On the Road with High Voltage

Engineering Thermoplastics Shape the Electrification of the Automobile

The future of automotive technology will primarily be electric: innumerable control elements in the interior with aerodynamic add-on parts and a variety of sensors in the exterior, moved along with electric drive, charging and storage elements. Plastics offer important properties for this, but these must become even more specific.

Voltage flashover on an Audi e-tron prototype in the Faraday cage of a Siemens high-voltage test field. The standard version of the electric SUV can charge up to 150 kW at fast-charging columns and is ready for the next long-distance stage after about 30 min (© Audi)

The automotive industry is in a stage of significant transformation. New mobility concepts, connected autonomous driving, powertrain electrification, and new partnership models change the industry. Digitization and connectivity links the automotive and electronics industries, turning the car of the future more and more into a kind of smartphone on four wheels.

In a dynamic environment where IT companies are making their inroads into automotive and traditional automotive manufacturer and suppliers need to quickly build up knowledge in software and electronics, fast application and technical developments become a core differentiator. With a long history and long track record in both electronics as well as automotive, the material supplier DSM Engineering Plastics B.V., Geelen, Netherlands, can support manufacturers as an appropriate partner to reduce development times and implementation risks.

End custumer acceptance of electrical cars continues to rise rapidly. Driven by increasingly tighter emissions regulations, dropping battery prices, better charging infrastructure and longer driving ranges, optimistic predictions show that electric vehicles (including hybrid, plug-in hybrid, battery electric and fuel cell) will represent a total share of 35 % of new electric vehicles sold in 2025. The peak demand will occur in mega-cities where emissions regulations will be the most stringent.

Electro Overhauled Combustion Engine

In addition, regulations put into place by the Chinese government on the battery range and number of electric vehicles are creating a big push for electrification in automotive. While Chinese manufacturers have a competitive edge due to their unmatched access to raw materials needed for vehicle electrification, as well as their leading global position in battery technologies, this power play is forcing foreign manufactures that want to do business in China to invest heavily in electrification.

The battery remains the costliest part of an electric vehicle, in the same way the combustion motor has always been the most costly part of an internal combustion engine (ICE). Batteries reach cost parity with internal combustion engines at around USD 150 to 200 per kWh. Once there is no difference in cost between electric cars and cars based on internal combustion engines, we will reach a tipping point where consumer demand for electric vehicles will increase exponentially.

The success of electric vehicles in the market has been hotly debated for some time. A few industry pioneers, such as Tesla, Inc., Fremont, CA/USA, have moved aggressively ahead, while current market leaders have continued to bet on internal combustion engines. Today, the majority of industry experts agree that the internal combustion engine will gradually disappear over the next 20 to 30 years, so we will see the major players decrease their investment into traditional internal combustion engines. As electric vehicle pene-

Fig. 1. Leading industrial companies invest in the development of hydrogen fuel cells. This also includes the strategically important expansion of the infrastructure (© DSM)

tration increases, the transition will be bridged by hybrid technology with performance improvements on the combustion side that focus on reducing fuel consumption, as well as CO_2 and NO_x emissions. Car manufacturers and tier suppliers will use the income generated from ICE technology (internal combustion engine) to fuel EV innovations and new mobility concepts. The aim is to evolve connected cars to the point of fully autonomous driving. Radical repositioning like this often requires new management, as companies sell off parts of the business that focus on old technology and refocus their strategy on new market conditions.

A Question of the Battery: Lithium Ion Accumulators

The use of electric cars has steadily increased with the greater regulatory focus on environmental issues. The market has introduced a variety of alternative electric vehicles, including hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), extended-range electric vehicles (E-REVs), and fully electric vehicles (EVs) with batteries as their only energy source. Moving beyond the standard nickel metal hydride (NiMH) battery, the latest generation of lithium ion batteries (LiBs) has much higher output and energy density, leading to growing usage across a variety of applications. The advantage to LiBs is that they are compatible for use in all electronics applications, from smartphones to electrical drive trains for cars. The cost of LiBs has come down by a factor of ten over the last decade. As of 2018, they need only a drop in cost by another factor of two to reach parity with internal combustion engines.

LiBs are composed of multiple interconnected cells stacked inside a housing, with an electrical control unit that drives the cells, and protects them from overloading or charging too fast. The battery cell housing ensures that each battery remains in position in spite of vibration or impact and protects the battery from harsh conditions the vehicle is exposed to. Since the individual cells are connected via busbars safeguarded by fuses, mechanical stability of the total system is essential. Any displacement of the cells will change the contact resistance and electrically stress the fuses, leading to potential failure of the cells or the entire module.

Application of Engineering Plastics in Batteries

This need for mechanical stability is one of the main reasons that thermally conductive polyphenylene sulphide (PPS) compounds were developed for this application. DSM's Xytron TC5070C and TC5018I grades provide high dimensional stability, very good chemical and temperature resistance, intrinsic flame retardance, and high thermal conductivity to ensure that the heat generated within the cells is conducted away to the active and/or passive heat sink of the module. This PPS innovation eliminates the typical flash formation during injection molding to enable good processability with no rework required after molding.

To support batteries, DSM has proposed replacing battery trays made from conventional plastics with those made from thermally conductive plastics. This enables the avoidance of local hot spots during the charging and discharging of the individual cells to spread via the thermally conductive materials to either metallic bus bars, or to the additional water cooling system. At the same time the material will fundamentally improve the total thermal management of the battery module, achieving higher efficiency and longer battery life. Depending on battery design, next to PPS also thermally conductive Arnite PET and Stanyl PA46 compounds can be used.

Another area where engineering plastics are used in batteries is in the sealing of prismatic cells. The main purpose of the material is to avoid electrolyte leakage at the cell contacts. The material must be highly resistant to chemicals, and provide very strong bonding between plastic and metal. Xytron PPS material is used in this type of seal, and demon- »

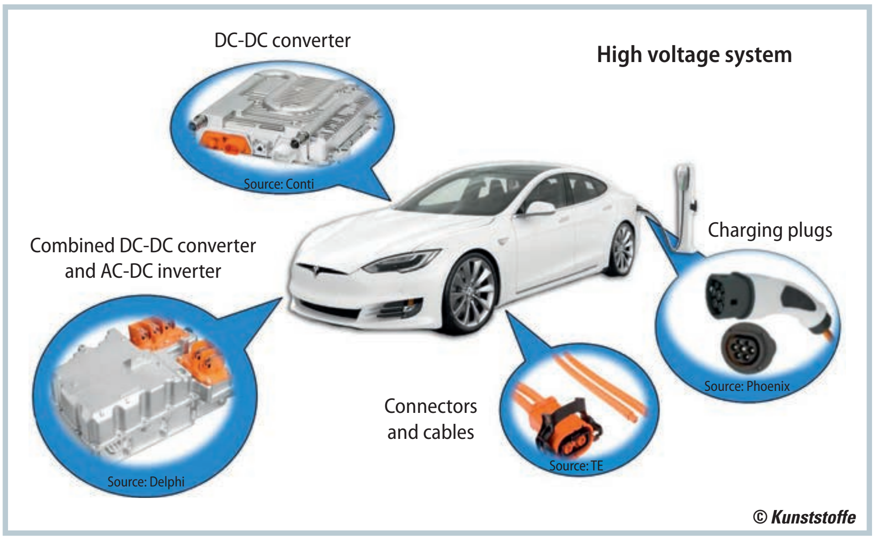

Fig. 2. Power connections and plugs transfer the energy of the storage system to the electric motor and drive train. Many of these components and groups are currently under development (source: DSM)

strates very good direct bonding to metal without the further need for adhesives or glues. It outperforms other PPS materials in processability with very low flash during injection molding.

Hydrogen Fuel Cells as Alternative

Major players are intensifying their engagement in hydrogen fuel cells – particularly in Japan, Korea and Germany (**Fig. 1**). These manufacturers are pushing hydrogen infrastructure for a number of reasons. Rather than carrying the required energy in the form of heavy weight batteries, the energy can be produced on board through a stack of fuel cells. Fuel cells charge six times faster than LiBs, and have a longer driving range – although the driving range for LiBs is improving quickly. There are also concerns about the availability of lithium, which is mainly sourced in China and Chile, and cobalt, two-thirds of which comes from the Republic of Congo.

Significant allies have recently been announced, which will pave the way for hydrogen infrastructure that will enable fuel cell technology. While the efficiency of fuel cells lags behind LiBs, fuel cell infrastructure is not reliant on lithium, reducing dependence on China for supply. This does not resolve the need for access to other rare earth minerals, such as neodymium and dysprosium – two rare earth minerals that are crucial during the high-temperature sintering of permanent iron-boron magnets used in e-motors. China is also strategically positioned to dominate the supply of these essential raw materials. At the same time China is world's third largest hydrogen producer, and the first country to run a fuel cell based tram. In the latest update of the strategic 5 years plan for China, fuel cell development plays an essential role. China is investigating significantly in fuel cells and strives to install 3000 hydrogen fuel stations by 2030 across the country. For electrified future of transportation China is betting on both LiB and H_2 fuel cell technology.

Hyundai as one of the global OEMs that already has fuel cell models in the market has the ambition to become the global leader targeting a market share of 25%. They recently announced to produce 500,000 fuel cell driven cars by 2030 together with some 200,000 mobile fuel stations for boats, fork-lift trucks and other commercial vehicles. Already by 2023 Hyundai wants to launch 1000 fuel cell trucks in Switzerland.

With the Tuscon model Hyundai had one of the first fuel cell cars in the German market, alongside similar offerings by Toyota and Honda. Daimler has with the GLC F-Cell a fuel cell car at very small volumes available. VW as the largest German OEM currently plans market launch by 2025, while the short-term focus will be primarily on Lithium-Ion battery-based technology.

In the future it can be expected that both technologies will coexist, depending on its specific application area. Due to the long range and fast loading characteristics, hydrogen is expected to have its greatest chances of success at the moment especially in the area of heavier commercial cars, airplanes and fork-lifters. The cost for installing the required infrastructure for charging batteries or fueling up hydrogen tanks is comparable. The first mover which can install more fuel stations faster will have a big strategic advantage.

In Germany some cities such as e.g. Hamburg have started to use hydrogen fuel cell buses. In Japan the city of Tokyo announced the roll-out of 100 fuel cell buses by 2020 well in time for the Summer Olympics based on the same fuel cell blocks as already commercially applied in the Toyota Mirai. The world's largest tier 1 Bosch announced together with the startup Nikola the launch of fuel cell trucks with a range of 3000 km by 2021 (**Fig. 1**). Combine such trucks with autonomous driving capability and you get a radical disruption of the entire transportation business making truck drivers obsolete in the future.

Potential with Lightweight Pressure Vessels

Green hydrogen production reduces the emissions over the entire life cycle of any accumulation system for excess electricity from renewable energies (power-to-X application). Various companies such as an alliance between Siemens, Shell and

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Tenne T are working on hydrogen electrolysis coupled to wind or solar energy which can then be transported through the natural gas network or via large gas tanks to the end customer. Such concepts are anticipating market launch around 2025 to 2030 for mass production.

In a fuel cell hydrogen is reacting with the oxygen from the air generating water vapor, heat and electricity. The source of energy generation will be permanently on board and the battery can be trimmed down to a much smaller size. However, the hydrogen needs to be transported in heavy, big gas tanks with pressures of 700 bar and more. DSM launched compressed natural gas (CNG) tanks made from engineering plastics, and has built on this platform to successfully demonstrate a lightweight hydrogen gas tank without the use of steel. The inner liner is made from blow-molded Akulon PA6, and ensures a tight inner tank that does not allow any escape of hydrogen by evaporation. The outer composite structure is made from EcoPaXX PA410 tapes to ensure the tank is protected against high burst pressures of 700 bar or above, which is essential for hydrogen storage.

EcoPaXX also provides the highest chemical resistance against compounds such as salt spray. Akulon/EcoPaXX provides very good mechanical performance between -40 °C and 85 °C, superior to that of competitive aromatic polyamides. It demonstrates very good compatibility with hydrogen compared with alternative high-density polyethylene (HDPE) solutions. It is a more economical solution that PA11, outperforms POM solutions on burst pressure, and offers full recyclability and much higher burst pressures than epoxy-based solutions.

Effects of High-Voltage Charging and Connection Systems

Electric vehicles require high-voltage charging and interconnection systems to enable sufficient power to drive the main e-motor, and acceptable battery charging times (**Fig. 2**). Yet, with high voltages, engineers need to take extra care in the design of parameters such as dielectric strength, creep, and tracking resistance, as well as dedicated color coding to enable safe handling by operators, as well as rescue teams in the event of an accident.

The industry has selected orange for the color of all components in the high voltage system and main charging path of batteries. DSM offers a wide range of flame retardant plastics that deliver the required electrical performance, with Comparative Tracking Index (CTI) of more than 600 V (**Fig. 3**), dielectric strength of more than 30 kV, and a Relative Temperature Index (RTI) of 140 °C. Based on the materials Akulon PA6, PA66, or PPA within the ForTii product group, these materials offer the high mechanical strength of polyamides, and work with a variety of assembly designs – including press fit, wave soldering, and reflow soldering.

These compounds are halogen-free, and free from red phosphorous, so that they can achieve the high CTI required for these applications. Additionally, by avoiding any ionic heat stabilizers, DSM has ensured full protection against potential electric corrosion of assembly bins or critical aluminum bonding wires within semiconductor chips. These compounds are available in a variety of colors, including the orange color used to denote components directly in the high voltage system as well as blue colors for the increasingly relevant 48 K charging system that is driven by Audi and others.

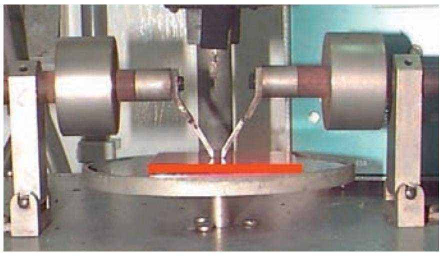

Fig. 3. In CTI measurements, a voltage is applied between the two electrodes, which is gradually increased until the material fails (left). The material properties can then be grouped together (© DSM)

Material group I:	600 V < CTI
Material group II:	400 V < CTI < 600 V
Material group IIIa:	175 V < CTI < 400 V
Material group IIIb:	100 V < CTI < 175 V

Material classification based on different CTI levels (source: DSM)

The surface resistance of an insulation material can be reduced due to contamination and environmental influences such as dust or moisture. Such contaminations always increase the risk of leakage currents and arcing. There are in principle three alternatives for a product designer to handle this risk:

- The creepage distance of the electrical contacts can be increased,
- the electronic components can be sealed in a box keeping the contamination out,
- a high CTI insulation plastic can be used.

A high CTI material (group I in **Table 1**) has the advantage that the creepage distance can be kept the same or even further reduced in order to miniaturize the application further (**Fig. 3**). The two DSM compounds ForTii TX1 and ForTii T11 even achieve a CTI value of 900 V and are therefore an ideal solution for the upcoming 800 V high-voltage grid.

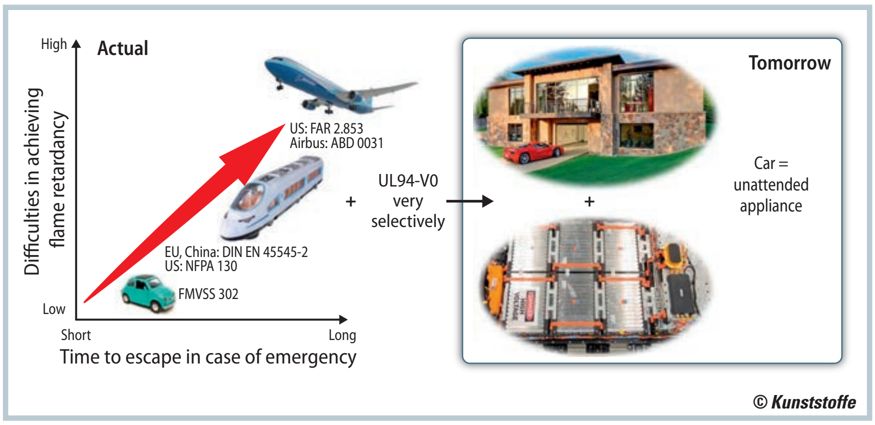

Fig. 4. Difficulty level of flame retardancy tests versus available escape time. Considered as "unattended electrical equipment", the flame retardancy requirements for electrically powered vehicles are increasing (source: DSM)

Connectors in the Focus of Compound Development

Connectors are essential, as even the most powerful computer would prove inef- »

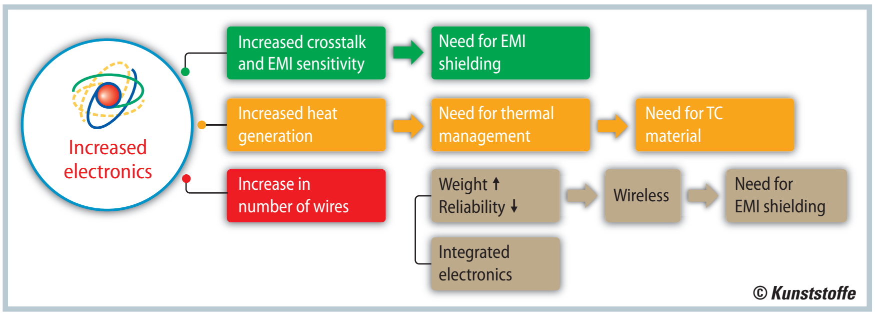

Fig. 5. The growth in automotive electronics requires thermally and electrically conductive plastics with special properties (source: DSM)

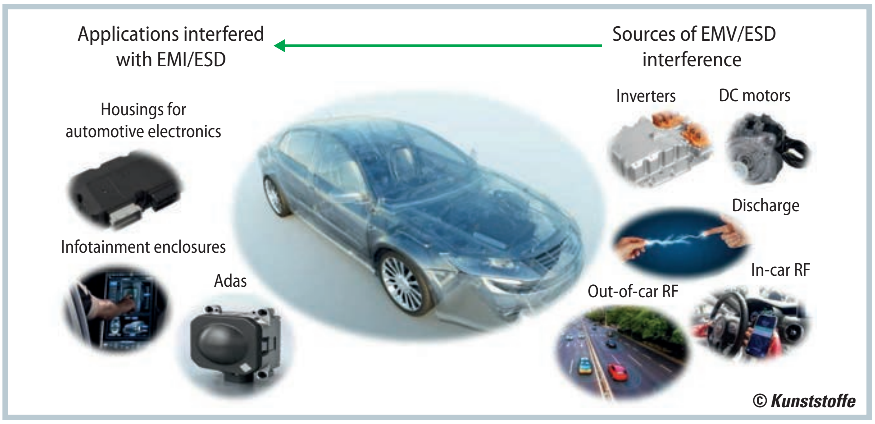

Fig. 6. Different electronic systems in the vehicle lead to interferences between the individual elements (source: DSM)

fective if any of these interconnects were to fail. These connectors must ensure the highest reliability and safety over the lifetime of the vehicle, even in the harsh and aggressive environmental conditions, including dust, moisture, temperature cycling, chemical exposure, and intense vibrations.

To enable safe and reliable operation during the use of the car, as well as throughout the manufacture of parts through the various tier processes, connectors ideally need to meet the following requirements:

- Unlimited shelf life (Jedec MSL1),
- no pin corrosion (insulation material free from halogens and red phosphorous, and without ionic heat stabilizers,
- high continuous use temperatures of 150 to 180 °C,
- very good chemical resistance,
- high ductility, and
- high electric strength and CTI of 600 V and above.

The DSM ForTii JTX2 and ForTii Ace JTX8 plastic grades combine the dimensional stability and low moisture absorption of polyesters together with the high mechanical strength of polyamides. ForTii Ace JTX8 is the only PA available around the world that meets Jedec MSL1, while ensuring zero blistering over an infinite shelf life. And with the very good mechanical strength, it ensures reliability during and after assembly, as well as after years of use in harsh conditions. DSM also offer ForTii T11, a UL94-V0 at 0.2 mm alternative material that delivers a high level of flame retardancy. These electro-friendly grades are free from halogen and red phosphorous, and do not include any ionic heat stabilizers (halide salts) which could outgas and corrode metals.

Increasing Requirements for Flame Retardancy

In view of the time available for passengers to escape compared to the train or plane, flame retardancy has so far played a less important role in automotive applications (**Fig. 4, left**). Only a few OEMs today specify the UL94 V-0 flame retardancy standard for applications such as plugs or batteries. However, completely electrically powered vehicles that are charged overnight in the garage at home, right next to living spaces, change this (**Fig. 4, right**). The risk of fire when charging the high-voltage system increases significantly; the car is to be considered similar to an unattended electrical device. It can therefore be assumed that fire protection requirements will increase.

Critical electronics systems like electronic control units (ECU) and power management modules are typically housed in metallic enclosures. The metal housing provides environmental protection for the board and conducts the heat of the processor and power transistors away to prevent overheating. At the same time, it effectively shields electromagnetic interference (EMI) caused by adjacent radio frequency signals that may interfere with the sensitive integrated circuits (ICs), and lead to malfunction (**Fig. 5**).

EMI shielding and thermal management are becoming increasingly important in automotive electronics. Critical applications such as ECU covers must fulfil both requirements. **Figure 6** shows some applications which can generate EMI (right side) and applications which are sensitive towards EMI (left side).

The DSM portfolio includes materials with different combinations of thermal and electrical conductivity. While electrical and thermal conductivity can be tuned by the use of different additives, the underlying polymer matrix defines the mechanical strength of the compound. At the moment polymer scientists work to find the right additive while ensuring the materials still passes the required drop and impact tests for various applications. DSM has developed compounds with in-plane thermal conductivity levels up to 14 W/mK and shielding levels of around 40 to 60 dB for the frequency range 20 MHz to 1.5 GHz.

DSM's portfolio of conductive plastics is used commercially across a variety of applications. Grades that enable the replacement of full metal enclosures include electrically conductive fillers that lead to shielding efficiencies of around 40 dB/mm of plastic thickness. Replacing die-cast aluminum housings by engineering plastics that combine thermal conductivity with electromagnet interference can lead to weight reductions of 50 %, while enabling more advanced designs that include extra design features such as the inclusion of brand logos in the plastic housings. ■