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2011 Symposium
Safety of high-voltage vehicles

November 22 – 23, 2011, Berlin

Unfallforschung der Versicherer

GDV

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Wilhelmstraße 43 / 43G, 10117 Berlin
Postfach 08 02 64, 10002 Berlin
unfallforschung@gdv.de
www.udv.de

Editor
Dr. Matthias Kühn
German Insurers Accident Research
Head of Vehicle Safety
German Insurance Association

Organisation
AZT Automotive GmbH
Allianz Zentrum für Technik
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Welcome and Introduction

Siegfried Brockmann
Chief Executive of German Insurers Accident Research (UDV)

In contrast with other electromobility events, there won't be any political speeches here. Electromobility is coming, that's for sure, and now it's time to begin looking at the details. One of those details – safety – is the focus of this symposium.

We insurers want to learn from you. Insurers calculate their premiums based on past experience with claims. But there is little background with electric vehicles, and so it's hard to classify risks. With your help, we can come closer to solving this problem.

You should also benefit from the symposium, of course, so we will also explore how a variety of insurance divisions handle the issue of electromobility. Another area of particular interest to manufacturers is type approval and specific issues related to first-time approval.

Participants in this conference have already dealt intensively with the various issues, so there is some hope that we can also talk specifically about solutions. We hope to gain in-depth knowledge about the technical issues and also – another departure from previous conferences on electromobility – to promote an intensive exchange of ideas. You are more than an audience – you will also be a parliament. You will be able to focus on details during three different sessions, and I hope that we will all reach reasonable conclusions.

Electromobility brings serious challenges for all of us. They include high voltage/electric shock, charging, and rescue services, to mention just a few. The issue of noise, or rather the lack of sounds from electric vehicles is often mentioned. However, in my view this is not the greatest problem – and it is certainly far from the only problem – of concern to us.

There is no doubt that rescue services still has the potential for further development, even though there have already been achievements in this area. For example, the issue of when a vehicle is disconnected must be addressed so that firefighters will know when they can approach a vehicle and what parts of it they can touch. Finally, not all firefighters can be trained; just think of all the volunteer firefighters in rural areas.

Many questions have already been answered, such as the placement of the battery, which is installed where it will be protected from crashes. Still, we can't rest on our laurels, and we must tackle issues and problems that are still unresolved. History shows that there have been many unforeseen events, such as airplane crashes or incidents in power plants. Before many of these occurrences, all the contingencies were hashed out and then written down in specifications and requirements, too. But when three or four problems occur at the same time, there can still be an incident – and we should always keep that in mind.

We hope that many opportunities for improvement will be discussed at this symposium. Electromobility certainly has some unusual features, and not all the issues have been resolved. But there's an answer to every question, and electromobility is nothing to be afraid of. So let's buckle down together here at the symposium and come up with some solutions!

Thank you.

The 2011 Symposium "Safety of high-voltage vehicles" at the Ludwig Erhard Haus Berlin was met with lively interest: in the plenary and chatting during the breaks.

Challenges and perspectives: Electromobility in Germany

Dr. Veit Steinle
Federal Ministry of Transport, Construction, and Urban Development

This symposium focuses on the safety of electric vehicles, and I am going to be telling you about the research and funding activities of the German Federal Ministry of Transport, Construction, and Urban Development in that area. I will also present the position of the German federal government.

The question of what advantages electromobility offers is relatively easy to answer: The entire transportation system must be made more efficient and sustainable if climate protection targets are to be reached, and electromobility is a key technology for sustainable transportation. It can play a decisive role in promoting greater independence from fossil fuels and reducing CO_2 emissions. Electrification of vehicles also offers the opportunity to diversify energy sources.

But the Federal Transport Ministry is interested in more than just high-voltage battery vehicles. The Ministry is funding many individual projects – including some in that area – as part of the National Hydrogen and Fuel Cell Technology Innovation Program. Suitability for specific applications and for daily use are especially important; a new technology will not be successful until it enjoys a high level of acceptance. Using hydrogen as an energy source has the potential to improve ranges and filling times. Battery-driven vehicles currently have a range of between 180 and 200 kilometers, depending on how they are driven. That relatively short range is a problem, and many automakers all over the world are working on hydrogen-fueled vehicles, which have about twice the range and can be filled in just a few minutes. For example, Hyundai will soon start marketing the IS 30, a fuel-cell SUV. Roughly 100,000 of them will be manufactured each year until 2015. Toyota has also developed a mid-size car that uses hydrogen technology, and Honda has developed the Clarity. Daimler began a trip around the world with three B-class vehicles using hydrogen fuel cells in January 2011. The cars went completely around the world one time – which wasn't easy, but showed that it's possible. Thanks to such good experiences, Daimler AG has announced that it will start series production of fuel-cell vehicles in 2014.

The German federal government believes that innovations and technologies like electromobility will allow new markets to be developed. This will greatly enhance Germany's reputation as a place to do business. Another advantage is increased independence from oil imports. All of those considerations have led the German federal government to make electromobility a priority. Germany intends to be the leading market for electromobility and the leading supplier of electromobility. The goal is to have one million electric vehicles on Germany's roads by 2020. That begs the question of what type of vehicles this means. Let's not forget two-wheeled electric vehicles such as Pedelecs, which are battery-powered bicycles. There have been astonishing developments over the past couple of years in this area. If vehicles of this kind were included in the count (and they're not), the one-million mark would quickly be reached. A large-scale study by the Transport Ministry of 600 e bikes in Stuttgart was very successful.

Generally speaking, all forms of electromobility will be tried, meaning not just passenger cars, but also electric or hybrid buses and logistics vehicles.

Electric commercial and service vehicles are also the focus of special interest, because many kinds of vehicles will be prohibited in city centers over the next few years under the system of congestion charges for environmental zones. Various manufacturers have already responded to this. For example, Ford has rebuilt a Transit for a project in Cologne (ColognE mobil). Studies show that companies can do very well with the ranges currently offered by vehicles of this kind and can charge or fill them overnight so that they are ready to use the next day. Larger vehicles have also proven themselves in our research programs. For example, 50 companies indicated their willingness to use mid-weight hybrid trucks by Daimler as part of a fleet study, and the experience was positive. The greatest challenges are currently heavy trucks, for which satisfactory solutions are not yet available.

There have been eight model regions for over two years now: Stuttgart, Munich, Rhine/Main, Hamburg, Berlin, Rhine/Ruhr, Oldenburg/Bremen, and Saxony. Two thousand different electric vehicles have been used in those regions, including two-wheelers, passenger cars, vans, buses, and mid-weight trucks. A very successful test of hybrid garbage trucks is also being conducted in the Ruhr and in the Rhine/Main model region. Garbage collectors and residents have responded very positively to the significant reduction in noise.

To build on these successful beginnings and get all the stakeholders to the table, the German federal government has created the National Electromobility Platform as part of the Electromobility Summit in May 2010. The Platform includes representatives from politics, industry, academia, and research, as well as consumers. There are seven working groups with 147 experts from the various sectors. The Transport Ministry received the Platform's initial interim report, which presented the situation and considered possible future approaches, back in November 2010. The second report was submitted in May 2011, and it presented the comprehensive results of the working groups and contained lively discussions. One subject was the question of whether each energy supplier should build its own charging stations or whether all users should be able to access their electricity suppliers at every charging point without discrimination. Based on that report, the federal government adopted a government program on May 18, which will be implemented without delay.

An additional €1 billion of federal funding will go to electromobility in 2012 and 2013. Three to five showcases (Schaufenster) will be developed, and technical beacon (Leuchtturm) projects are to be implemented.

The showcases are electromobility regions in which the interaction of electric vehicles, energy infrastructure, and mobility systems will be investigated on a large scale. The funding of the showcase program was announced on October 12, 2011. Regions and cities may apply to participate until January 16, 2012. The areas of energy, vehicles, and transportation and their innovative technologies and solutions will be integrated into an overall electromobility system in the showcase regions, where they will be intensively tested during everyday use in a limited regional area. Integration of the vehicles into the energy and transportation system is an important factor for success. It is hoped that the showcases will allow conclusions to be reached about the suitability of these mobility solutions for mass consumption, and that they will make the performance of German industry internationally visible, allowing people to experience it for themselves. The showcases will also serve as workshops for answering questions that have not yet been addressed.

In contrast, the beacons are made up of outstanding projects from particularly important technological areas and applications. Innovations in technologies that are central to electromobility will be funded, and innovation processes will be opened to multiple industries. The beacons' focus on key individual technological areas and applications makes them different from the showcases, in which the entire spectrum of electromobility and how it is used will be tested to allow people to experience electromobility for themselves. The beacons will be implemented according to the funding guidelines of the individual German federal ministries, which have already been published and successfully used. Four different ministries are responsible for electromobility: The leaders are the Federal Transport Ministry and the Federal Ministry of Economics and Technology, along with the Federal Ministry of Education and Research and the Federal Ministry of the Environment, Nature Conservation, and Reactor Safety.

Regulatory and tax law

A person in Germany who buys an electric vehicle will be exempt from the vehicle tax for five years. In China, the national government and some cities and regions pay generous subsidies as incentives. Anyone in France who buys an electric car with CO_2 emissions between zero and 50 g receives a bonus of €5,000. The bonus is lower for vehicles with higher emissions. Emission levels over 140 g will incur a penalty, which must be paid along with the registration tax when purchasing the vehicle. This could also affect the German auto industry; outstanding German vehicles like the S-class, Audi A8, and 7-series BMW have very good exhaust values according to the state of the art, but some of them do exceed 140 g. They are stigmatized on the market, and this in turn benefits the French car industry, which primarily offers smaller vehicles. A system of incentives like the bonus/penalty system cannot be introduced in Germany because there is no registration tax here. Therefore, there must be some compensation for the competitive disadvantages of electric vehicles compared with conventional vehicles: one possibility is to follow the system of taxation for company cars.

The Federal Transport Ministry is also considering the designation of special parking areas for electric cars and the issue of labeling. It is possible that signage on bus lanes could also be changed to allow electric vehicles to use those lanes. However, the municipalities had major concerns about this, because it could disrupt the flow and timeliness of bus transit. That is the reason for the showcases, which can test a proposal to see whether it is advisable.

Safety

Electric vehicles must be just as safe as vehicles with conventional drive systems. Type approval requirements and registration must therefore be adapted to include the requirements for electromobility. Safety and environmental requirements must be further improved. Today European regulations and directives are binding for the authorization and registration of motor vehicles in Germany. In the future, they will increasingly include international requirements developed by the United Nations Economic Commission for Europe (UNECE) and will be continuously updated in conjunction with technological developments. At present, UNECE working groups are appending specific factors like battery safety to existing provisions for electric vehicles. The Federal Transport Ministry is playing a leading role in those working groups. The greatest priority is to have coordinated specifications that will ensure a high level of protection internationally and break down barriers to trade.

The German federal government is representing German interests internationally to ensure the successful introduction of electromobility into the market. German automakers are the embodiment of high safety standards, and independent testing institutes for electrical systems and vehicle batteries will be needed to ensure that those standards are also met by electromobility. ZSW, the Center for Solar Energy and Hydrogen Research in Baden-Württemberg, has built a laboratory for battery technology known as the eLaB. One of its primary research topics is battery safety, so the eLaB will also have a battery test center funded by the Federal Transport Ministry.

Conclusion

As mentioned above, Germany will be the leading electromobility market and the leading supplier for electromobility. However, other countries are also very active in this area. Germany's main competitors are France, Japan, the U.S., and Korea. It is important to pinpoint all potential problems in the area of electromobility and find solutions to them, including sending a message to other countries. International competition is a reality, and we are ready to face that competition.

Dr. Veit Steinle
al-ui@bmvbs.bund.de
German Federal Ministry of Transport, Construction, and Urban Development, Head of the Environmental Policy and Infrastructure Department

Background conditions for electromobility – National Platform for Electromobility (NPE)

Dr. Thomas Schwarz
German Association of the Automotive Industry (VDA)

Challenges for the automotive industry: Finite oil reserves, climate protection, and increasing urbanization
Individual mobility faces many challenges, both today and in the future. They include increasingly scarce fossil fuels, climate protection and the associated need to reduce CO_2 emissions, and increasing urbanization all over the world, especially in Asia, Africa, and Latin America. The need for individual mobility in congested areas is growing drastically, especially in Asia.

Innovative mobility concepts must resolve problems such as how global CO_2 emissions can be reduced in spite of increasing traffic levels, and how the resulting noise emissions can be mitigated. Conventional internal combustion engines are one basis for increases in efficiency. Both gasoline and diesel engines have more potential for long-term reductions of about 25 percent. Possible improvements including downsizing cylinders while using supercharging to maintain power, direct injection, optimizing energy management through the increasing electrification of accessories, and fully-variable valve control systems. These developments will be supplemented by increased use of additives and new biofuels.

Obvious progress in reducing CO_2 emissions
Increases in the efficiency of cars made by German manufacturers are very impressive. Newly registered passenger cars from major German makers currently have an average CO_2 rating of 143.8 g/km. That corresponds to an average fuel consumption of only 5.4 L diesel/100 km or 6.2 L of gasoline/100 km, down 4.2 percent from the previous year. Vehicles from German automakers have had lower average CO_2 values than imports so far this year in all ten segments, from compact cars to family vans. German manufacturers already offer more than 400 models with a CO_2 value of less than 130 g/km, up more than 50 percent in just one year.

Electromobility will contribute to future mobility
In addition to improving internal combustion engines and using alternative fuels, it will be essential to develop alternative powertrain technologies. This will make electromobility a decisive component in the mobility of the future.

Electric vehicles are currently subdivided into the following types:

- BEV: Battery electric vehicle, which runs solely on electricity from its battery.
- PHEV: Plug-in hybrid electric vehicle, a complete hybrid with its own chargeable battery.
- REEV: Range-extender electric vehicle, which has an electric motor as primary drive and a small internal combustion engine that can be used to recharge the battery while moving.
- FCEV: Fuel cell electric vehicle.

BEVs, which are completely electric, already have lower CO_2 emissions than comparable conventional vehicles across the entire energy chain (“from the well to the tire”) using the current German energy mix. If BEVs are charged using electricity from renewable sources, they will become virtually zero-emission vehicles. Regardless of the energy mix, electric vehicles are always zero-emission vehicles while driving. That also applies to PHEVs and REEVs when they are operated in electric mode. All types also have lower noise emissions than conventional vehicles and no particle emissions when driven locally in electric mode.

The German automotive industry, which operates globally, is doing everything in its power to promote this trend. It also intends to maintain its position as technological leader in the future.

The National Platform for Electromobility: Germany to become the leading supplier and leading market for electromobility

The German federal government has invited representatives from industry, academics, politics, unions, and civic organizations to come together in the National Platform for Electromobility (NPE). The members of the NPE have agreed on a systematic approach that is oriented to the market and open to new technology, with the objective of developing German industry – including medium-sized companies and the skilled trades – into the leading supplier, and making Germany a leading market for electromobility. One million electric vehicles will take to the road in Germany by 2020.

The German automotive industry strongly supports the efforts of the German federal government to establish Germany as the leading market and leading provider of electromobility. Both objectives are ambitious but feasible if the background conditions for research, pilot production, and introduction to the market are right. One area of this cooperation that is unique in the world is the recommendations on how to reach the two elements of this objective. The Government Program on Electromobility, which implements the recommendations, has taken the first steps in the right direction, and it is now a matter of consistent implementation.

It is anticipated that the Platform will submit its first progress report in May 2012, within the framework of the monitoring process that was agreed to by the NPE. The report will focus on standardization, education, and qualification, and on promoting research and development. Significant progress has been made in research into batteries. For example, a plant for pilot production is being built in Ulm, and competence centers for battery research are being created in Dresden, Munich, Münster, and Ulm. An important aspect of this effort is the transparency and speed of awarding contracts for projects and providing funds.

The stage is being set in 2012 for the development of a market for electric cars in Germany over the next few years, and the planned showcase (Schaufenster) regions will play an important role. The showcases are intended to allow people to experience the total electromobility system and will also investigate user behavior, new mobility solutions, and business models. The public procurement program promised by the German federal government starting in 2013 will contribute to this and help promote acceptance of electromobility in society. The intention is to give customers concrete experience with electric vehicles and all of their components, because it is ultimately the customers whose decision to buy that will determine whether this technology is successful on the market.

The experts with the National Platform for Electromobility agree that in coming years the total cost of ownership of an electric car will still be several thousand euros more than that of a comparable passenger car with an internal combustion engine ("TCO gap"). This price difference is a major obstacle to buying an electric car. Sales have increased for about a year now, although they are still at a very low level overall. Germany, the United States, and Japan are the largest sales markets for electric cars. It is vital to maintain and improve Germany's position as competition between the countries intensifies. The matrix of actions recommended in the second report by the NPE is still the right approach.

German industry is in an excellent position to become the leading supplier. It is still a technology and innovation leader in many areas: automotive, electronics, energy technology, and chemistry. It must now assume the leadership role for electromobility, a technology of the future. The IAA impressively demonstrated that German industry has fulfilled the prerequisites across the entire value chain. The companies have made their decisions about research and development for the next few years. The automotive industry alone will be investing €10 to €12 billion to develop alternative powertrains over the next three to four years, which is 40 percent of all investment in research and development. During the same period, the various sectors of German industry combined will be investing as much as €17 billion in electromobility.

Dr. Thomas Schwarz
schwarz@vda.de
VDA (German Association of the Automotive Industry)
Industry Coordination for Electromobility

Key safety issues from the viewpoint of manufacturers

Dr. Jutta Schneider
Daimler AG

1. Introduction

Increasing numbers of motor vehicles with a variety of new power train designs have been brought to market over the past few years. Internal combustion engines have been supplemented with electric motors, or electric motors propel vehicles on their own. High-voltage systems and new energy sources like high-voltage lithium-ion batteries and hydrogen tanks are also being used in series-produced vehicles. These innovations impose extra safety requirements – some of them completely new – on manufacturers.

2. Safety aspects

Efforts in many areas will be necessary in order to ensure that everyone who comes into contact with high-voltage vehicles remains safe at all times. These areas include active and passive safety, occupational health and safety, safety when transporting and using vehicles, and traffic safety, to mention just a few. **Active safety**, in other words, accident avoidance, is very important for both electric and conventional vehicles. New or adapted assistance systems are needed because people's driving habits – including the way they accelerate – have changed with the advent of electromobility.

Another important aspect is **passive safety**. Here the question arises of how high-voltage vehicles should be treated after an accident, for example, by rescue workers. Should they simply allow the vehicle to burn, or can the fire be extinguished safely? Is the battery damaged? What special issues must be considered when towing?

Occupational health and safety and **safety when transporting vehicles** require vehicles to be safe even during the early developmental stages. An employee who works in development should not be injured when they get into a new high-voltage vehicle. The same applies to production and repair. Employees in the parts logistics department that supplies shops and garages, including warehouse workers, must not be exposed to danger either. This means protecting the entire process chain. Training everyone involved is a major challenge, because it involves manufacturers as well as dealership service centers and independent repair shops. Increasing the awareness of employees, providing training in high-voltage technology, and creating special workstations will all involve major investments.

In the area of **traffic safety**, issues like being able to hear quiet high-voltage vehicles in road traffic are the subject of intense discussion. One approach to improving acoustic perception is to use sound generators. Important issues related to operating safety include changes in the range of electric vehicles and safety when charging them. The use of cables to charge electric vehicles is being discussed in detail with customers who already use electric vehicles, so that their experience can be included in followup projects.

3. Influence of powertrain architecture

As mentioned above, the powertrains of future vehicles will be more diverse than those of the past. Internal combustion engines will continue to play a decisive role in coming decades: However, they will be increasingly supplemented with or replaced by electric motors to provide propulsive force. Reasons for this include efforts to reduce exhaust emissions from internal combustion engines, reduce dependence on petroleum, improve the quality of life in densely populated areas by using powertrains that are as quiet as possible and are emission-free, and minimize the increase of CO_2 in the atmosphere by using cars that can run on energy from renewable sources over the long term.

The technical design of powertrains will vary depending on the application and on customer requirements. For example, fuel-consumption hybrids are cars that use less fuel and have lower CO_2 emissions because they use hybrid technology. Range extender technology is an interesting approach. Vehicles can be certified as emission-free based on their range in electric mode only. Figure 1 shows the broad outline of how this works. The internal combustion engine is switched on only when the battery falls below a specific charge level. A range extender uses a relatively large battery, so it offers all the advantages of a battery electric vehicle, including a very comfortable ride, emission-free operation, and a fascinating driving experience because the car is in electric mode most of the time. It can be used almost like a conventional vehicle because it can be topped up at any time. The advantages of both types of powertrain are combined, although these cars use complex, expensive technology.

Figure 1: The range extender combines the advantages of both powertrain technologies

Fuel-cell vehicles by Daimler have a long history. Early experiments used methanol, and the vehicles were later fueled with hydrogen gas. One of the major challenges is to store the hydrogen safely in the vehicle and make it available. The first cars had very large tank systems. Today it is no longer possible to tell if a car is being run on hydrogen. Figure 2 shows the design of a fuel-cell vehicle. The tanks are located in the middle, the large battery is located in the trunk section, and the electric motor and its power electronics are in the front of the car.

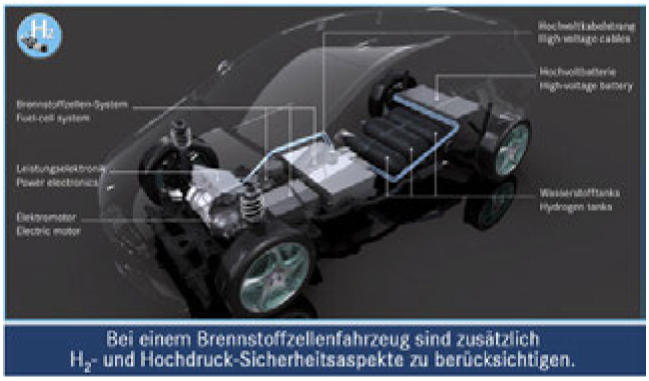

Figure 2: Parts of a fuel cell vehicle

These two concepts are related and yet different, and they offer a good example of the safety aspects that apply to both and those that pertain to the individual designs.

For example, both vehicles have high-voltage systems and wiring. One **passive safety feature** is the bright orange that clearly identifies the high-voltage wire. Other passive safety features include protection against direct contact, insulation, potential equalization, and passive discharge. In the event of a malfunction, **active discharge** is an important factor in addition to disconnecting the high-voltage battery. The voltage storage devices like capacitors and all high-voltage components (except for the high-voltage battery) are discharged to ensure that the wiring and components are guaranteed to be free of dangerous voltage. This means that there is no danger of coming into contact with live parts and being shocked after an accident. The vehicle is safe because it is in a de-energized state.

The need for active discharge is clearly evident when a vehicle crashes. There are different scenarios for crash detection. For example, a distinction is made between minor and serious crashes. It must be anticipated that parts will be damaged in a serious crash, so a safe state must be actively produced. As for minor crashes, the car should not have to be taken to the shop after every fender-bender: It must be possible to drive the car away afterwards. That's an absolute must. The necessary crash testing is conducted for both the entire car and the components. The existing tests had to be expanded because the new components require special care.

The **service disconnect** is one occupational health and safety measure that involves some effort. When working on the vehicle, for example, doing repairs, it must first be de-energized to avoid danger to the mechanics. The service disconnect is a mechanical solution that protects the vehicle against being reconnected to the high-voltage system. A part is removed from the vehicle to ensure that it cannot inadvertently be re-energized.

There is also an **interlock circuit** that connects all components in the high-voltage system to each other in such a way that a high-voltage connection is immediately recognized. In addition, the entire system is put in a de-energized state similar to the active discharge: in other words, it is switched off. An error or improper handling, such as failing to disconnect, will cause the system to shut itself off and switchto a safe state.

A specific challenge for battery-operated vehicles, range extenders, and plug-ins is **charging** the vehicle's high-voltage battery "from the outside" using a cable at a charging station or at home. This process must be safe for users. Ideas include locking the plug connection to avoid plugging in or unplugging at the wrong time, guarantee secure contacts, and minimizing transition resistances. Users should also be informed that charging has begun. It will become clear over time where that information can best be provided, either in or on the vehicle. Neither should it be possible to start or move the car during the charging process and for as long as the charging cable is plugged in. Protection against touching the cable, plugs, and sockets must also be provided to avoid contact with live parts, and the temperature should also be monitored.

If a hydrogen vehicle has been in an accident, it may be necessary to empty the hydrogen tank under certain circumstances. This is also done by means of crash detection, which is subject to challenges similar to those involved in active discharge. The objective of **emptying** is to reduce the pressure in the tank system. It is already ensured during the development phase that a flammable quantity of H_2 gas does not accumulate during emptying, and that emptying is safe and controlled.

In addition to technical precautions, **instructions for rescue workers** are also essential (Figure 3). Training and instructions for specific vehicles will need to be provided to rescue workers to ensure that they can deal safely with high-voltage vehicles from the outset. The instructions must contain information about the location of the individual high-voltage components in the vehicle. Simply labeling the components is not sufficient. The battery and the tank are positioned differently in each vehicle. Therefore, it is absolutely vital for rescue workers to be able to keep track of them: This must be communicated appropriately. The rescue card (Retttungskarte) may be helpful for these occasions. Intensive work – coaching sessions for fire departments – is underway to ensure that rescue workers will be properly trained.

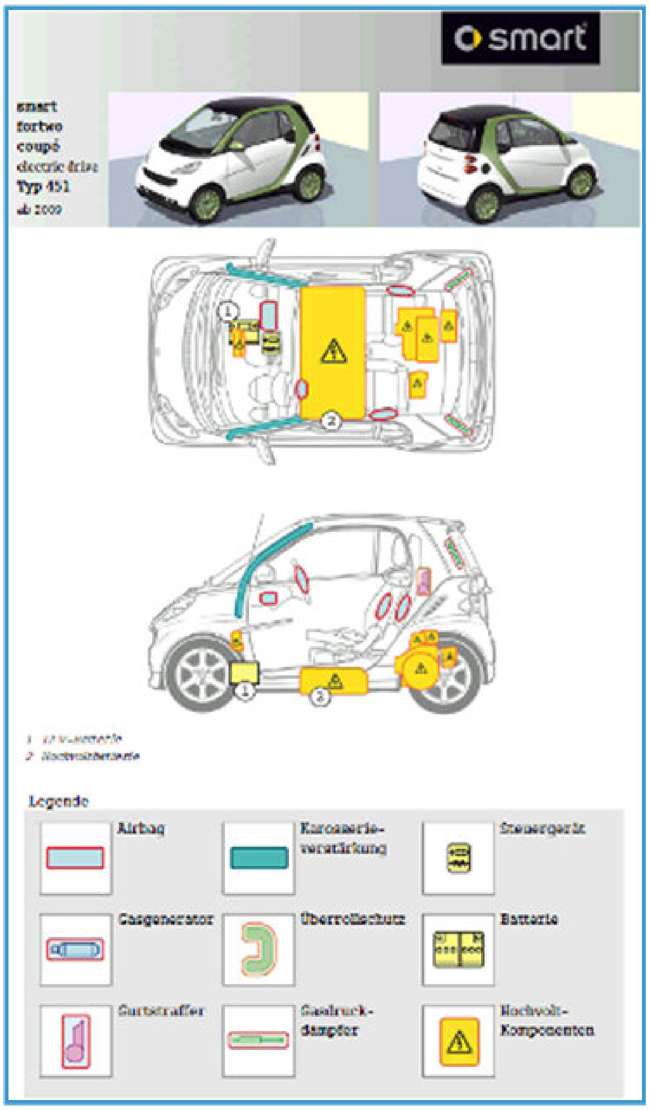

Figure 3: Instructions for rescue services

4. Conclusion

High-voltage vehicles are more than just a new and complex technology: They also represent a major new safety challenge for manufacturers. Additional steps related to technical and organizational factors and the provision of information have been and are still being taken. All of these steps will require consistent and systematic communication.

Dr. Jutta Schneider
jutta.schneider@daimler.com
Daimler AG
Director eDrive Powertrain Integration & Controls

The operating safety of electric vehicles

Dr. Patrick Seiniger
German Federal Highway Research Institute (BASt)

Introduction
The rollout of electromobility will offer many potential benefits to the general public. Traffic noise will decrease markedly, local environmental pollution will become a thing of the past, and CO_2 emissions caused by transportation could be almost completely eliminated, depending on the type of electric energy used. Last but not least, independence from petroleum can be achieved, which will certainly be advantageous for our economic system at a time of increasingly scarce resources.

However, electromobility – like every innovation – is also associated with challenges that must be resolved. The extensive introduction of electric vehicles could (in spite of the current euphoria) have trouble gaining acceptance if the new vehicles' level of safety does not match that of conventional vehicles and after the first serious accidents occur. To achieve the desired increase in market penetration, it will therefore be necessary to develop appropriate new requirements for electric vehicle safety while also avoiding ex-cessive regulations that could undermine the new technology.

The German Federal Highway Research Institute (BASt) is conducting research projects in this area before the vehicle requirements are developed. During this early phase, BASt is identifying potential risks, estimating the objective threats, seeking feasible solutions, and working with everyone involved (the legislature and the automotive industry) to develop appropriate requirements and update current requirements.

Electric safety
The presence of **electric voltage** in vehicles at a level that is potentially hazardous to human health is a new factor in the areas of vehicle technology and safety.

This means that appropriate safety features and requirements are needed in order to ensure the safety of batteries and protect passengers and other road users. International vehicle safety requirements have already been revised over the past few years for that purpose.

Personal injury is caused by electricity as a function of the intensity of the current and the length of exposure. The internal resistance of the human body is known to be within certain limits (500 Ω to 3,000 Ω), so voltage limits are specified in practice. Alternating current is dangerous at current strengths of 30 milliamperes (respiratory arrest), and death as a result of ventricular fibrillation can occur at 50 milliamperes. Injury from direct current begins to occur at higher current strengths.

Voltages above 30 volts AC and 60 volts DC are therefore no longer safe, and at the lower level of bodily resistance they will produce current strengths of about 60 or 120 milliamperes respectively. However, if the energy content is less than about 0.2 joules, the length of exposure will be in the millisecond range and personal injury will be negligible.

Electricity flows through the body when it closes a circuit. Home electric wiring is grounded, which is why merely touching a live conductor is sufficient to close the electric circuit. In electric vehicles, the high-voltage system is generally separated from ground by a sufficiently high insulation resistance. In that case, electricity flows through the human body only when both live conductors are touched.

Sufficient safety is therefore guaranteed,

- when no voltage above the limit values is present,
- when the energy content of the system is so low that the exposure time for the human body is negligible,
- when the conductor is protected by insulation resistance,
- when mechanical coverings (like terminal clamps) protect the conductor from being touched and those mechanical barriers cannot be removed without a tool.

Specific inspections to ensure that those conditions are fulfilled are described in ECE R 100, which contains requirements for protection against electric shock. Contact protection is inspected using standardized test tools according to IPXXB (test finger) and IPXXD (test wire).

Battery safety
Protection against electric shock should not be limited to the time when electric vehicles are being operated: it must also be provided in the case of an accident, as well as afterward. For that reason, the requirements for frontal and lateral collisions (ECE R 94 and 95) have been revised to reflect the requirements of ECE R 100. Battery safety in electric vehicles in the event of a crash is also being discussed in a UNECE working group. The safety of batteries in vehicles that are mass-produced is ensured primarily by a battery-management system that in turn fulfills the requirements of ISO 26262 (functional safety of electric systems), for reasons related to product liability. However, small production series and custom vehicles are not covered by the standard.

Quiet vehicles
One aspect that has already been discussed all over the world is the fact that electric vehicles are very quiet in the speed ranges that are typical of urban traffic. This has re-duced the human acoustic perception of vehicles. It is precisely in urban traffic that blind people and those who are visually impaired, as well as all other unprotected road users, must rely on their sense of hearing to localize an approaching vehicle. Quieter vehicles have deprived them of this guidance, and it is a societal obligation to ensure that these people do not experience added limitations to their freedom of movement.

However, the vehicles' relative quietness also offers the opportunity to reduce traffic noise significantly, thereby improving everyone's quality of life.

The problem of quiet vehicles has already been tackled by a UNECE working group (Informal Group on Quiet Road Transport Vehicles, assigned to GRB). The discussion has led to a recommendation to implement artificial noise at low speeds in these vehicles. The preparation of a Global Technical Regulation (GTR) has also been contemplated. To accompany this, BASt is doing tests on human subjects using conventional and elec-tric vehicles.

Control concept
Another research topic derives from the conflict between the goals of energy efficiency and safety with regard to the braking system.

At present, electric vehicles recover kinetic energy when braking by converting it into electric energy (recuperation). The (recuperation) decelerations of up to three m/s² caused by the process correspond to the maximum decelerations that occur in normal road traffic when pushing the brake pedal. Therefore there is a potential risk of **getting out of the habit of using the brake pedal**, with the risk of incorrect operation, especially in early mixed traffic, because experience with comparable motorcycle accidents shows that it is primarily during dangerous situations that people are likely to react incorrectly.

As a matter of principle, a vehicle is particularly energy efficient when it is successful at storing braking energy and later uses it to accelerate. This concept brings a vehicle's driving profile closer to the ideal state ("constant speed on a level road").

If a vehicle is properly equipped (electric generator, energy storage unit, and electric powertrain), it's operation will be especially efficient when the friction brake is not used during normal vehicle operation.

A very simple and technically robust design of the vehicle control elements will control recuperation solely through the accelerator, and configures it in such a way that all of the decelerations that are necessary for normal operation can be caused by use of the accelerator only. The friction brake is used in such cases only for unusually long decelerations (the concept of **"separating control devices"**[1]). Some electric vehicles that are currently produced in small series use a system of this kind. But vehicles that recuperate when the brake pedal is used can also fall into this category if recuperation when releasing the accelerator is sufficient to move the car in the normal traffic flow. A vehicle that is designed in this way de facto has two different activation variants that cause different decelerations ranges.

In more complex design variants, like those that were chosen for current hybrid vehicles, the brake pedal is partially decoupled from the friction brake system. Only decelerations that are comparable to today's engine braking effects can be produced by the accelerator. For major decelerations, use of the brake pedal is necessary, which in turn – depending on the desired deceleration – also causes both recuperation and use of the friction brake (**"conventional brake control"** approach). This system design offers the system developer far more free parameters for coordination, and so the effort for coordination and overall complexity also increase (see for example [1], page 8). Operating a car of this kind is comparable to operating a conventional car.

Each design variant has specific advantages and disadvantages. From the viewpoint of traffic safety, however, the variant with more obvious recuperation on the accelerator ("separation of control devices" approach) merits a thorough examination.

The braking behavior of motorcycle drivers is well known from field studies. For example, Präckel [2] shows that inexperienced motorcycle drivers in particular tend to use only one of the two brakes, including in panic situations ([2], page 129). It has also been shown that accidents can be caused by improper brake activation. Sporner ([3], page 174) mentions the use of the wrong brake as a cause of accidents in specific situations, and Weidele ([4], page 11) demonstrates a connection between incorrect braking and accidents.

Driving dynamics

An issue that has not received much attention is the driving dynamics of electric vehicles.

One aspect of driving dynamics includes recuperation. How do vehicles react to a change in load during steady-state circular motion if, for example, low friction values lead to instabilities? Furthermore, entirely new electric vehicle designs may lead to completely different driving behavior, because the arrangement of masses, position of the center of gravity, moments of inertia, moments on the wheels, and the like may differ considerably from the usual configurations.

The dynamic control systems of vehicles with conventional powertrains are still active when the engine stops or when the powertrain fails. But how will systems that are critical for safety, such as braking stabilization (ABS and ESP), react as the battery is drained while driving? More broadly, the question of the extent to which an electric vehicle that has broken down can still be towed must also be answered.

There is no information about the above questions on driving dynamics, but initial research is in progress.

1 See, e.g., http://green.autoblog.com/2008/11/24/abg-quick-drive-battery-powered-mini-e-w-video/

Vehicle inspection

The safety of a vehicle is important during its entire useful life, not just at the beginning of its life when it receives type approval. That is the reason for the system of periodic technical inspections. Here too, new questions have arisen due to the introduction of electric vehicles. The content of future technical inspections for vehicles of this kind has not yet been determined. Some elements like the exhaust gas check will not be needed for electric vehicles because they are irrelevant. Others, such as electric safety, are new. The factor of recuperation will potentially affect wear on friction brakes. If they are hardly ever used and corrode as a result, then their full braking power may not be available in an emergency. BASt recently began a project to explore the above questions about technical inspections, with the involvement of several testing institutes.

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Dr. Patrick Seiniger
seiniger@bast.de
Federal Highway Research Institute (BASt)
Active Vehicle Safety, Emissions, Energy

Crash safety requirements for vehicles with electric power trains

Rainer Justen
Daimler AG

Introduction

Key criteria for the long-term market acceptance of future hybrid and electric vehicles enfold suitability for daily use that is comparable to that of conventional vehicles, as well as sufficient range, short battery charging times, and acceptable costs. Maintaining a high level of safety will also be an important criterion for broad public acceptance of alternative propulsion vehicles. The requirements adjusted to electric powertrains and new energy storage units pose new challenges for crash safety, especially the safety of high-voltage systems and electric energy storage units, as well as their functional safety, user safety, and operating safety, including charging equipment.
Figure 1 shows the current product portfolio of Mercedes-Benz cars with electric power trains.

The crash safety requirements for vehicles with high-voltage systems are described below. Existing and under consideration rules and standards already account for the fundamental requirements for the integrity of high-voltage systems with regard to protection against electric shock after a crash, as well as avoiding fire and explosions of energy storage units in crash tests (see for example FMVSS 305, ECE R94/95, China GB/T 18384, and Japan Attachment 111). Based on the existing standards crash requirements are developed to live up to the "Real Life Safety" philosophy at Mercedes-Benz.

The seven-step safety concept in the Mercedes-Benz S400 Hybrid

In the Mercedes-Benz S400 Hybrid, in 2009 as world's first vehicle with a Lithium-ion battery produced in series, the seven-step safety concept was implemented. The concept included the following measures:

1. All high-voltage wiring is uniquely color-coded (orange) and all components are marked with safety instructions.
2. The entire high-voltage system contains continuous protection against contact in the form of generous insulation and newly-developed connectors.
3. The lithium-ion battery is enclosed with a high-strength steel housing. Possible shocks are effectively absorbed by a particular gel embedding the battery cells. There is also a blow-off vent using a rupture disc and a separate cooling circuit. An internal electronic controller continuously monitors all safety requirements and immediately signals any malfunctions.

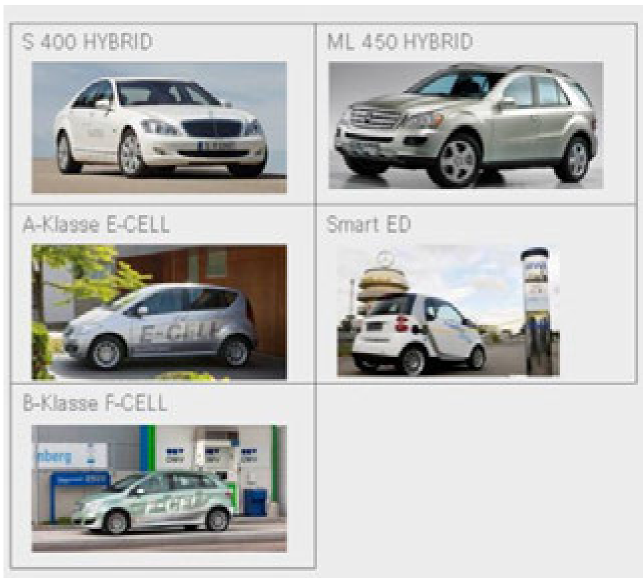


Figure 1: Mercedes-Benz 2011 hybrid and electric cars

4. The battery terminals are separated (no connection to ground through the vehicle body) and there is separate safety wiring for all high-voltage components along with continuous monitoring by multiple interlock switches. This means that all high-voltage components are connected by an electric loop. In the event of a malfunction, the high-voltage system will be switched off automatically.
5. As soon as the ignition is switched to “off” or in the event of malfunction the high-voltage system is actively discharged. The battery remains charged so that the engine can be started again at any time.
6. During an accident, the high-voltage system is completely disconnected from the power supply and discharged.
7. The high-voltage system is continuously monitored for short circuits.

Particular challenges for the crash safety of vehicles with electric power trains

For the crash safety of vehicles with high-voltages systems (Figure 2) three new challenges have to be considered:

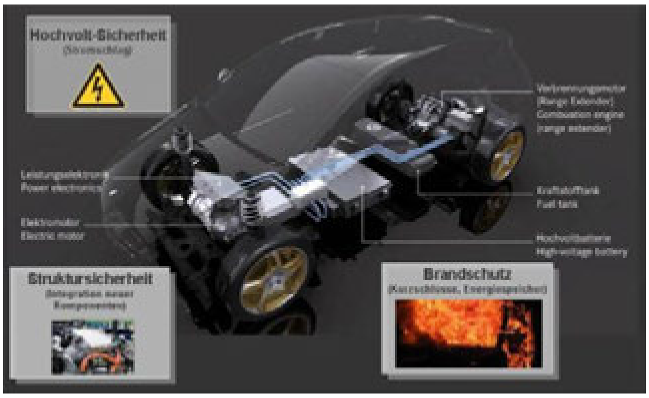


Figure 2: Particular safety requirements for high-voltage vehicles

1. Structural safety: The installation of additional subassemblies – some of which may be large, such as high-voltage batteries and electric motors – can be detrimental to deformation behavior in a collision. Under certain circumstances, the components can have a blocking effect and as well as causing undesired vehicle deformations can also influence the characteristic curve of the delay and therefore the passenger protection system. Depending on the vehicle design and weight, other aspects can affect compatibility (interaction of vehicles in a vehicle-to-vehicle crash) and ease of repair.

2. High-voltage safety: The electric powertrain in hybrid and electric vehicles operates at voltages up to several hundred volts. Voltages of > 60 V DC and > 30 V AC are in voltage class B. Enhanced requirements for protection against electric shock have to be applied because those voltages can cause serious injury.

3. Fire protection: Potential risks from crash-related damage, short circuits in high-voltage systems, and risks from the electric energy storage unit have to be taken into account for fire safety. At present, it becomes apparent that lithium-ion batteries will be the technological basis for traction batteries. The differences among various battery types, such as power batteries in hybrid vehicles and energy batteries in electric vehicles, have to be considered.

Safe integration of high-voltage components into vehicles

Essential for a good safety performance of electric and hybrid vehicles is the well-protected placement of high-voltage components in the vehicle. Vehicle sections with low deformation risk were derived from the analysis of approx. 9,000 vehicles that were involved in real world accidents using GIDAS (German In-Depth Accident Study) database especially the statistical frequency and extent of deformation [1]. Linking the frequency of damage in different sections of the vehicles to the frequency and severity of accidents allowed researchers to determine the likelihood of deformation in each section of the car in real world accidents.

By comparing this likelihood of deformation with vehicle deformation during crash tests it can be shown that crash tests are able to cover more than 90 percent of all vehicle deformations in real world accidents.

For a safe integration of high-voltage components the following sections are relevant (Figure 3):

1. Outer deformation sections in minor collisions in which passenger-restraint systems (like belt tighteners and airbags) are not yet activated. It must be avoided to place high-voltage components in these sections whenever possible, or else they must be protected to ensure that no damages occur.
2. Deformation sections in crash tests where a crash is detected. As a primary protection measure the high-voltage system can be cut-off.
3. Sections of the vehicle with a low frequency of deformation, in other words, no deformation occurs in crash tests. These are particularly interesting for placing energy storage units.

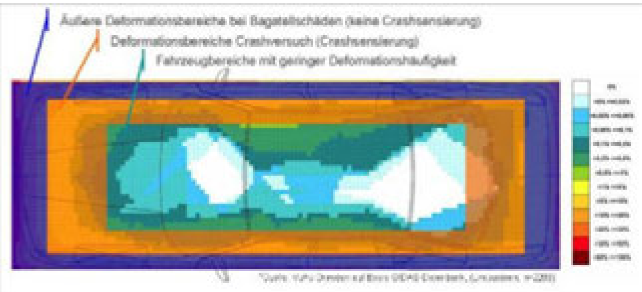
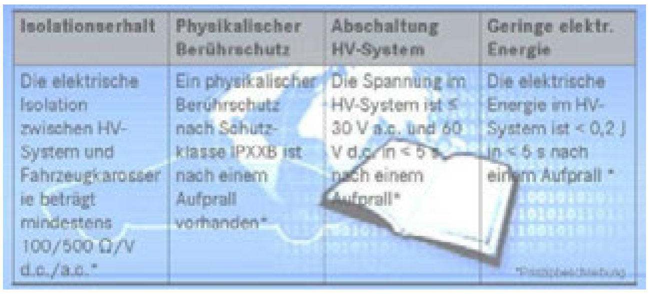


Figure 3: Frequency of deformation in individual sections of vehicles in real world crashes

Protection against electric shock by high-voltage components

The law permits four alternative options to offer protection against electric shock after crash (Figure 4):

1. Maintain electrical insulation of the high-voltage system with an insulation resistance of > 100 Ω/V DC or > 500 Ω/V AC.
2. Maintain physical contact protection according to protection class IPXXB (protection against finger contact Ø 12 mm).
3. Cut-off and discharge the high-voltage system to < 60 V DC or < 30 V AC in < 5 s.
4. Maximum electric energy present in the high-voltage system of 0.2 J in < 5 s.



Isolationserhalt	Physikalischer Berührschutz	Abschaltung HV-System	Geringe elektr. Energie
Die elektrische Isolation zwischen HV-System und Fahrzeugkarosserie beträgt mindestens 100/500 Ω/V d.c./a.c.*	Ein physikalischer Berührschutz nach Schutzklasse IPXXB ist nach einem Aufprall vorhanden*	Die Spannung im HV-System ist ≤ 30 V a.c. und 60 V d.c. in < 5 s nach einem Aufprall*	Die elektrische Energie im HV-System ist < 0,2 J in < 5 s nach einem Aufprall *

*Prüfbeschreibung

Figure 4: Four options for protection against electric shock according to ECE R94/95

The safety concept for Mercedes-Benz vehicles provides for a multi-level, partially overlapping combination of multiple of the above shown requirements (Figure 5).

In minor accidents in which the restraint system is not activated, the high-voltage system should not be damaged and all electric insulation should be maintained. Through this a restart after this kind of accidents can be ensured.

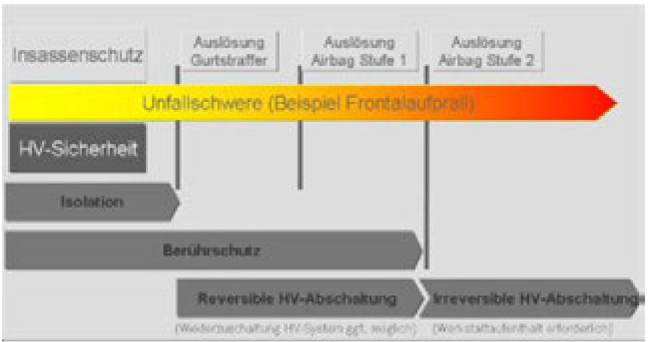


Figure 5: Safety concept for protection against electric shock after an accident

In minor to moderately severe frontal collisions, the electrical insulation should be maintained completely additionally to the reversible high-voltage cut-off because under certain circumstances a restart is possible.

For severe frontal collisions and any other accident with a high-voltage cut-off that can only be reactivated in an authorized garage no further contact protection requirements are necessary [2].

High-voltage cut-off in an accident

To avoid any risk of electric shock in the event of severe damage to the vehicle, the high-voltage system is electrically disconnected from the battery and discharged when an accident of sufficient severity is detected. The high-voltage battery is disconnected by opening the battery contactors. The voltage in the high-voltage system has then to decrease to less than 60 V DC respectively 30 V AC within five seconds. Components for which, due to their high energy content in the intermediate circuit, the passive discharge is not sufficient, an active discharge is used. Generally speaking, the high-voltage cut-off is connected to crash detection (including rollovers) and activation of the passenger-restraint system. There are two different types of high-voltage cut-off:

In less severe accidents, like frontal collisions in which only the belt tightener or airbag 1st stage is activated, cut-off of the high-voltage system is reversible. The high-voltage system can be reactivated if no insulation problems are detected (self-diagnosis).This ensures that vehicles which are still able to drive can be restarted.

In severe accidents, cut-off of the high-voltage system is irreversible, so the immediate restart after an accident is not possible. The high-voltage system cannot be restarted until it is inspected and repaired by an authorized service center.

Crash safety of high-voltage batteries

Even if the high-voltage system is cut-off as a result of an accident, the high-voltage battery cannot be discharged. Electrolytes have a corrosive effect and are in principle flammable. For this reason, damage to high-voltage batteries that could lead to opening of the housing and leakage of electrolytes in the event of a crash should be prevented. Therefore high-voltage batteries should with high priority be placed in sections of the vehicle with low deformation frequencies.

As shown in Figure 3 above, this can be ensured by positioning the high-voltage battery outside the direct crash zones in standard crash tests. These crash tests cover over 90 percent of the vehicle deformations that occurs in real world crashes. If necessary, supplemental protective measures such as structural reinforcements can further reduce the risk of damage.

Irrespective of the high level of design safety due to proper positioning, high-voltage batteries should also have a high degree of intrinsic safety. Therefore, all battery types used in Mercedes-Benz vehicles undergo supplemental component testing on system level in addition to the validation in crash tests [3, 4, 5]. The test parameters were obtained from crash simulations and tests, resulting in realistic load profiles. Depending on the size of the battery the tests are static or dynamic.

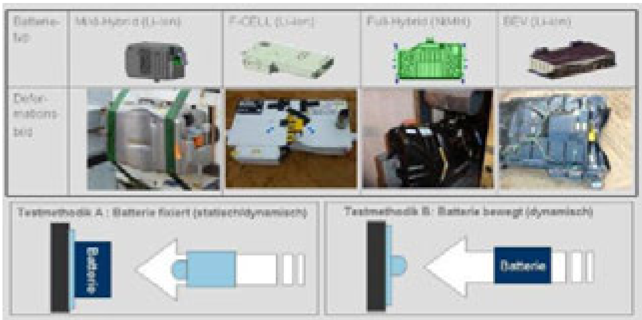


Figure 6: Test method and crash tests of high-voltage batteries

Figure 6 shows the test methods and the deformation patterns of high-voltage batteries after crash testing. Battery deformation achieved in every test was – sometimes considerably – higher than in the vehicle crash tests. Even in these more challenging tests no critical battery reactions occurred. The housings remained closed, so it was impossible to touch conducting parts inside the battery. No electrolyte leaked from the battery and there was no venting of the battery nor any fire. This proves that at elevated mechanical deformations, even exceeding these in the vehicle crash, the high-voltage batteries have high safety potential.

Integral safety concept for high-voltage batteries

Due to the size of high-voltage batteries, it is not always possible to position them in sections of the vehicle with a low deformation frequency. In particular for fully electric cars with high-voltage batteries in the dimensions 1200 x 500 x 200 mm, several of which may be needed, at least a partial installation in deformation sections may not always be avoided. Here, the integral safety is taken into account which offers a high level of mechanical stability even at direct deformation loads. The following aspects are being considered for the high-voltage battery safety concept:

- Battery materials: safety features of the cell chemistry (especially anode/cathode material and electrolyte)
- Battery design: housing material, inner clearances and inner deformation zones (like cooling connections and electronics)
- Additional reinforcements: the protective cage around the high-voltage battery as well as vehicle reinforcement
- Positioning of the high-voltage battery: the mounting design, possible shifts, support on the body and blocking
- Crash performance in the standard crash tests: loads, deformations and level of damage in the tests
- Load limits: the load level in static and dynamic component tests in which short circuits, leaks or fires occur

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Rainer Justen
rainer.justen@daimler.com
Daimler AG
Mercedes-Benz Cars Development
Head of Vehicle Safety of Alternative Propulsion Vehicles

Integrated vehicle safety: The rescue chain

Hans-Thomas Ebner
VDA (German Association of the Automotive Industry)

Automakers and rescue workers
The development of the automobile has certainly progressed over the past 125 years. There have been rescue workers from the beginning, and as motor vehicles underwent major changes and the amount of traffic increased, these workers have been swept along by the new realities. It is a great success that the number of road fatalities in Germany has fallen by 80 percent over the last 40 years. However, we can't rest on our laurels: More efforts must be made in all areas to at least move closer to the goal of accident-free driving. Vehicles are still developing, and they have progressed all the way to electromobility – which is why rescue operations will also have to adjust to these changes in mobility.

Information for firefighters
When information for firefighters and rescue services is compiled, the first question will be "What do rescue workers on the scene need to know in order to provide assistance?" That will be the basis for providing the appropriate information to rescue workers. More demanding requirements for vehicle safety have made it necessary to change rescue strategies. However, it should not involve a complete paradigm shift to ensure that changes remain understandable to rescue workers.

New communications strategies and technologies must therefore be comprehensible and as easy as possible for rescue workers to understand. The introduction of eCall is anticipated in 2015. This will offer the opportunity to take advantage of what is known as the "golden hour" during the worst-case scenario for the vehicle.

All vehicles must offer the same level of safety, whether they are powered by electric motors or internal combustion engines. By the same token, the information and options that are available to rescue workers must ultimately offer the same level of safety to accident victims.

VDA has long worked with firefighters and rescue services. The roots of the rescue data sheet – which in coming years will be included in a database that can be retrieved by rescue services when they input a license plate number – go back to 1994. Back then, the data sheet applied generally to all passenger cars. It primarily contained information about rescuing people from vehicles equipped with airbags. Today the information must be much more specific. The rescue data sheet has been further modified, and there are now individual rescue guidelines for each automaker in addition to the standardized rescue data sheets.

The first rescue data sheets were introduced in 2008 and standardized by VDA and VDIK (Association of German Automobile Importers) in conjunction with the rescue services. Data sheets for the first electric vehicles became available in 2010.

KBA (the German Federal Motor Transport Authority) has recently approved the use of official license plate numbers to retrieve vehicle data for special applications. License plate inquiries will be managed electronically by 2013 at the latest, allowing access to a database that will provide an individual rescue data sheet for each vehicle to rescue services. This can be combined with eCall, which will be used throughout Germany – and perhaps also in Europe – starting in 2015.

The question has not yet been answered as to whether rescue centers – which are necessary to operate eCall – will be created in the individual German Landkreis administrative districts. It should be noted that the Interior Ministries of the German states or the individual Landkreis administrative districts are responsible for managing this, not the German Federal Ministry of Internal Affairs.

Legislation
UNECE Regulation 100, which relates to the safety of electric vehicles, is of particular significance in the context of the global automotive industry. Regulation 100 is being revised to include the subject of battery safety. WP 29, the U.N.'s decision-making body for vehicle regulations, is considering a proposal to create worldwide authorization rules for the safety of electric vehicles. Sponsors of that regulation are Japan, the U.S., and the European Union. The objective of the automotive industry is naturally to support the advent of a worldwide regulation. However, we are also very interested in having the requirements of Regulation 100 transferred to a global regulation.

The draft version of the global regulation already includes an outline in which rescue data sheets are mentioned. Now it must be ensured that data sheets of this kind are formatted as uniformly as possible all over the world so that the industry can pool its efforts, which means working efficiently. At present, there are rescue data sheets in Germany, while France is discussing a standard on this subject. Efficiency means that all proposals must be combined to produce a single solution that has joint support.

Cooperation with firefighters and other rescue services
Cooperation with rescue services at VDA takes place in two work groups. The "Rescuing people from accident vehicles" task force originated the rescue data sheets. New technologies – for example, on how rescue services handle plastic windshields – have also been introduced. This group has also initiated cutting tests on new vehicles in order to generate a database for firefighters. Members of the task force also exchange information on the subject of eCall.

The second work group, the "Technical customer-service issues" group, is in close contact with ZDK. The subject of vehicle inspections is of great interest to this group, as it is to the German Federal Ministry of Transport. The goad is not a paradigm shift in this area, either. The powertrains of electric vehicles differ from those used in conventional vehicles, which means that there will be different assumptions for the electric vehicle inspection. However, the principle that electric vehicles must as safe as conventional vehicles applies here as well.

Outlook
A national database for rescue data sheets will soon be a reality, and we are confident that it can be combined with the license plate inquiry starting in late 2012. eCall will probably begin to be used in 2015. However, it must be ensured that existing systems (some manufacturers already have similar systems) are still compatible and operational.
In the future, rescue services will not only know that there has been an accident and where it happened: They will also know what vehicles were involved. Thanks to the rescue data sheets, they will also know what to do to help people who have been in an accident. The future networking of vehicles with each other and with the infrastructure will open up even more potential.

Hans-Thomas Ebner
ebner@vda.de
VDA (German Association of the Automotive Industry)
Head of Technology Department

Electromobility-related issues in insurance law and liability law

Dr. Martin Stadler
Allianz Versicherungs-AG

If the "automotive future" belongs to electromobility, then the question arises of whether the new technology will also change the laws on insurance and liability. This article will therefore explore the various effects on insurance and liability law of selected unusual features of electromobility

1. Electric vehicles are quiet

Diesel and gasoline engines can generally be clearly heard, but electric powertrains are quiet. Therefore, the first unusual feature to be analyzed from a legal standpoint is that electric vehicles are "noticeable by their absence." This affects pedestrians and bicycle riders in particular, because they are used to relying on their sense of hearing while on the road. The problem has now been recognized, and work is being done to develop solutions, such as the artificial generation of engine noise. The question of whether the electric vehicle can be "penalized" under the current legal rules precisely because it is quiet will be discussed below solely from a legal perspective.

1.1 Joint liability

The question first arises as to whether the inability to perceive the electric vehicle acoustically can lead to a higher liability quotient. In liability law, a determination of joint liability quotients pursuant to § 254 (1) BGB [German Civil Code] certainly takes into account whether the fault of one party is increased because the danger could be clearly heard. One example of this is the decision by the Düsseldorf Higher Regional Court [Oberlandesgericht] of March 12,1992 (Case 13 U 157/91), which involved injury to a customer in a scrap yard who was looking for usable parts near a crusher that was not properly secured. According to the court, the owner of the scrap yard was liable due to his failure to fence off the dangerous area around the crusher, as part of his legal duty to safeguard traffic [Verkehrssicherungspflicht]: but the customer was also considered to be jointly liable under § 254 (1) BGB because the hazard was recognizable and, in particular, was audible.

But does this lead to the opposite conclusion, that the owner or driver of an electric vehicle must always accept a higher joint liability quotient because his vehicle makes less noise? I think not. As a matter of principle, a person can be accused of a "fault" only if he has failed to meet an obligation that is incumbent on him. However, at present there is no obligation (at least not yet) for an electric vehicle to be loud. Therefore, by implication no misconduct (fault) can be derived from "being too quiet". Under German road traffic law, exceptions to the principle that no one is required to be loud apply, at most, in special circumstances such as the obligation of emergency vehicles use sirens in certain situations pursuant to §§ 35 and 38 StVO [German Highway Code] (see Düsseldorf OLG [Higher Regional Court] of November 11, 1991, Case 1 U 135/90). But this is an exceptional provision that is limited to a few specific situations. Therefore, increased (joint) liability of the driver of an electric vehicle cannot be assumed as long as German legislators have not specified a minimum noise level for electric vehicles.

1.2 Increased operational risk

In addition to fault-based liability of drivers, German road traffic law (§ 7 StVG [German Road Traffic Act]) also provides for an owner's liability for endangerment independent of fault. In that context, the question arises of whether electric vehicles are subject to increased operational risk because they do not make noise. In my view, the answer to this is also "no," although there is not yet any case law on this issue. Liability for endangerment pursuant to § 7 StVG is based on the idea that motor vehicles represent an abstract risk to the public that justifies making the owner of the vehicle liable solely due to the risk of endangerment from their vehicle, even though they are not at fault. Thie operational risk of a vehicle can be higher when the risk that is generally caused by a certain type of vehicle (for example, due to its size) is greater than that of other vehicles (see Karlsruhe OLG of October 20, 2010, Case 13 U 46/10). However, considerations of this kind do not establish an overall higher operating risk for an electric vehicle, because there is no special risk to the general public. The opposite is the case, because it is the intention of legislators to promote low-emission vehicles. Against the background of the constitutional principle of equal treatment of all road users under liability laws, in my view it would be problematic to discriminate against electric vehicles (see Hohloch in VersR [Versicherungsrecht] 79, 199, on the principle of equal treatment under liability laws).

2. The battery "doesn't last"

Another aspect that is worthy of closer legal scrutiny is the question of legal consequences if the high-voltage battery, which frequently makes up a considerable portion of the purchase price of an electric vehicle, fails to last as long as the manufacturer has promised.

2.1 Differences between a warranty and a guarantee

With respect to the legal consequences of a battery that is no longer (completely) functional, a distinction must first be made between liability for defects under the law (§ 437 BGB) and a voluntary guarantee.

Difference between guarantee and warranty

Liability for defects (warranty)	Guarantee
Seller liable	Generally a promise by the **manufacturer**, dealer, or insurer
Applicable **under the law**	Content **freely agreed by the parties**
Requirement: **material defect**	Generally a **promise of functionality** (in some cases limited to specific subassemblies)
Liability only for defects **that existed at the time of the purchase**	Liability **also for impairments** to functionality **that do not occur until later**
Presumption during the first **six months** that the defect existed at the time of shipment	**Customer** bears **complete burden of proof**
Warranty period 24 months (for new items) and **12 months for used items**	**Guarantee period freely agreed by the parties**

Liability for defects under § 437 et seq. BGB, commonly referred to as a "warranty," is a claim by the buyer against the seller (generally a car dealer), while a promise of guarantee is generally given by the manufacturer (but sometimes also the dealer). What is known as guarantee insurance [Garantieversicherung] (or repair-cost insurance) – under which the manufacturer or dealer appears merely as agent and the customer acquires a direct claim against the insurer under the guarantee – is also very popular.

A warranty and a guarantee differ significantly on the question of what parts of the vehicle are protected. The statutory warranty relates – without a substantial limitation – to the entire vehicle and its parts. Everything that was sold to the customer must be free of material defects. The meaning of "free of material defects" is defined in § 434 (1) BGB. Being free of material defects means that the actual condition of the product may not differ from the condition that the parties agreed to when entering into the purchase and sale agreement ("deviation of the target characteristics from the actual characteristics"). The guarantee, which generally promises that certain parts are functional, can be freely configured by the guarantor with regard to its scope (such as maximum mileage, guarantee only for certain subassemblies, and guarantee only against rust-through).

A warranty applies exclusively to defects that existed at the time of transfer of possession of the vehicle (or perhaps became apparent later), but a guarantee also applies to defects that do not become apparent until later. It is sufficient for a guarantee if the defect becomes apparent during the guarantee period. In both cases, the customer bears the burden of proof that there is a claim under the warranty or guarantee, although a statutory easing of the burden of proof applies to the first six months of a warranty if consumers suspect during that period that the defect existed at the time of transfer of possession (§ 476 BGB).

There are also considerable differences with respect to the time during which the warranty or guarantee applies. The law prescribes a two-year warranty period (§ 438 (1) BGB) for the former. Pursuant to § 475 (2) BGB, this may never be shortened for a consumer who buys new products, and it may be reduced to one year for used products (exclusion of a warranty is also possible in dealings with a commercial buyer). In the case of a guarantee, it is up to the supplier to specify the guarantee period. In practice, it is generally between one and seven years (Opel has now stopped offering a lifetime guarantee in its advertising).

2.2. Drop in battery performance as a defect

The decisive question for manufacturers of electric vehicles or manufacturers of high-voltage batteries will be when case law assumes there is a defect if there is a drop in battery performance (in particular, reduced capacity and thus a shorter range) during the guarantee or warranty period. A defect exists pursuant to § 434 (1) BGB when the actual condition of the product differs from the condition that the parties agreed to when entering into the purchase and sale agreement, so the decisive question is what assurances the manufacturer gave concerning battery performance. Case law has not yet decided what reduction in battery performance will be the cut-off for consideration as a defect. In connection with the related problem of a reduction in the performance of a rechargeable battery in a notebook computer, the Stuttgart Regional Court [Landgericht] affirmed a defect in any case when the actual performance fell below 50 percent of the operating time indicated at the time of the purchase (Stuttgart Regional Court of May 28, 1998, Case 6 S 69/97). However, a word of caution: Decisions of this kind from other areas should not be applied to electric vehicles, because the utility value is reduced less for a notebook when the rechargeable battery performs poorly – since it can be recharged anywhere and can also be plugged in – than it is for the buyer of an electric vehicle who can no longer get to work because of reduced battery performance (and may have bought the car precisely for that purpose). As is so often the case, it will all depend on individual circumstances. This means that the manufacturer faces a dilemma. On the one hand, customers will buy electric vehicles only if they are promised sufficient performance and longevity of the battery: but on the other hand, the liability risk increases considerably when promises are made that later cannot be kept.

2.3 "Chain guarantee" risk

Manufacturers of electric vehicles or manufacturers of high-voltage batteries are subject to another risk that should not be underestimated. This is the question of whether the two-year warranty period (for the replaced part) starts to run again after replacement of a defective battery. For the manufacturer that cannot control the quality of its battery, this would mean the risk of what is known as a "chain guarantee" (and really ought to be called a "chain warranty") that is constantly extended. The chain warranty phenomenon is disputed in the field of legal science and has been heatedly discussed for many years. Those who, with regard to this controversial issue, have previously assumed that the limitation period starts again (see BGH [German Federal Court of Justice] judgment of October 5, 2005, Case VIII ZR 16/05; Nuremberg OLG of August 23, 2005, Case 3 U 991/05; Graf von Westphal, ZGS [Zeitschrift für das gesamte Schuldrecht] 2002, 19) justify this by stating that the seller has recognized the breach of its obligation (delivery of the defective product) by replacing the defective part (as long as this is not done purely as a courtesy to the customer). However, according to § 212 (1) BGB, the limitation period begins to run again when the obligor acknowledges to the creditor that there is a claim. In contrast, the contrary opinion (such as Bolthausen/Rinker, ZGS 2006, 12) bases the expiration of the warranty on the initial delivery even in cases of subsequent delivery. Because this legal situation is still unclear, the manufacturer of a high-voltage battery should at the minimum include the risk of a chain warranty in its calculations.

It is clear that a chain warranty does not result from replacement solely as a courtesy to the customer. The chain warranty problem also applies only to the statutory warranty. Case law has previously denied restarting the limitation period in the case of a guarantee (see Celle OLG of March 8, 2006, case 7 U 205/05).

2.4 The statement of guarantee as an insurance transaction

One problem that is frequently overlooked is that a guarantee may be given outside of an insurance contract only in close connection with the sale of a product (sale of the vehicle or battery). The subsequent sale of a guarantee is legally problematic. The problem is that promises of guarantee as a matter of principle fulfill the criteria of an insurance transaction. According to case law (see BVerwG [German Federal Administrative Court] of November 25, 1986, Case 1 C 54,81 = VersR 1987, 297), an insurance transaction as defined in § 1 VAG [German Insurance Supervision Act] exists when an independent promise to pay benefits is made

- in return for compensation (capital reservoir)
- for a future uncertain event
- based on the law of large numbers

Pursuant to § 1 VAG, only insurers are entitled to carry out insurance transactions (a violation is punishable under § 140 (1) VAG). The decisive criterion for the legal classification of a promise of guarantee is the "independence of the promise to pay benefits." For example, if the guarantee takes the form of what is known as a non-independent ancillary agreement that is closely connected with the primary transaction of selling a car, there is no insurance transaction – which means that the manufacturer or dealer can make the promise of guarantee. However, a different principle applies when there is no direct connection between the guarantee and the sale of a vehicle. For example, the German Federal Administrative Court (decision of June 19, 1969, Case I A 3.66 = NJW 1969, 1978) prohibited a provider of extended guarantees for television sets from doing business, because it had entered into unauthorized insurance transactions: the guarantee was offered after the fact, independent of the sale of the television set.

2.5 Exclusion of the battery from the promise of guarantee

A problem specific to electric vehicles arises if the battery is to be excluded from the guarantee (which is relevant only for the guarantee but not for the warranty).

The current practice is to exclude the SLI (starting, lighting, and ignition) batteries used in vehicles with gasoline or diesel engines from the scope of the guarantee by including fine print to that effect in the terms and conditions of the guarantee offered by the manufacturer or repair-cost insurance provider. This is not a problem according to the law on general terms and conditions as long as it involves a gasoline- or diesel-powered vehicle, because customers in that sector understand that the battery is one of the expendable parts for which they do not expect a guarantee.

However, if a guarantee is given for an electric vehicle, exclusion of the traction battery could be considered a surprising clause as defined in § 305c (1) BGB, which could make the exclusion clause ineffective. A surprising clause is always considered to exist when the provisions it contains clearly differ from what a customer can typically expect from their contract in a fair business transaction. To avoid the surprise effect under § 305c BGB, and also to prevent later aggravation, all documents containing information on the guarantee for electric vehicles should clearly specify whether the guarantee includes the traction battery or not.

2.6 Information asymmetry

To conclude this legal overview of issues related to guarantees, I would like to take another look at potential economic effects. The uncertainty that results for customers from the fact that they cannot assess the real useful life of a battery without information from the manufacturer produces what is known as "information asymmetry."

Information asymmetry results from the fact that market participants do not always have the same level of information about the characteristics of the object of purchase (see http://de.wikipedia.org/wiki/Asymmetrische_Information). Because a person buying an electric vehicle cannot test the length of the battery's useful life and must rely on the general information available to the manufacturer about this subject, there is information asymmetry to the disadvantage of the customer. Economists believe that a lack of information of this kind will lead to lower prices or a decrease in demand because the feared quality risk reduces the demand side's willingness to pay. This problem can be resolved by what is known as "signaling," which means that markets in which there is a risk of information asymmetry remain functional when the partner with more information sends a signal about the quality of the product that is to be transferred. Possibilities for this include a quality seal from an independent organization or giving a promise of guarantee.

3. People assisting after accidents are at risk for electric shock

Another point of discussion that repeatedly arises in connection with electric vehicles is how to deal with the risk of shock faced by people providing assistance at the scene of an accident. The remarks below will relate exclusively to the legal aspects of this problem, which will otherwise be solved by technical measures and training of rescue workers.

The person providing assistance enjoys legal protection. He or she can claim compensation for physical injury and property damage, as well as for expenses incurred in providing assistance. The principle applies that a person providing assistance must not suffer any disadvantages from providing assistance. Claims for compensation (for both personal injury and property damage) may be made to the responsible statutory accident insurer (§ 2 (1) (13) (a) SGB [German Social Code] VII). There may also (depending on the specific circumstances) be claims against the party that caused the accident (§ 823 BGB) or the victim (§ 670 in conjunction with 683 BGB). In the latter two cases, the person who provided assistance and was injured can also assert claims directly against the vehicle liability insurer, which is liable under subrogation to the extent that the injury or damage to the person providing assistance can be attributed to "use of the vehicle."

The remaining question is whether the person providing assistance bears joint liability if he or she underestimated the danger from an electric vehicle after an accident. As a matter of principle, the answer to this must be "no." Case law takes into account the special situation of persons providing assistance if they take measures that after the accident (in retrospect) do not appear to have been the most reasonable. As a general rule, therefore, mistakes do not lead to joint liability of the person providing assistance, because it is taken into account that the assistance provider has no time to reflect in a dangerous situation that has occurred, through no fault of their own, and that is unpredictable for them, so they does not always do what is right and appropriate (see BGH of October 5, 2010, Case VI ZR 286/09). Case law will likely impose higher requirements or affirm joint liability only for professional providers of assistance after accidents (such as towing companies), because this group of people can be required to know about the specific risks of an electric vehicle that has been in an accident.

4. Damage during the charging process

In conclusion, I will briefly discuss the problem of damage during the charging process. Power lines are, as a matter of principle, a hazard that must be reduced by the responsible party in an appropriate and reasonable way. For example, the Bückeburg Regional Court [Landesgericht] (decision of April 24, 1997, Case 2 O 277/96) found that a municipality is required to sufficiently insulate power cables that are used for Christmas lighting. The municipality had neglected that legal duty to safeguard traffic and was therefore required to pay damages for pain and suffering to a dog owner whose dog first bit the power cable and then, as a result of the shock, its owner. However, the duties of safety in this regard may not be exaggerated. The Hagen Regional Court (decision of March 16,1999, Case 1 S 1/99) ruled, for example, that running an electric cable measuring no more than one centimeter in diameter over the ground at a weekly outdoor market did not violate the duty to safeguard traffic.

The owner of an electric vehicle who violates their duty to safeguard traffic during the charging process, and is therefore liable to a third party, is generally protected by their vehicle liability insurance, because case law is very generous in interpreting “use of the vehicle,” which defines the scope of vehicle liability insurance and distinguishes it from personal liability insurance. “Use of the vehicle” is understood to mean every action that has an adequate causal relationship with the intended purpose of the vehicle. There is no doubt that this includes getting into and out of the vehicle, and of course also driving it. But “filling up” is also considered to be use of the vehicle (see BGH June 26, 1979, Case VI ZR 122/78; with regard to use, see also Maier in Stiefel/Maier A.1.1 AKB margin no. 18).

The following situation would result if, due to a technical defect during charging, a fire broke out and both the vehicle and the garage or house were damaged. The damage to the electric vehicle is covered as fire damage to the extent there was “Teilkasko” [third party, fire and theft] insurance for the vehicle (on fire damage and “Teilkasko” insurance, see Stadler in Stiefel/Maier, A.2.2 AKB margin no. 6 et seq.). The damage to the house or garage is also covered as fire damage under the fire or homeowners’ insurance policy (on fire damage and fire insurance, see Armbrüster in Prölss/Martin, AFB 2008, § 1, margin no. 3). However, the insurer will verify whether the fire was caused by gross negligence when charging. In that case, the insurer would be entitled under § 81 (2) VVG [German Insurance Contract Act] to reduce its payment in accordance with the extent of the fault. If a defective product is suspected, the insurer would first settle with its policyholder and then assert subrogation claims against the manufacturer under § 86 VVG.

5. Conclusion and outlook

Electromobility raises some interesting legal questions. Very few of these issues are completely new: rather, they take a slightly different form due to their connection with electric vehicles. More thorough analysis is recommended, especially for the issue of liability for battery defects and possible models for guarantees to resolve the issue of information asymmetry.

Dr. Martin Stadler
martin.stadler@allianz.de
Allianz Versicherungs-AG
Chief Legal Advisor

High-voltage vehicles – distinctions in the type classification?

Dr. Jürgen Redlich
Gesamtverband der Deutschen Versicherungswirtschaft e.V. (German Insurance Association)

Type-class systems in automobile insurance

The statistics of German automobile insurers include over 20,000 vehicle types. Type classes are assigned to each vehicle type for purposes of motor-vehicle liability insurance and for comprehensive and partial insurance. This assignment is made based on the actual costs of claims of all insurers from previous years for each type of vehicle. A type class therefore provides information about a vehicle's insurance risk, including how often damage can be expected (claim frequency) and how expensive the average damage is (average claim). This article raises the questions of how a type class can be determined for new vehicles that lack past empirical values, and what distinctions might need to be taken into account in new classifications of high-voltage and electric vehicles.

Experience with hybrid and electric vehicles

The usual procedure for predicting the expected frequency of accidents and claims for a new vehicle is based on empirical values. These values are adopted from the type statistics of previous models (such as Golf VI – previous model Golf V) or of comparable models from the same manufacturer or competitors. The consideration underlying this procedure is that similar vehicles also have a comparable customer profile and therefore comparable customer driving behavior. In the case of electric and hybrid vehicles, these empirical values don't exist yet, or only a few values are available. For example, the Golf Citystromer still accounts for the largest volume of values in the type statistics of liability insurance (as of Dec. 31, 2010), even though this model was included in the type statistics beginning in 1995 when only 114 cars were built. This seems to contradict the reality on the streets. However, by far the largest share of electric vehicles seen today on the streets still consists of limited-series vehicles or individual registrations. Normally, these vehicles have not been assigned a type, that is, a type code number, by the German Federal Motor Transport Authority. This is a prerequisite for inclusion in the type statistics

The situation is different for hybrid vehicles. Nevertheless, the experiences are concentrated on Toyota and Honda vehicles. There are no evident distinctions for hybrid vehicles based on the available data material.

What characteristics could influence the claims frequency for electric vehicles?

Do customers who buy electric vehicles represent a particular group? Does their driving and user behavior differ significantly from customers who prefer conventional cars? The high purchase prices due to the battery and also the limited range could suggest this. One answer could possibly be that users of high-voltage vehicles have a more defensive driving style in order to go easy on the electric driving range. This would have a positive influence on the claims frequency. Another factor would be the vehicles' primary use in urban areas – a reasonable assumption due to the limited range. However, it is difficult to predict the extent to which this preferred usage area leads to a higher or lower number of accidents, and as a result to higher costs. Experience has shown that more accidents occur in urban areas compared with highways or autobahns, even though in many cases the accidents are more likely to be minor. Another consideration pertains to the nearly silent operation of electric cars.

This could theoretically lead to more accidents with pedestrians, which is a problem that is already being discussed in other fields.

Due to the lack of empirical values, these particular factors can be managed when these vehicles are selected by considering the typical purpose of high-voltage vehicles: In this case, the purpose is for use in city areas, smaller vehicle size, and other uses. Otherwise, they are treated like conventional cars.

Can higher damage costs be expected in general with high-voltage vehicles?

The bulk of actual accidents occur at low speeds. In statistics related to comprehensive insurance, minor accidents very clearly dominate the total incidence of accidents. In one million cases of collision damage per year, the average damage costs are less than €3,300. In one quarter of the cases, the average costs are even less than €1,500. This amount not only applies to the actual repair costs, but also includes all related costs for settling the accident claim. In the case of liability insurance, the average repair costs are less than €1,900 for property damage only.

This means that the insurance classification of new vehicles is based on so-called minor accidents. Standardized crash tests, in which the vehicle is driven against a fixed, stiff barrier at 15 km/h, provide information on the vehicles' ease of repair and the costs that can be expected. Just as for a normal accident, the damages are assessed and the repair costs determined. A total of three damage zones are included in the calculation: front left, back left, and the left side. Figure 1 shows an example of damage after a crash test to the front left. The assessment covers visual damage to the fender, bumper, hood, and headlight areas. If these attached parts are dismantled (Figure 2), it is clear that the bumper system absorbed the crash energy and the vehicle structure is undamaged. For most vehicle manufacturers today, this kind of result is standard.

Figure 1: Typical scope of damage after an RCAR frontal crash at 15 km/h

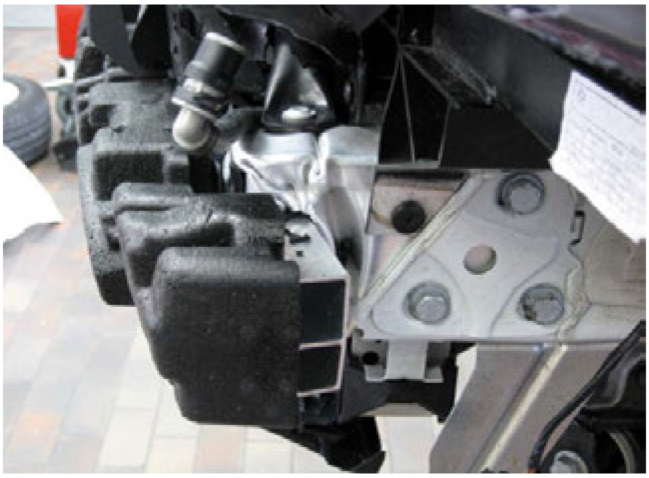


Figure 2: Typical scope of damage after an RCAR frontal crash at 15 km/h

Where can potentially higher costs occur in the repair of electric or hybrid vehicles?

Applied to high-voltage vehicles, the study of accidents on the one hand and crash results on the other show that damage occurs only very rarely in the areas where the typical costly components are found in high-voltage vehicles – provided that no errors were made in the package. High-voltage vehicles can therefore be assessed using the same benchmarks as conventional vehicles. Nonetheless, some characteristics should be addressed.

Expensive parts like additional radiators and the power electronics should not be placed in an exposed position, in other words, not close to the vehicle's external shell. While this applies equally to conventional drives, the costs are higher for high-voltage vehicles. Stiff components that can cause secondary damage to other components, such as the charging sockets, should also not be positioned in exposed locations. The high-voltage cable must be laid as far as possible in the protected area, and in no case in the vehicle's exterior areas.

One problem that is not easy to resolve is the additional space required by components for hybrid or range-extender vehicles. In these vehicles, two drive systems must be accommodated in the same space. A conflict of goals is unavoidable. The Opel Ampera and the Chevrolet Volt can be cited as examples. The resulting space problem means that components are positioned in areas that are at risk. If, however, in the future the vehicle architecture is designed to better meet the needs of high-voltage vehicles, these factors can be taken into account from the start and resolved.

The absence of voltage must be verified before repairs are started on high-voltage vehicles. Specially trained personnel may be necessary for this type of repair. There is also the additional time required for this item of work, which increases the costs for each case of damage repaired. This raises the question as to whether it is possible to differentiate. Are there conceivable repair processes or repair zones for which it is not necessary to remove the voltage? With respect to the coating process it must be clarified as to whether the high-voltage battery could sustain damage due to its temperature sensitivity. In practice, the problem is frequently a lack of sufficient information in the repair shops. As a result, unnecessary work is performed out of ignorance, which increases the repair costs.

From today's perspective, it is totally unclear whether the battery pack is at particular risk of theft due to its high value. A vehicle that in and of itself is at no risk of theft may become a theft-prone vehicle due to its electric power train.

Summary

Although high-voltage vehicles are vehicles with a special power train, they do not have or require a special status in the classification process. There are no information on the accident frequency of purely electric vehicles. For hybrid vehicles, no distinctive features compared to conventionally powered vehicles have been identified. If the manufacturers position the expensive high-voltage components in crash-proof locations, the repair expenses are comparable in normal accidents. Additional costs are possible for the necessary safety measures during the repair process. However, these costs can be minimized or completely avoided by providing the best possible information to repair shops.

Dr. Jürgen Redlich
j.redlich@gdv.org
Gesamtverband der Deutschen
Versicherungswirtschaft e.V.

The market for used HV vehicles

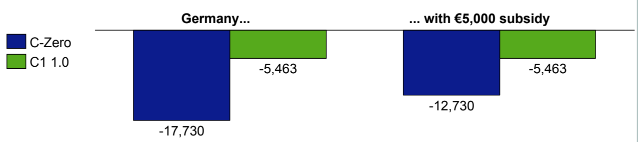
Steffen Schick
EurotaxSchwacke GmbH

This presentation covers electric vehicles from the perspective of the used car market. This market is important to successful new car sales to the extent that the (expected) loss in value of electric vehicles results in a significant overall cost disadvantage compared to conventional power trains. The following article quantifies the problem and highlights methods of resolution.

Everyone's talking about alternative power trains these days. There's no doubt that emission-free or low-emission vehicles are the only way to ensure our mobility over the long term.
Today the electric power train is the most environmentally friendly technology, if it is powered with green electricity. Electric vehicles (EVs) are nothing new; they have been around for over 100 years. Their value proposition for customers has not changed substantially: range, fun driving, and low operating costs. Only the environmental aspect has been added. Is this factor sufficient to successfully launch EVs on the market? Most experts currently assume that the global market share will reach about two percent of new registrations by 2020. The predictions are more optimistic for Europe, where the share could reach ten percent (BEV, plug-in BEV, and BEV+range extender).

One factor that is barely a part of public perception is the used car market for EVs. Although this market will remain negligible in the new few years, it should receive more attention due to its importance to successful new car sales. This is ostensibly because every car becomes used as soon as it is registered for the first time. The much more important reasons are that the loss of value of EVs is a larger cost driver than for traditional combustion engines, and that commercial customers represent a large percentage of the buyers.

In the high-volume segments for traditional power trains, the ratio of the loss in value to the total costs is almost fifty percent for fleet customers, who have a typical holding period of three years and an annual distance of 30,000 km. For EVs, the ratio is higher due to the much higher list price. Using the Citroen C-Zero as an example, this means that after 36 months and a realistic annual distance for EVs of 10,000 km, the buyer of a C-Zero must bear a higher loss of value – totaling about €12,000 for the vehicle, including the battery – than the buyer of a comparably sized C1 1.0. Despite the lower operating costs, substantial government subsidies will be necessary in order to make the EV come even close to being competitive for the first owner (in France, for example, a subsidy of €5,000 is provided for an EV). While nearly half of private end-customers in Germany claim to be willing to pay more for a new EV, the incremental willingness to pay is limited to less than ten percent for more than two-thirds of the potential buyers surveyed.



	C-Zero	C1 1.0		C-Zero	C1 1.0
Net list price	29,550	8,672		29,550	8,672
Remaining value (%)	40%	37%		40%	37%
Remaining value (€)	11,820	3,209		11,820	3,209
Loss of value (€)	17,730	5,463		12,730 (incl. €5,000 subsidy)	5,463

Source: EurotaxGlass's

Figure 1: Loss of value of a Citroen C-Zero vs. C1 1.0 (vehicle incl. battery)

Used car buyers are traditionally more cost-conscious and may be less inclined to pay higher acquisition costs.

However, it would be remiss to conduct this discussion purely in terms of loss of value. The essential challenge for EVs is that the overall cost problem is exacerbated by the customers' uncertainty. This uncertainty results from a number of factors, although the battery causes most of the concerns. For one thing, customers do not have reliable knowledge about how long the battery will deliver the expected performance and how "good" a battery still is on any day in its service life. For another, it is difficult for customers to compare different business models, for example, those of EVs versus cars with combustion engines, but also within the range of EVs offered when the vehicles are sold with or without batteries or battery leasing/rental concepts are offered. This uncertainty leads to deductions for risk and so to an additional decrease in value, provided that the end customers bear the risk, in other words, the risk is not covered by long-term guarantees.

Depending on the segment, the battery accounts for between one-fourth and one-third of the purchase price. As long as the end-customer is expected to bear the full risk of failure/loss of value of the battery, EVs will hardly be competitive. The expected decrease in battery prices will reduce but not close the gap for the foreseeable future. The current cost of around €600 per kWh should drop to about €350 by 2020, but part of the price improvement will need to be used to increase the EV's range.

In addition to the government, car manufacturers in particular will be asked to limit end-customers' uncertainty and to limit the first owner's overall cost disadvantage (typically three to four years) caused by the loss of value. Long-term guarantees longer than six years, battery leasing concepts, and cross-subsidies are conceivable and are promising in this respect.

The final example illustrates the advantage of the battery leasing over the battery purchasing concept, but also the current overall cost disadvantage compared to conventional power trains. The effect of a long-term battery guarantee is comparable.

36 months (years 1-3) / 10,000 km p.a.	EV (Leased Battery) - Exemplary	Citroen C-Zero	Mitsubishi i-MiEV	VW Polo 1.2l	Citroën C1 1.0l
List price (gross)	25,000 €	35,165 €	34,390 €	12,800 €	10,320 €
Fuel/energy costs	0.25 € / kWh	0.25 € / kWh	0.25 € / kWh	1.50 € / l	1.50 € / l
Loss of value	333 €	590 €	577 €	135 €	138 €
Service, maintenance, and repairs (SMR)	19 €	19 €	19 €	20 €	29 €
Insurance	115 €	115 €	115 €	115 €	115 €
Vehicle tax	0 €	0 €	0 €	2 €	2 €
Monthly battery lease	100 €	0 €	0 €	0 €	0 €
Fuel/energy	26 €	26 €	26 €	69 €	56 €
Costs per month	**593 €**	**750 €**	**737 €**	**340 €**	**340 €**
Costs per kilometer	**0.71 €**	**0.90 €**	**0.88 €**	**0.41 €**	**0.41 €**

-21%

Purchase vehicle/ lease battery | **For business model: Purchase vehicle incl. battery**

1) Current EV offer
Source: EurotaxGlass's

Figure 2: Comparison of overall cost of an EV1) vs. a gasoline engine, private customer, three-year-old vehicles, annual distance: 10,000 km, Germany

Steffen Schick
steffen.schick@eurotax.com
EurotaxSchwacke GmbH
Managing Director Global Services Division

Operations Workshop

Approximately 20 participants in the Operations Workshop discussed diverse aspects of this topic, from potential problems with acoustic perception to driving performance to the effects on repair operations. The diversity of the topic also reflected the range of organizations in this workshop. In addition to automobile manufacturers and insurers, they included technical services, engineering service providers and a representative of Berlin's public transport services. Two impromptu presentations opened the workshop.

Workshop leader:
Dr. Patrick Seiniger, German Federal Highway Research Institute (BASt)

Acoustic perception

Knut Junge
Deutscher Blinden- und Sehbehindertenverband e.V.
(German Association for the Blind and Visually Impaired)

The intention of associations for the blind and visually impaired is to bring the concerns of this group of people before society and to provide them with accessibility. The goal set by the German federal government is for one million electric vehicles to be driving on German streets by 2020. Should these vehicles produce sounds and, if yes, what sort of sounds? This article will provide food for thought on this subject and draw attention to the situation of all traffic participants, in particular that of the blind and visually impaired.

Figure 1: Did you look? Why, I can hear you!

Raising awareness / typical danger zones for the blind and visually impaired

Figure 1 shows a classic situation: While children are capable of perceiving cars visually, they cannot yet estimate distances and speed. They do a better job of doing so with a combination of acoustic and visual stimuli. The situation is even more difficult for the blind, that is, for people who have absolutely no visual perception. They rely on acoustic or tactile stimuli, and the latter are not a viable option with regard to vehicles. When it comes to traffic, the problems for the blind and visually impaired are diverse. These people lack eye contact with other traffic participants. They can process stimuli only sequentially, and are disadvantaged when it comes to estimating distances and assessing risks. Furthermore, it is difficult for them to find safe road crossings like the crosswalks at traffic lights. They face an increased risk of injury due to obstacles like traffic signs and construction zones. These kinds of obstacles also result in unwanted changes in direction. In reality, given the current situation, the blind and visually impaired already need a lot of courage in order to get around.

Another problem will be added to the list in the future, when many more of the typically quiet electric vehicles will be on the streets: It will be impossible for the blind to perceive these cars in a timely way. This will hinder their ability to participate in social life as is established in the German Equal Opportunities for Disabled People Act (Behindertengleichstellungsgesetz). A street that can be perceived as such through sounds is also helpful as an orientation guide in getting around on sidewalks.

Children, the blind and visually impaired, and the elderly are particularly affected by the risk associated with quiet electric vehicles. WHO statistics from 2002 (Figure 2) show that in Germany about 164,000 people are blind, and the number of visually impaired is nearly one million. This number will continue to grow because there will be increasingly more elderly people due to demographic change. Therefore, the subject concerns everyone to a certain extent, and people with normal sight and without disabilities will also benefit from potential solutions.

WHO figures (2002)		
164,000 blind people	≈	0,2 %
1,066,000 visually impaired people	≈	1,3 %
The trend is expected to increase due to rising life expectancy		

Figure 2: WHO statistics from 2002

An excerpt from the German Road Traffic Regulations (Strassenverkehrsordnung) is quoted with regard to the possible sounds that electric cars could produce: §1 Basic rules: “1. Participation in road traffic requires constant attention and mutual consideration. 2. Each traffic participant must behave in a manner such that no other participant is injured, endangered, or impeded or disturbed more than is unavoidable under the circumstances.” Naturally, the blind and visually impaired are also required to pay attention and show consideration. The second point is more of a problem: How loud may a sound be and still not be considered a disturbance, or how loud must it be at a minimum so that the safety of traffic participants – especially the blind and visually impaired – is not compromised, in other words, they are not endangered in traffic as they move around. Other questions pertain to the location of sound emission and the potential adaptation of vehicle volume to the background noise level. In addition, the sound emitted by the electric car should provide information on how fast it is traveling and whether it is accelerating or braking.

An important guide for the blind and visually impaired is the implementation of the “two-senses” principle. Sensory information is provided on at least two sensory channels. In road traffic, these channels are acoustic and visual perception. For example, emergency vehicles have both flashing lights and a siren, which fulfills the two-senses principle. This would not be the case for silent electric vehicles. In addition to visual perception, acoustic perception must also be ensured: This would increase the traffic safety of all.

By 2020, one out of every 50 cars will be equipped with an electric motor. The main problem during the transitional period is that there will still be cars with traditional combustion engines in addition to electric vehicles. Imagine that you are blind and walking in a residential area, where there are seldom safe road crossings like crosswalks and traffic lights. You hear a car, and somewhat farther away another car. You walk between the sounds, so to speak. This is dangerous if an electric car is driving between the two audible vehicles – without an acoustic signal, this electric car is not perceptible.

Position paper of the BKB

In a project executed by the German Federal Competence Center for Accessibility (Bundeskompetenzzentrum Barrierefreiheit, BKB) on electric vehicles, a position paper was issued that includes various demands with regard to the sound production of electric vehicles.

Currently, sound must be emitted at speeds up to 20 km/h. The biggest problem exists in residential areas where, as mentioned above, there are usually no safe crossing options. In these areas, the normal speed limit is 30 km/h. This means there is a gap between 20 and 30 km/h; and in addition, people rarely drive at exactly 30 km/h, but usually somewhat faster. Moreover, in winter there is often snow on the streets in residential areas, and snow has sound-absorbing properties. For these reasons, the position paper demands sound up to speeds of 40 km/h – the first deviation from the manufacturers’ or the VDA’s demands.

There are numerous proposals with regard to the type of sounds needed. Potential sounds were presented during initial testing. Blind people clearly preferred the sound of a diesel engine. This is not surprising, since we

have all grown up with it and are familiar with it from childhood. At the same time, understanding must be shown for the car manufacturers, who would like to have a new sound for a new type of power train. Therefore, the challenge is to find a suitable and distinctive sound. In addition, it should be as uniform as possible, or at least sound similar across all types of electric vehicles.
In addition, it must not be an option to disable the sound. Of course, this would be more pleasant when drivers are stuck in a traffic jam, but nobody could guarantee that the sound would be enabled again afterwards.

Another requirement pertains to driver assistance systems, for example, systems that signal the driver to pay attention to a pedestrian. The position paper takes a stand against these systems; the blind and visually impaired would have to rely on this system, which would place their safety entirely in the hands of the driver.

The complete position paper can be downloaded free of charge from www.barrierefrei.de.

Conclusion

The blind and visually impaired are also in favor of traffic sound reduction. However, these sounds must still be perceptible or must fulfill the demands of the two-senses system. The sound that vehicles produce must still have a signaling function. The problems addressed here will require the close cooperation of all parties involved.

Knut Junge
knut.junge@gfuv.de
Deutscher Blinden- und Sehbehindertenverband e.V.
(German Association for the Blind and Visually Impaired)

Operating experience with high-voltage vehicles

Pascal Mast
TÜV SÜD Automotive GmbH

High-voltage projects

Over the past 24 months, we have provided support for two projects carried out by the German Federal Ministry of Transport, Building, and Urban Development (Bundesministerium für Verkehr, Bau und Stadtentwicklung, BMVBS) – the EleNA project (retrofit kits for diesel commercial vehicles) and the IKONE project (an integrated concept for sustainable electric mobility). In the Ikone project, 50 electric Vito E-CELLS were used in the Stuttgart metropolitan area. The objective was to ensure safety throughout the entire duration of the project. The participants consisted of individual small companies, the fire department, the police department, and parcel services. These customers have an advantage in that their routes can be planned very easily. The EleNA project studied the implementation of a drivable prototype. The risks and dangers were deliberately analyzed up to and including at the system level.

Procedure for risk analysis/specific dangerous situations

In the field of electric mobility, four important factors are taken into consideration in a risk analysis: access to the HV potential, electrical and functional safety (electronic/electrical system malfunctions), chemical risk (before and after a crash as well as during transport, maintenance, and repair), and mechanical safety.

In the area of logistics, it must be ensured that a vehicle will not present a danger to users, even after a six-to-eight-week trip in an overseas container. Basically, the transport of electric vehicles may entail completely new problems that must be taken into account.

Start-up by customers

When customers pick up a rental car from the rental company's underground garage, they normally drive off immediately without reading the car manual. The customers' need for safety is already satisfied, even if the customers are not completely familiar with the vehicles. It is debatable whether this would also be the case with electric vehicles. When customers drive off with their vehicles, they would like to know how long the driving range will be and whether using the seat heating, radio, light, or air-conditioning will affect the range.

Accidents

Another important question concerns proper behavior in the event of an accident or breakdown. Can an electric vehicle simply be towed away just like any other car? What happens if the driving wheels rotate during towing? Will the towing service personnel know that they are dealing with an electric vehicle when they set out to tow an illegally parked car? How can they identify an electric vehicle? Rescue workers must also know how to properly respond to an accident involving an electric vehicle. What actions must they take to ensure that neither they nor people who will deal with the vehicle afterwards (like the towing service) are endangered?

Environmental impacts / influences

Is the driver of an electric vehicle at risk after a small animal bites a cable? Are there problems if users drive an electric vehicle through a deep puddle? What risks are posed by unauthorized accessories, which drivers will certainly be able to order online very soon?

Unauthorized actions by third parties can potentially be just as dangerous. At a school workshop, the children

were asked whether they would crawl under a vehicle with a running engine to retrieve a ball that had rolled underneath. No child would do this. However, with an electric vehicle, it is not so easy to recognize whether the vehicle has been switched on and is ready to drive. A dangerous situation can also occur if children are playing in a vehicle that suddenly begins to move because nobody realized that the vehicle was ready to operate.
What happens if a thief short-circuits two wrong cables?

Service and maintenance
When an undefined vehicle comes into a shop, the employees do not know what has happened to the vehicle, nor do they know the condition of the battery. What has to be changed in the usual TÜV (Association for Technical Inspection) main inspection? What defects can people readily detect in electric vehicles today? At what point should or must an electric vehicle be taken off the streets?

Training is necessary for employees in all areas, including towing services, repair shops, and disposal companies.

Hazards of hybrid vehicles
More and more components outside of the classic power train are fed with high voltage – the air-conditioning system, steering, and in the future possibly the auxiliary air-conditioning systems and other components. Users do not receive any warning when they come close to energized parts. For converted vehicles that have received EC100 approval but do not have a functional safety concept, the isolation monitoring can take up to 20 seconds when the vehicle is deactivated. A hybrid vehicle can also be active even though the motor is not moving.
After a crash, the battery condition is very difficult to assess. Extreme caution is imperative during painting, and the battery must never be overheated.

Tuning
In this area, for example, additional DC/DC-DC/AC converters can pose a problem if they are not installed professionally. Getting this and other modifications under control is practically impossible if users do not go to a shop. It is also not guaranteed that a TÜV employee will recognize this type of modification.

Another topic is software tuning. Many electric vehicles have a Vmax limit, that is, a speed limit. Overriding this limit is fairly simple. The battery’s temperature range and the vehicle’s safety shutdown range can also be extended relatively easily. Other tuning options include boosting performance by extending the peak. Another procedure that is also prohibited, but practiced nonetheless, is the use of HV power when the vehicle is stationary.

Excerpts from the guideline “Working safely on electric vehicles during repair”
We have written various guidelines for working safely with electric vehicles during repair, derived from experience acquired so far with high-voltage vehicles. If a vehicle is taken to a shop for repair, the mechanics must first determine what condition the HV system is in. If the on-board diagnostics system is not functioning, it must be dealt with as a vehicle with known faults in the HV system until the vehicle is repaired. This is the only way to protect all employees who come into contact with the vehicle.

Working on high-voltage and low-voltage systems simultaneously is problematic, because the HV contactors can be closed inadvertently; an open HV circuit would then be closed suddenly.

The entire HV range must not be activated except under supervision or after documented approval by a qualified electrician. It is also very important to document the fault and the completed work in detail before the vehicle is transferred to another service area. In general, meticulous attention is required for direct work on HV-operated components.

Summary

The chemical risk posed by the battery must not be underestimated. In addition, the high-voltage circuit feeds not only the traction components, but also other systems (like air-conditioning and power steering), and these systems may be energized. After an accident, it is difficult to determine the condition of the battery and of the entire HV system, depending on the type of damage. New measures are currently being researched at several workshops in Baden Württemberg in areas that include the recognition of electric vehicles. Anyone who becomes aware that an electric vehicle has been involved in an accident could place a pylon on the vehicle's roof to signal this information to the approaching rescue workers. If a vehicle is deactivated, a sufficient amount of time must allowed for the system to self-discharge. Before work is started on the vehicle, a measurement must be taken to verify that no voltage is present.

Pascal Mast
pascal.mast@tuev-sued.de
TÜV SÜD Automotive GmbH
Head of Emissions Test Center Heimsheim

Discussion results „Operations Workshop”

The discussion dealt with the following topics:

1. Approval and general inspection
2. Information
3. Battery and charging
4. Acoustic perceptibility

1. Approval and general inspection

1.1 General inspection

Within the topics of general inspection and repair shops, the now lower load on the (rear-axle) braking system due to recuperation (electro-regenerative energy recovery) and the associated poorer performance of the brakes was discussed. This problem is already affecting hybrid vehicles today. On the other hand, the increased mass of future vehicle because of the battery packs could compensate for the reduced use. The group felt that this problem should nevertheless be watched in the future. The activities of the Association of German Technical Inspection Services (VdTÜV) were referenced for other adaptations to the general inspection of motor vehicles. The group was also in agreement that special attention should be paid to the safety of small-scale production vehicles.

1.2 Effects of different recuperation methods

Activating the recuperation of electric vehicles can be accomplished in a variety of ways. What is common in a majority of vehicles is activation when the brake is actuated. However, there are other concepts in which great recuperative deceleration is triggered by releasing the accelerator pedal. The group was basically of the opinion that a learning effect is established relatively quickly for such new operating concepts. It was also suggested that limit values could be established for the recuperation deceleration in pertinent regulations (for example, UN ECE R13). Triggering the brake light during recuperation has already been defined.

1.3 Safety of the high-voltage system

The consequences of manipulation or damage to high-voltage cables in vehicles – for example, from rodent gnawing – were discussed. For this type of problem, electric vehicles are designed to be intrinsically safe by, for example, installing so-called insulation monitors. It was also pointed out that intrinsic safety is also required for small-scale production vehicles to which the UNECE regulations do not apply. The inspection is then within the scope of responsibility of the approved expert.

2. Information

The qualification of personnel who work on high-voltage electric vehicles is defined in Professional Association Information Bulletin (BGI) 8686 and is generally recognized. However, the group was in agreement that end consumers should be made explicitly aware of potential risks in their vehicle manual.
In general, the consumers of these types of vehicles should be informed of the peculiarities as early as possible, for example, during driving school courses.

3. Batteries and charging

3.1 Charging stations

On the topic of charging stations, it was noted that so far only voluntary acceptance inspections and annual inspections exist. An inspection analogous to BGV A3/ Industrial Safety Regulation[1] was favored, as well as a plug that is standardized throughout Europe.

3.2 Getting stranded with a dead battery and breakdowns

The question about what to do in the case of dead batteries and breakdowns on the open road was addressed. The manufacturers in attendance explained that regular roadside assistance services could charge batteries on site, and that they would tow the vehicle to the next charging station in cases of doubt. Towing electric vehicles is dealt with in the respective vehicle manuals. Even if the vehicle manual prohibits towing by the drive axle, it was reported that slowly pushing electric vehicles over short distances is possible, as a rule.

1 Professional association regulation for safety and health in the workplace BGV A3 "Electrical Systems and Equipment"

3.3 Assessing the battery after an accident

More difficult is assessing the batteries of electric vehicles that have been involved in an accident, especially lithium-ion batteries. It was pointed out that legislators are responsible in this case for defining practical approaches. This has reportedly been tackled by a research project by the Ministry of the Environment that has already been initiated. Nevertheless, it was felt that there is still a need for research here.

3.4 Thermal load of batteries during accident repairs

Batteries age when they are exposed to higher temperatures. Studies by vehicle manufacturers have shown that if vehicle parts need to be painted after a minor accident, the temperature increase in the battery even after several hours of painting work in a paint-spray chamber is negligible, so that premature aging of the battery is not to be anticipated.

4. Acoustic perceptibility

The acoustic perceptibility of electric vehicles was discussed. Analogous to the regulation already discussed, the group was in agreement that electric vehicles should be acoustically perceptible over the entire speed range and, in cases of doubt, by using additional noise generators. Driver assistance systems, which initiated autonomous braking to prevent pedestrian accidents, could in fact complement acoustic perceptibility. For further issues, reference was made at this point to the UNECE Working Group “Quiet Road Transport Vehicles” [2].

In conclusion, the group was in agreement that the discussion of practical experience with electric vehicles should take place on a regular basis in the future. It would be conceivable that an exchange of this experience should take place comprehensively and regularly within the framework of the “Electromobility Model Regions” Initiative or subsequent initiatives.

2 UNECE Working Group “Quiet Road Transport Vehicles”, http://www.unece.org/trans/main/wp29/wp29wgs/wp29grb/qrtv_9.html

**Symposium participants in dialog with the workshop leaders: (from left)
Dr. Axel Malczyk, German Insurers Accident Research, Dr. Patrick Seiniger, German Federal Highway Research Institute,
Dr. Matthias Kühn, German Insurers Accident Research, Carsten Reinkemeyer, AZT Automotive GmbH**

Crash Safety Workshop

Approximately 40 people participated in the workshop, which was attended in particular by representatives of the automobile industry. However, there were also numerous representatives from the insurance industry and organizations of independent experts. The goal of the workshop was to point out factors that affect passenger safety in an accident, but also direct first-responders after an accident. In doing so, not just so-called catastrophic accidents were supposed to be handled, but also less severe commonplace accidents. While very severe accidents make high demands on vehicle structures and, with a high level of probability, affect components of the high-voltage system, a goal should be established that no high-voltage components will be affected, if possible, in the case of a minor accident. The workshop began with impromptu presentations on the topics of "Behavior in a Crash", "Battery Technologies", and "Legal Regulations".

Workshop leader:
Carsten Reinkemeyer, AZT Automotive GmbH

Crash Safety

David Kreß
DEKRA Automobil GmbH

Current accident situation

In 2010, 3648 people were killed in traffic accidents in Germany. While the number of traffic deaths shrank, at the same time the number of registered vehicles grew. By January 2011, there were 42.3 million registered vehicles in Germany, with electric and hybrid cars accounting for only 0.095% (40,000 vehicles). Nevertheless, a clear trend in registration figures can be seen: by June 2011, 5,500 additional electric and hybrid drive vehicles had been registered.

Role of the crash test in vehicle development

Electric vehicles are not a new invention, but have been around for over 100 years. However, today is the first time mass-produced high-voltage technology has had a chance of penetrating the market. “High-voltage system” is a very general term for vehicles equipped with an electric drive with a voltage range of 60-1500 V DC/25-1000 V AC. Combined with resistance, this results in very high currents, thus enabling vehicle manufacturers to employ a broad range of drive and battery technologies. The methods for testing these high-voltage technologies include vehicle and crash simulations, component tests, and tests of the overall vehicle.

This last test type serves to check the active and passive safety of the entire vehicle and demonstrates, among other things, conformity of production. In other words, these tests guarantee that safety standards are met throughout a specific production period. They also serve to monitor the physical, thermal, and chemical state of the high-voltage components. Additional low-speed crash tests can also be used for assigning vehicles to specific insurance categories and no-claims classes.

Vehicle-specific features of high-voltage vehicles

High-voltage vehicles explicitly differ from conventionally-powered vehicles in several of their features. Nevertheless, both types of vehicle must conform to the same standards of passive safety for passengers. One basic difference relates to the installation location and requirements for the energy storage unit and high-voltage wiring, a concept covered by the term “packaging.” This refers to the fact that in high-voltage vehicles, generator sets can be uncoupled or mechanically disconnected from the main unit, resulting in geometrically variable front structures that can make a positive contribution to passenger and pedestrian safety. At the same time, new requirements are being placed on the properties and arrangement of electronically controlled safety systems.

Another special feature of electric vehicles relates to the more complex requirements for battery management. The vehicles also differ greatly in terms of their effect on environmental conditions. “IP protection classes” serve to classify electric drives according to the various ways in which they influence environmental conditions. In addition, such drives place additional demands on service and workshop staff.

Figure 1 provides four examples of different installation locations for vehicle and high-voltage batteries.

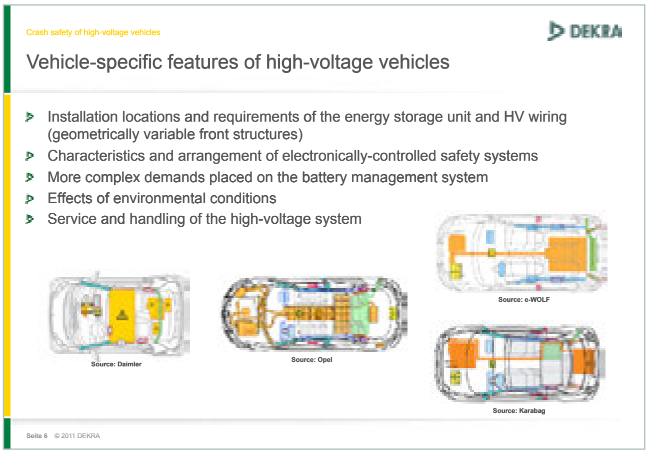


Figure 1: Vehicle-specific features of high-voltage vehicles

Of the hybrid and high-voltage vehicles currently being driven on German roads, most were not specifically designed as high-voltage or electric vehicles, but were subsequently converted. This explains why there is a fixed installation location for the batteries' high-voltage storage systems in the trough of the fuel tank, which can be mounted more or less advantageously in the vehicle.

The Opel Ampera was specially designed for an electric drive. The battery was moved along the transmission tunnel to the area of the vehicle that is statistically the least likely to be damaged or deformed in an accident. This brings up the question of whether the conversion from an internal combustion engine to an electric drive creates new safety hazards, and whether the same safety standards should be applied to both electric vehicles and vehicles with internal combustion engines.

In particular, it should be noted that the battery cannot react as effectively to dynamic loads like a conventional fuel tank. For this reason, electric vehicles – which are trimmed down to achieve a light-weight construction – are reinforced in the relevant areas around the battery to prevent penetration or the intrusion of other vehicle components. At the same time, however, such reinforcement increases battery load and acceleration values.

Crash performance by hybrid and electric vehicles based on the example of the Toyota Prius II

In 2009, a three-year-old used Toyota Prius with an odometer reading of 124,000 kilometers was crash-tested at the DEKRA Crash Test Center. The Toyota Prius was chosen because it was the world's biggest-selling hybrid vehicle in 2009, and the vehicle with the highest registration figures in Japan at that time.

The car had a nickel-metal hydride battery with a rated voltage of 201.6 V that was mounted behind the rear seats. An inverter was housed in the front left-hand area of the vehicle. The inverter converts the battery's DC voltage to AC for the electric drive and converts the recuperated AC voltage to DC for storage in the battery. The high-voltage lines followed the same route as the fuel lines. The test was performed in accordance with FMVSS 305, which includes FMVSS 208, and involved a frontal impact at an angle of 30 degrees to the vehicle's longitudinal axis with a 100% overlap against a stationary, non-deformable barrier.
The collision speed was 49.1 km/h, meaning that it was within the upper range of the tolerance specified in the standard. The test vehicle weighed 1557 kg. In contrast to rating tests performed by Euro NCAP, impact was to the left vehicle side because this is where the inverter is located. The point was to test this critical area.
As a result of the high energy absorption on the left side of the vehicle, both the A-pillar and B-pillar buckled at the roof rail. The tremendous force was transferred to the left side of the vehicle body through the load paths of the side member and door sill area. The cable duct was wedged in the axle but the high-voltage cable below it was not damaged.

When the vehicle detected the crash, it activated a safety fuse that protected the high-voltage battery against short circuits and disconnected it. The inverter and electric motor were also actively short-circuited, which prevented reverse currents to the battery that might have also been applied to the vehicle body.

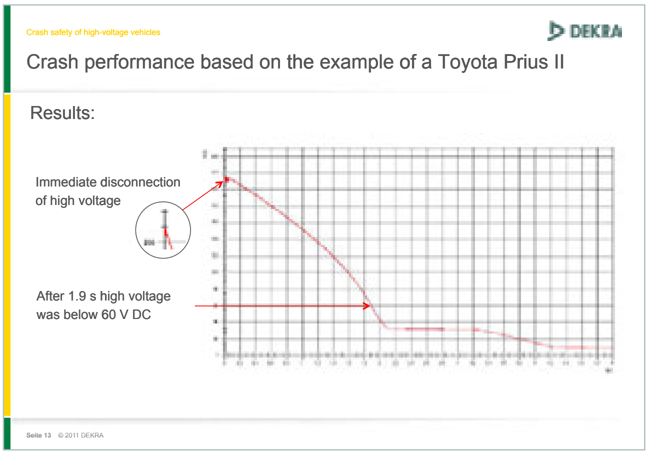


Figure 2: Crash performance based on the example of a Toyota Prius II

The graph of measured values (Fig. 2) indicates that the high voltage immediately dropped when the crash was detected (in the Toyota Prius, this is accompanied by airbag deployment) and – in accordance with the DIN standard – fell below 60 V within five seconds (in this case within as little as 1.9 seconds).

To summarize, neither the high-voltage cable in the vehicle undercarriage nor the inverter was damaged, despite the high loads. The vehicle body, which was also highly stressed, contributed to passenger safety. All limiting values for the dummies were within the range of tolerance. The battery shifted within the harness but no connections were torn away and the battery casing was undamaged. There was no risk of fire or explosion at any time during the crash test.

Further actions

- Active safety is especially important in the case of high-voltage vehicles.
- It is important to discuss the exact moment at which the vehicle’s high-voltage system should be disconnected. The possibility of a secondary collision must also be taken into account.
- Rescue workers and passengers at the crash site are often unable to unambiguously identify whether a vehicle really has been disconnected. An important issue in this case is the standardization of battery cut-off.
- Another question to be discussed is whether converted vehicles should be required to meet the same safety standards, or whether the requirements for electric and high-voltage vehicles operated in urban areas are at all comparable to those for conventional vehicles.

David Kreß
david.kress@dekra.com
DEKRA Automobil GmbH
Project manager crash tests

Battery Technologies, Battery Safety

Armin Gräter
BMW Group

BMW and electromobility

After 40 years of research into electromobility technologies based on individual vehicles, in 2009 a test fleet of around 600 MINI E vehicles was released on the market. Currently the company is working on a test fleet of some 1000 of the first ActiveE vehicles – a tremendous expenditure, but justified and necessary for purposes of research, and above for examining customer behavior in the everyday use of electric vehicles. In the area of hybrids, BMW introduced the X6 in 2009 and the 7 Series in 2010. The 5 Series has also been released and its market launch is planned for the beginning of 2012. The BMW 3 and 5 Series are full hybrids with a very limited electric range, which keeps the battery size manageable.

Drive integration

These vehicles demonstrate how an electric drive can be subsequently integrated into a conventional vehicle concept, provided the manufacturer already planned for the possibility during the design phase. The new BMW 3 Series was designed for a possible conversion without any increase to the weight or cost of the basic vehicle. Space is reserved in the vehicle for potential electromobility components. The 8-cylinder all-wheel drive used to be BMW’s top model in terms of weight limit and vehicle layout. Today the hybrid variant represents the weight limit and thus defines the vehicle pulse and crash properties.

Market penetration

The energy density of modern lithium-ion vehicles has changed considerably since the 1970s. Nevertheless, the number of cars with internal combustion engines will continue to be disproportionately high in the future. Most likely, the vision of a million electric vehicles on Germany’s roads by 2020 is realistic only if calculations include single- and double-track vehicles with range extenders and plug-in hybrids. Purely electric vehicles like the BMW ActiveE and BMW i3 are designed for city driving. An electric universal vehicle suitable for all fields of application doesn’t seem possible by today’s standards. It is unlikely that electromobility will ever entirely replace the internal combustion engine, which is why it is so important to discuss solutions involving hydropower and fuel cells.

Battery technologies

At this time, BMW has various battery technologies on the market (Fig. 1). The full hybrid vehicles are equipped with lithium iron phosphate round cell batteries from A123. The BMW ActiveE and the BMW i3 and i8 have prismatic cells from SB LiMotive, a joint venture between Samsung and Bosch. A123 round cells have been around for some time. Similar cells are also used in consumer electronics. These cells are extremely dynamic, deliver power quickly, and can be very quick to recharge.

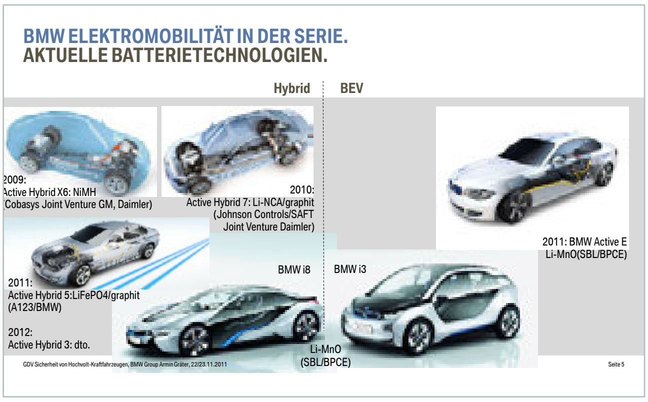


Figure 1: Current battery technologies

Longer-range vehicles need high-energy cells. BMW uses the above-mentioned prismatic cell, which is encased in aluminum. Pouch cells have the same chemical design. Their cathode and anode are in the same location but are wrapped inside a film, which reduces their weight and takes up less space. In BMW’s storage concept, heat is dissipated at the base of the cell, which is why the aluminum body of the prismatic cell is so advantageous given the excellent conductivity of the battery’s aluminum base plate and of the coolant.

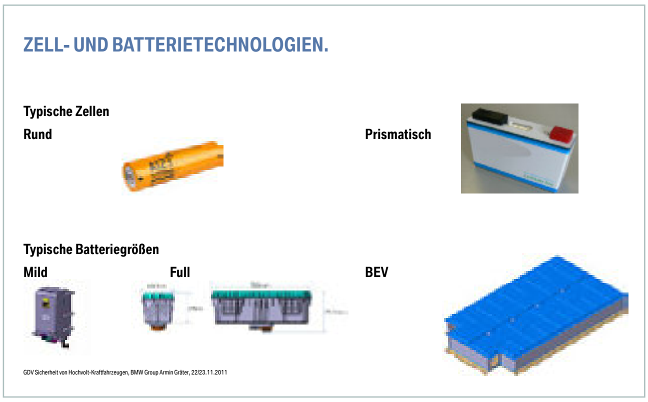


Figure 2: Cell and battery technologies

Fig. 2 shows a mild hybrid battery. The illustration is not quite true to scale – in fact, the battery is even smaller. A full hybrid battery is about 60 cm wide and is sometimes located behind and sometimes above the axle in an area that is extremely well protected against crash damage. This battery also has a protective casing. Thus the casing and the vehicle itself must meet certain requirements in terms of accident safety. In an electric vehicle the battery is not crash-protected by its installation location, but the cells are enclosed in a casing. In this case, crash performance depends on the installation space and on the vehicle itself.

Vehicle safety

BMW’s overall safety concept also takes into account the risks of electric shock and vehicle fires. Specifically, three crash functions were built into the vehicles:

1. Crash shut-down by the airbag control unit with direct line to battery contactors: Safe and fast disconnection of battery from on-board power supply and redundant disconnection via the bus system.
2. Active short-circuiting of electric motor: To prevent current induction in accidents where the vehicle continues to roll, the IGBTs switch to an internal short circuit, thus converting the created energy to heat before high voltage can enter the on-board power supply.
3. Active discharge of capacitances in the DC link by means of powerful capacitors that return much more than 60 volts and a certain amount of energy to the system when they are passively discharged. For optimal fire protection, a very fast discharge in the two-digit millisecond range is required.

Summary

Intensive, systematic analyses of all the risks relating to electromobility were conducted and appropriate actions were taken covering a vehicle’s entire life cycle, from development, to production, all the way to disposal.

- Following an accident, the risks posed by batteries should not be underestimated. In the case of the relatively minor accidents that are highly relevant for insurance companies, the integrity of the high-voltage system is preserved. At most, a reversible cut-off is required that involves no costs after the accident.
- In the case of extremely serious accidents in which passenger protection is pushed to its limits, battery damage is possible. Depending on the accident scenario, the battery may be deformed or the cells damaged.
- The risk of a battery fire cannot be completely ruled out.
- A metal fire could theoretically be caused by the aluminum casing. However, the battery cells contain no metallic lithium. The unfortunately widespread claim that almost all battery fires are metal fires has no basis in reality.
- A battery fire must be cooled and, if possible, extinguished with large amounts of water. This can serve to dilute any corrosive liquid that may leak out and bind any gases.

- The BMW plant fire brigade recommends the following extinguishing agents, depending on the specific situation: water, foam, sand, or metal fire extinguisher. The same recommendation applies equally to electric and conventional vehicles.
- Under certain circumstances, controlled combustion may also be attempted.

Armin Gräter
armin.graeter@bmw.de
BMW Group
Corporate Manager Functional Safety

Electric safety regulations

Gerd Kellermann
Federal Ministry of Transport, Building and Urban Development

International and National Regulations
International regulations for electric safety are enacted by the Economic Commission for Europe. Non-European contracting states have also joined the UNECE (United Nations Economic Commission for Europe). If nothing else, the harmonization of regulations is in the best interest of vehicle manufacturers because it significantly reduces expenditures. The high level of safety in Germany should also apply in other countries so that foreign vehicles coming into Germany are just as safe.

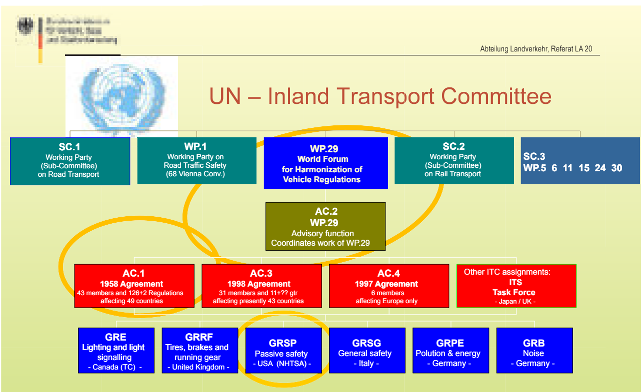


Fig. 1: UN Inland Transport Committee of The Economic Commission for Europe

The Economic Commission for Europe includes a UN Inland Transport Committee, where the World Forum for Harmonization of Vehicle Regulations is estalished. It includes six formal groups. The Working Party on Passive Safety (GRSP) deals with passive vehicle safety. France heads up the World Forum, the U.S. is in charge of the GRSP, and Germany directs the Group on Electric Safety as well as the group addressing battery safety. Japan, the U.S., and Germany are sponsors of the group that deals with the safety of hydrogen / fuel-fuel cell vehicles. This group has developed a global technical regulation that was presented in Geneva. These regulations do not fall under the 1958 agreement, which states that the approval of components in all other contracting states must be recognized. Therefore, if the Kraftfahrtbundesamt (KBA) in Germany approves a component, it will also be recognized in France, Romania, and other countries.

With regard to the safety of high-voltage vehicles, quite a few regulations have already been put into place, for example, 01 series of amendments to Regulation no. 100 for functional safety as well as crash regulations in Regulations 12, 94, and 95, and Regulation 10 concerning electromagnetic compatibility. So far the latter has only been adapted for passenger vehicles, but in the near future commercial vehicles will be included. This is especially problematic in the case of high-voltage vehicles because of the effect on other parts. The European Commission is not developing its own regulations on electric safety, but is adopting what was developed in Geneva. This will then apply on a mandatory basis to all 27 Member States of the European Union. In addition to the U.S., other countries like China and Korea – in other words, important vehicle manufacturers – are not contracting parties to the 1958 agreement.

There is an EC type approval on the European level. All manufacturers arrange to have their vehicles or vehicle series undergo a type approval. UNECE regulations such as Regulation 100 are used for process. Specific transitional periods are in place so that manufacturers can adjust to new regulations and can continue normal production. However, it is unacceptable in certain areas for transitional provisions to last too long, for example, with regard to the functional safety of high-voltage vehicles.

All motor vehicle type approval authorities in Europe agreed that high-voltage vehicles must satisfy Regulation 100. Although there is no legal obligation, the regulation must be satisfied in order to put a vehicle on the market.

The type approval only applies to mass-production vehicles. Individual vehicles or retrofitted vehicles are examined and approved on a national basis. This appears to be problematic: The concern relates primarily to retrofitted vehicles. Who decides whether a retrofitted auto gets approval in Germany? In the German Motor Vehicle Safety Regulation, § 30 states only very generally that no one may be injured or more than unavoidably injured, impeded, or inconvenienced. This requires a more precise regulation. Before such a vehicle is approved, a technical approval certificate issued by the technical service (TÜV, DEKRA, or GTÜ) must be submitted. In the meantime, there is a uniform instruction sheet that is the basis for the approval certificate. This is a step in the right direction, but not a binding regulation.

Requirements for batteries and battery tests

A Battery Working Group is revising Regulation 100 in an 02 series of amendments and eight different tests will be required: Vibration, Thermal shock and cycling, mechanical impact, fire resistance, external short circuit protection, overcharge protection, Over-discharge protection, and Over-temperature protection. Two tests were singled out as examples: the fire and mechanical impact tests. Both of them can only be conducted or only make sense in the context of the entire vehicle. A stage-by-stage component approval would also be potentially conceivable. The other tests could also be conducted, for example, by the battery manufacturer. This would relieve vehicle manufacturers of the costs, and production would again be more reasonable. Costs are still a problem in general.

Outlook

One of the next steps will be to adapt the aforementioned electromagnetic compatibility for commercial vehicles. In addition, the World Forum for Harmonization of Vehicle Regulations decided to establish two informal groups for addressing the global technical regulations for high-voltage vehicles. One is dealing with safety and the other with environmental regulations for high-voltage vehicles. At their first meeting, these groups will decide on more precise objectives and approaches.

The battery regulations in Regulation 100 should be completed from a technical point of view in January 2012 and be adopted by the GRSP in May. There is an urgent need for revision in terms of the German Motor Vehicle registration approval act; it is imperative that this has to be adapted to international regulations.

Gerd Kellermann
gerd.kellermann@bmvbs.bund.de
Federal Ministry of Transport, Building,
and Urban Development
Innovative and Communicative Vehicle Technology,
Automotive Engineering (vehicle safety)

Discussion results “Crash Safety Workshop”

The workshop was dominated by discussion of Revision Status 2 (Rev2) of ECE-R100[1], which Mr. Kellermann discussed in his impromptu presentation, and which deals with very important requirements for the safety of high-voltage motor vehicles. These regulations are currently being developed in conformity with the Government Program on Electromobility[2] and go beyond the requirements of the valid Revision Status 1 (Rev1).

The discussion portion of the workshops covered the following three topics:

1. Approval regulations
2. Deactivating the high-voltage system
3. High-voltage batteries after an accident

1. Approval regulations

1.1 Simplified safety requirements for pure electric vehicles

Whether simplified safety requirements should apply for purely electric vehicles was discussed, because they can be classified as purely urban vehicles in terms of their typical ranges. However, this was deemed impractical, because a clear separation is not possible and accidents within city limits can also make high demands on the vehicle's safety performance.

1.2 Retrofitted vehicles

Retrofitted vehicles – which must accommodate high-voltage components in a car body that was originally built for a combustion engine – were fundamentally viewed as problematic. Known forms of retrofitting are based on the vehicles in the compact or small-car segment. Because their tank chambers are for the most part small, batteries are installed, for example, in the trunk, which means that rear-impact protection must be given special importance. However, qualified structural adaptations are typically not observed here. Special test methods were proposed but were not considered expedient, because these retrofitted vehicles will not be approved according to the process described by Mr. Kellermann. In fact, it is typically the individual inspections according to national regulations that are anyway considered to be inadequate, so that approval is largely at the discretion of the examiner: Approval regulations that were not prepared for this application and are considered to be too general are applied.

In the case of production vehicles, the tests according to ECE 100 Rev2 that are in the process of being approved are already being applied in development, and so in the group's estimation they guarantee a high level of protection. This can be achieved either by component tests of the battery against impact or by impact tests of the entire vehicle.

1.3 Converted vehicles and after-market modifications

A similar question is related to modifications, by so-called “tinkerers.” It can be anticipated that in the future, upgrades of batteries with advanced technology will also be ordered from sources other than OEM distribution channels. Likewise, it is possible to imagine that more powerful batteries or other components will be offered by “tuners.” These measures would not necessarily be covered by § 27 German Motor Vehicle Safety Regulation (StVZO), and therefore the components could potentially evade approval testing. In these cases, we could not foresee how these parts would react in the event of a crash.

On this point, there was consensus that there is a significant risk from this scenario, for example, from low-quality components.

2. Deactivating the high-voltage system

2.1 Automatic shut-off of the battery after an accident

Shutting off the battery in an accident was also discussed. It was established in this regard that intrinsic safety is already being required by ECE-R100 Rev1, either by secure access protection or by self-monitoring with shut-off of the system. This shut-off can be coupled, for example, to airbag deployment. This matter was explored to the extent that a decision about the drivability of the vehicle after the accident will be made by battery

1 Group of interested experts on Rechargeable Energy Storage Systems (RESS), http://www.unece.org/trans/main/wp29/wp29wgs/wp29grsp/elsa/elsa_subgroup2_6.html
2 The Federal Government: Government Program on Electromobility, http://www.bmbf.de/pubRD/programm_elektromobilitaet.pdf

management, which was also viewed as critical. This was opposed by representatives of several vehicle manufacturers who feel that a two-stage shut-off should be realized as a solution. This permits ongoing operation of the vehicle after minor accidents and passage of a self-test. Only after a very severe accident should reactivation of the system be prohibited except by a repair shop. Basically, however, the requirements according to ECE-R100 Rev1 are already considered to be adequate for peoples' safety.

2.2 Shut-off using a disconnect plug

Another point of discussion was the disconnect plug for the battery, also called a service disconnect, which can be used to disconnect the battery from the HV network. In the case of the Opel Ampera, this plug is available to the fire department in the passenger compartment. The discussion dealt with the standard availability of this plug after an accident, which is currently not the case. Based on legal requirements, an "always-off" relay is being installed in high-voltage (HV) motor vehicles during production: in other words, in the event of the failure of the 12-V supply on the relay, the high-voltage battery will be disconnected from the network by the relay/contactors. This 12-V supply is interrupted in the case of shut-off by an accident and the battery is disconnected. As a result, some workshop participants viewed the disconnect plug as unnecessary. At the least, the possibility of being able to see that shut-off has occurred was cited as desirable. In addition, the information about this safety behavior should be disseminated to vehicle users and first responders.

3. High-voltage batteries after an accident

3.1 Handling damaged batteries

An essential point is managing the high-voltage battery after an accident. In the opinion of representatives of the vehicle manufacturers who were present, ECE-R100 Rev2 already provides a high level of protection from the consequences of damage. However, handling these batteries after the actual occurrence of battery damage has not been adequately regulated yet. In this case, manufacturers' guidelines for the respective vehicle are deemed to be necessary, and in this case as well, reference was made to the necessity of providing more information to affected parties, for example, towing services. A concrete suggestion was made that VDA Taskforce "Rescuing Persons" deal with this subject.

3.2 Transporting the damaged battery or battery parts

After accidents, in some circumstances the battery as an individual part or modules thereof must be salvaged and transported separately from the vehicle. The workshop participants felt that there is an urgent need for action in this case, because lithium-ion batteries may only be transported outside of the vehicle in a very restricted manner. The current regulatory situation has possibly been shaped by previous experience with batteries that were based on metallic lithium, and does not correspond to the current reality. As a result, practically all transports take place under exceptional arrangements.

The group viewed it as the responsibility of the VDA and the BMVBS to submit proposals to amend the legal situation.

3.3 Endangerment of passengers from escaping battery chemicals or fire

Further discussion points related to the endangerment of vehicle passengers from gas escaping from traction batteries as well as the endangerment of cleaning services and fire departments after the discharge of electrolytes. It was stated in this regard that lithium-ion batteries do not contain large quantities of electrolytes, and any amounts that do escape normally do not remain in liquid form because of chemical reactions. According to the current draft of ECE-R100 Rev2, escape into the passenger compartment is not permitted within 30 minutes of the accident, and in general only seven percent of the electrolytes may escape. This also implicitly covers the entrance of gases that are formed from the electrolytes of the traction battery into the passenger compartment of the vehicle. More comprehensive protection is also intended for this eventuality. The topic of fire after battery failure or damage was also addressed. With regard to controllability, a greater risk is seen in the event of a fire after an accident than in the case of electrical hazards. However, it was not possible to deal with this subject in more detail because of a lack of experience. The prevailing opinion was that in an accident, reliably disconnecting the battery from the high-voltage system and actively discharging the high-voltage system should be given the top priority.

Rescue Chain Workshop

Approximately 30 participants in the Rescue Chain Workshop actively discussed factors related to rescue from high-voltage motor vehicles that have been involved in an accident. They also addressed the special characteristics that need to be considered when assessing and salvaging vehicles with these types of propulsion that have been involved in an accident. It was especially gratifying to see the great diversity of organizations that sent representatives to this workshop. In addition to international automobile manufacturers, fire departments, and police authorities, these organizations also included associations from the automobile industry as well as towing and service providers. Three impromptu presentations provided a jumping-off point for the topic of the rescue chain.

Workshop leader:
Dr. Axel Malczyk, German Insurance Association,
German Insurers Accident Research

Interdisciplinary VDA / VDIK Working Group: Fire Departments and Emergency Services and Vehicle Manufacturers

Jürgen Peitz
Adam Opel AG

1. Initial situation

Everyday VDA or VDIK work is handled by working groups made up solely of manufacturers, but the “Interdisciplinary VDA / VDIK Working Group: Fire Departments and Emergency Services and Vehicle Manufacturers” is different: it deals exclusively with saving human lives. In this situation, an interdisciplinary cooperation is intended to produce uniform conclusion and regulations. The working group’s first meeting in 2007 consisted of a discussion at the Interior Ministry: The topic was the problems that fire departments were having with the high-strength and ultra-high-strength steels that are increasingly being used. A common direction was lacking, and it was unclear how the required information should be obtained. At the suggestion of the VDA, a working group was formed composed of the VDK, VDIK, representatives of fire departments, an emergency response physician and guest consultants, and service providers from Moditech, ADAC, DAT, and KBA.

2. Previous results

In 2009 the standardized rescue data sheets were updated in terms of content, layout, and legends. At the same time, the fire department adapted the VFDB guidelines to the new information. At the request of the working group, the law was amended in 2011 by the German Bundestag: since that time, a license-plate checking function has been authorized for emergency command posts. The next step, which should be implemented in 2012, is already in process: using the command post’s license-plate checking function, emergency responders will immediately receive (in under five seconds) a display of the vehicle rescue data sheets automatically selected for the vehicle involved.

3. Composition of the working group

The VDA is comprised of German automobile manufacturers. A representative in the VDIK brings the interests of its members to the working group. A fire department representative officially appointed by the Interior Ministry has a central leadership role in the group. Experts from fire departments in Berlin, Ludwigshafen, Munich, Hamburg, and Wiesbaden provide questions and assignments for the group. The working group’s broad base is especially crucial. The KBA was responsible for creating the database retrieval function, the federal ministry introduces legislation, the ADAC provides consulting services to the group, and the professional association has also become involved. Vehicle manufacturers prepare specific rescue data sheets that have a standardized layout according to the information needs of the fire departments. DAT, a company that is part of VDA, VDIK, and ZDK, has been commissioned in the meantime to generate a central database with an integrated license-plate checking function.

4. Most important content of the rescue data sheets

The rescue data sheets contain uniform information that covers all relevant automotive technology. Practical experiences and any resulting requirements are discussed directly and continuously with the fire departments, the emergency response physician, and the vehicle manufacturers. The rescue data sheets are always structured the same way. Figure 1 shows the rescue data sheets for high-voltage vehicles. It shows, for example, how the vehicle can be prevented from rolling and how it can be

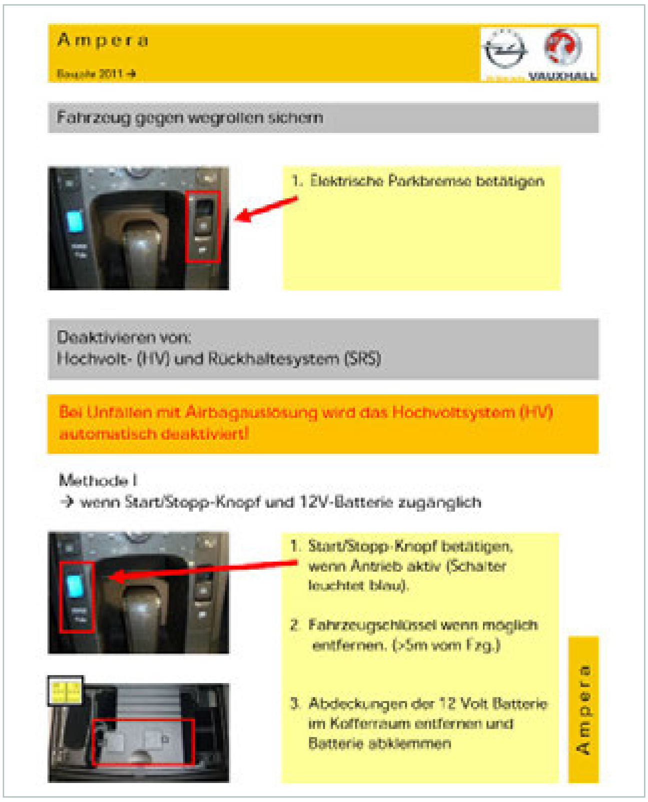


Figure 1: Rescue data sheet for high-voltage vehicles

deactivated. It also includes various scenarios for potential accident situations (Fig. 2 and 3). This standardization has already occurred and has been implemented universally.

Figure 2 and 3: Rescue data sheet for high-voltage vehicles

5. Outlook

The working group is currently dealing with details that include rights of use. This detail work should not be underestimated. A variety of official requirements have to be met on the subject of data protection alone. In March 2012, the so-called pre-pilot phase began using dummy data records from the KBA to make fictitious requests under real conditions. The pilot phase will begin four weeks later: five fire departments will test the system over a period of six months and record any deficiencies. If these test phases go smoothly, the system can be introduced in September 2012.

In addition, a dialog has already been initiated with other countries about how the license-plate checking function can be conducted legally for foreign vehicles. This would definitely be feasible technically, but the subject of data protection is more problematic. Discussions with an association of Swedish automobile manufacturers revealed Sweden's great interest in the German system of license-plate checking and their desire for international cooperation. The English have also expressed their interest.

One of the biggest challenges is providing information for and training fire departments. There are 40,000 professional firefighters in Germany and one million volunteers, making the training measures correspondingly expensive. High-voltage equipment and laptops are not yet part of the fire departments' basic equipment. In addition, it must be clarified as to whether the planned eCall content meets the requirements of the fire departments. A database linking both systems has already been taken into consideration, in terms of the system requirements.

Jürgen Peitz
juergen.peitz@de.opel.com
Adam Opel AG
Insurance Classification (TIC)

Safety after accidents

Dirk Breuer
Toyota Deutschland GmbH

1. Introduction

Toyota has already sold 3.3 million series-produced hybrid vehicles over the past 15 years. During the six years of production from 1997-2002, 130,000 vehicles from the first Toyota Prius series were built. From 2003-2009, 1.2 million Prius 2 were built. Currently an average of 45,000 Prius 3 are being built per month, for a total of one million within the past two years. All generations are equipped with high-voltage technology and, instead of one transmission, a hybrid transmission with two motor generators. An inverter/converter unit controls both e-motors. The battery is located in the trunk. The hybrid drive was developed so that it could be installed in the usual longitudinal position or transversely under the front hood. Theoretically, all conceivable drive configurations can be achieved with a hybrid drive, including those of the LEXUS rear-wheel and all-wheel drive. There are 13 different models with hybrid drives worldwide. All auxiliary equipment, such as servo steering and water pumps, are now electrically powered as well. There is no longer a v-belt. The cars' forward and backward propulsion is purely electrical and even the air conditioner is operated by high voltage. When more power is required, the internal combustion engine is activated and supports the e-motors as needed. Through regenerative braking, the hybrid battery is recharged by braking as well as in manual operation.

The battery must be relatively large, with 201.6 V and a maximum current of about 110 amperes. Braking is by cooperative control. In each situation, the electronics in the car decide which component will do most of the braking work, the hydraulics or the generator. As with any other car, the hydraulic brakes are controlled by means of the brake pedal. The difference, as described above, is that a portion of the kinetic energy that would be lost in a normal car is stored in the battery.

This technology can be used with all types of car body. We began providing the Toyota Auris with a hybrid drive in 2010. Since then, the same is being done with the Lexus CT 200h, and additional hybrid vehicles will follow in 2012. The cost of the drive is about the same as for diesel but weighs 35 kg less.
The ex works price of a single battery is 1,545 euros, not including VAT. The Toyota Prius is available in a van version (Prius+). In the U.S. it is available as a five-seater with the battery in the trunk. In Europe, a seven-seater van is being introduced with the battery in the center console between the driver and front-passenger seats.

2. Risk factors and risk prevention

The battery cables are not routed through the interior, so there is no risk of passengers coming into contact with high voltage. The battery is installed so that the cables are routed beneath a cover directly behind the seats where they exit the interior and – like the fuel and brake lines – run along the vehicle underside and terminate in front at the inverter/converter. All cables are “coaxial,” meaning that they are shielded by a metal mesh, which serves to monitor damage to insulation.

In the past few years, Toyota dealers have been trained to handle high-voltage technology. The German statutory accident insurance has published corresponding brochures and training standards. In Germany, there is now a standardized procedure that all Toyota dealers have learned as part of further training.

The battery is composed of individual plates held together by tie bolts. The position of the battery is such that the risk of its being damaged in an accident is very slight. However, if an impact is so severe that it extends to the area of the rear seat, the battery is initially shifted as a whole. Even if the tie bolts shear and the battery breaks apart, no liquid can escape because the battery comprises sealed cells that, theoretically, can also be removed separately. Thus, the system has an extremely safe design. The battery also contains various safety components, including a current sensor that checks whether the battery is charging or discharging, as well as relays that disconnect the battery from high-voltage cables when, for example, the ignition is switched off or in the event of a crash.

Pressing the start button switches on the relays. When the car is switched off, the relays are opened and current stops flowing. The system also checks whether the relays have actually been mechanically opened. This check is important because at 110 amperes, a defect could theoretically cause these contacts to melt and thus immobilize them.

Several years ago, Auto Bild magazine tested the safety of the battery. A Toyota Prius was driven into a wall such that the impact affected high-voltage parts. The result: “...sustains even a severe impact without posing any electrical risk.”

Each battery also has a safety plug that mechanically disconnects the battery cable. The plug contains a fuse that is activated at 125 amperes (for example, if there’s a short circuit in the cables). Even if the fire department should damage a high-voltage cable, there is no risk of electric shock when touching the car body because, unlike 12-volt systems, the car body is not used as a “negative pole.” Instead, it is connected to the engine compartment separately via a cable. The air conditioner compressor is also connected to the battery via two cables that, of course, are no longer supplied with power after an accident occurs.

Dirk Breuer
dirk.breuer@toyota.de
Toyota Deutschland GmbH
Press Officer Technology

Emergency Rescue and Fire-fighting with High-voltage Vehicles

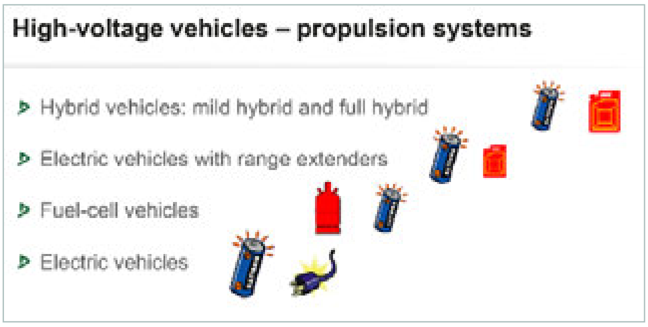
Markus Egelhaaf
DEKRA Automobil GmbH

1. Accident situation

According to official statistics, there were 3,648 traffic fatalities in Germany last year. In other words, an average of 10 people died every day in road traffic, and the number of people injured on Germany's streets is approximately 1,000 per day. There are more than 41 million registered passenger vehicles. The number of vehicles powered by alternative fuels is very low, at 468,000 automobiles (1.12 percent). This figure includes electric, hybrid, natural gas, liquefied gas-powered vehicles, as well as hydrogen vehicles with direct combustion. In January 2010, the percentage of electric and hybrid autos was only 0.07 percent (30,450 vehicles): but by mid-2011, a substantial increase was noted, with 3,500 electric and 42,000 hybrid motor vehicles. Future growth is to be expected.

2. Propulsion systems

When police, the fire department, or emergency services first respond to an accident, they have no idea what type of vehicle they are dealing with. There are conventionally powered autos (diesel, gasoline), those powered by natural or liquefied gas, and high-voltage vehicles. Hybrid autos are divided into in mild and full hybrid systems. They have a battery and a fuel tank normally containing gasoline, but in some cases natural or liquefied gas or, less frequently, diesel. There are also electric vehicles with range extenders, which have a correspondingly large battery and a small fuel tank with gasoline and soon also diesel. Fuel-cell vehicles have a battery and also contain hydrogen, which is a focus of risk and which is still new for emergency responders. In addition, there are also purely electric autos, which have only a battery and no additional fuel tank.



3. Accident analysis

Accidents with electric vehicles are rare, but the reason is that until recently there were very few of these types of autos on the roads. If international accident statistics are consideed, one can see that the accident and damage pattern for these vehicles does not differ significantly from that of vehicles with conventional propulsion. The loss totals in the hybrid sector alone have turned out to be higher, because most of the time two systems require repairs after an accident, that is, both the electric and the conventional propulsion system. According to an NHTSA study, there is also a higher risk for pedestrian accidents, but DEKRA statistics were only able to confirm this conditionally.

Hybrid vehicles performed well in a crash test commissioned by the magazine Auto Bild. The test was conducted using the U.S. standard. The test vehicle was a used car with a service life of over 100,000 kilometers. The emergency shut-off deployed within five seconds, and the voltage disconnect also functioned reliably. In addition, the inverter was not damaged and the high-voltage cables also did not present a problem in the crash.

Hybrid vehicles performed well in a crash test

4. Rescue from high-voltage vehicles

At present there is still a training deficient among emergency responders. The German Association of the Automobile Industry (VDA) has formed a working group to begin changing this. Because of the decentralized organizational structure of German fire departments, and the limited amount of time available for training in the case of predominantly volunteers, it is very difficult to bring the results gathered by the working group to emergency responders on a comprehensive basis. In addition, identifying the types of vehicles is also problematic. There is a wide range of propulsion and fuel systems. These are not readily identifiable by looking at the auto, but for tactical reasons related to the response require different courses of action. However, there is now hope for more clarity with the license-plate checking function that has been initiated. Another problem is the overlapping nature of various risks, for example, hydrogen and electricity. Added to this is the "unknown" variable of direct current. Every emergency responder knows what to do in the event of an electrical accident. However, completely different medical procedures are required for a direct-current shock than for an alternating-current shock. Only very few emergency responders are aware that emergency services personnel need appropriate instructions for this eventuality.

The rescue guidelines that were on the market before rescue data sheets were introduced in some respects contained very contradictory manufacturer-specific information. Manually deactivating the HV electrical system involves in many cases a paraphrasing of the repair instructions. Deactivation should be performed by trained electrical personnel wearing protective gloves. But most of the time, at the scene of an accident there are neither appropriately trained personnel nor the required protective gloves.

In the event of accidents, shocks from current-carrying components must be anticipated, and without appropriate material there is no possibility of quickly and reliably checking whether an emergency shutdown has actually taken place. These systems are reliable, and in most cases the emergency shutdown functions. Added to this is the fact that the electrical systems are self-contained. This means that touching parts of the car body is not critical in the case of contact between a conductor and the car body. The remaining residual risk of electric shock can therefore be classified as minimal.

The battery is a factor in and of itself. If any fluid escapes, corrosive substances must be anticipated. In addition, depending upon the battery type there may be a risk of fire. In addition, a battery might not catch fire until some time after the collision. Moreover, depending upon the type of damage to the vehicle, there could also be a short circuit resulting in a fire inside the battery if the vehicle is moved after the accident, for example, during salvage operations.

5. Fire scenarios

So far there is no indication that electric vehicles made by well-known manufacturers have a greater risk of fire than conventionally powered vehicles. In the case of vehicles with nickel metal hydride batteries, the battery can burst in the event of a vehicle fire; however, this only happens beginning at temperatures of approximately 100 to 110 degrees Celsius. In this case, fluids that are harmful to health are released.

The problem with lithium-ion batteries is that this term is used to describe batteries with extremely different internal systems whose risks have often not been well researched. In addition, the question arises of what happens to the vehicles during charging: what relays are open in this case? Are the systems consistently shut down in the event of a collision? This is the case with a majority of manufacturers’ vehicles, but unfortunately not with all of them. The deployment of airbags is cited by some manufacturers as a reliable indicator for the electric systems shut-off. While charging this indicator is not available.

In terms of extinguishing electric vehicle fires, conventional methods with water or foam can be recommended based on current knowledge. If this does not extinguish the battery, it will burn out on its own and there is no further risk. Initial tests with extinguishing agents such as F500® or Cold Metal® are still in the early stages.

6. Topics for discussion

An indicator of system shutdown would be meaningful for emergency responders so that it is possible for them to reliably identify whether shutdown has actually occurred. In addition, information about a vehicle that is included in the rescue data sheets should be formulated by all manufacturers in such a way that it is easy to implement on damaged vehicles even under emergency conditions. It must be possible for emergency responders to access shut-off equipment on the vehicle easily even under adverse conditions, and they must be able to operate this equipment using standard means without additional electrical training if the manufacturer has indicated in the rescue data sheet that actuation of this equipment is a required step. A standard plan should be developed in conjunction with fire departments and emergency services that is available as a working basis for the creation of future standards for fire-fighting. Just as important is pressing ahead with the retrieval of vehicle data using the license plate.

Markus Egelhaaf
markus.egelhaaf@dekra.com
DEKRA Automobil GmbH
Accident Research

Discussion results “Rescue Chain Workshop”

The discussion among the workshop participants included three main issues:
1. Information about and identifying HV vehicles
2. Rescue from HV vehicles
3. Fire or the release of substances from HV vehicles

1. Information about and identifying HV vehicles

1.1 Informing emergency services, fire departments, towing companies, and other parties about the safety aspects of high-voltage vehicles

Despite the fact that the automobile industry has developed rescue data sheets including HV models, communication of general information related to handling these types of vehicles must be improved. For example, a very heterogenous level of knowledge on this subject prevails among workers at towing and salvaging services. The instructions from the Germany Statutory Accident Insurance on qualifications for working on HV passenger vehicles (Professional Association Information Bulletin BGI 8686) is viewed as a good first approach for providing basic information. The police have also expressed an interest in obtaining information about HV vehicles. This might concern a police officer as a first responder at the scene of the accident, but also employees who are involved in taking custody of and identifying vehicles that have been secured. The level of information that is required still needs to be clarified.

1.2 Uniform labeling of HV vehicles for emergency workers

Uniform identification from the outside, even with small adhesive labels, for example, cannot be expected. Currently, HV vehicles must be identified as such by manufacturer-specific labels or model designations. However, accessing KBA data via the license-plate number would provide information about the type of propulsion (electrically assisted as opposed to combustion engines). Access to the database is supposed to be possible for a low annual fee (approximately €50). In particular, reference was made to small-scale manufacturers who are converting conventional small cars or delivery vehicles to electrical power. At first glance, these vehicles cannot readily be distinguished from their conventionally powered large-scale production models, and because of their small unit numbers they are frequently not identifiable at the KBA by a separate code number. Even though rescue data sheets are available for some of these conversions, there is doubt about whether the vehicles offer the same level of intrinsic safety as the HV system. The question arises as to whether in these cases the licensing authority should impose a requirement on manufacturers for an identification marking. These manufacturers are not organized within the VDA or VDIK. The Federal Association of Solar Mobility (Bundesverband Solare Mobilität e.V. (BSM) could be a potential contact point.

1.3 Clear identification of vehicle model and drive type for rescue workers

In this regard, the automobile industry is betting on the potential future retrieval of basic KBA vehicle information by rescue workers. This will allow the models represented in rescue data sheets to be allocated to the actual vehicle involved in an accident. In addition, if these data become accessible via a database, as mentioned in the impromptu presentation, and the database were linked to eCall data, in the future it could be possible in the event of an automatic emergency call to the emergency command post to provide fire departments with specific information for the rescue while they are en route to the scene of the accident. Representatives from a large professional fire department pointed out, however, that the IT equipment in their emergency vehicles does not currently allow this option. In particular, wireless internet access is nowhere near being made a requirement or standard for rescue organizations.

1.4 Documentation of accidents and incidents involving HV vehicles during the introductory phase

The representatives of several organizations and also manufacturers expressed an interest in a register that logs the details on accidents involving these types of vehicles. In addition to specifics about the models involved and the particular circumstances, this log should ideally also document the measures taken by the fire department and other rescue personnel. Accidents could be described in which vehicle's safety components and shut-off devices operated as intended, and so positive aspects of the behavior of high-voltage vehicles after a collision could be logged and placed in relationship to complications in other cases. However, the personnel and financial details of such a prospective study would still have to be clarified. In addition to this approach, it was suggested that data from the GIDAS accident research (German In-Depth Accident Study) and German Insurers Accident Research (UDV) be examined.

2. Rescue from HV vehicles

2.1 Risk of electric shock for rescue workers and first responders when approaching or touching the vehicle

This concern was clearly rejected by representatives of the automobile industry. In addition to the shut-off mechanisms that are activated in the event of a severe accident along with airbag deployment, large-scale manufacturers also provide safety precautions that shut down the high-voltage system in the event of damage to the insulation of high-voltage components, among other things.

2.2 Shutting off the high-voltage network

The desire expressed numerous times by rescue workers to be able to actuate a service disconnect switch for safety purposes (manual disconnect device of the battery from the remaining high-voltage system) is not favored by some manufacturers, because the entire on-board vehicle power supply can be immobilized. This switch is therefore intended only for trained technical personnel in repair shops. In some models, particularly for the American market, locations defined for disconnection (solely by rescue workers) in the low-voltage supply network are marked in order to also activate shut-down of the high-voltage network resulting from power loss in the 12-V range, and to prevent any potential recovery of transformed voltage from the high-voltage network into the 12-V network. The desire for a clearly marked indicator for rescue personnel that shut-off has taken place was put forward once again in this context.

2.3 Comparability of intrinsic safety in large-scale production passenger vehicles and other HV vehicles

Because corresponding representatives of this sector were not present, it was not possible to dispel doubts that the intrinsic safety of small-scale production models or after-market conversions of popular models might not reach the level of large-scale manufacturers. Similar concerns were expressed with respect to commercial vehicles. The unit numbers are naturally low in this area, and multiple manufacturers are involved in the fabrication of a commercial vehicle by supplying the chassis, creating the superstructures for the intended use, and making conversions.

3. Fire or the release of substances from HV vehicles

3.1 Hazards from burning battery cells and appropriate extinguishing techniques

Representatives of the automobile industry explained that no explosion risk can be anticipated from burning or otherwise thermally stressed HV batteries, but conceded that there are different levels of safety depending upon the design. They stated that explosive reactions were still most likely in the case of conventional lead-acid batteries. A “bonfire” test is reportedly in the works as a global standard for battery behavior under the effects of open fire. A battery fire or fire in the individual cells is nonetheless to be avoided insofar as possible. If the battery is affected completely or partially by fire, the use of generous quantities of water is unanimously recommended as an extinguishing tactic in order to cool both the affected and surrounding areas. However, it is not possible to extinguish lithium-ion cells that are already burning. The use of foam agents is not considered harmful, but could obscure the view of hidden embers. Fighting fire with CO_2 is not recommended.

The concern that toxic substances could form in hazardous concentrations from massive damage to battery cells or contact of the open cell with water that could endanger vehicle passengers as well as emergency personnel and first responders was disputed by the automobile industry. They pointed out that past negative experiences with lithium-ion batteries in laptop computers should not be applied to the batteries used in automobiles, because a different technology is used. As a rule, the concentration of any hydrofluoric acid that might escape is reportedly quite safe. However, it was recognized as a limiting factor that some details of the battery chemistry are still unknown, and that – in contrast to the fire department, which is able to use breathing masks when fighting fire – this protection is not available to other rescue workers.

3.2 Handling batteries that are not installed in a vehicle

Even though this situation is conceivable only in the most severe accidents, it cannot completely be ruled out that in the event of an impact, the HV energy-storage device is ripped from the vehicle and then must be handled and transported separately. Conveying batteries damaged in this manner by a towing service, for example, is subject to stricter requirements, including those relating to qualifications of the personnel, than transport when still installed in a vehicle involved in an accident. Solutions are required for this unclear legal situation.

Essential Findings of the Symposium

Inform	• Need to provide information to emergency services, police and fire departments • Clarification of shut-off logic in the event of accidents or other malfunctions of the high-voltage system • Need to provide information to users concerning special risks or peculiarities when operating high-voltage vehicles, e.g., by driving schools • Periodic exchange of experience on an interdisciplinary basis
Ensure safety	• There must be acoustic perceptibility at all speeds • Clear visualization of the status of the battery or the high-voltage system – especially after an accident • It must be possible for emergency services, fire departments and police to identify high-voltage vehicles • Conduct testing to prevent battery malfunctions in connection with the exposure of persons to gas, electrolytes and fire • Collect information about damage, accidents and incidents with high-voltage vehicles
Develop regulations and approval	• Future approval regulations will address battery safety and electric safety more clearly • No differences in safety standards between large and small-scale production vehicles • Address the danger of alterations and after-market modifications
Standardization	• Desire for a manual, standardized (if possible) shut-off possibility (disconnect plug) • Uniform charging plug – at least a European standard must be created quickly
Facilitate battery transport	• Handling of damaged traction batteries or parts thereof must be regulated appropriately • Transport regulations must be set up more realistically, because they are unduly restrictive

Outlook and Final Remarks

Siegfried Brockmann
Head of German Insurers
Accident Research (UDV)

I have brought four points away with me from the workshops in this symposium that, in my opinion, require special consideration.

One point relates to the issue of **"tinkerers"** namely, in the area of maintenance as well as tuning: It's possible that we have no idea whatsoever of the kind of havoc that can be wreaked in the garages of private individuals.

Just as important is the problem of **battery transport** by emergency personnel. They cannot be required to obtain special approval for every accident in order to tow away a vehicle involved in an accident along with its battery.

Furthermore, the topic of **providing information** is enormously important. Information needs to be provided to the public, police, and towing companies. This need still exists with respect to fire departments as well.

The final point relates to the **noise production** of electric vehicles. The prevailing opinion among the working group was that electric vehicles should produce noise, but what kind of noise remains to be seen at this point. Safety is being dealt with prior to the issue of noise pollution.

I have been very impressed by the results of the workshop, even though in a few cases it was established that there is a need for more research. But this is also very natural in the case of such a new technology. Even if several questions still need to be clarified, this event has resulted in establishing that electromobility is a safe form of transportation that nobody needs to fear.

My expectations were more than met, and I hope that we are able to continue the discussion in the future.

Many thanks!

Gesamtverband der Deutschen Versicherungswirtschaft e.V.
Unfallforschung der Versicherer

German Insurance Association
German Insurers Accident Research

Wilhelmstraße 43 / 43G, 10117 Berlin
Postfach 08 02 64, 10002 Berlin

Phone 030 / 20 20 - 50 00, Fax 030 / 20 20 - 60 00
www.udv.de, unfallforschung@gdv.de