e-generation

Research project with a positive balance

____Under the leadership of Porsche, a research consortium developed new components for electric vehicles and tested them in three electric sports cars based on the Porsche Boxster. In early 2015 the *e-generation* project sponsored by the German federal government and in which Porsche Engineering played a major role came to an end. Significant gains were achieved in terms of the range, cost reductions and day-to-day usability of electric vehicles.

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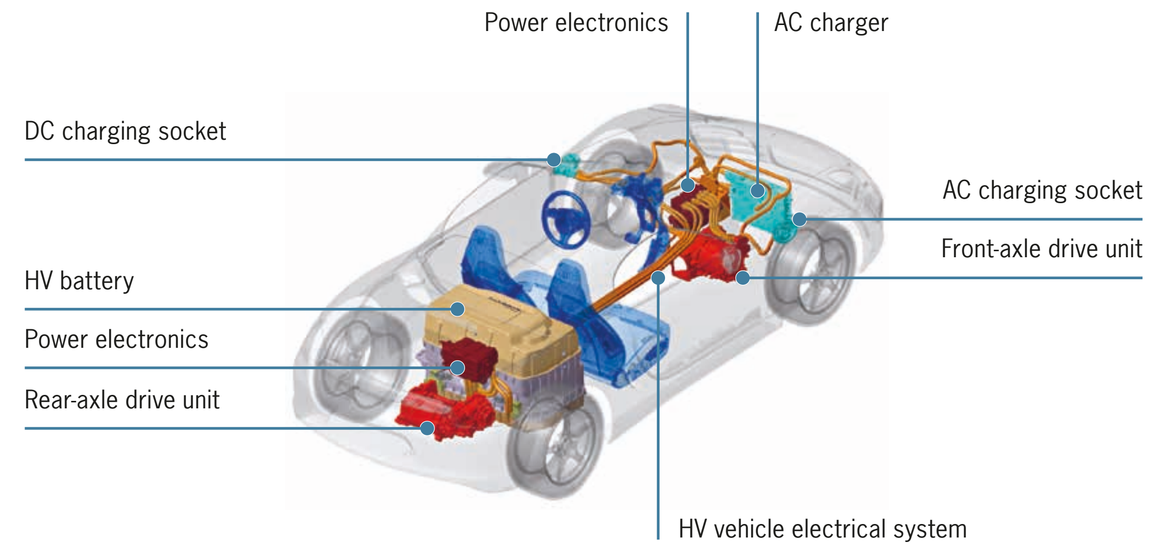
Research vehicle of the project e-generation



Overview of high-voltage components in the vehicle

Back in 2010, three electric-powered Porsche Boxster research vehicles were created under the aegis of Porsche Engineering. The cars were driven over 70,000 kilometers and evaluated in several hundred life-like test drives. The vehicle concept was a success. The driving behavior and reliability were rated positively, while limitations were noted—as expected—particularly with regard to range and vehicle weight.

After that, the three-year *e-generation* project was started in April of 2012 with 13 partners from the fields of research and industry. The project was supported by the Federal Ministry of Education and Research (BMBF) and ended on schedule in early 2015. The primary objectives were the following:

> reduced electrical energy demand (focus: drive unit and air conditioning),
> reduced vehicle weight,
> reduced costs for drive components,
> comfort and day-to-day usability like that of a series Porsche.

The test vehicles were three newly built prototypes from the Development Center in Weissach. The vehicles received the necessary approvals in late 2013 and have been tested on public roads since that time.

Drive concept with two electric motors and all-wheel drive

In the concept phase, numerous drive models were examined and evaluated through simulations. The primary premise was to find a configuration that would meet the project objectives and yet enable the driving characteristics expected of a Porsche sports car. Moreover, the existing construction space and the configuration of the chassis had to be taken into account. Given these circumstances, a drive concept emerged in which a transversely mounted electric motor on each of the front and rear axle would power the vehicle.

Two new electric motors designed for greater efficiency were developed under the aegis of Robert Bosch GmbH. As part of that process, RWTH Aachen University designed a permanently excited synchronous motor (PSM) and an asynchronous motor (ASM) was created in collaboration with the Braunschweig University of Technology. For both motors, Bosch subsequently handled the design and manufacturing for operational use. ›

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The sponsoring partners

The PSM powers the front axle and the ASM is located under the rear luggage compartment. Two power electronics units from Bosch control the motors. The drive management system is based on Bosch software, while Porsche provided the application and parameterization. The front axle has up to 120 kW at its disposal, while the rear axle has a maximum output of 140 kW. Together they can accelerate the vehicle from 0 to 100 km/h in 5.2 seconds. The driver can also switch between the driving programs Normal, Sport and Range. In Range mode, mainly the more efficient PSM on the front axle powers the car. In Sport mode, both axles are always supplied with power, which enables typical Porsche driving characteristics.

The high-voltage battery for the research project was designed and developed by Porsche Engineering.

Energy supply through newly developed high-voltage battery

The high-voltage battery (HV battery) in the 400 volt range was designed and developed by Porsche Engineering. Thanks to rigorous lightweight construction and modern cell technology, approximately 35 kWh of energy are available, or 20% more than in the 2010 prototype. The usable electric power tops out at around 270 kW.

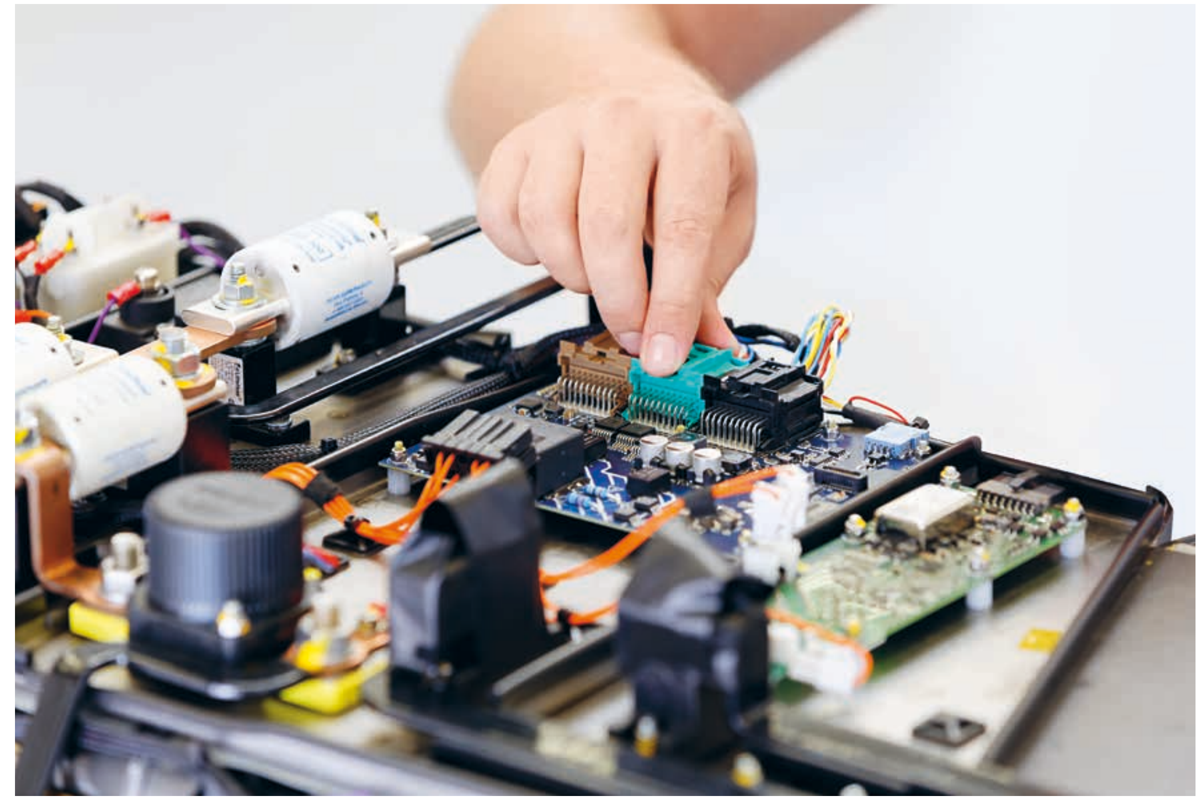
The battery is liquid-cooled and can be heated up via PTC heating foils. A new cooling concept was developed that dispenses with the previously common, relatively heavy metal plates. Instead, cooling elements were developed that are directly attached to the cell poles. This resulted in weight savings and improved heat dissipation.

The prototypes have several connections for charging the battery. Depending on the energy source, the integrated charger delivers up to 22 kW of electric power. This makes it possible to charge an empty battery in roughly one-and-a-half hours. At rapid charging stations, the battery can be charged to 80% of its capacity in less than 20 minutes.

The battery development in the research project is a further development of the components used in the previous vehicle in 2010. The principle is based on the following design:

> two cell module layers with five cell modules each,
> circular support frame as the central structural element,
> two housing covers in a fiber-reinforced lightweight design,
> division of traction paths within the battery into one connection each in front and back.

The fundamental difference to the concept of 2010 is the in-house development of the cell modules using pouch cells from the LG Chemicals company. The module development features numerous innovations: The independent modules with integrated cooling/heating, the Battery Management System (BMS) and the modular structure within a minimal construction space create a compact package. The connection of the cell terminal and surface cooling results in a highly efficient module cooling for performance-oriented applications. The developers also broke new ground with the first-time use of a PTC heating foil for efficient heating directly on the cell. Finally, the battery management system is a completely in-house development by Porsche Engineering for voltage ranges up to 800 volts and can be applied optimally in various drive systems.



The battery management system (BMS) for voltages of up to 800 volts can be applied optimally to various drive systems.

Over the three years of the project, the engineers developed a complete high-voltage energy storage unit and built three prototype batteries. Every battery module has a cell controller developed by Porsche Engineering. It monitors all cell voltages and temperatures of the module. The data is transmitted to the central control unit of the battery. That is where the evaluation and monitoring of electric insulation takes place. Via the CAN bus, other components can also receive this data.

Distribution of the cooling medium in the battery is done using a parallel connection of the module coolers with one coolant distributor per module layer. The coolant connections on the module cooling system and the coolant distributors are comprised of standard parts from the Norma Group. This guarantees tight seals and high quality. The battery also has two non-spill quick release connectors from the Stäubli company that enable the fast and easy installation and removal of the traction battery including frame.

A glass fiber-reinforced cover protects the battery against spray from above, while a Gore membrane ensures pressure regulation. The complete electrical shielding for good electromagnetic compatibility (EMC) is done using a coating of metalized paint on the two plastic covers on the top and bottom. The technical specifications and specific operating data of the battery are summarized on the following page.

Crash-safe mounting of the battery in the vehicle rear

The battery package is mounted in a crash-safe location in the rear of the vehicle. Safety is assured above all by the ring-shaped support frame made of high-strength aluminum. Its structure-optimized design enables it to withstand all normal loads as well as crash loads for accelerations of up to 60*g*. The support frame essentially transfers the rear crash concept from the series Boxster with a combustion engine to the electric vehicle. The two cell module layers are permanently attached to the support frame—the upper one directly, and the lower one indirectly through a glass fiber-reinforced plastic cover.

To accommodate the 360-kilogram battery in the vehicle, a few changes to the body-in-white were necessary. The changes affected both the rear of the vehicle, to which the battery is fastened, and the front end in order to create space for the front-axle drive unit. On production lines designed for series production, special parts such as a hybrid ›

Technical data

Cell manufacturer	LG Chem
Cell type	Pouch P2.6 (PHEV)
Cell chemistry	NMC
Capacity	25.9 Ah
Rated voltage	3.7 V
Circuitry	100S4P, 10 cell modules
Energy content	38.3 kWh nominal, 35.8 kWh usable
Output	270 kW (420 V, 650 A)
Current	370 V nominal, 410 V maximal
Range	> 200 km
Battery cooling	Terminal and area cooling with water / glycol

HV battery specifications

Cell share of total volume	31% (84 l of 271 l)
Module share of total volume	61% (166 l of 271 l)
Cell share of total mass	64% (230 kg of 362 kg)
Module share of total mass	81% (295 kg of 362 kg)
Structure share of total mass	15% (54 kg of 362 kg)
Power density per kilogram	754 W/kg
Electric energy per kilogram	106 Wh/kg

cross member developed by Porsche Engineering and made of fiber-reinforced plastic were built (see *Porsche Engineering Magazine* 1/2015).

Thermal management reduces energy consumption

Batteries function best in climatic conditions that are also agreeable to humans. If temperatures are too low or too high, the lifetime of the energy storage unit is affected and the power available is also lower at low temperatures. For that reason, batteries need to be cooled and heated depending on ambient conditions. The energy required for that is drawn from the battery itself, which, however, reduces the range.

In case of low exterior temperatures, the battery is heated during the charging process with a portion of the applied electricity. That saves energy from the battery and ensures that the drive system has access to the maximum performance power capacity as soon as the drive begins. As the efficiency of the battery is roughly 95%, the self-heating process, at roughly five kilowatts, is relatively minimal when the vehicle is operating at high energy levels. Only when exterior temperatures exceed 30 degrees Celsius is a cooling cycle required that cools the battery to below the ambient temperature through a cooling process.

Since electric motors and HV batteries are highly efficient, they produce relatively little residual heat compared to a combustion-powered vehicle. But if it is necessary to heat the passenger compartment, energy from the HV battery must be used. This naturally reduces the range of the vehicle.

As part of the *e-generation* project, the Mahle Behr company led the development of a thermoelectric heat pump with which low residual heat can be warmed to a temperature that is suitable for heating the passenger compartment. This heat pump works most efficiently at ambient temperatures between 10 and 15 degrees Celsius, as are common in Central Europe. The coefficient of performance is an impressive two. This means that the energy requirements of the high-voltage battery can be reduced to 50 percent.

Testing confirms day-to-day usability

In the first testing phase, the prototype covered several thousand test kilometers while being continuously enhanced and optimized. To be approved for road traffic, the vehicle was tested for functionality and robustness at the testing grounds in Weissach. The optimization of the drive system and chassis was primarily conducted at the Porsche testing grounds at Nardò in southern Italy. The prototypes held their own in the wintry Alps as well: the fully electrical Boxster was ready to go even after a night of negative 25 Celsius outdoor temperatures.

Various assistance systems were developed over the course of the project to improve the day-to-day usability. Together with the Karlsruhe Institute for Technology (KIT), a linear guide system was developed that uses predictive route data to calculate the most efficient speed plan for the route ahead. The system not only enables the vehicle to operate optimally in traffic, but also makes it possible to navigate corners safely and dynamically when driving on open rural roads. Together with RWTH and KIT, a coasting assistant was developed that advises the driver when it is the optimal time to take the foot off the accelerator before corners or speed zone changes.

Outlook

The *e-generation* project will be followed by *e-volution*: Together with partners from the fields of industry and research, Porsche is now pushing the ongoing development of electric vehicles in the third successive project. *e-volution* is aimed at further increasing the range, day-to-day usability and performance of electric vehicles. ■

Two Porsche Boxsters from the e-generation *research project on a wintry test drive in the Alps.*