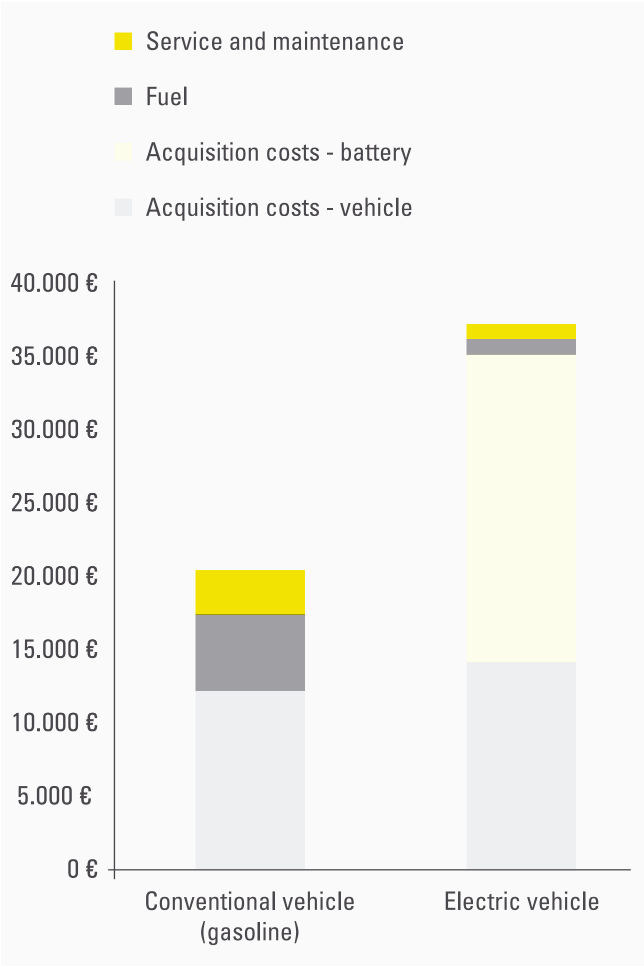


Fig. 22: Distribution of life cycle costs (main cost drivers) of conventional and battery electric vehicles for a useful life of 5 years[24]

According to this study, conventional and electric vehicles have a completely different cost structure, which is substantiated for the most part in the high differences between the purchase costs (an electric vehicle is significantly more expensive than a conventional vehicle) and the operating costs (an electric vehicle is significantly less expensive than a conventional vehicle).

From Fig. 23 it is evident that battery electric vehicles start to become more attractive for the customer than combustion engine vehicles at an oil price of approx. 130 USD per barrel (with an assumed battery price of 500 USD per kWh; kilometrage: 14,500 km).

One possibility for adapting the cost structure of electric vehicles to the cost structure of conventional vehicles, that the user is more familiar with, is the development of battery leasing models. Here the expensive component, the battery, is taken out of the purchase price of a vehicle and financed via a monthly leasing payment. For example, Renault offers this financing model for the electric vehicle Fluence Z.E. that has been on the market since September 2011. Fig. 24 shows that with conservative assumptions for energy and gasoline costs, the electric vehicle is indeed still more expensive than the conventionally powered Fluence Dynamique but, through battery leasing, the purchase and operating costs of both propulsion concepts are similar.

Whether innovative financing models such as battery leasing increase users' disposition to buy will be shown with the market introduction of the first series production models in the next few years. A large-scale fleet trial with different electric vehicles in the 90s in the Swiss city of Mendrisio clear demonstrated that innovative sales models can be the determining factors for success. After introduction of battery leasing, significantly more vehicles were sold in the city than were previously sold through conventional sales [Piffaretti (2011)]. As one of the first German manufacturers, Smart announced that it would offer the Electric Drive with a combination of vehicle purchase and battery leasing, starting in 2012 [Automobilwoche (2011)].

Due to the operating cost advantages of electric vehicles, these will first pay-back financially with high vehicle utilization. Consequently, the first noteworthy penetration of electric vehicles that extends beyond the private purchase of early adopters should be expected in vehicle fleets. These could be car sharing and company fleets, as well as delivery vehicles, taxis and municipal vehicle fleets.

»Of central importance for the acceptance of electric cars is the TCO relative to the combustion engine cars. Other factors, such as the oil price, enter into the purchase considerations via the relative TCO.«

Marco Piffaretti, Managing Director, Protoscar SA

24 Authors own illustration I Assumption: Battery size 16 kWh, kilometrage: 10,000 km/year

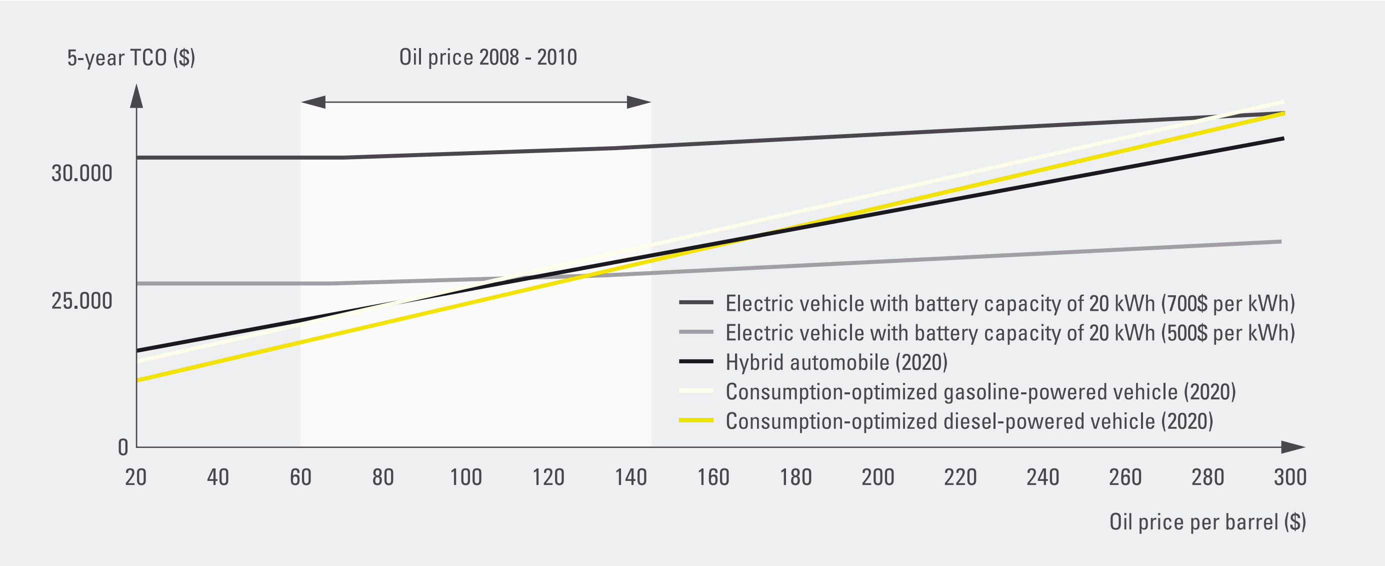


Fig. 23: 5-year TCO for five different vehicles (purchased in 2020 and driven 14,500 km per year in Germany)[25]

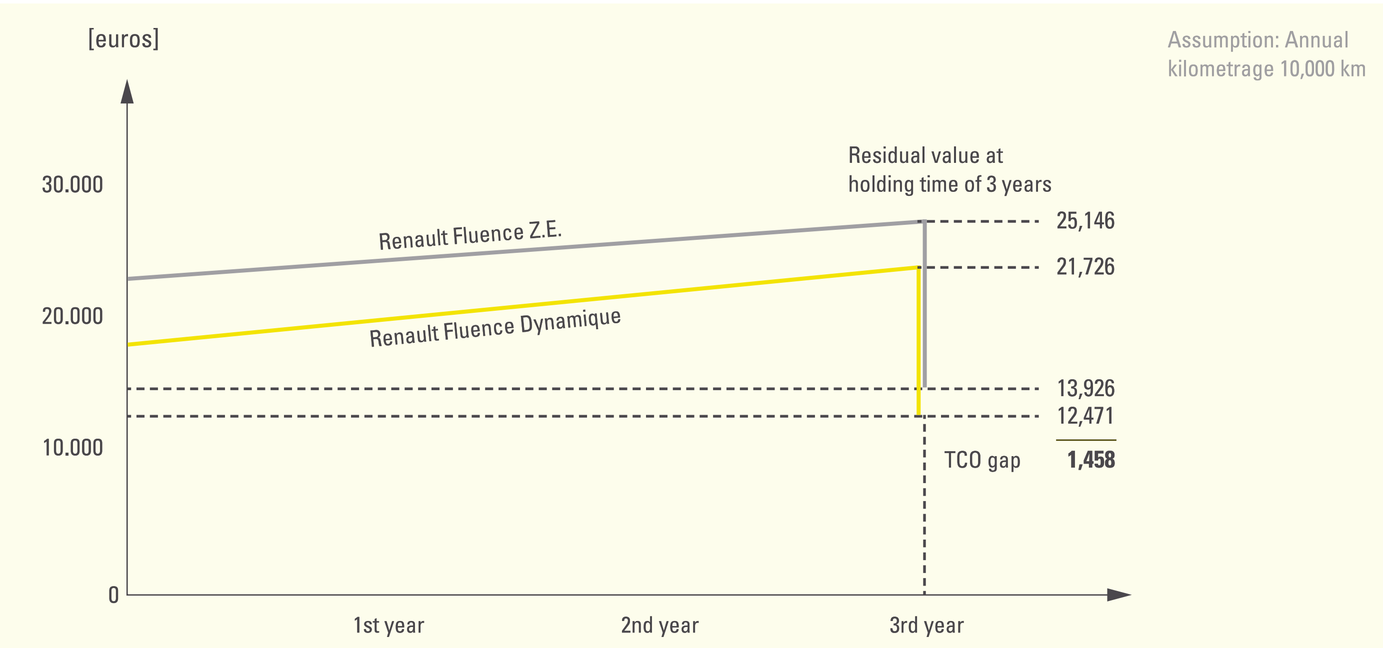


Fig. 24: Cost comparison - Renault Fluence Z.E. (battery-electric) and Renault Fluence Dynamique (Otto engine)[26]

25 BCG (2009) I Assumptions: Annual kilometrage: 14,500 km and no changes in the taxation model. The calculation contains an analysis of the depreciation of the vehicle, gasoline costs, power consumption, battery costs, value added taxes and CO_2-based taxes; insurance and maintenance costs were not considered.
26 Author's own research, see manufacturer's information, Renault; net prices; assumptions; Gasoline costs 1.35 €/l, electricity costs, 17 ct/kWh, kilometrage 10,000 km/year

2.4.3 CONVERGENCE OF SECTORS

The automobile industry sees itself facing very great challenges in the course of electrifying the drive train. Development of new components and systems, as described in the previous sections, will ultimately result in completely new vehicle concepts. For the automobile industry this development, even though its timeline is still attended by uncertainty, means the greatest change since the industry came into being with the development of the combustion engine. Even beyond the classic automobile and supplier industry the development of electromobility has already started. Electromobility as a cross-industry development will therefore not only have an influence on the technology developments of specific industry sectors, but will and must lead to a convergence of the industries for the development of successful solutions.

ENERGY

Electric vehicles must be charged in a manner that is compatible with the battery and with the grid, and will thus become an issue for the energy industry. Charging stations in the private, public, and semi-private sector connect vehicles to the power grid and thus constitute the filling station network of the future. Electric vehicles differ significantly from conventional consumers in the power grid because, as opposed to household appliances or industrial consumers, they represent mobile loads, and thus must be charged at different times and at different locations. The million electric vehicles on German roads demanded by the German Federal Government for the year 2020 would only cause an increase in electricity consumption of 9.5 percent according to studies.[27] The simultaneous locally concentrated charging of some ten or a hundred vehicles, as well as the fast charge process, could however cause local peak loads and thus grid overloads.
Consequently, integration of electric vehicles in the grid requires intelligent control. The increased infeed of renewable energies requires a new alignment of the power infrastructure and storage capacities, as well as flexible consumers, all of which could equalize the fluctuating supply. Through controlling the times available for charging and possibly, in the distant future, the reverse feeding of energy from vehicle batteries into the power grid, electric vehicles can make positive or negative standby energy available to the utility, and thus can be used as an equalizing element for grid stabilization [System Analysis - BW^e mobile (2010)].

Even if a directly sustainable business model for energy suppliers cannot yet be derived from the charging of electric vehicles, vehicle manufacturers are already cooperating with energy suppliers in joint pilot projects to test new possibilities of collaboration and business models for the future (see also chapter 2.5).

INFORMATION AND COMMUNICATION TECHNOLOGY

In conventional vehicles information and communication technology (ICT) is already becoming increasingly important. Today, high-end vehicles already have up to 40 percent computer controlled components; the value-creation share of ICT in the vehicle will continue to increase in the future [Systemanalyse BW^e mobile 2010].

In addition to the increasing number of driver assistance systems and control systems in conventional vehicles, electric vehicles require additional ICT components inside and outside of the vehicle:

- In hybrid and fully electric drivetrains extended and new electronic components, control systems and bus systems are being used (see section 2.2.2).
- Secure communication and identification must take place between private and public charging stations and vehicles
- Users get IT-supported access to charging stations and shared-use vehicles.
- The development of intermodal traffic concepts requires the networking of different traffic carriers through data fusion, data processing and data provision for the user.
- For integration of electric vehicles in fleets (car sharing, company fleets and municipal fleets, taxis and delivery fleets, etc.) fleet management systems must be adapted to the special requirements.
- Locations such as parking facilities and underground garages, where in the future many electric vehicles will be charged in a manner that is concentrated in time and location, require a charging infrastructure with overlapping charging and load management systems in order not to jeopardize grid stability.
- The infeed of renewable energies into intelligent networks (smart grids) for use in electric vehicles, as well as the controlled charging of these vehicles, requires innovative regulating and control mechanisms.

27 Assumptions: Consumption of 0.2 kWh/km, kilometrage 15,000 km/year

ICT is enjoying ever greater significance in the vehicle and for the connection of vehicle and energy infrastructure, for networking of the user and for development of overlapping mobility management systems, and it is the connecting link between the automotive sector and the energy sector.

NEW BUSINESS MODELS

For development of new business models for electromobile propulsion concepts, the priority is to compensate for specific disadvantages, such as reduced range, and to optimally exploit the advantages of electromobility (see Fig. 26).
For example, these advantages are lower energy costs, (primarily lower costs for fuel and maintenance) and good performance data. Thus, with electric vehicles, high torque can be achieved at low rpm and powerful acceleration (in the low speed range) can be achieved. The environmental compatibility of the vehicles through local emission-free driving and low noise level, additionally results in image advantages over conventional combustion engine vehicles. These characteristics make battery electric vehicles the ideal city car. In the major metropolitan areas in particular, the conflict between the compelling necessity for mobility of people and goods, and the negative effects of traffic (such as noise, the pollution burden on people and the environment, as well as the requirement for resources and space) is clearly evident. Given the prerequisite of a specific market penetration, electromobility promises

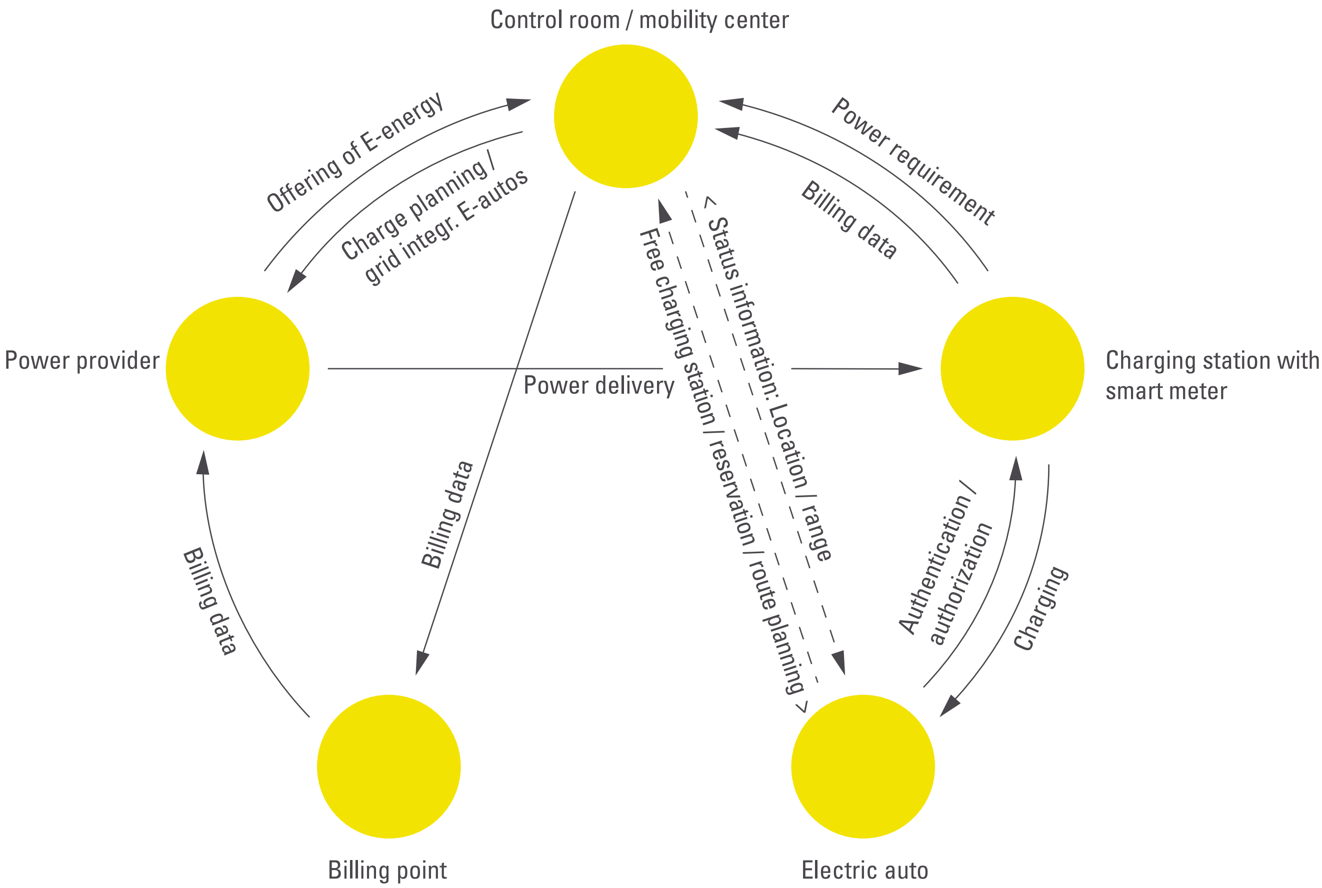


Fig. 25: ICT as the key to successful electromobility[28]

28 Fig. based on: BMWi (2011)

incredible advantages, particularly for cities. Accordingly, battery electric mobility for the near future can be viewed as „urban mobility“ and can contribute to increasing the quality of urban life.

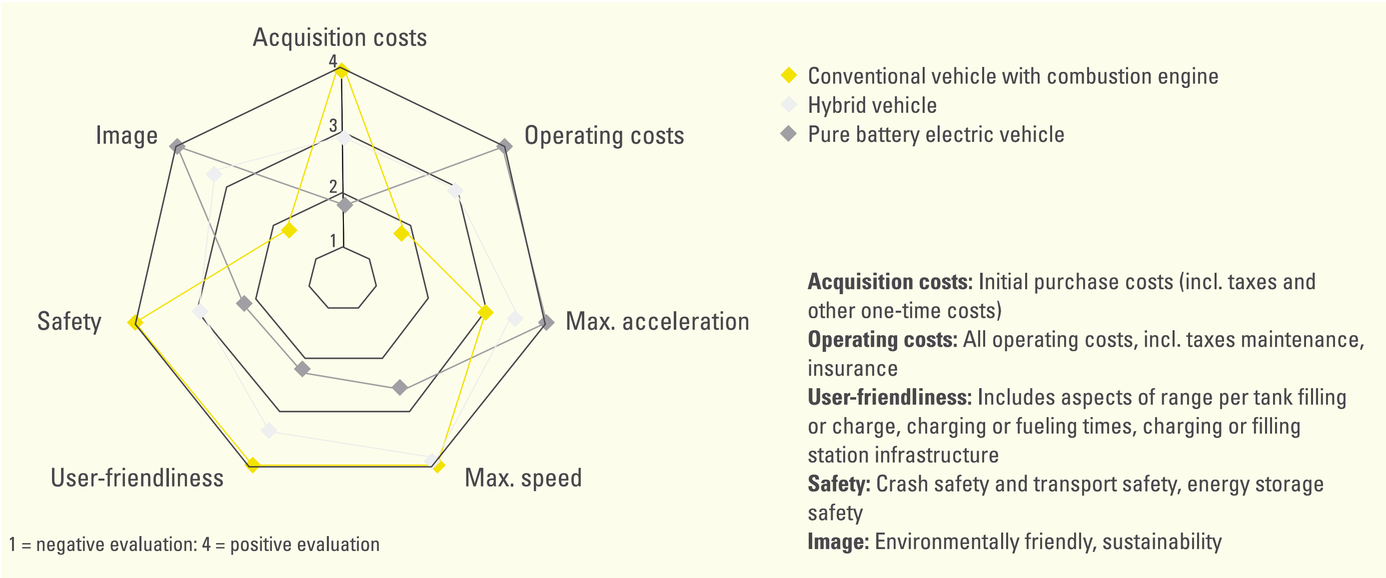


Fig. 26: Advantages and disadvantages of different propulsion concepts[29]

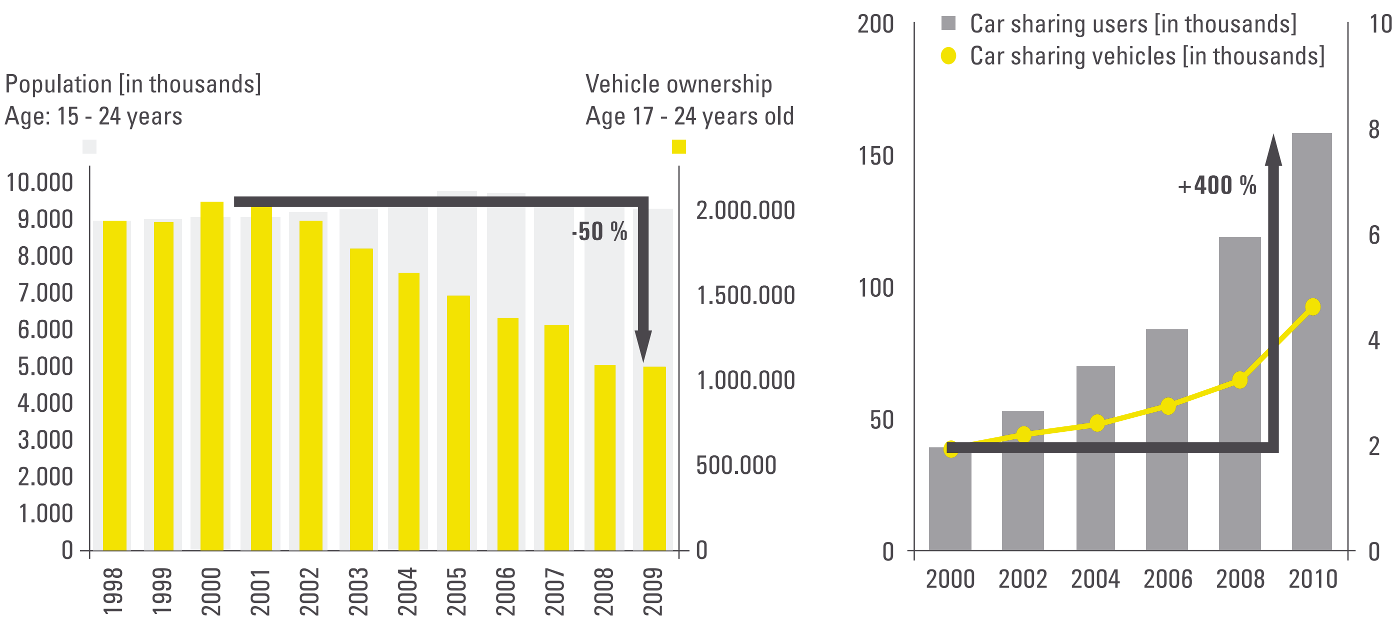


Fig. 27: Changes in vehicle ownership and car sharing use 2000-2010 in Germany

29 Author's own illustration I Comment: The lower safety level for the pure battery electric vehicle is primarily based on vehicles that have been converted to electric propulsion (conversion vehicles).
30 Author's own illustration based on data from: Federal Motor Transport Authority und Federal CarSharing Association

Greater distances can be covered with hybrid propulsion concepts.

It is not just electrification of the drivetrain that is getting the automobile, ICT and energy sectors moving. Today there are already indications that less significance could be ascribed to private ownership of vehicles in the long-term. The indication is the decrease in vehicle ownership among younger users in recent years, with a simultaneous significant increase in the use vehicle sharing schemes, as Fig. 27 shows.

The industry has recognized this trend: With its well-known car sharing scheme, car2go (www.car2go.com), Daimler has taken the step from being a manufacturer to becoming a mobility service provider. BMW too, in cooperation with the auto rental agency, Sixt, now offers a similar concept under the title Drive-Now (www.drive-now.com). Other established car sharing providers are integrating the first electric vehicles in their vehicle fleets, as Fig. 28 shows. This development offers opportunities for new ownership models and business models in the area of individual, but shared, mobility. For integration of alternative propulsion concepts with the necessary charging infrastructure in these types of sharing concepts, a close cooperation between the automobile, ICT, and energy industries is required.

If this development, which is still in the very beginning stages, continues, major effects on the requirements imposed on new vehicle concepts will occur, and the value-creation chain of the vehicles will also change. New potential arises in the area of mobility services and owner models for shared use of mobility resources, that also extends to the infrastructure in the case of electric vehicles. In this regard, the position of the mobility service provider may be occupied by vehicle manufacturers, energy suppliers, auto renters or new „mobility integrators“. In each case, electrification of the drivetrain, in conjunction with its intelligent integration in the grid and the occurrence of new mobility concepts, results in a convergence of the automobile industry, the ICT industry and the energy industry; the close cooperation of these industries is requisite for shaping the mobility of tomorrow.

Provider	Stadtmobil	cambio	DB Carsharing	Zipcar	Car2go	Yélomobile
Locations	Germany	Germany, Belgium	Germany	USA, Canada, England	Germany, USA, The Netherlands	France
Users	>25,000	>38,000	>65,000	>500,000	>34,000	>450
Vehicles	>1,000	>1,200	>2,000	>8,000	>800	>50

Fig. 28: Selection of carsharing providers with electric vehicles in their fleets[31]

31 Author’s own figure I Comment: The number of vehicles shown represents the totality of the respective fleet. Electric vehicles, which currently make up only small part of the total fleet, have not been itemized further.

2.5 OVERVIEW OF SUBSIDIES

The advantageous characteristics of electric vehicles, such as local emission-free driving and low operating costs of the vehicles, are still accompanied by a cost structure today that is not competitive compared with that of conventional vehicles. Consequently, in order to establish electromobility on the market, intelligent planning and suitable funding instruments are required.

»Setting long-term goals for the industry so that the planning security and investment security are increased is even more important than the financial support of politicians.«

Marco Piffaretti, Managing Director, Protoscar SA

SITUATION IN GERMANY

The funding landscape in Germany is diverse. Beyond the topic-specific funding possibilities addressed below, there are programs that are not specifically linked to electromobility, which however are open to the respective sectors.[32] German funding activities were structured through the National Development Plan - Electromobility of 2009. With funds from the Economic Stimulus Package II, by the end of 2011 subsidies will be provided for electromobility to the amount of 500 million euros from the participating ministries for Economy and Technology (BMWi), Transport, Building and Urban Development (BMVBS), Environment, Nature Conservation and Nuclear Safety (BMU), as well as Education and Research (BMBF). For better coordination, the joint Electromobility Office of the German Federal Government was set up in 2010 [BMWi (2010)] and it functions as the central contact point. In the same year, with the National Platform for Electromobility, a consortium of industry, science, politics, unions, and society came into being, that will deal with issues that are relevant for electromobility in seven work groups [BMU (2010)]. In this regard, multiple recommendations have been made for funding of electromobility that extend beyond the term of Economic Stimulus Package II. As a result, the Federal Government published the Government Electromobility Program [Bundesregierung (2011)], through which an additional billion euros will be primarily devoted to fundamental research.[33] Likewise, showcase projects will be supported to improve visibility of electromobility technologies and to promote increased acceptance in Germany [NPE (2011a)]. To achieve the latter goal, in addition to monetary incentives, special parking places and the release of bus lanes or special lanes for electric vehicles are being discussed [Bundesregierung (2011)].

Experts particularly emphasize the systemic approach in Germany, which is internationally unique. In addition to fundamental research and applied (battery) research, testing of new mobility concepts in interaction with energy enterprises is also being promoted.

»Through the system approach, Germany is the international pioneer in public subsidies. Within the subsidy system a central role must be accorded to research, because products and technologies can be generated through research. For the market, this is critical for success in the initial stage.«

Heiko Herchet, Director of the Competence Center, EDAG Group

Funding is available in the German States that extends beyond the Federal programs. In Bavaria, the electromobility promotion program started in 2009. This program's goal is to support research on vehicles with electric propulsion and the associated components [STMWIVT (2009)]. In the model municipalities, Garmisch-Partenkirchen and Bad Neustadt, as well as in the Bavarian Forest [HS Deggendorf (2010)], holistic mobility concepts will be provided and implemented through infrastructure and technology management measures [Garmisch (2010); E-Mobility (2010)]. In North Rhine-Westphalia the funding program, ElektroMobil.NRW, was concluded in early 2010. Twenty-two projects will be funded, mainly in the areas of battery development and infrastructure, with a total of 46.5 million euros [NRW (2010); Autocluster NRW (2010)].

BADEN-WÜRTTEMBERG

In an initial state electromobility initiative, the state of Baden-Württemberg provided a total of 28.5 million euros for the years 2010 to 2014. For 2011, an additional subsidy to the amount of 2 million euros was provided for the State Agency for Electromobility and Fuel Cell Technology e-mobil BW, for establishing a coordination point - lightweight

32 For medium-sized enterprises the Central Innovation Program - Medium-Sized Business, should be cited here.
33 The following are specified as subsidy areas: Cells and batteries, electric vehicle, charging infrastructure, and grid integration.

construction [Logistik BW (2011)]. In principle, the state agency functions as an umbrella organization to coordinate the activities in the electromobility sector in Baden-Württemberg.

In concrete terms, significant sums of money will be allocated for the establishment of a strategically important research structure. To support development of the Ulm area as a competence center for battery research, the state invested more than 4 million euros to construct the eLaB research laboratory at the Center for Solar Energy and Hydrogen Research (ZSW) in Ulm, and will also subsidize a research project to set-up production of lithium-ion rechargeable batteries with 5 million euros [ZSW (2011)]. The newly-founded Helmholtz Institute for Electrochemical Energy Storage (HIU) in Ulm receives an annual subsidy of approximately one million euros.

However subsidy offerings could also be extended with the aid of funds from the private sector. For example, in March 2011, Daimler AC made 1.75 million euros available to set up a doctoral study course at the Karlsruhe KIT [Daimler (2011)].
An informative overview of the funding possibilities for Baden-Württemberg companies has been published by the State Agency for Electromobility and Fuel Cell Technology BW [eMobil BW (2011)]. e-mobil BW supports companies and institutions in the search for suitable funding possibilities in the area of electromobility.

SITUATION WORLDWIDE

Subsidy and promotion measures are also provided in other countries. A comparison of worldwide subsidy strategies shows different approaches in different countries. The European Union (EU) has set the goals of becoming less dependent on oil imports and of limiting climate change. Several measures have been initiated and defined to achieve these goals. The European Green Cars Initiative has the greatest funding volume, with a total of approximately 5 billion euros, of which 4 billion is for loans. Additional focus is placed on non-monetary regulation measures (noise, consumption, CO_2, etc. investigations of consumer expectations, promotion of common standards, as well as specific qualification measures [European Commission (2010)].

Within Europe, Germany pursues a systemic approach to funding; however it has not introduced purchase incentives. The later are increasingly found in Northern European countries such as Denmark (See Fig. 29). France focuses its electromobility funding on the collaboration of several automotive manufacturers and on the establishment of a charging infrastructure (1.5 billion euros) [European Commission (2009)]. Moreover there are purchase incentives for low-CO_2 vehicles (5,000 euros) [GTAI (2011a)].

In the USA, the funding emphasis is on battery technologies and additional system components (2 billion dollars) [GTAI (2010)] and on the development of fuel-saving vehicles (loans in excess of 25 billion dollars). Of the loans made available in 2009, more than 9.1 billion dollars have been called up [USA Today (2011)]. In addition, electric vehicles will be purchased for public administration in the amount of 300 million dollars [Bloomberg (2011)]. Further, there are several federal and state purchase incentives and, in some cases, this amounts to 7,500 dollars on the federal level alone.

In Asia, China is pursuing an extensive funding approach. The country has committed itself strongly to electromobility through the 12th five-year plan (2011–2015). Thus by 2020, approx. 11 billion euros will be invested in the development sector for alternative propulsion concepts

Maximum purchase incentive for electric cars in 1000 euros in selected countries

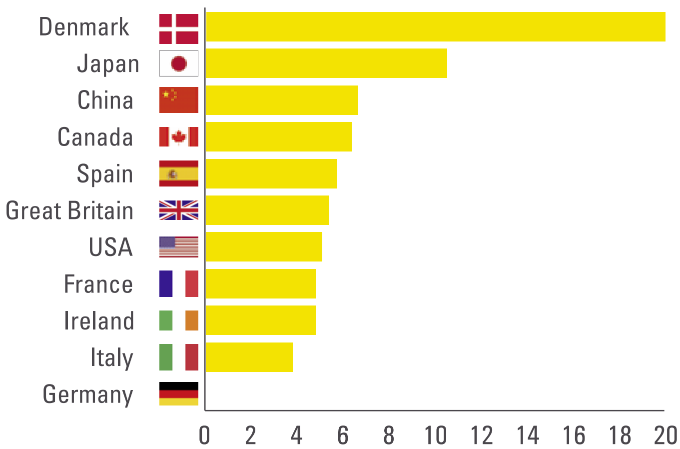


Fig. 29: Purchase incentives for electric cars in different countries - overview[34]

34 Autogazette (2011) I EDIE (2010) I GTA I (2011c) I Autohaus (2009) I U.S. Department of Energy (2011) I Spiegel (2011)

and in demonstration projects [GTAI (2011)]. In 5 Chinese metropolises (Shanghai, Changchun, Shenzhen, Hangzhou und Hefei) electromobility will be tested in practice, through purchase incentives of as much as 6,500 euros [NY Times (2010)]. In the second largest Asian economy, Japan, high purchase incentives (e.g. approximately 15,000 dollars for a Mitsubishi i-Miev) should help in establishing electromobility [GTAI (2010)]. In addition, battery research will be supported with approx. 200 million dollars [GTAI (2011b)].

In summary, it can be stated that, internationally, no distinct trend can be discerned among the various funding strategies. At best it can be said that purchase incentives seem to be becoming more prevalent. In this area, Denmark has the leading position with tax advantages exceeding 20,000 euros (see Fig. 29) [Autogazette (2011)]. For the most part, the tax advantage is implemented with remission of the extremely high vehicle registration tax that is levied in Denmark in addition to VAT. To date, no purchase incentives are planned in Germany.

EUROPE
- European Green Cars Initiative
  - 4 billion euros loans (via Risk Sharing Finance Facility and European Clean Transport Facility), period 2007 - 2013 (RSFF) or 2009 - 2012 (ECTF)
  - 1 billion euros subsidies
- Funding of energy technologies (with focus on transport): 730 million euros, period 2007 - 2013

USA
- Funding of battery technology and additional system components: 2 billion $, start of funding: 2009 (American Recovery and Reinvestment Act)
- Fuel-saving vehicles: 25 billion $ (loans), start of funding: 2008, previously 9.1 billion $ called up
- Demonstration project, infrastructure: 400 million $, start of funding: 2009 (ARRA)
- Various purchase incentives

GERMANY
- Economic Stimulus Package II: 500 million euros, period: 2009 - 2011
- National Innovation Program - Hydrogen and Fuel-Cell Technology: 1.4 billion euros, period: 2006 - 2016
- Government Program Electromobility: 1 billion euros, period: 2011 - 2013

FRANCE
- Funding of carbon-free vehicles: 250 million euros (loans), period: 2009 - 2010
- Demonstration funds: 400 million euros, period: 2009 - 2013
- Funding of the charging infrastructure: 1.5 billion euros, period: 2009 - 2015
- 5,000 euros for vehicle < 60 gCO_2/km, period: 2010 - at least 2012

JAPAN
- Battery research: approx. 200 million $, period 2011 - 2012
- Purchase incentives: approx. 10,000 $ for Nissan Leaf, approx. 15,000 $ for Mitsubishi iMiev
- Purchase incentives: Toyota Prius approx. 17,000 $

CHINA
- Funding of electromobility: approx. 11 billion euros, period: 2011 - 2020
- Purchase incentive: approx. 6,500 euros for BEV, approx. 5,400 euros for PHEV, start of funding: 2010, until 50,000 vehicles have been sold

Fig. 30: Worldwide funding efforts in the electromobility sector - overview[35]

35 Author's own illustration I German government (2011) I Fortiss (2010) I Oekonews (2009) I European Commission (2009) I GTAI (2011a) I European Commission (2011a) I European Commission (2011b) I EIB (2008), EGCI (2009) I European Parliament (2009) I GTAI (2010) I USA Today (2011) I GTAI (2011) I NY Times (2010) I GTAI (2011b) I Autoblog (2010) I GTAI (2010a)

Chapter 3

CONSEQUENCES OF THE CHANGE FOR BADEN-WÜRTTEMBERG

3.1 THE SIGNIFICANCE OF THE AUTOMOBILE FOR BADEN-WÜRTTEMBERG

Baden-Württemberg is considered the most significant automobile location in Germany and enjoys an outstanding reputation nationally and internationally. The unique concentration of vehicle manufacturers, automotive suppliers, research institutes and universities with specialized courses of study offers outstanding location conditions for automotive manufacturing.

3.1.1 AUTOMOBILE LOCATION BADEN-WÜRTTEMBERG

With Daimler AG and Porsche AG, two of the most renowned automotive manufacturers are headquartered in Baden-Württemberg; in addition Audi AG is present with a major production and development location. In addition to companies in the commercial vehicle sector (such as Volvo Busse Deutschland GmbH, Kässbohrer Geländefahrzeug AG, Mercedes-Benz LKW or IVECO), the Baden-Württemberg location is also home to a number of major supplier enterprises. The companies, ZF Group, Mahle, Behr, Getrag, Kolbenschmidt Pierburg, Eberspächer, Freudenberg, Peguform, as well as Mann+Hummel, are among the world's 100 largest automobile suppliers [Automobil Produktion (2011a)]. Overall, more than 20 companies that employ 1,000 or more people are established or represented with production facilities in Baden-Württemberg [IHK (2011)]. Fig. 31 shows regional distribution of the most important suppliers in Baden-Württemberg and the main activity areas of these suppliers.

> *»Baden-Württemberg has always been the state of ‚Tüftler' (inventors). The available engineering art and the tight networking of universities, research and business, offer the best prerequisites in areas such as power electronics or engines and transmissions, for developing practical solutions for electrification of the drive train.«*
>
> *Jürgen Jost, Division Director, Research & Development, Dürr Systems GmbH*

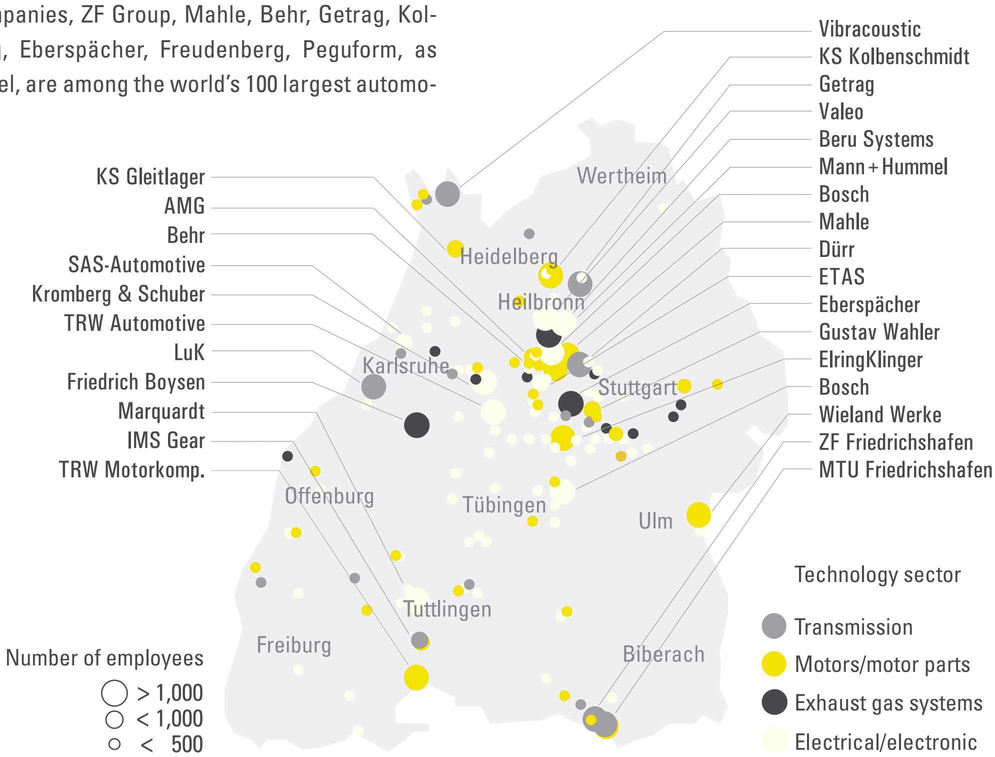


Fig. 31: Map showing the important automobile supplier companies in BW[36]

36 Author's own illustration

3.1.2 CURRENT DEVELOPMENTS IN NEW REGISTRATIONS

In 2010, in all of Germany, approximately 3.3 million vehicles were registered, from a total population of 45 million vehicles. There were approximately 450,000 new registrations in the state of Baden-Württemberg, for a population of approx. 7 million vehicles. In the area „new registrations of electric vehicles“ (pure electric propulsion and hybrid propulsion) the number of newly registered passenger vehicles in Germany increased by approximately 30 percent compared with the previous year, to more than 11,000 vehicles [Kraftfahrtbundesamt (2011a)].

In this regard, the state of Baden-Württemberg achieved the highest growth, in a comparison of all the states, for registrations of pure electric passenger vehicles. Approximately one of every five electrically powered vehicles was registered in Baden-Württemberg. For hybrid vehicles, Baden-Württemberg takes third place behind the states of North Rhine-Westphalia and Bavaria [Kraftfahrtbundesamt (2011a)].

Fig. 32 shows the development of „alternative vehicle concepts“ based on new registrations from previous years. The total population of electric and hybrid passenger vehicles in Germany as a whole is approximately 39,600 vehicles. Baden-Württemberg's share of these vehicles is over 5,300 units [Kraftfahrtbundesamt (2011b)].

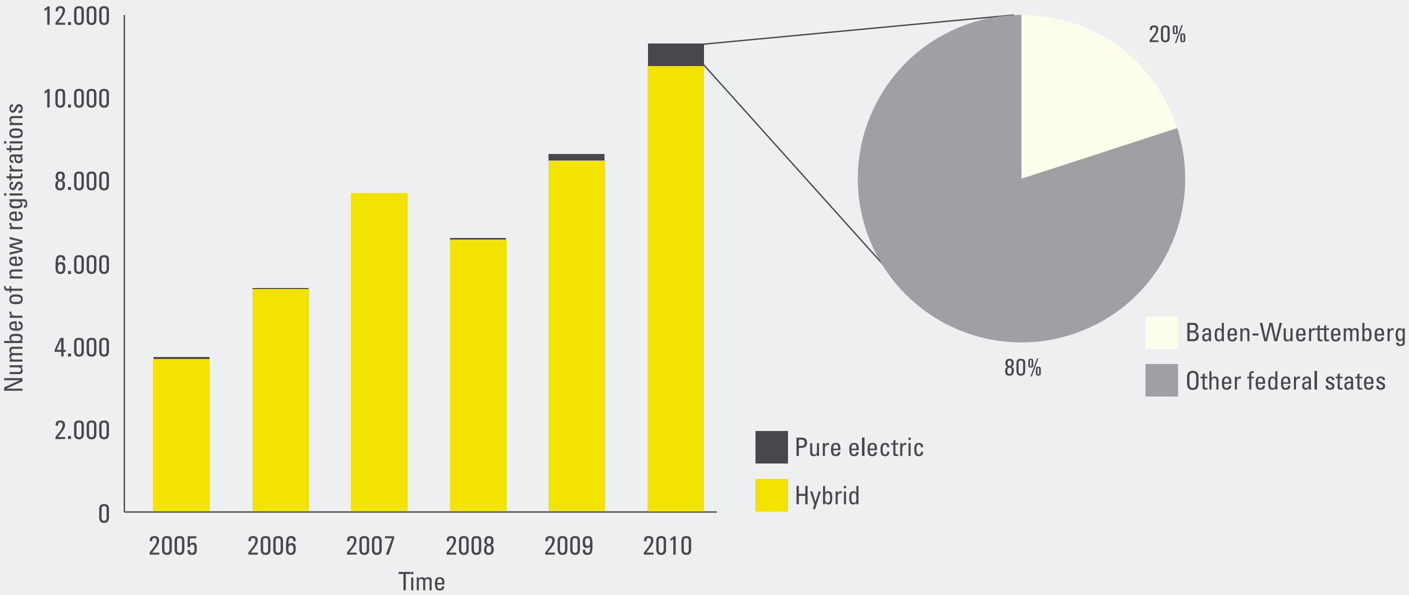


Fig. 32: Comparison of new registrations of electric and hybrid personal passenger vehicles[37]

37 Author's own illustration I Kraftfahrtbundesamt (2011a)

3.2 STRUCTURE OF THE AUTOMOBILE INDUSTRY IN BADEN-WÜRTTEMBERG

The automobile industry, together with its suppliers, has a key function in Baden-Württemberg. In 2010 nearly 200,000 employees subject to social insurance contributions, were active here in more than 300 companies involved in vehicle manufacturing and having an annual industry turnover of 70 billion euros [Statistisches Landesamt Baden-Württemberg (2011a)].[38]

An analysis of the automotive sector in accordance with the classification system for the sectors of the economy in the European Union (NACE rev. 2) however, results in an undervaluation of the actual economic significance of the automobile industry [Kinkel (2007)]. In addition to the companies that must be directly assigned to vehicle manufacturing as „manufacturers of motor vehicles and motor vehicle parts" (WZ-Nummer 29), additional companies from other sectors of the processing industry, such as the chemical industries manufacturing rubber and plastic goods, or the machine tool industry, should also be considered. As important suppliers (for all preliminary performance stages) or outfitters for vehicle manufacturing, they have a significant share in the manufacturing of the automobile.

An analysis from the Fraunhofer Institute of System and Innovation Research ISI (Survey „Modernization of production 2009") revealed that approximately 13 percent of all employees in the chemicals industry, approximately 20 percent of all employees in the rubber and plastics processing industry, and 32 percent of all employees in firms that manufacture metal products, are likewise

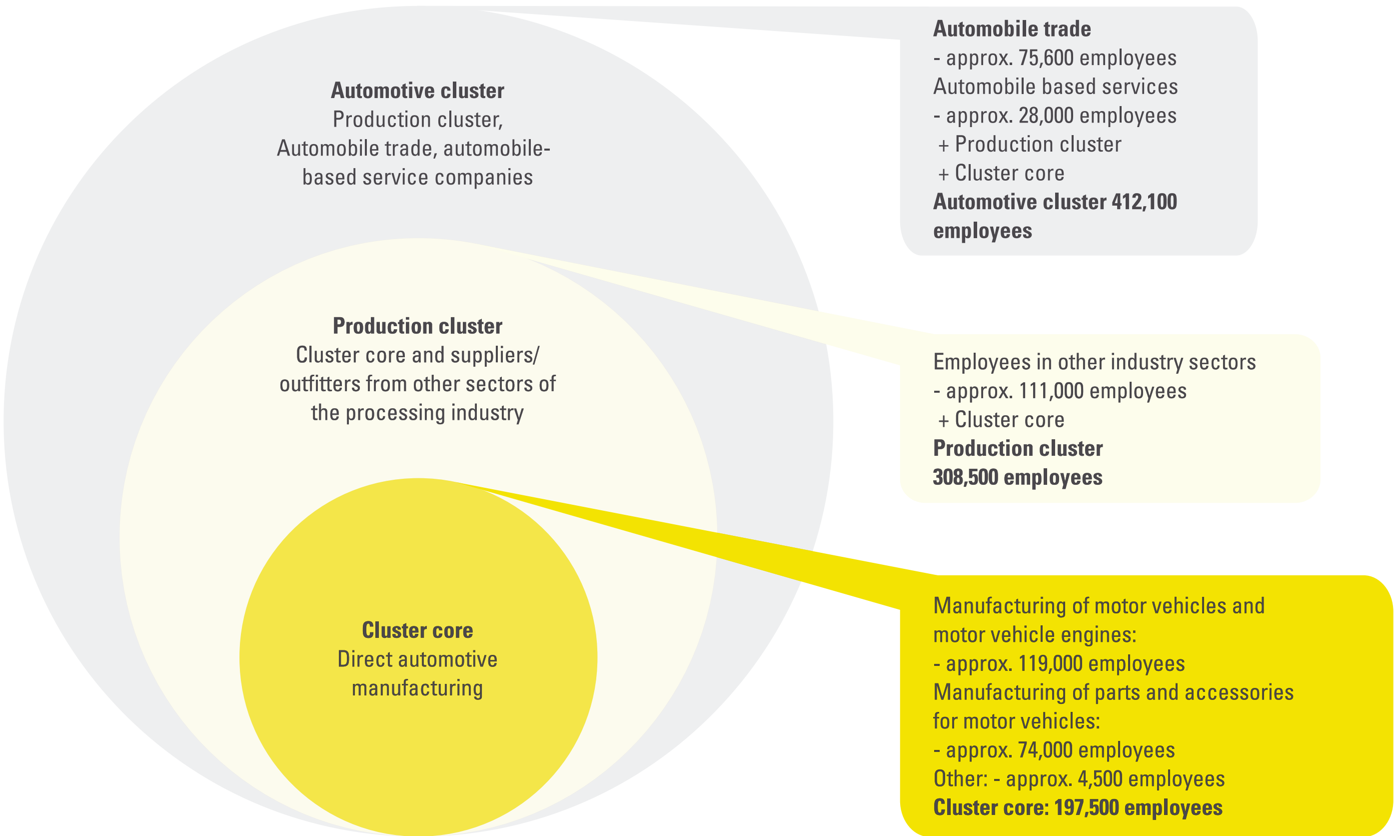


Fig. 33: Structure of the automobile industry in Baden-Württemberg[39]

38 According to official statistics the industry branch „Manufacturing of motor vehicles and motor vehicle parts" (WZ-Nummer 29) is used for the survey. Companies with 20 or more employees are included in this regard. The analysis is based on the NACE Classification Revision 2, which has been valid since 2008 Author's own research, based on: Statistisches Landesamt Baden-Württemberg (2011a) I IMU Institute (2011) I IHK (2011) I Jaeger (2009)
39 Own diagram i.a.w.: Statistisches Landesamt Baden-Württemberg (2011a) I IMU Institut (2011) I IHK (2011) I Jäger (2009)

included, in the extended sense, in the group of automobile suppliers [Kinkel (2007); Jaeger (2009); IHK (2011)]. Thus, in Baden-Württemberg, approximately 600 firms fall into the group of automobile suppliers [(IHK (2011)].

In addition, the automobile trade, as well as numerous automobile-based service companies (R&D, engineering offices, hardware and software companies) employs a large number of people in Baden-Württemberg. With due consideration of all the areas cited, overall in the state of Baden-Württemberg more than 400,000 employees contribute directly or indirectly to the automobile value creation chain.[40] Measured by the total number of employees in the state, this is approximately every 10th person. In the Stuttgart region as many as 17 percent of employees earn their money through the automobile [IMU Institute (2011)].

To summarize this data, the automobile industry can be understood as a multi-level construct, as shown in Fig. 33. According to the NACE system (NACE class 29), at the core of the cluster there is the industry sector „manufacturing of motor vehicles and motor vehicle parts", which can be understood as directly manufacturing automobiles. In the production cluster, in addition to the manufacturers and suppliers from the cluster core, employees from other processing industries, who are active in other supplier companies or outfitters, can also be added. Ultimately, the entire automotive cluster is comprised of the totality of the employees from the cluster core and the production cluster, as well as the employees of the automobile trade and employees of automobile-based service companies.

3.3 THE AUTOMOBILE VALUE CREATION CHAIN AND ITS EFFECT ON THE EMPLOYMENT STRUCTURE

Measured by turnover, the Baden-Württemberg employment structure has an approximate 22 percent share of the German automobile industry (317 billion euros in 2010) and approximately 6 percent of the worldwide automobile industry [Statistisches Landesamt Baden-Württemberg (2011b); VDA (2011); BMU (2009)]. For companies as well as for state policy, and also for the employees, the forthcoming technology change to electromobility raises the question of whether Baden-Württemberg can maintain a significant portion of automobile value creation and the associated jobs, in the future. According to a projection by the Federal Environment Ministry, the total market for the automobile industry could be approx. 1440 billion euros by 2020 [BMU 2009]. In this regard, the market volume of alternative propulsion components will amount to approximately 115 billion euros [McKinsey (2011a)].

3.3.1 CHANGES IN MANUFACTURING COSTS FOR BATTERY-ELECTRIC VEHICLE CONCEPTS

In order to quantify the influence of the technological change to electromobility on value creation, and ultimately in order to analyze the effects on the employment structure, it is necessary to estimate costs for the components in question. In this study, the period between the present date and the year 2020 was selected for performing this estimate. In addition to technological progress in development, possible scale effects and learning curve effects must be considered for future series production. The estimate of costs and cost reduction of the individual components is based on a meta-analysis of published studies.[41] The results have been validated by experts and updated for the period between the last analysis/evaluation in 2009, and the present point in time (2011). In terms of costs, the manufacturing costs assessed showed that the manufacturer must either pay for in-house manufacturing or for purchase of components. Mark-ups, for example in the form of dealer margins, marketing costs and transport expenses were not considered.

40 Author's own projection, based on: IMU Institute (2011) I IHK (2011) I Statistisches Landesamt Baden-Württemberg (2011a)

41, see also: Santini (2010) I Miller (2011) I International Energy Agency (2011) I BCG (2010) I Gargner (2009) I Deutsche Bank (2010) I Electrification Coalition (2009) I Electrification Coalition (2010) I SAE International (2011) I Universität Stuttgart (2009) I U.S. Department of Energy (2010) I European Commission (2005) I Mock (2010) I MIT (2008) I MIT (2007) I EPRI (2001) I Cristidis (2005) I Dixon (2002) I Delorme (2009)

From the component perspective, the power electronics and the battery system can be identified as the essential cost factors for the entire vehicle. Although depending on vehicle size, the battery system is currently still responsible for approximately between 50 and 65 percent of manufacturing costs, significantly lower manufacturing costs can be projected for the year 2020. Forecasts of manufacturing costs in the year 2020 vary on average between 200 €/kWh and 400 €/kWh depending on the study. Although there are varying opinions concerning the size of future manufacturing costs, the cost reduction potential is uniformly estimated to be at least 50 percent, with respect to the present value [Miller (2011); NPE (2011b)]. The reasons for this are the advancing development work in the area of battery cells, the learning progress in production (components, cell, module and pack) and the scale effects associated with mass production.

Fig. 34 shows the gradual decrease in cost expected for battery packs. In addition to the cost estimate of the National Platform for Electromobility, there are two sample curves for different systems (pure electric vehicles (BEV) and hybrid vehicles (PHEV 10–40 mile range)) shown. Currently manufacturing costs for the electric machine range from 12 €/kW to 18 €/kW based on the study and the motor design. Manufacturing costs forecast for the year 2020 are increasingly based on quantities greater than 100,000 units, with a nominal power for the propulsion system of between 50 kW and 60 kW. The bandwidth in this regard is between 6 €/kW und 13 €/kW. Basically this assumes a mature technology for the electric machine, nevertheless a cost reduction through future mass production appears to be realistic. However, the target values of 4.70 $ US/kW (approximately 3.40 €/kW) that the U.S. Department of Energy is striving for by the year 2020, appear to be too optimistic because this price barely suffices to cover the material costs [U.S. Department of Energy (2010); Universität Stuttgart (2009); International Energy Agency (2011)].

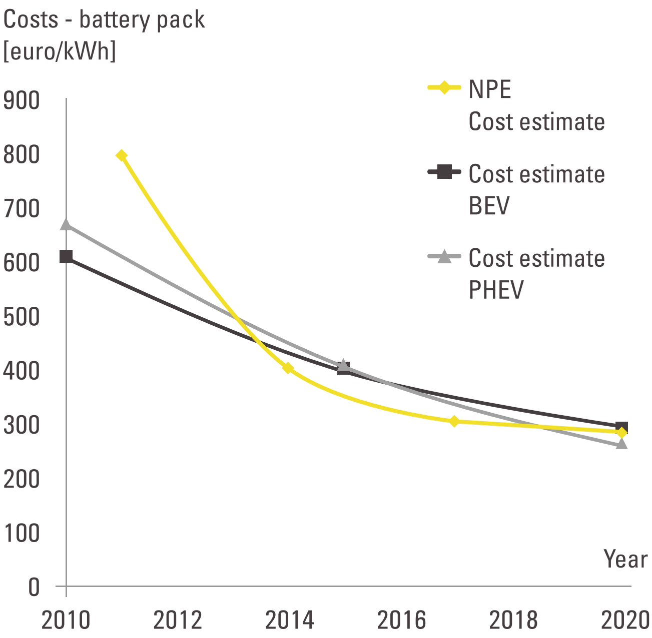


Fig. 34: The expected gradual cost reduction for battery packs[42]

»The manufacturing costs of a cell will be approximately 70 percent due to the process and procedure costs and not, as often assumed, due to the material costs.«

Dr. Andreas Gutsch, Project Director Competence E at the Karlsruhe Institute for Technology (KIT)

In the more restricted sense discussed below, for the power electronics the components of the pulse inverter (and its subcomponents) are understood. As of the present date, costs shown for manufacturing the so-called inverter still vary significantly depending on the specific study considered. Depending on the design of the motor, manufacturing costs between 8 EUR/kW und 25 EUR/kW are shown [for example, see Mock (2010); Universität Stuttgart (2009); Dolorme (2009)]. A significant reduction in the manufacturing costs for these components is expected by the year 2020. The potential for savings due to possible series production is estimated at up to 70 percent of present costs [for example, see U.S. Department of Energy (2010); European Commission (2005); Cristidis (2005)].

In Fig. 35 the cost breakdown for a small and a large battery electric vehicle is presented. The present cost breakdown and the possible cost breakdown for the year 2020 are listed. For the electric propulsion system, a motor power of 47 kW (small vehicle) and 160 kW (large vehicle) were used as the basis for the comparison. A capacity of 16 kWh (small) and 48 kWh (large) was assumed for the battery.

42 Authors' own illustration based on [NPE (2011b); Miller (2011)]. The values for the BEV and PHEV vehicles are based on a currency conversion rate of 1.35 €/$.

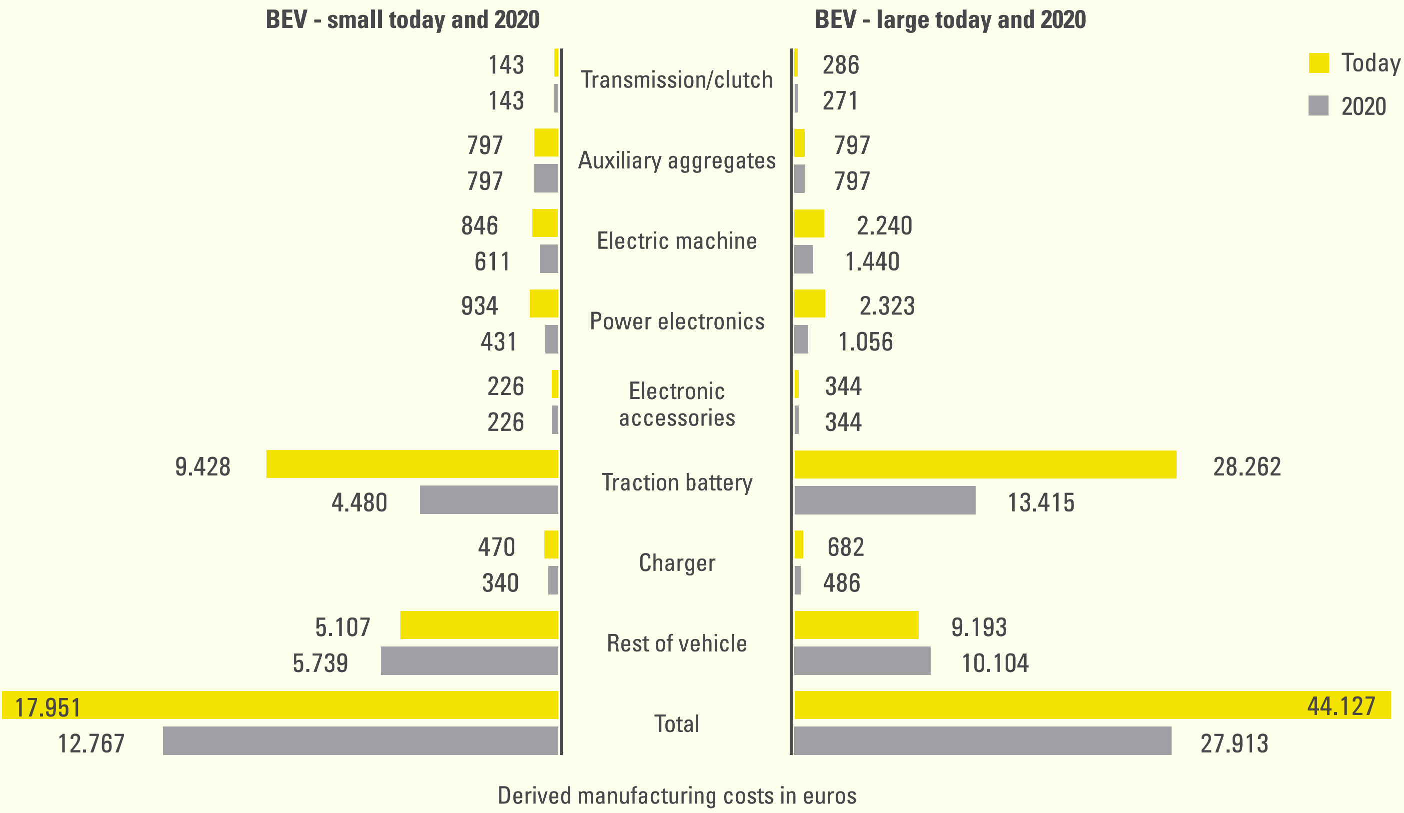


Fig. 35: Comparison of changes in the manufacturing costs of battery electric vehicles[43]

Over the period considered, for the small vehicle a cost reduction of approximately 5,000 euros occurs, and for the large vehicle a cost reduction of approx. 16,000 euros occurs; this can primarily be attributed to the low manufacturing costs of the traction battery, the electric machine, and the power electronics. Compared to equivalent passenger vehicles with a conventional combustion engine, in the year 2020 there will still be a difference in the manufacturing costs of approximately 4,800 euros (small vehicle) and 8,500 euros (large vehicle) based on the underlying calculation model.

3.3.2 MARKET DEVELOPMENT - DRIVETRAIN COMPONENTS

To enable an overview of possible changes in global market volume (on the basis of manufacturing costs) relative to the specific sensitive components of the present status, until the year 2020, current and future possible sales figures for automobiles were used based on the respective propulsion concept (see chapter 2.4.1), and multiplied by the determined component costs (present/future) of the respective vehicle concepts. The difference between the present „market volume" of a component and the future estimate equals the change in the market for the respective components and thus allows conclusions to be drawn with regard to the employment effects in this area. These global effects will be

43 Author's own illustration

subsequently broken down for the state, with due consideration of the international positioning of Baden-Württemberg in the automobile industry.[44] As the basis for the definition, a selection of vehicle models (models already available or announced on the market) was chosen. Due to the still limited market forecasts relating to the distribution of fuel cell vehicles in the year 2020, this propulsion type was not used in the calculation.
It was possible to further extend the data basis as compared with the previous study (2009/2010). Nevertheless, the different estimates concerning cost development of electrified drivetrain components, and the different forecasts relative to market developments, make a detailed prediction difficult. Although at the time of the first study (2009/2010) a somewhat more restrained picture was formed of the sales figures in the year 2020, the market scenarios investigated as part of the Structure Study 2011 on average show higher sales. The underlying value of these for the year 2020 is 87 million vehicles sold.

For the conventional technology of the combustion engine, by 2020 market growth of well over 3.3 billion euros can still be anticipated. In addition to the marginally higher sales figures of conventional vehicles with combustion engines, the thermally powered motor is also used in hybrid vehicles. In this case, however, it should be noted that there is a trend toward smaller motors (not only in hybrid vehicles).

Through the efforts to achieve increased fuel efficiency and to meet the requirements for propulsion systems with lower pollution levels, optimizations associated with the combustion engine (efficiency technologies) can generate significant market growth by 2020. Accordingly, for gasoline engines, an increase in fuel efficiency by the year 2020 of as much as 30 percent is conceivable (with additional costs of up to 50 percent) and for diesel engines of as much as 20 percent (with additional costs of up to 15 percent) [McKinsey (2011); BCG (2011); Electrification Coalition (2010)]. The German Federal Environmental Agency assesses the additional manufacturing costs at 281 to 329 euros, with an assumed CO_2 saving of 20 percent on the Otto engine [Umweltbundesamt (2008)]. Optimization potential for so-called efficiency technologies offers approaches, such as direct injection, motor downsizing, turbocharging, variable compression ratio and cylinder deactivation. Moreover, additional savings can be achieved through start/stop systems or an improved configuration of the cooling circuit [Mock (2010); Universität Stuttgart (2009)]. These developments indicate that in these areas, by the year 2020, an increase in the market value by 25.1 billion euros could occur.

In conjunction with the thermally powered motor, the exhaust system can also generate growth in market volume in the period to 2020. As a guide, additional costs of 50 euros (gasoline) and 210 euros (diesel) can be assumed for maintaining the emission limits of the forthcoming Euro-6 standard (based on EURO 5) which will have binding effect on passenger vehicle manufacturers from 2015. By 2020, another reduction in CO_2 emission is scheduled, from 130 grams CO_2/km to a target value of 95 grams CO_2/km, which will result in additional new production costs [Mock (2010); Robert Bosch (2011); Umweltbundesamt (2011)]. The necessity for an exhaust system in the hybrid concepts of the serial hybrid, plug-in hybrid, and parallel hybrid vehicles also results in growth in market volume. Overall, for this component there is a positive change of approximately 11.3 billion euros by the year 2020.

Transmissions will continue to take a strong position and likewise achieve a significant increase in market volume of approx. 18 billion euros by the year 2020. On the one hand, efficiency-optimized transmissions for vehicles with a conventional combustion engine will continue to be developed and, on the other hand, a number of, in some cases extremely complex, hybrid transmissions will also be required. Hybrid transmissions, in particular, take a subordinate position due to the low number of vehicles to date and thus represent significant growth potential by the year 2020.

In the group of auxiliary aggregates, the components, steering (electric compressor for electrohydraulic steering and components for electromechanical steering) as well as air conditioning were considered. In this regard it is clear that auxiliary aggregates will continue to be electrified to achieve better consumption values for pure combustion vehicles or hybrids. This in turn results in higher costs and thus an increase in market volume (change +14.7 billion euros). The dynamo for a hybrid vehicle will be replaced by the existing generator and cannot grow as strongly in response to the forecasted market development. Marginal growth only is also expected for the starter battery.

44 In the underlying model, manufacturing costs were intentionally assessed for calculation of the „market volume". On the one hand the mark-up costs, which must be added to the manufacturing costs for determination of actual sales, vary dependent on the study and, on the other hand, it must be assumed that mark-ups of new drivetrain components will deviate from those of conventional components.

The electric machine, as the core of the electrified drive train, can generate a strong market volume by 2020. In this regard, growth is expected to approximately 18.4 billion euros, which is attributed to increasing hybridization and the forecast share of pure battery electric vehicles of more than 5 percent of global sales in 2020.

For the components of the power electronics and the other electronics, in the course of electrification of the vehicle, clear sales growth of approximately 13 billion euros (power electronics), and 5.1 billion euros (other electronics) can be assumed. The market for chargers will also grow significantly (+4.7 billion euros).

Battery technology, with a growth of almost 60 billion euros, lies in first place by 2020, in front of the efficiency technologies, being a beneficiary of the trend toward more energy-efficient automobiles. In this regard, it should be stated that the relatively low sales numbers of today's hybrid and battery powered vehicles, in relation to the forecast sales figures in 2020, as well as the relatively high value share of the entire battery system, will cause a significant change in global market volume.

Thus, worldwide (given the correct assumption) for the components considered (on the basis of the manufacturing costs) there is a change in market volume of approx. 175 billion euros. More than half of this growth by 2020 will be attributed to pure „electrified components" (power electronics, E-machine, battery system, charger).

3.3.3 CONSEQUENCES FOR BADEN-WÜRTTEMBERG

The changes in the global market that can be expected and the effects of these changes on the Baden-Württemberg location are examined below. Given the premise that Baden-Württemberg companies in the automobile industry will also have the same market share of approximately 6 percent of worldwide sales in 2020, the resulting employment effects are presented. Based on the forecasts that by 2020 the combustion engine and the

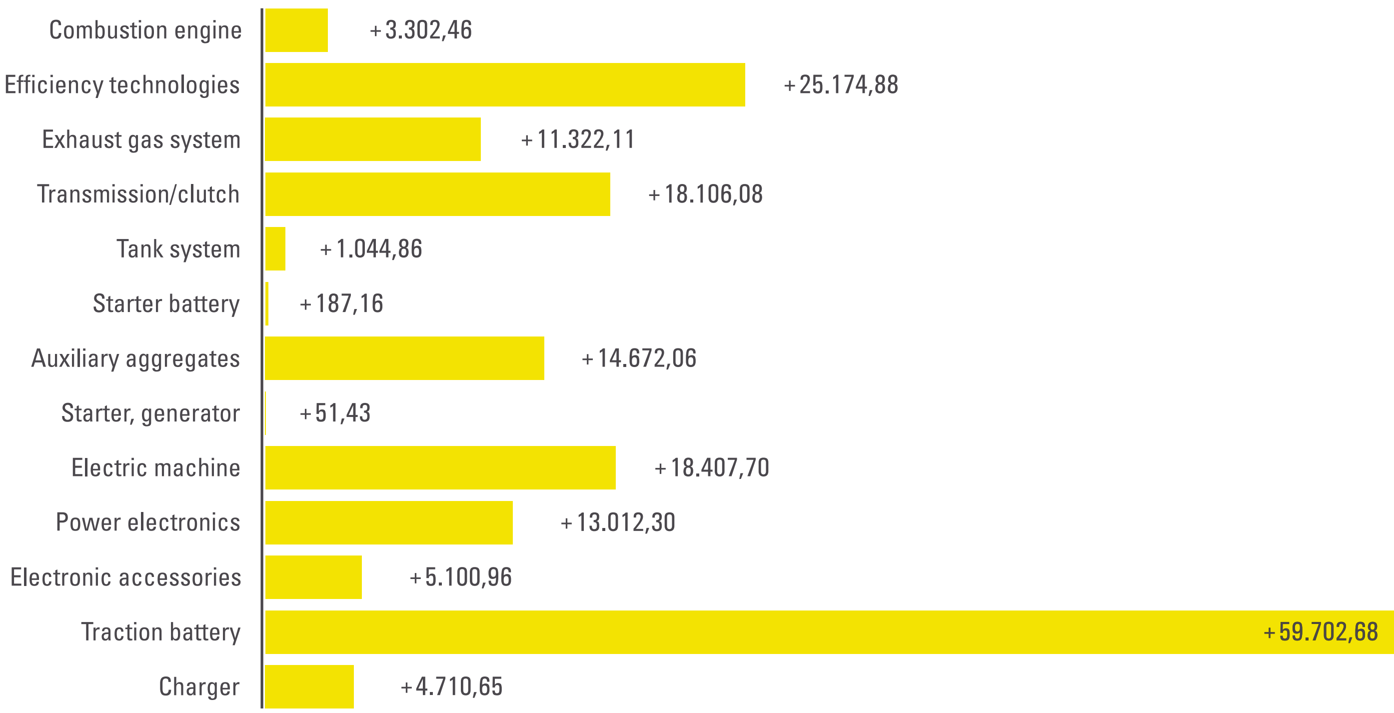


Fig. 36: Change in global market volume: Present - 2020 [in millions of euros][45]

45 Author's own illustration

associated components and technologies will make up an even higher share of total market volume than the „new propulsion components“, this assumption can be plausibly substantiated. No conclusions are drawn with respect to market and employment developments beyond the year 2020. However, it should be noted that even an increase in the market shares of pure battery-electric vehicles of between approx. 5 and 15 percent (with a simultaneous decrease of 10 percent in the combustion sector) in the underlying calculation model would cause clear cut-backs in the growth of conventional components and thus would also lower the effect on employment in these areas.

The focus of the consideration is on the components of the drivetrain. Potential employment effects that could occur in the automobile trade or in the automobile-based service sector have not been examined. Calculation of job effects was made using the coefficient of the full-time equivalent (FTE = 100 percent level of employment). The value assumed for this is 400,000 €/FTE.[46] A summary has been made for the components, combustion engine (combustion engine + tank system), auxiliary aggregates (+ starter and generator), power electronics (LE, E/E and charger) and traction battery (traction battery and starter battery). The results are summarized in Fig. 37.

Major significance is still ascribed to the classic combustion engine in the year 2020. For Baden-Württemberg, in this area an increase in market volume of approximately 240 million euros is expected, which however only corresponds to an annual growth rate of one half of one percent. Significant gains of nearly 1.4 billion euros by 2020 can be shown for efficiency technologies. At the assumed value of 400,000 €/FTE, the growth in these two areas would correspond to approximately 4060 full-time jobs.[47]Furthermore, for the components, exhaust system (+0.62 billion euros or 1,560 FTE), transmission (+1.0 billion euros or 2490 FTE), as well as consumption-optimized or modified auxiliary aggregates (+0.81 billion euros or 2020 FTE), the increasing sales volume offers clear employment potential for Baden-Württemberg.

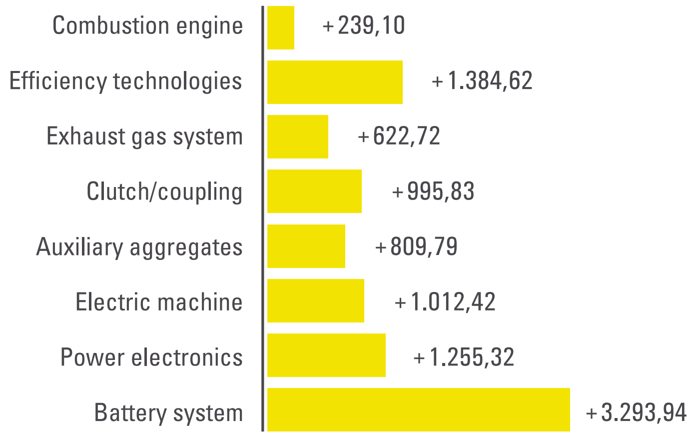


Fig. 37: Change in market volume for Baden-Württemberg: Present - 2020 [in millions of euros][48]

Components that are used due to electrification of the drivetrain, such as the electric machine (+1.0 billion euros), the power electronics or other electronics (+1.26 billion euros) or the battery system (+3.3 billion euros) can profit from the forecast developments and generate attractive growth. Given the assumption that raw materials represent the only imported materials, different maximum shares in value creation that can be achieved occur for the different components [McKinsey (2011b)]. In the area of the electric machine this would result in a maximum possible value creation share of 50 percent and an employment effect of approximately 1270 full-time equivalents. For the power electronics, 2820 full time jobs would be created (at a maximum value creation share of 90 percent). The battery system (battery cell, as well as battery integration) can have an effect of 5769 full time equivalents at an assumed value creation share of 70 percent.

Nearly half of the job potential shown by the year 2020, stands in a clear relationship with electrification of the drivetrain, and indeed through new components, such as the electric machine, the power electronics and the battery system (see Fig. 38).

46 For the calculation, a cross section of the ratio of sales to number of employees of the participating industry sector in the production cluster was formed based on official statistics (ES) (see Fig. 33). The industry sectors „Manufacturing of motor vehicles and motor vehicle parts“ (direct automobile construction ; ES-number 29), „Manufacturing of chemical products“ (ES-number 20), „Manufacturing of rubber and plastic goods“ (ES-number 22), „Manufacturing of metal products“ (ES-number 25), „Manufacturing of electrical equipment“ (ES-number 27) and „Machine tools“ (ES-number 28) were referenced with the possible respective proportions of employees within the automobile industry. The conversion of jobs shown to full-time equivalents has been considered through an internal calculation. Possible substitution effects or spin-off effects have not been considered. Statistisches Landesamt Baden-Württemberg (2011a) I Kinkel (2007).

47 Another approach for calculating the employment effects can occur via determination of the German or Baden-Württemberg share of value creation in the individual components.

48 Author's own illustration

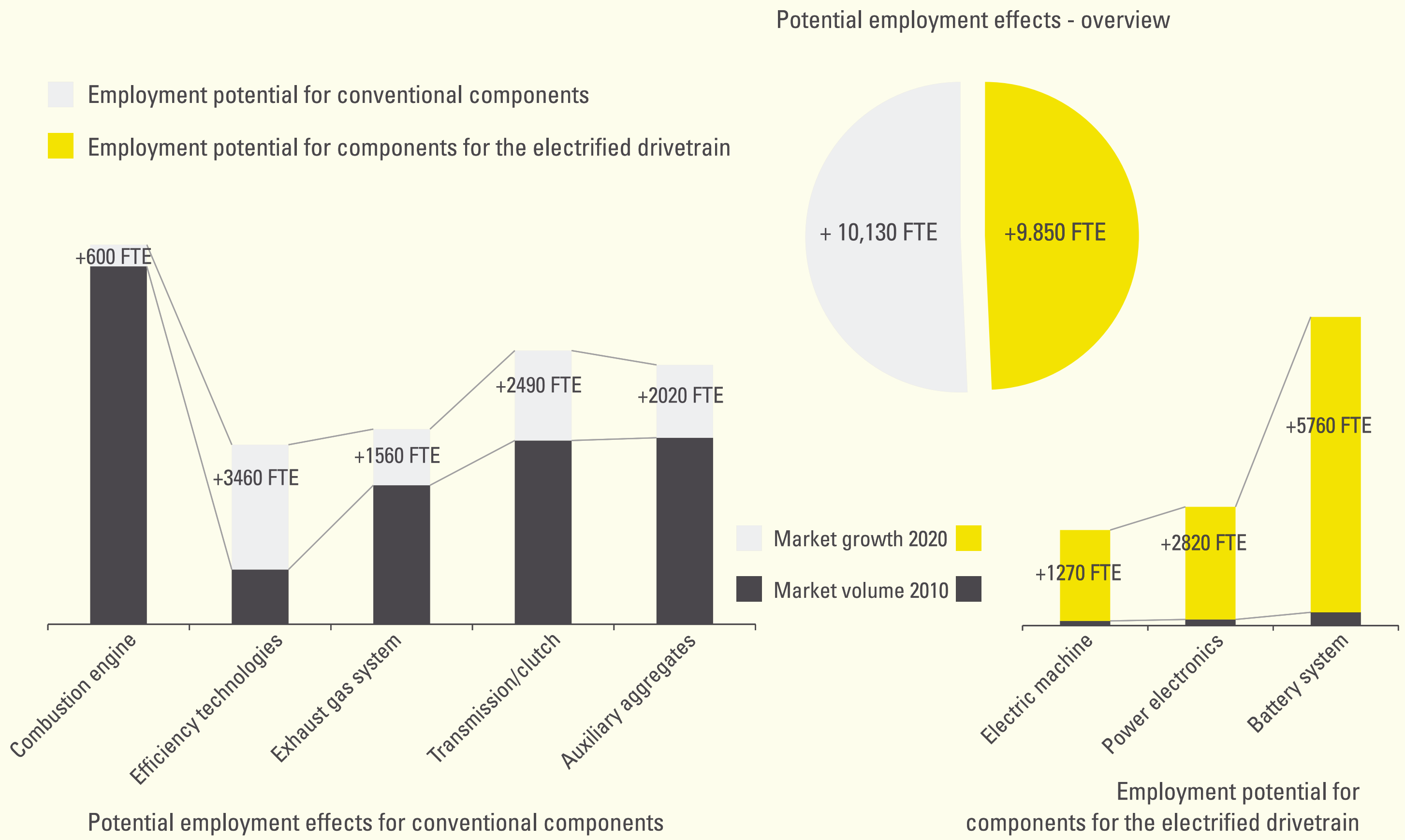


Fig. 38: Potential employment effects in Baden-Württemberg in 2020[49]

Because Baden-Württemberg is considered as today's technology leader for combustion engines, there are now questions concerning the extent to which the job potential shown in the analysis, in the „new" components can be realized in the future and whether the existing world market share of Baden-Württemberg enterprises can continue to be realized.

The current situation for the planned manufacturing of electric machines permits the assumption that the majority of these components, under some circumstances, will not be manufactured in Baden-Württemberg. The newly-founded joint venture between the Baden-Württemberg companies, Bosch and Daimler, will presumably start production of electric motors for the automotive sector in Hildesheim, Lower Saxony [Automobil Produktion (2011c)]. Moreover, in the sector of high-quality automatic and hybrid transmissions, for example, the ZF Group will increase its foreign investments to meet the market requirements in the respective countries [Automobil Produktion (2011d)].

49 Author's own illustration

In terms of the manufacturing of battery cells, it must be stated that currently the state of Baden-Württemberg does not yet have a large-scale cell manufacturing facility in the traction battery sector. However, according to a Roland Berger study, in the year 2015 excess capacities in the production of lithium-ion batteries will predominate. Manufacturing of these components will then be taken over by a few large companies and a consolidation of the market will occur [Roland Berger (2011a)].

In spite of these estimates, a projection beyond the years 2030 and 2040 makes it clear that the essential value creation of the future automobile industry lies in the traction battery. For companies in Baden-Württemberg, the question arises as to the areas where increased value creation and job potential can be tapped. Stronger alignment in the area of cell manufacturing or a concentration on cooling, packaging and system concepts, and thus on manufacturing and integration of complete systems, represent possible alternatives.

»There are risks that the value creation chain will not be extended in Baden-Württemberg or, if it is, then only too late, or that investments will not be made as long as the direction of the suppliers is unclear (quantities, task areas, etc.).«

Sebastian Wider, CEO, SW-Engineering Services, SW-Engineering GmbH

»Overall the small automobile suppliers at the second and subsequent stages of the supply chain are still inadequately included. There is a lack of information and, above all, a lack of awareness of the alternative propulsion technologies. A better flow of information between the small suppliers and the OEMs must come about, which does not yet exist in the necessary form.«

Manfred Müller, Department Manager - Industry and Transport, IHK Region Stuttgart

3.4 PRODUCTION TECHNOLOGY AS A KEY COMPETITIVE FACTOR

In order to gain essential shares of the value creation market in the state of Baden-Württemberg, a company headquartered here must succeed not only in the area of research & development, but also in securing a top position in the global competition in the significant manufacturing sector of electrified drivetrain components. In this regard, achievement of an extensive depth of value creation is an essential primary prerequisite for the creation of jobs. In addition, through planning and installation of production plants by companies headquartered in the state and the optimizations required in the course of operative use, significant value creation can also be generated.

»Wage-intensive production is always difficult in Germany. However, this is precisely the challenge for production research, namely, through innovative approaches, to produce the essential elements of the value creation chain competitively in a high-wage location.«

Dr.-Ing. Gisela Lanza, Management Board, WBK Institute of Production Science, Karlsruhe Institute of Technology (KIT)

»Industrialization of the new components for the electromobile drivetrain poses a central challenge, i.e. to make Baden-Württemberg as strong as possible as a production location for electromobility and to further strengthen its position as a technology location.«

Dr. Jürgen Dispan, Project Director and scientific employee, IMU Institute

In this respect, experts from research and industry are for the most part unified in their view that production of „new" components, such as the traction battery (battery cells, as well as battery system), the electric machine and the power electronics, as well as the fuel cell, should be established in Germany or in Baden-Württemberg.[50] Here the important thing, in addition to the pure economic consideration is also to be aware of the aspect of

50 Kampker (2011) I Expert interview with Dr. Dr.-Ing. Gisela Lanza I Expert interview with Jürgen Jost I Expert interview with Dr. Andreas Gutsch

product differentiation as a strategic competitive advantage of German or Baden-Württemberg manufacturers relative to foreign competitors. For example, in the future, high-quality power electronics, special high-performance traction batteries, or innovative developments in the electric machine can maintain the existing excellent reputation of Baden-Württemberg engineering art in the area of premium vehicles.

„The OEMs and suppliers in Baden-Württemberg have always taken a pioneering role in vehicle development and production processes. Furthermore, there is a lot of competence available for the manufacturing of electrified drivetrain components that is being specifically extended."

Jürgen Jost, Division Director, Research & Development, Dürr Systems GmbH

Aspects, such as the extremely high value-share of the components and a level of automation for manufacturing and installation processes that is as high as possible (with the prerequisite of high quantities), in general offer good prerequisites for regionalization and thus for manufacturing of essential drivetrain components in Baden-Württemberg. However, in this regard, it should be noted that in the future optimal alignment of the entire production network is required between all participants in the value creation chain. This is the only way to achieve consistent competitive structures with the advantages of reduced logistics and customs expenses, as well as achieving compliance with important quality and safety standards.

„In order to set up competitive production, Baden-Württemberg must adapt itself to the practices of the new Federal States, that offer massive support with state funds (which in some cases represent 25 percent of the investment totals)."

Dr. Andreas Gutsch, Project Director Competence E at the KIT, Karlsruhe Institute for Technology (KIT)

MANUFACTURING OF COMPONENTS

With establishment of a pilot production plant for lithium-ion batteries in Ulm, the first cornerstone has been laid for determining profitable solutions in the area of battery manufacturing. Cell manufacturing in the future plant should serve as a central contact point and dialog possibility for the participating companies and German research institutions that develop lithium-ion cells. Currently the transfer of newly developed production procedures, materials and components, into the pre-series production batteries for electric vehicles can be viewed as a significant challenge from the technical production perspective [BMBF (2011)]. In addition, it is important to establish the quality assurance standards and methods, to develop clean-room and dry-room concepts for large-scale production of battery cells, and to continue working on coating processes and intelligent handling and automation solutions [Lanza (2011a)].

For production of the electric machine, the automation of process steps offers potential for achieving economic progress, and thus potential to establish differentiation from production in low-wage countries. In this area, mechanical engineers and plant engineers with innovative production technology, in particular, can participate in a support capacity. The strong position of Baden-Württemberg in mechanical engineering and plant engineering, in particular, must be used as the essential advantage of the location. With more than 50 percent of all German machine tool manufacturers and precision tool manufactures, Baden-Württemberg has optimal prerequisites for offering full-strength support with innovative concepts and production technologies to companies in the automobile industry, now and in the future. Optimally trained specialists and good networking between companies and universities can be identified as additional advantages for Baden-Württemberg, that must be further extended in the future [VDMA (2011)].

Power electronics serve as an essential component in the electrified propulsion concept, where the issue is establishing an optimal connection between battery and drivetrain. However, manufacturing the individual components, such as power modules, film capacitors or control electronics, requires extensive knowledge and experience in semiconductor technology and the high-voltage area. Companies, such as Robert Bosch, Kolbenschmidt Pierburg and Valeo can already show documented activities in the area of power electronics, according to a research study of the Fraunhofer ISI. Nevertheless, the focus of Baden-Württemberg supplier companies is increasingly on the activity fields of „traction batteries" and „air conditioning of the electric vehicle" [IHK (2011)]. However, numerous process steps and sophisticated quality assurance, particularly in the area of power electronics, require intelligent, matched processes that must be developed with regard to possible large-scale production. Here in particular, efforts must succeed in establishing competencies (not only in the development area) that are already available in the state, such as in railway and rail technology, accessible and usable for new applications of electromobile vehicle concepts.

»In Germany, and particularly in Baden-Württemberg, we have an outstanding starting position, if we are successful in transferring our existing competencies in the area of train and railway technology to the automotive world.«

Sebastian Wider, CEO, SW-Engineering Services, SW-Engineering GmbH

The manufacturing of complex transmissions, as used in parallel hybrid or power-split hybrid vehicles, can also be viewed as a capacity of the German automobile industry and of the manufacturers in the „Ländle" (e. g. ZF Friedrichshafen AG, Getrag GmbH, Cie KG, LuK GmbH), for the future market of electromobility. In this regard, the development tasks that must be performed in the area of automation and increasing the transmission ratio spread or the number of gears form the focus. From this perspective in particular, a transfer of the new concepts into series production must be viewed as a great challenge for the next few years [Automobil Produktion (2011b)].
Numerous studies still forecast, from the short-term or medium-term perspective, a high share for the combustion engine as the essential propulsion component [for example, see Dietz (2010); Frost & Sullivan (2010); Roland Berger (2011b)]. Thus, starting from current estimates, due to the parallel development of different propulsion concepts the question arises as to the extent to which synergies in the various drivetrains are present and as to the extent to which integration of processes required for manufacturing in the existing aggregate plants can occur smoothly. Here, in particular, efficient manufacturing procedures and factory planning concepts must be developed that enable industrialization of electromobility from the technical production perspective [Lanza 2011b)]. Since in the next few years there will still be extremely low quantities in the electric vehicles sector, it will be difficult to achieve effects of scale. Approaches, such as product developments that are appropriate for manufacturing and installation, as well as cost-optimized innovations in process design, must move further into the foreground [ATZproduktion (2011)]. If existing vehicle concepts will no longer just be „modified" in the future, (see conversion vs. purpose design), but will be fundamentally redesigned, then factors such as weight, insulation, and lighting in vehicles must be re-evaluated. Use of materials that formerly were unknown is conceivable in this respect. Large-scale use of CFRP in series production of structural components, as is already the case in aircraft construction, may already be conceivable in the foreseeable future. The effects on production would be enormous.

VIEW OF THE COMPETITION IN ASIA

China has classified electromobility as a sector to be promoted. In addition, the country can rely on years of experience in manufacturing lithium-ion batteries in the consumer sector. The extent to which this could pose intense competition for the Baden-Württemberg automobile industry will become evident in the foreseeable future, since development directions in this quite new application field of electromobility have not yet been fully tapped.

»In order to establish a leading market presence for electromobility in Germany and Baden-Württemberg, and in order to further pursue the goal of ‚leading provider' the establishment of production of powerful, cost-effective and simultaneously safe batteries in the state, is required. Particularly for cell production, there is an enormous catch-up requirement compared to Asia. The number of patent applications is one indicator in this regard. At the Chinese Patent Office, the number of patents applications in the field of battery technology exceeds the number of patent applications for this field in Germany, several times over.«

Manfred Müller, Department Manager - Industry and Transport, IHK Region Stuttgart

In addition, it should be noted that the spread of battery quality is still quite high, which makes a new realignment of production necessary. Moreover, safety requirements in the production of batteries impose additional challenges that must first be solved through innovative approaches from the technical production perspective, on the way to economical production.

3.5 TRAINING AND QUALIFICATION

Changed requirements profiles for employees go hand in hand with electrification of the drivetrain. This affects both the research and development area, as well as production, sales and after-sales. Work Group 6 of the National Platform for Electromobility has considered the qualification requirements induced by electromobility in its work [NPE AG6 (2010)]. The work group determined that a particularly great need exists to network all the participants in academic and vocational training. Consequently the project „Qualification Platform for Education and Continuing Education in Electromobility" (QEMO), coordinated by the University of Ulm and in collaboration with the Weiterbildungszentrums Brennstoffzelle e.V. (WBZU), has been initiated and funded with 1.1 million euros by the BMBF [University of Ulm (2011)]. The objective of the project is the establishment and maintenance of a networking platform with the goal of networking training and learning content in the area of electromobility in a manner that extends across industries. In addition to networking the participants, the NPE views intensification of the pre-competitive research at the universities as an important means for ensuring practice-oriented training of the next generation of scientists and for contributing to the networking of science and business [NPE (2011a)].

On the 28th and 29th of June, Work Group 6 presented its analysis for discussion at the National Education Conference for Electromobility in Ulm [Göschel (2011)]. In the discussions and presentations [QEMO 2011] it became clear that with electromobility, new competence requirements would be imposed on employees. In general, a greater interdisciplinarity and understanding of the overall system, as well as thinking beyond industry boundaries, are sought after. Further, the required technical competences are extended by knowledge in fields such as power electronics, electrochemistry, battery technology, electric machines, high-voltage systems, etc. If the attempt is made to promote all the new required competencies and skills, and to establish new courses of study and industrial training, then conference participants are united for the most part in the view that this will not lead to achievement of the goal. The available job profiles are suitable for integrating new training modules and the established courses of study are suitable for satisfying the new qualification requirements by adapting the study content and by networking and combining existing subjects. This integration of the qualification demands induced through electromobility into the existing lines of academic and vocational training is also consistent with the accepted background that, over the next decades, combustion engine hybrids and electric propulsion concepts and vehicle concepts will coexist.

Whereas fewer new offerings will then be created in academic and vocational training, rather existing offerings will need to be modified; however the situation is different in the area of continuing education. Thus, some time will still be required for implementation of the new content in the industrial training and courses of study, and the respective graduates will only be available to the labor market 3 to 5 years later. This means that the industry can only count on a sufficient number of academically educated and trained personnel who meet the quality requirements, in the years 2017 to 2020. At least until then, continuing education offerings, both as part-time and full-time programs, are urgently required. This is particularly the case for handling high-voltage systems. Employees in production and after sales, as well as researchers and developers in companies and research institutes, must be trained in the safe handling of semi-electric and completely electric vehicles, to avoid accidents. Due to the heterogeneity of the supplier spectrum and the associated diversity of qualification offerings, particularly relative to safety-critical qualification measures, a standardization of qualification content and degrees is required.

> *»If the goal is to keep the value-creation chain closed it is important that specialist topics are driven forward and that a suitable training curve is generated. On one hand, there is a need for academics who drive research and development and, on the other hand, if the goal is to become the leading market and leading provider for the technology, infrastructure and products, then we must also keep industrial training in the areas of production, maintenance and repair in view.«*
>
> *Dr. Stefan Senitz, Division Head - Technology, with responsibility for the Technology organization of the Baden-Württemberg Chamber of Commerce and Industry, Karlsruhe Chamber of Commerce and Industry*

Chapter 4

BADEN-WÜRTTEMBERG ON ROUTE TO ELECTROMOBILITY

4.1 STAKEHOLDERS AND COMPETENCIES IN THE AREA OF ELECTROMOBILITY

In Baden-Württemberg the topic of „electromobility“ is being discussed and actively driven on a broad level: Automobile manufacturers, suppliers to the automobile industry, energy utilities and many other enterprises from different industries are involved in research in this area, in numerous projects extending from the fundamentals to applications. In addition to its status as the automobile state and technology location, Baden-Württemberg is also very well positioned in research and development (R&D). For example, in addition to the Karlsruhe Institute of Technology, important stakeholders from the research area are the Center for Solar Energy and Hydrogen Research (ZSW) in Ulm, the German Aerospace Center (DLR), various Fraunhofer institutes, as well as the Universities of Reutlingen and Esslingen, the University of Stuttgart and the Baden-Wuerttemberg Cooperative State University Stuttgart (DBHW).

»In particular, small and medium-sized businesses, as suppliers to the automobile industry, must be further sensitized to the opportunities as well as the risks associated with the structural change that goes hand in hand with the topic of electromobility, in order to be equipped for the future.«

Dr. Stefan Senitz, Division Head - Technology, responsible for the Technology organization of the Baden-Württemberg Chamber of Commerce and Industry, Karlsruhe Chamber of Commerce and Industry

Below the activities, participants, and the positioning of Baden-Württemberg are analyzed with respect to the categories of total vehicle, battery technology, electrified drivetrain and lightweight construction. The topics of fuel cell and charging infrastructure and thermal management in the vehicle are also discussed briefly. The information and communications technology sector (ICT) is not considered in this listing, for information on this sector see the study „System Analysis BW[e] mobile: ICT and energy infrastructure for innovative mobility solutions in Baden-Württemberg“ [Spath (2010)].

4.1.1 THE TOTAL VEHICLE

In the area of full electric and hybrid electric vehicles, the companies headquartered in Baden-Württemberg are actively working on total vehicle concepts. Daimler AG’s activities extend over the entire product portfolio. Hybrid fuel cell and full electric concepts are being developed for passenger vehicles (Mercedes A-Class, B-Class, and S-Class, Smart fortwo electric drive), as well as for commercial vehicles (Vito E-CELL) and buses (Atego). Daimler AG, among others, is also active in several fleet tests.

With the models, Panamera, Cayenne, and 918 Spyder, Porsche AG has developed multiple hybrid vehicles. The 918 Spyder will soon be on the market in limited quantities. The first pure electric Porsche, the E-Boxster, is currently being tested in the model region Stuttgart with three research vehicles.

Audi AG is developing hybrid and battery-electric vehicles under the e-tron label, and is expanding its Neckarsulm electromobility competence center. For example, the models A6 and A8 hybrid and the sports car R8 e-tron will be manufactured at the Neckarsulm location in the future. Additional vehicles, such as the A1 and A2 e-tron should follow.

Small and medium-sized business also develop complete vehicles. Examples are ID-Bike GmbH in Stuttgart with the development of the ELMOTO E-bike, and the firm X-Tronic in Magstadt, that is currently working on a new edition of the Schwalbe (Swallow), the so-called E-Schwalbe.

4.1.2 BATTERY TECHNOLOGY

»The state government needs a demonstrator that shows that automotive cells can also be manufactured in Baden-Württemberg.«

Dr. Andreas Gutsch, Project Director Competence E at the Karlsruhe Institute for Technology (KIT)

Baden-Württemberg is in a good starting position, particularly in the area of research and development. The research location, Ulm, has developed itself into a center for battery research with the Center for Solar Energy and Hydrogen Research (ZSW), the University of Ulm and the Helmholz Institute for Electrochemical Energy Storage. The ZSW activities range from development of new storage materials, through system technology and modeling,

to battery systems and safety tests, with a broad spectrum of issues concerning energy storage in batteries and supercapacitors [ZSW 2011a)]. At the ZSW, the new research and development lab „eLaB“ was opened in the fall of 2011. The eLab, subsidized with state and federal funds, should strengthen the establishment of a regional battery industry and close the gaps in the value-creation chain. Building on these efforts, starting in 2011, with funding through the Federal Ministry for Education and Research (BMBF) and through the state of Baden-Württemberg, a pilot production facility for lithium-ion batteries will be established in Ulm [BMBF (2011a)]. In addition to collaboration in the innovation alliance „Lithium Ion Battery LIB 2015“ [LIB2015 (2011)], the ZSW is also participating in the „Elektrochemie Kompetenz-VerbundSüd“ program with other research institutes from Baden-Württemberg, such as the Karlsruhe Institute of Technology (KIT), the University of Ulm, the Max Planck Institute for Solid Body Research and the German Aerospace Center (DLR) in Stuttgart. In the „Kompetenznetzwerk Lithium-Ionen-Batterie (KLiB)“ program that is coordinated by the ZSW, currently 29 companies and research institutes have come together from along the entire value creation chain for lithium-ion batteries.

»Almost all the manufacturers of production systems for lithium-ion batteries are headquartered in Baden-Württemberg and thus are dealing with the critical key topic for the manufacturing of batteries in Germany. These are primarily medium-sized companies that have experience in plant engineering, who are active worldwide, and thus make Baden-Württemberg strong.«

Dr. Werner Tillmetz, Member of the Management Board – Electrochemical Storage Technologies, Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW)

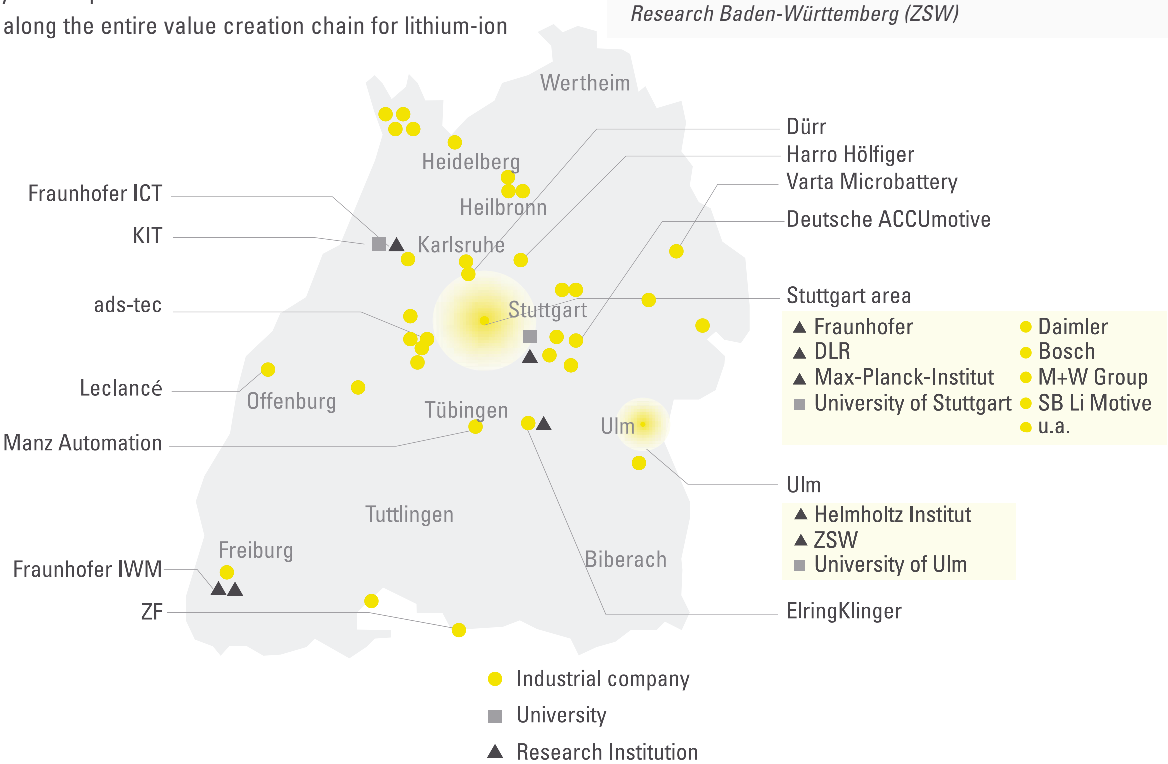


Fig. 39: A selection of participants in the battery-technology sector[51]

51 Author's own illustration

Additional strengthening of Ulm as a technology location is being driven with the foundation of the new Helmholtz Institute Ulm for electrochemical energy storage (HIU) by KIT in cooperation with the University of Ulm, and thus the systematic establishment of competence in the sector of electrochemical and battery research in Baden-Württemberg is being extended. Connected partners are the DLR as well as the ZSW [BMBF (2011b)].

Moreover, in the area of battery technology, the Fraunhofer Institute for Chemical Technology (ICT) and the Fraunhofer Institute for Material Mechanics (IWM) must also be cited as know-how specialists. As an additional competence network, the Fuel Cell and Battery Alliance Baden-Württemberg, with approximately 70 members from the science, industry and public administration sectors, has set the goal of promoting the development and implementation of products that are ready for the market.

In addition to research organizations, various institutes are also active in the area of battery technology; a selection of companies is presented below as an example.

Dürr AG is involved in the development of production facilities for all aspects of the vehicle battery and battery charging stations. Dürr AG views cell manufacturing as an additional topic area and sees synergies in the coating of electrodes [WRS (2011a)].

ads-tec GmbH specializes in automation technology for battery installation systems, produces its own modular high-performance energy storage device and offers customer-specific battery designs [WRS (2011a)]. Together with other companies, such as ZF Friedrichshafen and Continental, ads-tec develops components and manufacturing processes for lithium-ion batteries and commercial vehicles as part of the „Future goes Electric" project (FUEL), funded by the Federal Ministry for Education and Research, [ADS (2011)].

The technology for manufacturing rechargeable batteries and battery systems is the focus for Leclanché S.A., with the business unit Leclanché Lithium and its production location in Willstätt. This is where Leclanché pursues industrial manufacturing of large-format, high-capacitive lithium-Bi cells (up to 20 Ah), as well as electrode coating, separator production and quality management [Leclanché S.A. (2011)]. Another company, Varta Microbattery GmbH in Ellwangen, is involved with research and development in the area of lithium batteries. ElringKlinger AG, headquartered in Dettingen/Erms, is pursuing further development of its competencies in the area of battery technology. System solutions for manufacturing lithium-ion batteries are offered by Harro Höfliger Verpackungsmaschinen GmbH.

For development of manufacturing technologies for battery production, Manz Automation AG must be cited. As part of the innovation alliance „Production Research for High-Performance Lithium-Ion Batteries", Manz Automation AG, together with other partners, wants to research manufacturing technologies and apply their research to the requirements of large-scale production [Baden-Württemberg International (2009)]. The Stuttgart-based plant engineering firm, M+W Group, has developed a concept for the planning and construction of lithium-ion battery factories with modular bundling of the production processes. In 2010, the first order was placed for the construction of a lithium-ion factory in Finland [M+W Group (2010)]. For bundling of competencies, various joint ventures have been formed, such as SB Li Motive, the joint venture of Robert Bosch GmbH and Samsung SDI, that develops battery packs and battery systems in Stuttgart [SB LiMotive (2011a)].

Another joint venture, the German ACCUmotive GmbH & Co. KG, headquartered in Nabern, has been formed between Daimler AG und Evonik Industries. Its location for the production of lithium-ion batteries is in Kamenz (Sachsen) in the direct vicinity of Li-Tec Battery GmbH.[52]

Actual production of the cell, from the module to the system, will remain the reserve of large enterprises, due to the immense investment costs and, from the present perspective; this will be increasingly established in other federal states. In the area of production equipment, innovation potential is increasingly offered for small and medium-sized businesses.

4.1.3 ELECTRIFICATION OF THE DRIVETRAIN

In addition to the battery as a central component of electric vehicles, a high level of significance is ascribed to the electric machine, the power electronics and transmission technology. In Baden-Württemberg not only the large globally-active companies, but also many small and medium-sized companies, have become active in the area of electromobility.

52 Li-Tec Battery GmbH is an additional joint venture of Daimler und Evonik: 50.1 percent of the shares are held by Evonik, 49.9 of the shares are held by Daimler. On the other hand, for Deutsche Accumotive GmbH, 90 of the shares are held by Daimler and 10 percent of the shares are held by Evonik [Automobil Produktion (2009)].

The State Statistical Office lists approximately 84,000 employees in more than 300 firms in Baden-Württemberg in the area of electrical equipment; this currently also includes the production of electric motors [State Statistical Office Baden-Württemberg (2011)]. Thus there is great potential for extending new business segments and thus value creation in this area.

ELECTRIC MACHINES

In addition to Daimler AG, Bosch, is also active in almost all areas associated with electrification of the drivetrain. Moreover, Bosch and Daimler AG have founded the joint venture, electromobility-motive GmbH, for the manufacturing and sales of electric motors [Robert Bosch (2011a)].

»The fact that EM-motive, the new joint venture of Daimler and Bosch for traction electric motors, will settle its development in Baden-Württemberg must be welcomed. However, the downside for the regional economy is that production of these e-machines for pure electric vehicles will not also take place in Baden-Württemberg.«

Dr. Jürgen Dispan, Project Director and scientific employee, IMU Institute

Further, SEW-EURODRIVE GmbH & Co. KG in Bruchsal is involved with propulsion system issues. In early 2011, together with Brose Fahrzeugteile GmbH & Co. KG, the firm founded the company Brose-SEW Elektromobilitäts GmbH & Co. KG, that markets propulsion and charging systems for electric vehicles and hybrid vehicles [Brose (2011)].
There is also a collaboration between Aradex AG in Lorch and ate GmbH in Leutkirch, which together develop and market the VECTOPOWER electric propulsion system [Vectopower (2011)]. Other companies are active in the area of propulsion technology, such as Schopf, AMK automotive GmbH, and Ricardo AG.

In the area of research on alternative propulsion concepts, the KIT and the University of Stuttgart, the DLR with the Institute of Vehicle Concepts, as well as the universities of Esslingen, Ulm, and Karlsruhe, must be cited. Moreover there are collaborations between industry and research. In this regard, the founding of „Projekthaus e-drive" should be mentioned, within which Daimler AG and the KIT started a research cooperation in the area of electric propulsion in 2008 [Idw (2008)]. In addition to the power electronics, control and regulating technology sectors, electric machines, and electric energy storage devices should also be researched uniformly, „under one roof".
Moreover, in 2011 the doctoral program, „Projekthaus e-drive", came into being through Daimler and the Stuttgart supplier, Behr GmbH, through which an initial ten doctoral candidates are being supported for four years [KIT (2011a)].

POWER ELECTRONICS

»I think that production of the power electronics is predestined for Baden-Württemberg.«

Jürgen Jost, Division Director, Research & Development, Dürr Systems GmbH

Companies from the power electronics sector include the large enterprises such as Bosch, Daimler AG and Porsche AG for example, as well as the AMK Group headquartered in Kirchheim/Teck, Lauer & Weiss GmbH from Fellbach and Bertrand AG, headquartered in Ehningen.
A cooperation of industry and research/teaching that is unique in Germany is the Robert Bosch Center for Power Electronics that was opened in June 2011; it was founded and co-financed by Bosch. At both locations of Reutlingen University and the University of Stuttgart, in coming years approx. 30 million euros will be invested in extending the infrastructure, professorships, and new courses of study. In October 2010, the master's degree program in power electronics and microelectronics was extended to include the focus areas of optical and power electronics and information technology. The bachelor's degree program in mechatronics adds a new focus area. In addition, a new part-time master's degree program, nano electronics and optoelectronics & power electronics, has been developed [RB Center (2011)]. Further, the KIT, Esslingen University and the DLR are pursuing research in the area of power electronics.

TRANSMISSION

Transmission technology, in particular, offers new fields of application in the area of parallel hybrid or power-split hybrid vehicles. Baden-Württemberg companies are working on innovative solutions in this area including, for example ZF Friedrichshafen AG, the third-largest supplier to the automobile industry in Germany. ZF is active in the area of hybrid vehicles and electric vehicles. LuK, as a Schaeffler Group company, is also active in the areas of development, manufacturing, and sale of transmissions, as is the Getrag Corporate Group in Untergruppenbach.

4.1.4 LIGHTWEIGHT CONSTRUCTION

Lightweight vehicle construction is a key technology for energy-saving and low-emission vehicles. In Baden-Württemberg there are many recognized research institutes and a number of companies that are active in this field, particularly with regard to weight reduction in vehicle manufacturing and also in the area of electromobility, in particular. The DLR, the Fraunhofer Institute for Chemical Technology (ICT), the Karlsruhe Institute for Technology and the University of Stuttgart have been working closely together for several years at the Competence Centre for Automotive Light-Weight Solutions (KFL). The Innovation cluster KITe hyLITE at the Fraunhofer Institute for Chemical Technology in Pfinztal, with more than 30 partners from research and industry, places its focus on researching new technologies for hybrid lightweight vehicle construction. The core KITe hyLITE team consists of three institutes of the Fraunhofer organization (ICT, IWM and LBF) and four institutes of the KIT. On the company side, in addition to the three OEMs headquartered in Baden-Württemberg (Daimler, Porsche and Audi) the broadly based supplier industry and numerous innovative small and medium-size machine-tool companies are also integrated [Fahrzeugleichtbau (2011)].
The „Alliance for Fiber-Based Materials – Baden-Württemberg“ (AFBW) as a cross-industry network, is a platform for exchange and

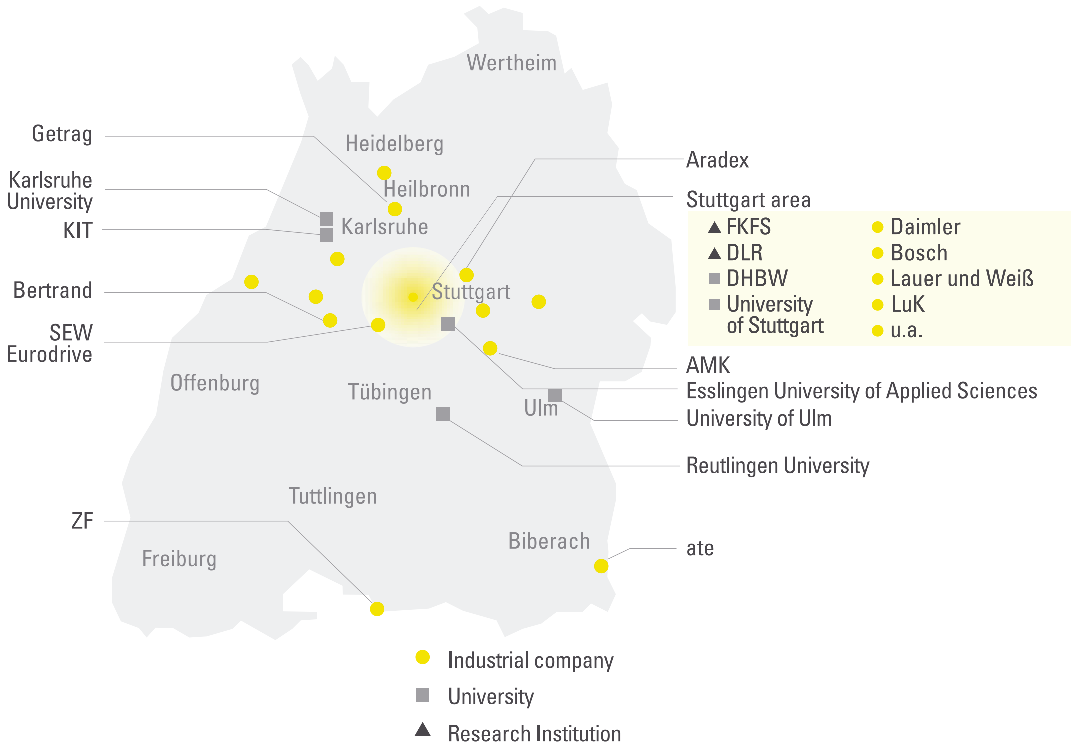


Fig. 40: A selection of participants in the electrified drivetrain sector[53]

53 Author's own illustration

knowledge transfer between companies, scientists, and politicians. One particular topic and research field of this alliance is involved with the mobility sector [AFBW (2011)]. The Lightweight Construction Center Baden-Württemberg, LBZ-BW e.V. offers another networking platform for research institutes and companies that are involved with the topic of lightweight construction and supports its members by organizing collaborations [Lightweight Construction Center (2011)]. The innovation cluster „System-efficient hybrid lightweight construction", with sponsors from the Lightweight Construction Center - Baden-Württemberg, links the competencies of different branches of industry and networks them with research institutes and other clusters and networks, including the AFBW, automotive bw, and KITe hyLITE.

The Baden-Württemberg Ministry for Finance and Industry promotes the establishment of a Technology and Transfer Center - Lightweight Construction TTZ - through the State Agency for Electromobility and Fuel Cell Technology e-mobil BW GmbH.

With the foundation of a technology cluster composite (TC²) instigated by the Ministry for Science Research and Art of the State of Baden-Württemberg, diverse research institutes, such as KIT and the University of Stuttgart, the DLR, the Fraunhofer Gesellschaft and the Institute for Textile and Process Technology Denkendorf, as well as the universities of Ravensburg-Weingarten, Esslingen, and Constance, have come together to bundle their competencies in the area of composite materials in Baden-Württemberg [KIT (2011b)].

Today, as in the past, lightweight construction is an important topic in the automobile industry. It plays a central role in reducing the energy requirements of vehicles and thus reducing the necessary battery capacity, through its weight-reduction possibilities, particularly for electric propulsion concepts. The three OEMs headquartered in Baden-Württemberg (Daimler, Porsche, and Audi) are further strengthening their activity in this field. At the Neckarsulm location, among other things, Audi focuses on technical development in the area of lightweight body construction. The automotive manufacturer

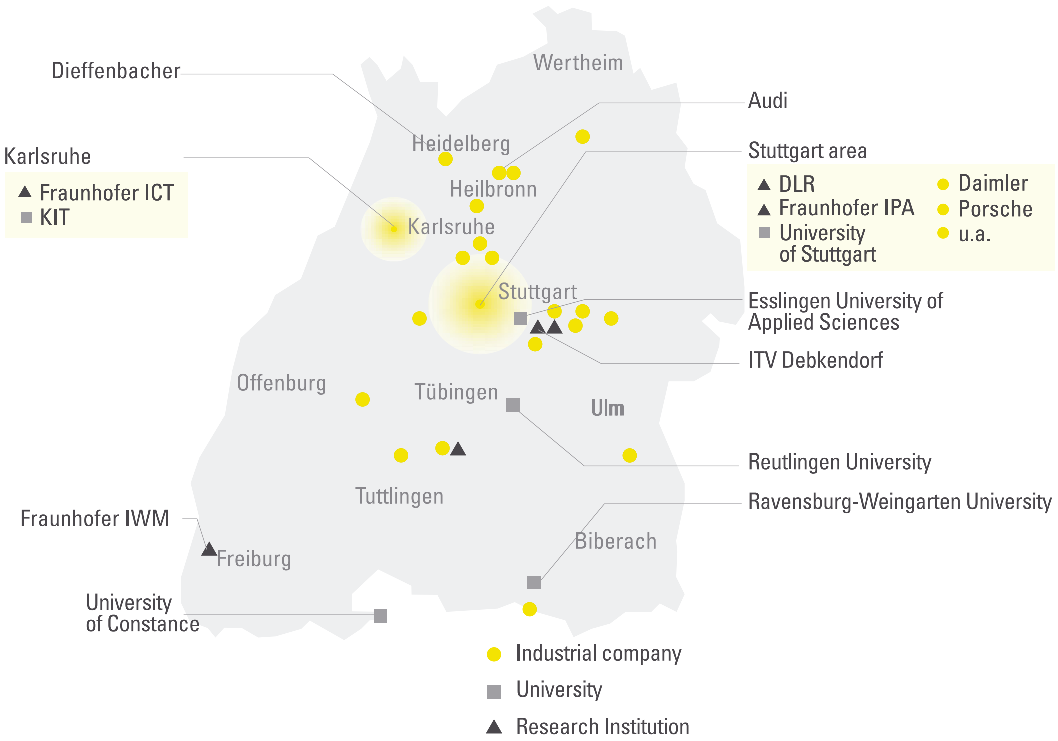


Fig. 41: A selection of participants in the battery technology sector[54]

54 Author's own illustration

Daimler plans, in the future, with the Japan CFRP manufacturer Toray, to produce lightweight parts for its automotive production in Esslingen, near Stuttgart [Daimler (2011a)]. In addition to the large OEMs, numerous small and medium-sized companies are involved with the topic of lightweight construction, for example, Maschinen- und Anlagenbauer Dieffenbacher GmbH, headquartered in Eppingen, which also relies on fiber-reinforced plastics for use in the automobile [Dieffenbacher (2011)].

»In the fuel cell industry, Baden-Württemberg is extremely well positioned, particularly in the area of research and development. In this regard, various institutes of higher education and Daimler AG with its development center in Nabern, near Kirchheim/Teck, stand out in particular. Expansion to the complete Baden-Württemberg production location with a supplier network, which already possesses very good approaches, has not yet been realized.«

Dr. Jürgen Dispan, Project Director and scientific employee, IMU Institute

4.1.5 THE FUEL CELL

In the area of fuel cell technology, Baden-Württemberg is extremely well positioned both nationally and internationally, in terms of its industry and research landscape. It should be emphasized that the Stuttgart region has a nationwide, if not even worldwide, unique concentration of activities in the area of fuel cells (see Fig. 42) and thus is one of the world's leading research and development centers, as well as technology and economic centers. The Center for Solar Energy and Hydrogen Research (ZSW) at Ulm works on the fundamentals of fuel cell research and on development of new fuel cells for the automobile, portable and stationary applications and fuel cell systems, from pure experimental systems to industrial prototypes [ZSW (2011b)]. The Max Plank Institute for Solid Body Research in Stuttgart develops membranes for fuel cells; the Fraunhofer Institute in Karlsruhe is involved in developing, amongst other things, electrocatalysts and electrode structures for direct fuel cells [ICT (2011)].

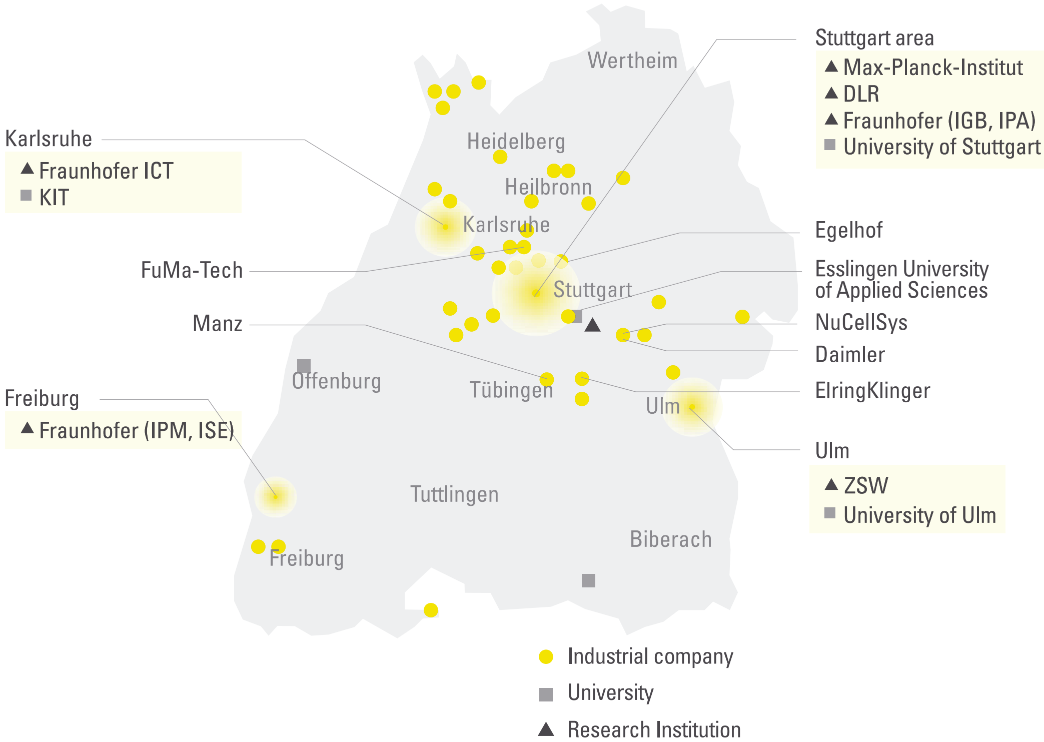


Fig. 42: A Selection of participants in the fuel cell sector[55]

55 Author's own illustration

In addition to a number of other research institutes, universities and technical schools, numerous companies are working in the field of hydrogen technology and fuel cell technology. As a subsidiary of Daimler AG, NuCellSys GmbH is one of the leading companies in the area of development and manufacturing of fuel cell systems for vehicle applications. In addition to system development and design, component and software development, as well as system validation and integration, as a small-scale production facility for fuel cell systems it has been in existence since 2003 [NuCellSys (2011)]. Moreover, Daimler AG is assembling fuel cell vehicles, such as the B-Class F-CELL, in Nabern near Kircheim/Teck. As a company in the field of special seals and housings, ElringKlinger AG, has established manufacturing facilities for fuel cell components and stacks as a new sector for its business [ElringKlinger (2011)]. Many small and medium-sized companies offer special technologies, materials, and individual components for the manufacturing of fuel cells. For example, FuMA-Tech GmbH, develops membranes for use in fuel cells, Otto Egelhof GmbH has special valves and air supply systems in its product line [Egelhof (2011)]. In addition to the development of components and complete systems, several Baden-Württemberg companies, such as Manz Automation Tübingen GmbH, also have competencies in the development of production facilities for fuel cells.

An overview of the diverse participant landscape in the fuel cell technology sector is shown in Fig. 42, with a selection of research organizations, universities, technical universities and companies. The competence networks listed in chapter 4.2 also offer information on participating members on their web sites.

4.1.6 INFRASTRUCTURE

»Rapid progress in standardizing the interface between automobile and infrastructure is an essential factor for implementation of electromobility.«

Heiko Herchet, Director of the Competence Center, EDAG Group

The prerequisite for electrification of the drivetrain is the development and establishment of a suitable charging infrastructure. In the charging technology sector, the Bosch subsidiary, Bosch Software Innovations, develops software solutions for the charging operation and for networking the stations [Robert Bosch (2011b)]. The companies, Conductix-Wampfler, SEW-Eurodrive, Lapp Kabel, Heldele und Kellner Telecom, are involved in innovative projects for electric vehicles.

In terms of energy supply and the establishment of charging columns, EnBW is extremely active as the largest energy supplier in Baden-Württemberg. Together with Daimler AG, Bosch, SAP and other companies, EnBW, in the recently concluded MeRegioMobil project, is investigating the optimal networking of power grid and electric vehicles via modern information and communication technology (IuK) [MeRegioMobil (2011b)]. The company is also active in the H_2 Mobility project, which involves the establishment of a hydrogen infrastructure, the iZEUS (intelligent Zero Emission Urban System) project funded by IKT for Electromobility II, the German/French fleet test CROME and in the IKONE project. CROME focuses on cross-border operability and fast charging.

MVV Energie AG also, as a regional provider with a Germany-wide network of utilities, is involved in infrastructure projects such as „Model City Mannheim" [Modellstadt Mannheim (2011)] and „Future Fleet" together with SAP AG [RegModHarz (2011)]. Moreover, other energy suppliers and smaller providers of infrastructure solutions are involved in Baden-Württemberg.

»Because the future of the automobile will be shaped by electric vehicles with battery and fuel cell propulsion, establishment of a consistent charging and hydrogen infrastructure in Baden-Württemberg as well as throughout Germany is essential. The technology will first spread and become established where the infrastructure is also present.«

Peter Froeschle, General Manager - Strategic Energy Projects & Market Development Fuel Cell/Battery Vehicles, Daimler AG

The FKFS of the University of Stuttgart, KIT, the Fraunhofer IAO, the Fraunhofer ICT and the ZSW are active in the area of research. In 2011 the research charging station, ELITE, was placed in service by the FKFS. In addition, research is also underway in the area of inductive charging [FKFS (2011)]. Among other things, KIT is involved in the MeRegio and Smart Home projects focusing on the topics of grid integration of electric vehicles. The Fraunhofer IAO is erecting a total of 30 charging stations and a fast charging station for research purposes in the employee parking facility for the Institute center.

»When more vehicles are on the market, the extension of charging columns will develop successively. However, the municipalities must now provide the boundary conditions for the expansion of a supply infrastructure in the medium-term. To do this, areas must be designated and made available to possible operators at favorable costs. This involves clarification of legal issues and thus is highly time-intensive.«

Manfred Müller, Department Manager - Industry and Transport, IHK Region Stuttgart

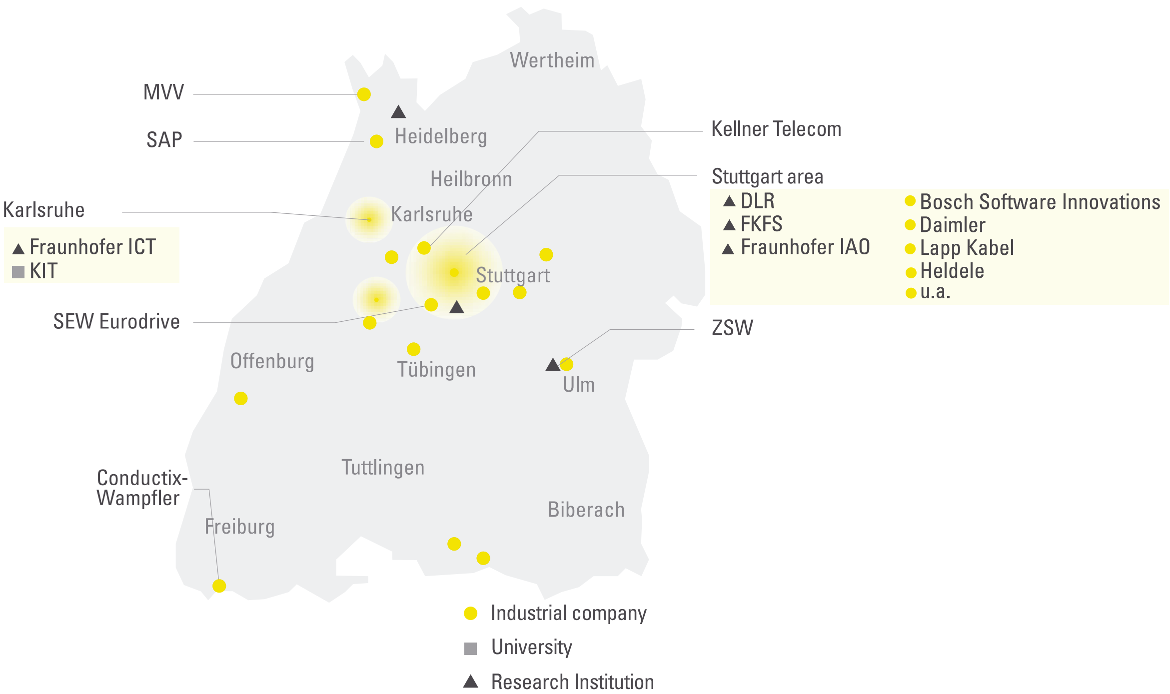


Fig. 43: A selection of participants in the charging infrastructure sector[56]

56 Authors' own illustration

4.1.7 THERMAL MANAGEMENT

An essential challenge for the development of electric vehicles is thermal management, since, in comparison to conventional vehicles, engine heat is no longer available for heating the interior of the vehicle, and cooling is provided through auxiliary aggregates that consume a lot of energy. The range, which is already restricted as compared to that of conventionally propelled vehicles, is further reduced through the power requirements of electric heating and cooling elements. This effect becomes greater, the higher the power consumption of the components for interior air conditioning. Nevertheless, to counteract this effect and still be able to generate a high level of climate comfort in the vehicle interior, innovative air-conditioning concepts must be developed (see chapter 2.2.3).
In the area of air conditioning and thermal comfort concepts for electric vehicles, the Fraunhofer Institute for Building Physics has been working on this issue in the „E-Comfort" project. Behr GmbH & Co. KG in Stuttgart is active in topics that involve thermal management. The company, J. Eberspächer GmbH & Co. KG, headquartered in Esslingen am Neckar, develops and produces heating concepts for efficient heating of electric vehicles. In addition, Robert Bosch GmbH in Gerlingen-Schillerhöhe, and Bosch Engineering GmbH in Abstatt are participating in a research project devoted to thermal management for electric vehicles.

4.2 NETWORKS AND CLUSTERS

In addition to the thematically assigned networks and clusters already cited, a number of additional networks and associations exist in Baden-Württemberg for interdisciplinary promotion of electromobility and fuel cell technology in the state.
The State Agency for Electromobility and Fuel Cell Technology Baden-Württemberg, as the central contact point in the electromobility sector and for networking all important participants, initiatives, projects, and funding activities in the state, assumes the role of an umbrella organization and state-wide platform. The declared goal of e-mobil BW is to promote the exchange of knowledge, identify innovation potential and to initiate collaborative research projects in this manner. A particular work focus of e-mobil BW, in this regard, is better integration of small and medium-sized businesses in the electromobility innovation process. The „Electromobility Southwest" cluster, with the motto „road to global market" today includes approximately 80 participants from business and science in the Karlsruhe – Mannheim – Stuttgart – Ulm region. As a regional concentration and network of innovative participants, it connects with the understanding of the three technology approaches, the automobile, ICT and energy industries, and the interdisciplinary field of production. With the goal of industrializing electromobility, the cluster participants jointly address the three essential levers for making electromobility competitive: „Market and costs" (provision of competitive life-cycle costs), „Handling and comfort" (satisfying customer expectations for e-vehicles) and „networked mobility" (increasing the usability of electrified modes of transport). Through its synergies, it acts as a catalyst, particularly for small and medium-sized companies, because it integrates them in the knowledge transfer between large companies and research organizations and thus actively prepares for the change to electromobility. e-mobil BW handles the overall cluster management and is a competent contact for all cluster members.

In this sense, the state-wide network „automotive bw" promotes further development of Baden-Württemberg as an innovative supplier location, and the bundling of companies and their activities as part of a cluster [automotive bw (2011)].
The Fuel-Cell and Battery Alliance Baden-Württemberg (BBABW), which also has an interface and consulting function, works closely with its more than 70 members from business, research, and public administration, with partners such as Wirtschaftsförderung Region Stuttgart GmbH (WRS) and e-mobil BW, to accelerate market preparation and industrialization of battery and fuel cell technologies, jointly with its members.
In the FutureCar innovation network, under the direction of the Fraunhofer Institutes IAO and IISB, and the Swiss company Protoscar, supplier firms are supported in their positioning in electromobility [IAO (2011)].
Aid in development and research is also offered by Baden-Württemberg's Mechatronics Competence Network, which is a communication platform for its partners for collaboration and knowledge transfer in the development of technical solutions, to improve solution competencies in Baden-Württemberg and make these competencies known beyond the state borders [mechatronik (2011)].

Wirtschaftsförderung Region Stuttgart GmbH coordinates the model region, Electromobility Stuttgart, as the project management point. Moreover, it is a project partner in the INTERREG IVC program „Producer Services for European Sustainability and Competitiveness" of the EU. The project addresses the needs of sustainable mobility and thus profits from the experience of the Stuttgart region in the area of electromobility [WRS (2011b)].
In the „Sustainably Mobile - Region Stuttgart" project, that came into being in February 2011 through several federal ministries, electromobility researched in the model region Stuttgart will be extended through additional topics, such as protection of the climate, urban development and intermodality. At the time this study was produced, the project was still in the phase of content and organizational alignment [eMobil BW (2011a)].

4.3 PUBLICALLY FUNDED RESEARCH PROJECTS IN BADEN-WÜRTTEMBERG

»Funding instruments must be designed in such a manner that the risk from these long-term topics also remains manageable for medium-sized businesses.«

Dr. Werner Tillmetz, Member of the Management Board – Electrochemical Storage Technologies, Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW)

Since 2009, in particular, in Baden-Württemberg several projects and initiatives have been funded in the field of electromobility. Many projects can be attributed to the federal research funding program for electromobility, within the Economic Stimulus Package II. However, the state of Baden-Württemberg also makes significant funds available (see chapter 2.5). For example, as part of the state initiative in the period 2010-2014, approximately 28 million euros have been provided - to which the founding of e-mobil BW as a state agency can also be attributed [Leßnerkraus (2010)].

The greatest volume of research funds for electromobility is made available from the BMBF. Thus, for example, in the „Association Southwest for Electrochemistry for Electromobility" alone, the Baden-Württemberg participants were funded with 14 million euros [Environmental Ministry (2010)]. Numerous research projects funded by the BMBF, are frequently organized as composite research in business and science, and lay the foundations for projects that are closer to application and that are frequently better perceived in the public eye.
Among these near-application projects, certainly the Model Region Electromobility Stuttgart must be highlighted. Under the leadership of Wirtschaftsförderung Region Stuttgart WRS, it has succeeded in positioning Stuttgart as a model region of the Federal Ministry for Transport, Construction and Urban Development, BMVBS. In the Model Region Electromobility Stuttgart, a total of 100 charging stations will be set up. In addition, in the context of the initiative, more than 800 vehicles with electric drivetrain are in use in the Stuttgart region; the majority of these are electric two wheelers [NOW GmbH (2011)]. Overall, the model region Stuttgart has a funding volume of 16.2 million euros that is distributed over 32 partners. Together with the funds supplied by the participants themselves, the total sum for the model region Stuttgart amounts to 33.5 million euros [Region Stuttgart (2011)]. In this respect, Model Region Stuttgart consists of several projects that are briefly described below.

- In the IKONE project, under the coordination of Daimler, 50 battery-powered Mercedes Benz Vito E-Cells are on the road, to investigate the use of electrically-powered vans in commercial transport. The project on urban commercial transport addresses an extremely interesting area of implementation for electric vehicles. Thus the routes that must be traveled can be effectively planned and the positive effects of the local emission-free propulsion are particularly evident in urban areas.
- In a field test with the largest electric scooter fleet in Germany, EnBW is demonstrating electromobility in everyday use [EnBW (2011)]. 500 trialists, referred to as electronauts, have the opportunity to ride on electric scooters for a specific time period over the course of the project. The electric moped, Elmoto, is used for this project. This was developed by the design office, ipdd, headquartered in Stuttgart, and is now produced by the newly founded company, ID-Bike. As of the 2nd of October, 2011, the trialists had traveled 965,760 km. The EnBW has provided another 100 electric scooters for use in municipal fleets.
- Under the direction of Stuttgarter Straßenbahnen AG, five diesel hybrid buses have been placed in service to test further electrification of public commuter transport. For the buses, pure electric operation is possible, e.g. when driving out to the bus stops. The buses are deployed on a topographically demanding line (Line 42).

- In the EleNA project (Electric Propulsion Retrofit kits for Diesel Delivery Vehicles) several smaller automobile suppliers from the region are developing an electric propulsion retrofit kit. This kit enables retrofitting of conventional small delivery vans to hybrid propulsion
- Currently in Ludwigsburg 15 electrically propelled vehicles are deployed in the fleet of the municipal administration. The goal of this field trial is to investigate whether the mobility requirement of a municipal administration can be covered with different types of electric vehicles (passenger vehicles, small vans, electric scooters, pedelecs and segways).
- At the Böblingen/Sindelfingen airfield, a test was executed to determine how electromobility can influence the development of a city district.
- By the end of 2011, the bicycle rental system of Deutsche Bahn AG (Call a Bike) will be equipped with 100 Pedelecs. These can be rented at 45 terminals.
- Porsche has built 3 electric Boxsters, to test the durability of batteries, the charge and discharge cycles, the range and acceptance.

In addition to projects within the DMVBS funded model region, Baden-Württemberg project consortia have also been able to place significant funding projects in the fields of vehicles, information and communication technology and energy in the programs of the BMWi with the projects MeRegio and MeRegioMobil [MeRegioMobil (2011a)], and in projects of the BMU with the Future Fleet project [Future Fleet (2011)]. Thus in the MeRegioMobil project the establishment and operation of an intelligent charging and recovery infrastructure for electric vehicles is being driven forward with up to 600 charging points. In the FutureFleet project, SAP uses approx. 30 electric vehicles in its own fleet and researches the intelligent management of these vehicles.
The fleet test, CROME (Crossborder Mobility for EVs), funded by BMVBS and BMWi, is designed to demonstrate cross-border electromobility. For this project, by the end of 2013, approximately 100 purely electrically propelled vehicles will be deployed in the German/French border area. The goals include testing of charging in a foreign country, analysis of charge behavior and evaluation of customer acceptance.
The state of Baden-Württemberg is sponsoring a companion study to the project „ZUMO – Future Mobility in the Black Forest Vacation Region". The object of the study is to determine the potential of sustainable mobility in tourism to compensate for revenue losses that occur due to the climate change. Fig. 44 presents a summary of current and planned research projects and demonstration projects in Baden-Württemberg.

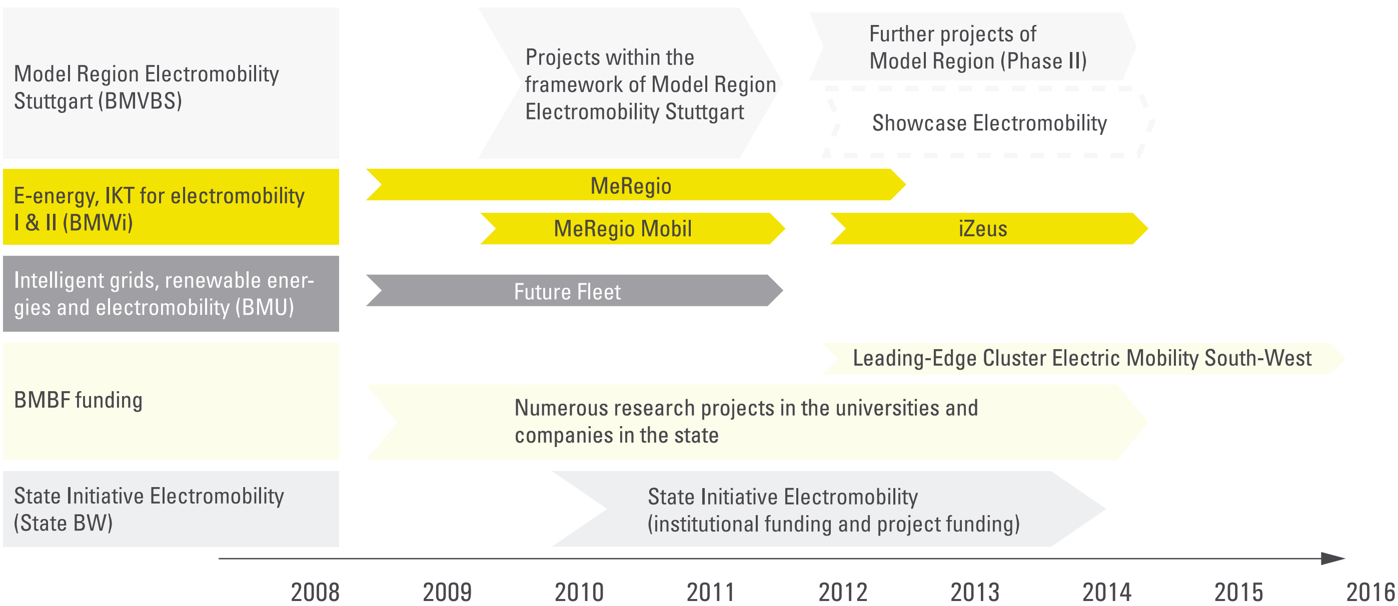


Fig. 44: Summary of current and planned research projects and demonstration projects in Baden-Württemberg[57]

57 Authors' own illustration

Chapter 5

SUMMARY OVERVIEW

In the structure study, „BW^e mobile 2011“, secondary data research (technology studies, market scenarios, project reports, press release, etc.) as well as interviews with experts from industry and science, have been brought together to analyze the expected effects and the positioning of Baden-Württemberg in the technology field of electromobility. To accomplish this task, the existing data basis of the preceding structure study, BW^e mobile, was extensively reviewed, updated and extended with new, relevant topics. Within the framework of the summary consideration it is clear that:

- The change toward an electromobile society is advancing with major steps and with this change new challenges arise for the participants in the automobile value creation chain.

- Electromobility must be systemically thought through and a knowledge transfer between companies and research institutions must begin taking place today and include the relevant industries, automobile, ICT and energy.

- Optimal exploitation of future employment potential can only be achieved in the state of Baden-Württemberg if essential shares of the „electromobile“ value creation chain are ensured within the state. These extend from production of essential components to market introduction of the end product.

- The basis for the future competitive capacity of Baden-Württemberg is qualification of medium-sized businesses. This can only happen if small and medium-sized companies in the state can actively profit from the long-term planning of large companies and thus can autonomously participate in shaping the change to electromobility.

The changes in the automobile value creation chain and the challenges, such as ensuring considerable value creation shares, are offset by numerous opportunities that can be seized by industry based in the state. New value creation potential exists at the component level in the areas of the electric machine, power electronics and, in particular, in the area of the traction battery.

The state of Baden-Württemberg is well positioned due to its unique structures in the sectors that are relevant for electromobility. For the positioning and attractiveness of Baden-Württemberg as a location for research, development and production of electromobile systems, it will be critical for success to bring together the numerous available enterprises that are leaders in their field, research institutions and educational institutions in a functioning cluster. Such a cluster with participants who cooperate in all pre-competitive subject areas with mutual trust, a short line to state politicians, and including all the value creation stages and sectors concerned, can unfold a unique penetration power.

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LIST OF FIGURES

ABBREVIATIONS

ABS	Anti-lock braking system
AFBW	Allianz Faserbasierte Werkstoffe Baden-Württemberg
AG 6	Arbeitsgruppe 6
AISBL	Association internationale sans but lucrative
ASM	Asynchronous machine
ASR	Traction control
BBA-BW	Brennstoffzellen- und Batterie-Allianz Baden-Württemberg
BEV	Battery Electric Vehicle
BMBF	Bundesministerium für Bildung und Forschung
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
BMVBS	Bundesministerium für Verkehr, Bau und Stadtentwicklung
BMWi	Bundesministerium für Wirtschaft und Technologie
BW	Baden-Württemberg
CAI	Controlled Auto-Ignition
CEP	Clean Energy Partnership
CFK	Carbon fiber reinforced plastics
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
CROME	Crossborder Mobility for EVs
ct	Cent
CVT	Continuously Variable Transmission
DC/DC-Wandler	DC-DC converter
DHBW	Duale Hochschule Baden-Württemberg
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DoD	Depth of Discharge
EERE	Office of Energy Efficiency and Renewable Energy
EnBW	Energie Baden-Württemberg AG
EU	European Union
FCEV	Fuel cell Electric Vehicle
FKFS	Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart
Fraunhofer IAO	Fraunhofer-Institut für Arbeitswirtschaft und Organisation
Fraunhofer I	CT Fraunhofer-Institut für Chemische Technologie
Fraunhofer IISB	Fraunhofer-Institut für Integrierte Systeme und Bauelementetechnologie
Fraunhofer ISI	Fraunhofer-Institut für System- und Innovationsforschung
Fraunhofer IWM	Fraunhofer-Institut für Werkstoffmechanik
Fraunhofer LBF	Fraunhofer-Institut für Betriebsfestigkeit und Systemzuverlässigkeit
FuE	Research and development
GaN	Gallium nitride
GTAI	Germany Trade and Investment

H_2	Hydrogen
HCCI	Homogeneous Charge Compression Ignition
HEV	Hybrid Electric Vehicle
HIU	Helmholtz-Institut Ulm für elektrochemische Energiespeicherung
HV	High Voltage
IAA	Frankfurt Motor Show
ICE	Internal Combustion Engine
IEA	International Energy Agency
IGBT	Insulated-gate bipolar transistor
IHK	Chamber fo Industry and Commerce
IKT	Information and Communications Technology
IMU	Institut für Medienforschung und Urbanistik
INTERREG IVC	Innovation & Environment Regions of Europe Sharing Solutions
IT	Information Technology
IuK	Information and Communications Technology
iZEUS	Intelligent Zero Emission Urban System
KFL	Kompetenzzentrum Fahrzeugleichtbau
Kfz	Motor vehicle
KIT	Karlsruher Institut für Technologie
KLiB	Kompetenznetzwerk Lithium-Ionen-Batterie
KMU	Small and medium enterprises
kW	kilowatt
kWh	kilowatt-hour
LBZ-BW e.V	Leichtbauzentrum Baden-Württemberg e. V.
LCC	Life Cycle Cost
$LiCoO_2$	Lithium cobalt oxide
$LiCoPO_4$	Lithium cobalt phosphate
$LiFePO_4$	Lithium iron phosphate
Li-Ion	Lithium-ion
$LiMn_2O_4$	Lithium manganese oxide
$LiNiCoAlO_2$	Lithium nickel cobalt aluminum oxide
$LiNiMnCoO_2$	Lithium nickel manganese cobalt oxide
$LiNiPO_4$	Lithium nickel phosphate
$LiSi_5$	Silicon - anode material
LPG	Liquified Petroleum Gas
max.	maximum
Mio.	million
Mn_3O_4/C-Gemisch	Manganese oxide/Carbon mixture
MOSFET	Metal oxide semiconductor field-effect transistor

Mrd.	Billion
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
Nd-Fe-B-Magneten	Neodymium-iron-boron magnet
NiMH	Nickel metal hydride
NPE	Nationale Plattform Elektromobilität
NRW	North Rhine Westphalia
NV	Low voltage
NVH	Noise-Vibration-Harshness
OEM	Original Equipment Manufacturer
PHEV	Plug-in-Hybrid Electric Vehicle
PKW	Passenger automobile
PSM	Permanently excited synchronous machine
PTC	Positive Temperature Coefficient
REEV	Range-Extender Electric Vehicle
SiC	Silicon carbide
SoC	State of charge
SSM	Current excited synchronous machine
STMWIVT	Bayerisches Staatsministerium für Wirtschaft, Infrastruktur, Verkehr und Technologie
SyR	Synchronous reluctance machine
TCO	Total Cost of Ownership
TiO2	Titanium dioxide
TTZ	Technologie- und Transferzentrum Leichtbau
TÜV	Technischer Überwachungs-Verein
US-$	US-Dollar
V	Volt
VDA	Verband der Automobilindustrie
VDMA	Verband Deutscher Maschinen- und Anlagenbau e.V.
VES	Verkehrswirtschaftliche Energiestrategie
VVTL	Variable Valve Timing and Lift-intelligent System
VW	Volkswagen
VZÄ	Volt time equivalent
W/kg	Watts per kilogram (power density)
WBZU	Weiterbildungszentrum Brennstoffzelle e.V.
Wh/kg	Watt hours per kilogram (energy density)
WRS	Wirtschaftsförderung Region Stuttgart GmbH
ZSW	Zentrum für Sonnenenergie- und Wasserstoff-Forschung

INTERVIEWS WITH EXPERTS

Interview with expert Jürgen Dispan
Project Director and Scientific researcher
Research in the areas: Civic and regional development, cluster projects/ industry projects, regional politics and business development.
IMU Institute, conducted on 08/11/2011

Interview with expert Peter Froeschle
Director Strategic Energy Projects & Market Development
Fuel Cell/Battery Vehicles.
Daimler AG, conducted on 09/21/2011

Interview with expert Dr. Andreas Gutsch
Project Director Competence E at the KIT,
Karlsruhe Institute for Technology (KIT), conducted on 09/05/2011

Interview with expert Heiko Herchet
Director of the Electromobility Competence Center
EDAG Group, conducted on 08/15/2011

Interview with expert Jürgen Jost
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Interview with expert Martin Kreuter,
Corporate Development, New Business – Industry Innovation
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Interview with expert Prof. Dr. -Ing. Gisela Lanza
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Interview with expert Manfred Müller
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Interview with expert Dr. Werner Tillmetz
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Interview with expert Sebastian Wider
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SW-Engineering GmbH, conducted on 08/19/2011

Publishing information

Publisher
Ministerium für Finanzen und Wirtschaft Baden-Württemberg
e-mobil BW GmbH – Landesagentur für Elektromobilität und Brennstoffzellentechnologie
Fraunhofer-Institut für Arbeitswirtschaft und Organisation (IAO)

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Fraunhofer-Institut für Arbeitswirtschaft und Organisation (IAO)
Prof. Dr.-Ing. Dr.-Ing. e.h. Dieter Spath, Florian Rothfuss, Florian Herrmann, Simon Voigt, Marius Brand, Susanne Fischer, Thomas Ernst, Hannes Rose, Martha Loleit

Coordination study
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Layout/Setting/Illustration
Fraunhofer-Institut für Arbeitswirtschaft und Organisation (IAO)
Hannah Würthwein
TEAM STRUNZ | tswa.de
Agentur für Marketing & Kommunikation

Photos
@ fotolia.de: Tom-Hanisch
@ istockphoto.de: MichaelUtech, KEMAL BA, Lya_Cattel, lvdesign77, Nikada

Printing
E&B engelhardt und bauer Druck und Verlag GmbH
Käppelestraße 10
76131 Karlsruhe
Germany

Distribution and sales
e-mobil BW GmbH
Leuschnerstraße 45
70176 Stuttgart
Phone: 0711 / 892385-0
Fax: 0711 / 892385-49
E-Mail info@e-mobilbw.de
www.e-mobilbw.de

2nd amended edition in December 2011

e-mobil BW GmbH

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info@e-mobilbw.de | www.e-mobilbw.de

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Papier aus verantwortungsvollen Quellen
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Print CO2 kompensiert
Id-Nr. 1218185
www.bvdm-online.de