01
23

Porsche Engineering Magazine

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Developments for the battery electric vehicle of tomorrow

Vehicle-to-X New battery technologies Future of procurement


S GT 525
Our hardest challenge:
Making it street legal.
Sportmade. The new 911 GT3 RS.
Perfection is never the start. But always the goal. Experience the new 911 GT3 RS in top form. For an increased racetrack performance thanks to maximum downforce for unbridled euphoria and the lightweight construction. More at www.porsche.com/GT3RS
Fuel consumption (in l/100 km) urban 17.6 · extra urban 9.8 · combined 12.7 (NEDC); combined 13.4 (WLTP);
CO_2 emissions (in g/km) combined 289 (NEDC); 305 (WLTP)

PORSCHE

Dirk Lappe
Managing Director of Porsche Engineering

Dear Reader,

For 20 years now, we at Porsche Engineering have been involved in work on electromobility, the subject we've chosen for this issue's cover story. It all began with an unusual project: In 2003, we were commissioned to develop an innovative new water vehicle, one which would be pulled through the water by an electrically powered turbine. The project gave rise to the Cayago Seabob water scooter, which we are continuing to advance and upgrade even today.

I personally joined Porsche Engineering in 2002, taking up the mantle of Managing Director in 2009—the very year Porsche presented the first prototypes of the Cayenne S Hybrid. Back then, the technology was still very much in its early days. Finding the right expertise was as difficult as getting hold of components suitable for vehicles powered by electric batteries. At Porsche Engineering, we did have something like a head start: The experience gained from our Seabob project. And so we came to be involved in a research project in 2009 to develop the first prototype Porsche Boxster with an electric drive.

Since then, the importance of electromobility for the automotive industry and for our company has done nothing but grow. Together with our customers in Europe and in China, we have developed a diversity of battery electric vehicles (BEVs) over the years, registered a multitude of inventions, and consistently expanded upon our expertise. Our goal has always been to serve as technology partner of our customers in highly innovative areas, for example in the fields of high-voltage or battery technology.

This issue will also examine intelligent platform concepts for BEVs and new ideas for recuperation. We explain how battery management systems affect service life and performance, and offer a glimpse into the various procedures we use for testing high-voltage components.

Our guest article explores how the virtual and real-life worlds are becoming increasingly blurred. When the playing fields of the Internet and the physical world combine to form a new reality in what is known as the metaverse, the effect on our future development capabilities could be profound. Interestingly, parallels can be drawn here to virtual vehicle development, as this also involves modeling the complete physical environment for use in interplay with real vehicles. This technology can be ported directly to developments in the metaverse. However, sustainability in relation to the use of computing resources is also an important factor.

There's even more we can do in terms of sustainability besides converting our vehicles to battery power. Software development, too, holds great potential, in both the physical and the virtual realm. In this respect, we're keeping our ear firmly to the ground when it comes to 'green coding', which is the development of software that requires only the barest minimum of computing power and energy. I'm really excited to see where this trend will lead us and look forward to doing our part in making it happen.

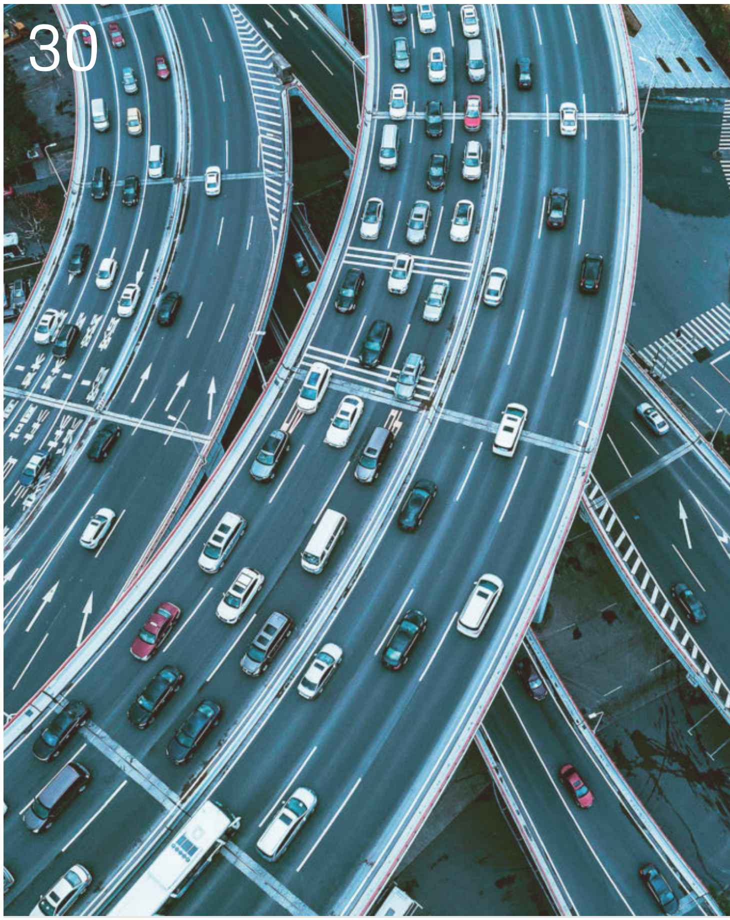
Shaping technologies for sustainable mobility: At Porsche Engineering, we're making this our mission. On top of the emotion, dynamics, and sheer driving pleasure you'll get out of our battery-powered developments, of course.

I hope you enjoy reading this issue of the magazine.

Dirk Lappe

ABOUT PORSCHE ENGINEERING: Porsche Engineering Group GmbH is an international technology partner to the automotive industry. The subsidiary of Dr. Ing. h.c. F. Porsche AG is developing the intelligent and connected vehicle of the future for its customers—including functions and software.
Some 1,600 engineers and software developers are dedicated to the latest technologies, for example in the fields of highly automated driving functions, e-mobility and high-voltage systems, connectivity, and artificial intelligence. They are carrying the tradition of Ferdinand Porsche's design office, founded in 1931, into the future and developing the digital vehicle technologies of tomorrow. In doing so, they combine in-depth vehicle expertise with digital and software expertise.

Connected: The vehicles of tomorrow will communicate with each other and with their environment.



Time for testing: Antonio Toma (left) and Andrea Casaluce from the NTC prepare a battery for a misuse test.

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PERFORMANCE AND EXPERTISE

PORSCHE ENGINEERING DIGITAL

Optimized: Sebastian Steudtner and his team at work in the Porsche wind tunnel to achieve the perfect stance on the board.

Highly promising: Anodes made of silicon have a significantly high storage capacity compared to graphite.

TRENDS AND TECHNOLOGIES

PORSCHE AND PRODUCT

SECTIONS

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NEWS 01/2023

Taycan Turbo

Consumption data in the WLTP:
CO_2 emissions (combined): 0–0 g/km
Power consumption (combined): 23.6–20.2 kWh/100 km
Power consumption (city): 19.2–16.3 kWh/100 km

Consumption data in the NEDC:
CO_2 emissions (combined): 0 g/km
Power consumption (combined): 26.0 kWh/100 km
Energy efficiency class: A+++

As of 10/2022

The new Porsche Engineering office is located in the Chaoyang District of Beijing.

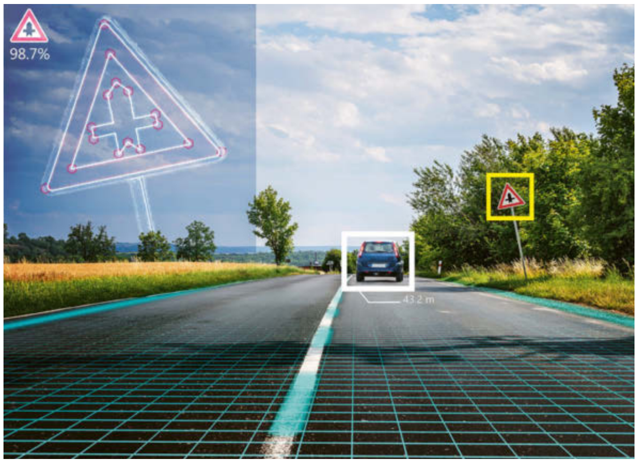
Porsche Engineering in China

NEW OFFICE IN BEIJING

"The opening of Porsche Engineering's new Beijing office is an important step towards realizing our goals of adapting to the special characteristics of the Chinese market and developing specifically for Chinese vehicles."

Uwe Pichler-Necek
CEO of Porsche Engineering China

Porsche Engineering is opening a new office in Beijing to bolster its role as a strategic development partner to Porsche AG and Porsche China and to even better meet the ever-expanding localization needs for the Chinese market, particularly in terms of highly automated driving, connectivity, infotainment, and assistance systems. The new R&D office is located in Chaoyang District where a host of well-known automotive companies have set up their offices. The new office extends and complements the competencies of the location in Shanghai, where more than 130 employees are already working on various high-tech automotive projects. "We have already been well positioned for this in Shanghai, and the Beijing office's close proximity to key customers will support us in our plans to build an even stronger presence on China's market, further strengthening our capabilities in developing intelligent and connected vehicles." says Peter Schäfer, CEO of Porsche Engineering and Chairman of the Advisory Board of Porsche Engineering in China. In China, Porsche Engineering employs primarily experts for highly automated driving, chassis, high-voltage systems, connected services and infotainment. "With the expansion of Porsche Engineering in Beijing, I expect a fast growth of the overall R&D and engineering capabilities of the Porsche Group in China, and further contributions to our success in the global market while promoting local innovation." adds Michael Kirsch, President and CEO of Porsche China.



Advanced driver assistance systems

SMART MEASUREMENT TECHNOLOGY DEVELOPMENT

Porsche Engineering has developed a new measurement technology for use in testing traffic sign recognition and perception functions for advanced driver assistance systems. It accesses the images from the front camera and redirects them to evaluation software as a webcam image, with developers using the software to assess whether traffic signs and objects such as cars or pedestrians are being correctly recognized in road traffic. Compared to previous solutions, the new development is distinguished by its significantly lower costs, greater robustness and the ease with which it can be integrated into the vehicle. In combination with other newly developed software for the ComBox from Porsche Engineering, relevant data can be filtered out and be sent to a server while the vehicle on the road or in the evening, which speeds up the evaluation significantly.

Porsche Engineering in Romania

GETTING INVOLVED IN THE COMMUNITY

In 2022, Porsche Engineering's rapidly growing community of volunteers in Romania participated in a number of different initiatives, ranging from tree planting to clean-up events. It also held its first in-house meeting to talk about the importance of volunteering. The organization CERT Transilvania, which provides care for disadvantaged children, was invited as a special guest. Together with CERT Transilvania and a local orphanage, Porsche Engineering Romania's 'Ladies in Technology' community intends to develop a long-term program that will support children by sharing knowledge and organizing educational activities.

bcm

best of content marketing 2022

BCM Awards

AND THE WINNER IS...

Porsche Engineering Magazine 02/2021 with its cover story 'Intelligent. Connected. Digital' won a silver award in the 'Automotive Magazine' category at this year's BCM Awards (Best of Content Marketing). The prize, which is presented annually, is considered one of the most important awards for corporate communications. In 2021, the 01/2021 issue won a gold award with the cover story 'Next Level'.

TO THE POINT.

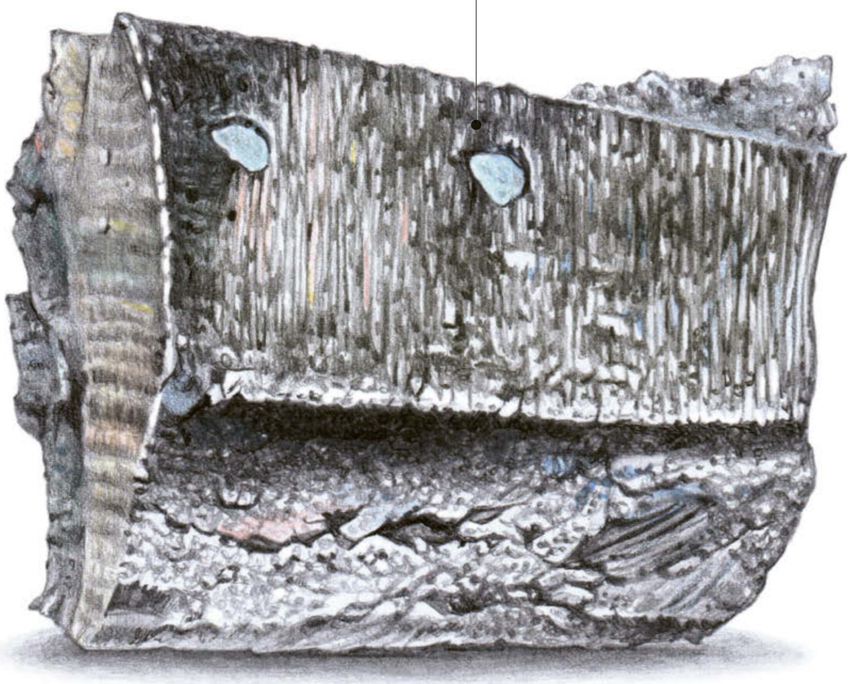
New technologies are driving development in the automotive industry. In this section, we get straight 'to the point' on the hot issues of the moment.

Magnetic raw materials

Neodymium and other rare earths make electric motors with high power and torque densities possible. Fortunately, these important raw materials are not quite as rare as their name suggests. Research is also being conducted into new recycling processes in order to meet rising demand in the future.

When people talk about electro-mobility, the term 'rare earths' often comes up. Chemists use this term to refer to the 17 'rare earth metals' in the periodic table of the elements, for example praseodymium, lanthanum, neodymium, dysprosium, terbium, and lutetium. Some of them play an important role in motors and batteries for electric vehicles.

The magnets in electric traction motors, for example, consist of around 30 percent rare earths in addition to iron. Neodymium, in particular, is used for this application, but so are dysprosium and terbium. The greatest advantage they offer is that even small magnets generate strong magnetic fields, which



Nd

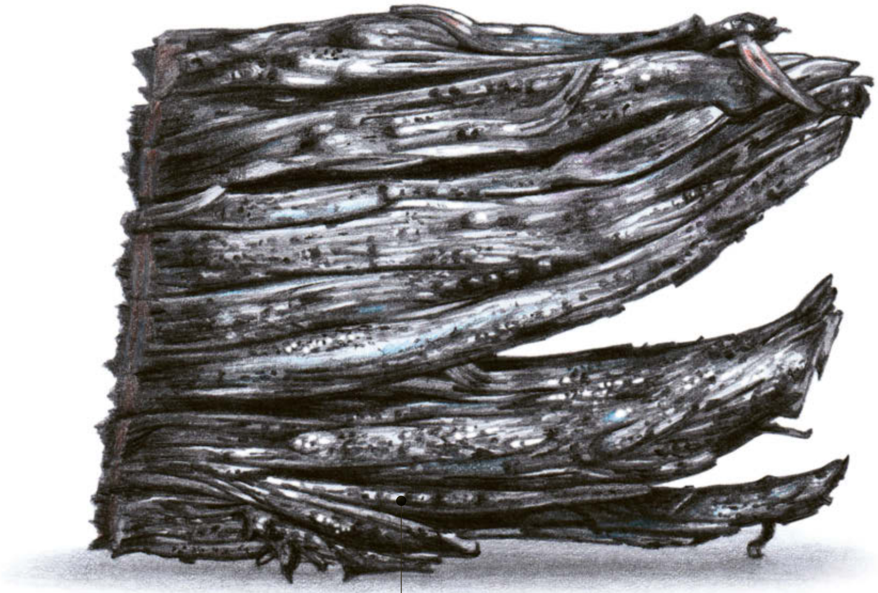
Neodymium

Atomic number
60

Melting point
1,024°C

Boiling point
3,030°C

Text: Christian Buck
Illustration: Oriana Fenwick



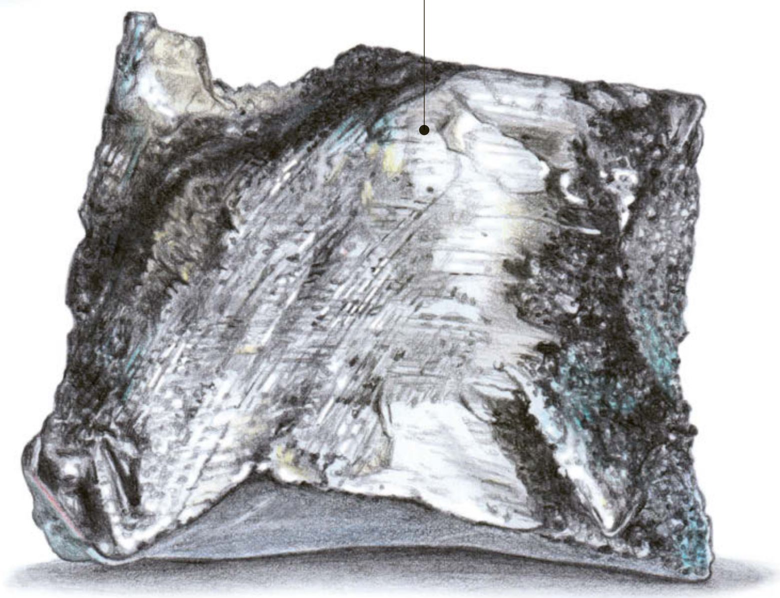
Tb

Terbium

Atomic number
65

Melting point
1,356°C

Boiling point
3,123°C



Dy

Dysprosium

Atomic number
66

Melting point
1,407°C

Boiling point
2,600°C

benefits electric drives. "Thanks to the rare earths in the magnets, permanently energized electric motors attain very high power and torque densities, something that, in turn, increases the efficiency of the entire drive," reports Dr. Rafał Piotuch, Project Engineer for Electric Motors at Porsche Engineering. "Other magnetic materials such as ferrite do not require rare earths, but they come with their own disadvantages in terms of the weight and installation space of electric motors."

As alternatives to permanently energized electric motors, some electric vehicles use separately energized and asynchronous motors. However, neither achieves the high power density and performance of their counterparts with rare earths in the magnets. This means that neodymium, dysprosium, and terbium are unlikely to be replaced any time soon, especially in sports cars.

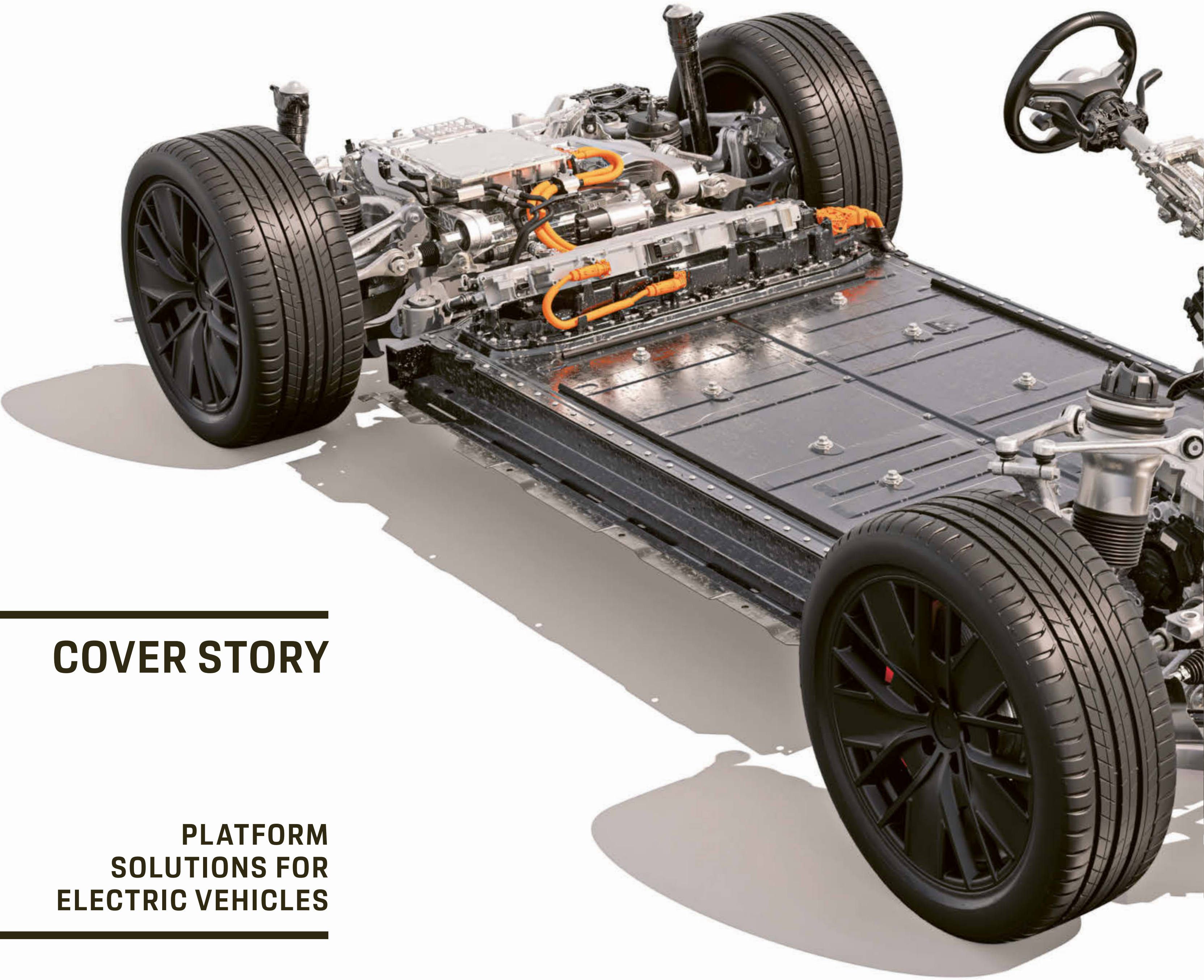
The question remains: Are rare earths actually rare? No, they are not—some of them are even more abundant than lead, and in 2021, around 280,000 metric tons of rare earth oxides were produced worldwide. "However, extraction involves a great deal of effort," explains Matthias Böger, Specialist Engineer Engine Simulation at Porsche Engineering. "They are extracted from ores in a complex process in which the rare earth oxides are separated from the ores and finally converted into pure metals." What's more, deposits are unevenly distributed around the world, so only a few countries have major deposits.

Demand for rare earths is expected to rise sharply in the future. For electric traction motors alone, estimates suggest that global demand will increase to twenty times its 2018 level by 2040. Wind turbines are also dependent on these raw materials, and demand in this sector is expected to increase by a factor of almost four over the same period. To ensure long-term security of supply, intensive research is therefore being carried out into processes for recycling neodymium and the like.

ONE FOR ALL

Intelligent platform strategies reduce the time and costs involved in developing electric vehicles. Porsche Engineering has extensive expertise in platform development and supports its customers from the initial concept idea all the way to the production-maturity vehicle. The result is platforms that are flexible and positioned for the future.

Text: Richard Backhaus



COVER STORY

PLATFORM SOLUTIONS FOR ELECTRIC VEHICLES

One single platform for a multitude of vehicle models: This approach has been followed for years now for combustion-engine vehicles, helping to develop a large number of different models and derivatives and to bring vehicles to series production at justifiable expenditure of time and money. In production, the approach results in economies of scale: Fewer components in high volumes reduce component costs and ensure high product quality. Volkswagen was one of the pioneers of a consistent platform strategy with its Modular Transverse Matrix (MQB). Since 2012, it has formed a shared foundation for a large number of models with gasoline or diesel engines. More than 32 million vehicles based on this platform have been produced across the Group.

Volkswagen was quick to apply the principle of the MQB to electric vehicles with its Modular Electric Drive Matrix (MEB), improving development and production efficiency in this field, too. The new Premium Platform Electric (PPE), developed in tandem by Audi and Porsche, adds to the electric vehicle platform concept's scope of application. For Porsche, this creates new opportunities to launch high-volume models with high technical standards at profit, thus taking the electrification of its portfolio another step further. The Stuttgart sports car manufacturer intends for more than 80 percent of its new deliveries to be fully electric by 2030.

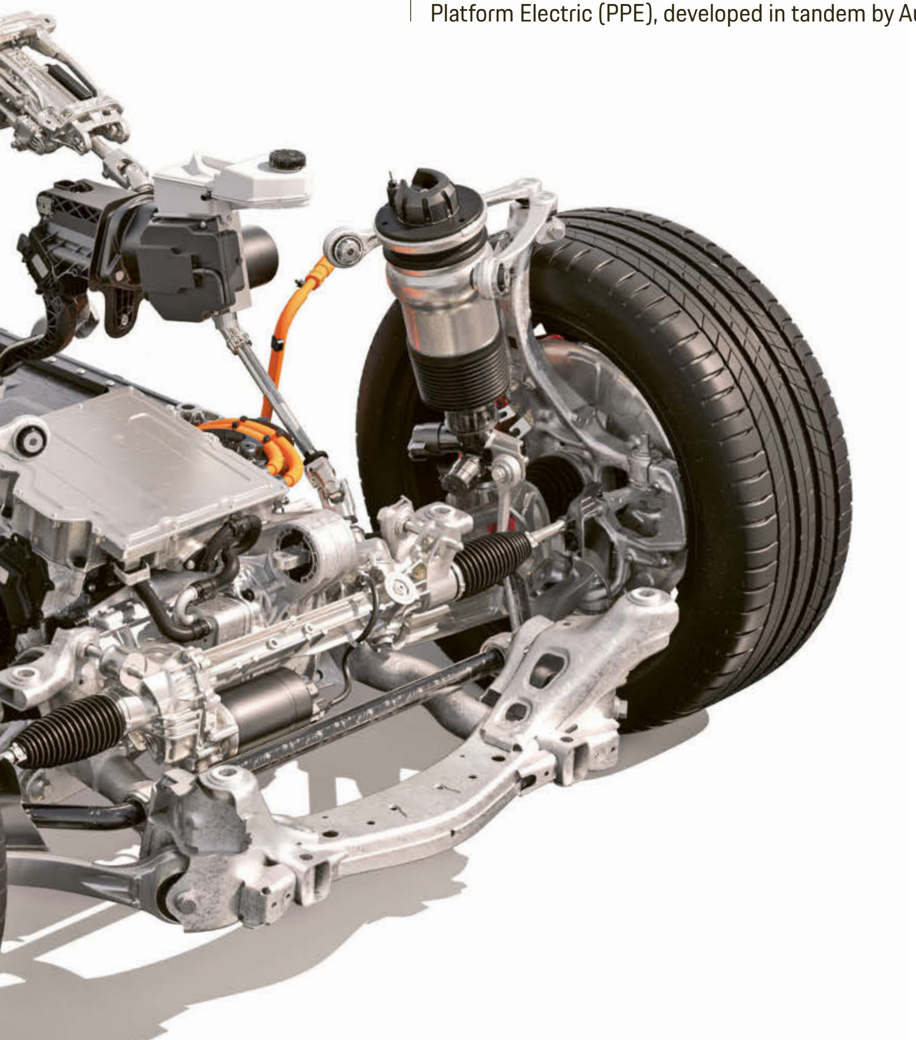
The PPE makes it possible to capitalize on the benefits of an all-electric platform in a variety of ways. One example, beyond package and space, is integrating the lithium-ion battery into the underbody. In fleshing out the design amid the conflicting requirements of range, performance and sustainability, Porsche remained true to its philosophy by focusing on travel time. At the same time, the architecture offers lots of leeway when it comes to the wheelbase, track width, and ground clearance, allowing for a variety of performance levels for models with either rear- or all-wheel drive in different segments.

AN INDEPENDENT CHARACTER

This flexibility allows Porsche models to retain their strong, independent character. To start off with, system output will cap at 450 kW, with maximum torque at more than 1,000 Nm. The first Porsche based on the PPE will be the all-electric Macan. With its 800-volt architecture, powerful latest-generation electric motors, and advanced battery and charge management, this model offers the level of electric vehicle performance you'd expect of Porsche. The successor to the acclaimed compact SUV has its sights set on becoming the sportiest model in its segment. Besides reproducible best-in-class driving performances, development goals include a range suitable for long-distance travel and high-power fast charging.

The benefits a platform for electric vehicles might offer are obvious—designing one, however, presents the engineers with a highly complex challenge. A myriad of aspects need to be taken into account, while some of the development goals stand in outright opposition to one another. This is generally true for any kind of vehicle, but applies especially to those with electric drives. After all, the individual drive components offer greater leeway when it comes to design than you get with a combustion engine—for example, in setting up the platform for broad scalability or making it flexible enough to allow the modular drive system to serve as a basis for entirely different vehicles. The platform makes it possible to implement rear-wheel, all-wheel, or front-wheel drive simply by choosing the position of the electric motor or even by adding another one—something a combustion engine does not allow.

Over the years, Porsche Engineering has acquired extensive overall system expertise from projects in this field, enabling the developers to optimally coordinate platform concepts. Today, the company's service portfolio covers all steps along the entire process



Electrified portfolio: The Premium Platform Electric (PPE) enables Porsche to bring high-volume models with high technical standards to market profitably.

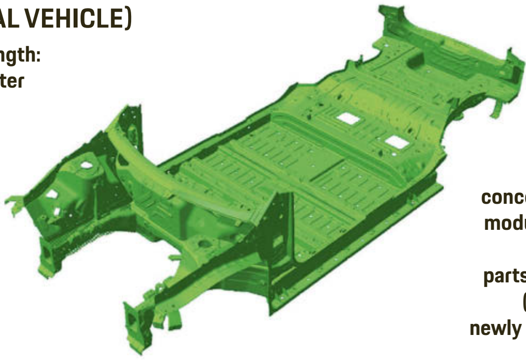
PLATFORM CONCEPTS: SCALABILITY CONSIDERED FROM THE START

Covering all segments with a single platform

Porsche Engineering developed a platform concept for a customer, taking scalability into account even in the first drafts—the wheelbase increments for the various wheelbases of different vehicle models were defined, for example, so that the next-in-line battery module would always plug the gap in the vehicle underbody. This way, the customer was able to cover all intended vehicle segments—from compact cars to sedans to SUVs—with one single platform.

SUV (INITIAL VEHICLE)

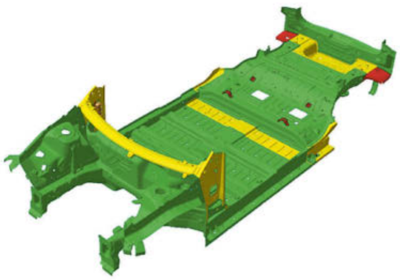
Wheelbase length: 2,940 millimeter



The platform concept is based on modular wheelbase lengths. Some parts were modified (yellow), others newly designed (red).

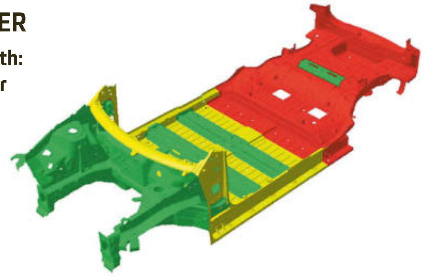
CITY SUV

Wheelbase length: 2,810 millimeter



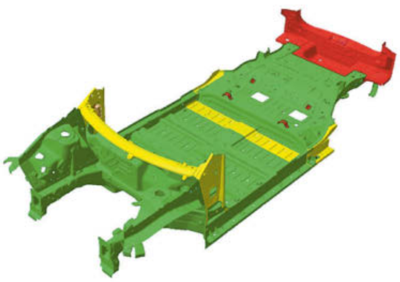
TRANSPORTER

Wheelbase length: 2,990 millimeter



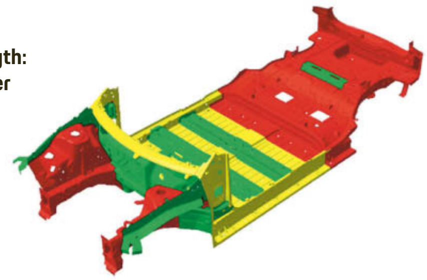
SEDAN

Wheelbase length: 2,810 millimeter



LARGE SUV

Wheelbase length: 2,990 millimeter



“The platform’s very first drafts already accounted for scalability.”

Humberto de Campos do Carmo
Senior Manager Vehicle Concepts and Package at Porsche Engineering

chain for platform engineering—from the initial project idea to detailed platform definition. In most cases, the foundations are laid by an initial feasibility study, which examines whether a project is technically viable within the specified framework parameters. This takes the customer’s subjective preferences and converts them into objective, physically testable and measurable properties.

COMPUTER-AIDED ENGINEERING

The next step is to work out the concept dimensions. The development team determines all of the vehicle’s and its components’ relevant dimensions. “This way, we keep on refining development further and further until we get a digital study of the vehicle as a whole,” explains Humberto de Campos do Carmo, Senior

Manager Vehicle Concepts and Package at Porsche Engineering. Precise specifications are created using simulations, for example for the shape of the body-in-white, for the battery, the seats, the powertrain, and the body support structure. Computer-aided engineering culminates in a virtual model, referred to as a digital mock-up (DMU), which includes definitions of the main components. At this point, the project version passes to the vehicle manufacturer in order to develop it further into a production-maturity vehicle.

Here, too, Porsche Engineering continues to support its customers in development, simulation, and testing of components, systems, and the complete vehicle. “Porsche Engineering’s comprehensive expertise makes the collaboration particularly valuable for us, as it provides us with seamless support across all areas and departments,” says Klaus Bernhard, Senior Manager Physical Architecture Platform and Dimension Concept at Porsche. “This cuts down on coordination work and makes development easier, because you always need to think of an electric vehicle platform as a holistic system. It’s the only way significant development content like crash safety, package, center of gravity, weight, and functions can be considered in parallel.”

SHOWCASING THE BRAND TO ITS BEST ADVANTAGE

With this in mind, it’s easy to see how the battery plays a key role. It’s the electric vehicle’s energy store, of course, but for reasons of installation space and weight, it should also act as an integral part of the crash structure and underbody reinforcement and be a component of the cooling system. “Porsche specifically uses the flexibility of the platforms to design vehicles that bring the brand-specific characteristics of Porsche sports cars to the fore—high suitability for everyday use and outstanding driving performance,” says Bernhard. This includes, for example, the design of the driver’s seat and the seating position, which must be ergonomic, sporty yet comfortable, and suitable for a broad customer group worldwide.

The overriding principle of platform development is that you should not start on a specific vehicle project until the platform has been defined. After all, it is only then that the individual development goals can be balanced in the best possible way and components such as the battery, front and rear axles, or even the size of the wheels, be designed optimally. Any changes after the fact are very time-consuming and costly, and sometimes just downright impossible. Many—often the smaller—automobile manufacturers don’t consider how a platform strategy might benefit them when they set out to develop a vehicle project. “It’s a shame, but it happens again and again that people get in touch with us when they already have a vehicle model and then want us to develop further derivatives—which the platform isn’t suitable for at all,” says de Campos do Carmo. “This puts the manufacturer up against a choice: Develop an entirely new platform or compromise and choose a solution that doesn’t meet all requirements.”

“Porsche Engineering’s comprehensive know-how makes the collaboration particularly valuable for us.”

Klaus Bernhard
Senior Manager Physical Architecture Platform and Dimensional Concept at Porsche AG

One example of a customer that sought cooperation with Porsche Engineering at an early stage, thereby saving considerable development expenses, is a customer that was planning to launch an electric vehicle model series. “Even the first drafts for the platform took scalability into account, and we also developed a modular system for the most important vehicle systems,” explains de Campos do Carmo. For the different wheelbases of the various vehicle models, for example, the development team defined the increments so that, for each wheelbase increase, the next-in-line battery module would plug the gap in the vehicle underbody. This way, the customer can cover all intended vehicle segments—from compact cars to sedans to SUVs—with one single platform.

HIGH FLEXIBILITY REQUIRED

Another aspect when designing a modern platform is its future viability. Even if, for example, the first plans only include rear-wheel drive vehicles, other options should also be accommodated at this point. This way, the platform will be able to handle vehicle models that haven’t even been brought to table yet, for example front-wheel or all-wheel drive variants. A high degree of flexibility is just as important for the design, as there needs to be room to integrate future technologies. After all, electromobility and its components, like batteries and electric motors, as well as the electrical systems and electronics architecture, are progressing in leaps and bounds. “Due to a platform’s long lifetime, you can’t predict the innovations you’ll need to be integrating into the vehicle in a few years’ time when you’re designing the platform,” explains Bernhard.
De Campos do Carmo adds: “When developing a new platform, you always have to weigh up which technologies will be ready for series production within that timeframe, and in which form they’ll end up being incorporated into the platform.”

SUMMARY

Platform concepts have aided in the development of different models and derivatives and the launch of production vehicles with reasonable time and cost for years now. For electric vehicles they offer many benefits. Designing one, however, presents a highly complex challenge: A myriad of aspects need to be taken into account, while some of the development goals stand in outright opposition to one another. Porsche Engineering supports its customers from the initial concept idea all the way to the production-maturity vehicle.

Efficient solution: Thanks to recuperation, the brake does not need to be made larger, despite the increase in the demands on it, and therefore does not have a negative impact on range either.

Braking for more

Battery electric vehicles place new demands on the chassis, particularly when it comes to braking and recuperation. Developers at the Porsche Group are working on new concepts for brake force distribution which will enable better recuperation without compromising comfort.

Text: Constantin Gillies

Chassis developers are challenged by electrification on two fronts: Batteries make the vehicles heavier but, on the other hand, the vehicles often exhibit better driving dynamics. Both of these factors usually necessitate a more powerful hydraulic wheel brake. However, this reduces efficiency and sacrifices range because the weight increases and consumption rises.

The Porsche Taycan gets by without a larger brake system—thanks to recuperation: As soon as the driver presses the brake pedal, the electric motors switch to generation mode. Once they do, it is no longer the motors driving the wheels, but the other way around. This brakes the vehicle and, at the same time, generates electricity that can be used to charge the battery. What's crucial for chassis developers is that recuperation does not require the brake to be made larger despite the increase in driving dynamics. The brake therefore has no negative impact on the range.

In the Taycan, 90 percent of all times the driver brakes in everyday situations, this can be done using electric power only, i.e. without the involvement of the hydraulic system. The latter is only used at speeds below 5 km/h, when the electric motors develop barely any braking power. In addition, the friction brake steps in when the electric motors do not have sufficient deceleration power, for example during full braking from high speeds. The Taycan Turbo S can generate up to 290 kW of electric power during braking. At this power level, two seconds of deceleration are enough to generate electricity to drive around 700 meters. Overall, recuperation increases the range by up to 30 percent.

One of the major technical challenges in chassis development for battery electric vehicles (BEVs) is blending, which is when regenerative and hydraulic braking are combined. "The driver must not feel the transition between the systems," emphasizes Martin Reichenecker, Senior Manager Chassis Testing at Porsche Engineering.

Guaranteeing a smooth transition places great demands on the technology, because the braking systems operate differently: While an electric motor always delivers the same braking torque, the torque from its hydraulic counterpart may vary each time due to environmental influences such as temperature and humidity. It therefore may be the case that the hydraulic braking power differs from the electric braking power at the transition point. The driver feels this as a jolt.

BRAKE CALIBRATION

Porsche has developed algorithms for the Taycan that prevent this from happening. They monitor the hydraulic system continuously: During each charging process, the brake is calibrated to determine the current ratio of brake pedal travel to brake pedal force. This allows the algorithm to estimate how much power the hydraulic system will deliver the next time the vehicle is braked, and deploy it precisely so that the transition to recuperation mode remains smooth.

↓

90%

of all times the driver brakes in everyday situations, this can be done using electric power only in the Porsche Taycan.

↓

Up to

290

kW of power can be generated by the Porsche Taycan Turbo S during electric braking.

"The driver must not feel the transition between the systems."

Martin Reichenecker
Senior Manager Chassis Testing
at Porsche Engineering

The Taycan Turbo S

Consumption data in the NEDC:
Power consumption (combined): 26.0 kWh/100 km
CO_2 emissions (combined): 0 g/km

Consumption data in the WLTP:
Power consumption (combined): 23.4–21.9 kWh/100km
CO_2 emissions (combined): 0–0 g/km

As of 11/2022

Roughly

700

meters of range are gained from two seconds of electric braking in the Porsche Taycan.

In vehicles, braking power is usually unequally distributed: Two thirds of it is provided by the front axle, one third by the rear axle. The same ratio applies for the electric system in the Taycan: The front electric motor provides two thirds of the braking power, the rear one provides one third—although the rear motor is larger and could theoretically contribute (and recuperate) more. This potential could be leveraged by varying the distribution of the braking force between the axles. In this context, it is important to note that, for reasons of driving stability, the maximum rear-axle contribution must be limited according to situation to ensure a sufficient stability reserve. "The electric motor that can absorb the most energy would then deliver the greatest braking torque," explains Ulli Traut, Function Developer and Integration Engineer Regenerative Braking at Porsche AG.

CORRIDOR FOR DISTRIBUTION

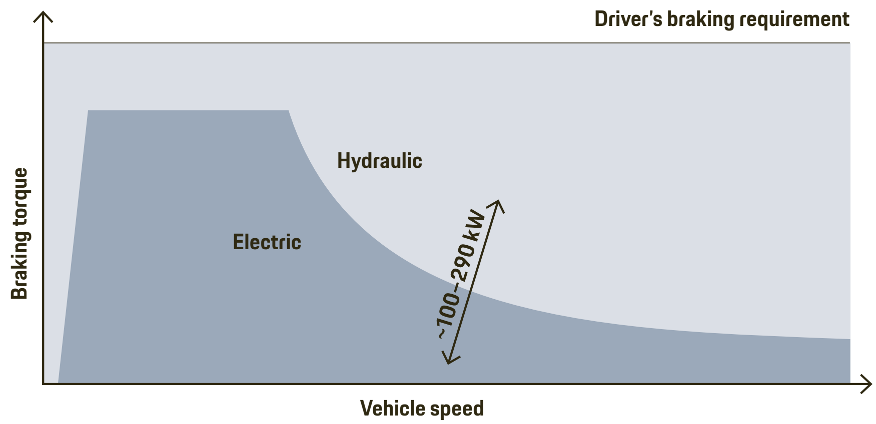
As with the interaction between the hydraulic and generative brakes, the shifts in forces must not compromise driver or passenger comfort. One solution would be to have two algorithms operating at the same time: The first one analyzes the driving situation and suggests a 'corridor' in which the braking force is optimally distributed between the front and rear axles—based on test bench data. A second algorithm selects a distribution that suits the current driving situation from the most efficient 'corridor'. According

DIVISION OF LABOR: HYDRAULIC AND ELECTRIC BRAKES IN THE TAYCAN

The graph shows how the hydraulic (light area) and electric (dark area) shares of the brake in the Taycan supplement each other to brake the way the driver needs in tandem.

The area showing constant power (hyperbola) remains variable—according to how much energy the powertrain can currently absorb (approximately 100 to 290 kW).

Recuperation reaches its maximum productivity at around 140 km/h and is only reduced again when coming to a standstill at speeds below 12 km/h. At speeds below 5 km/h, only the hydraulic system is used for braking.



“We expect that brake pads will have to be replaced due to aging in the future rather than wear.”

Ulli Traut
Function Developer and Integration Engineer Regenerative Braking at Porsche AG

to expert Traut, this solution would guarantee ideal deceleration and bring a “significant gain in range”.

Until now, the brake in automotive engineering has been a relatively isolated system of its own. This has now changed in electric vehicles, because many more parts of the vehicle are involved in deceleration: Powertrain, power electronics, and battery. What’s more, the brake has its own display in the instrument cluster. All of this requires more interdisciplinary work from chassis developers. The engineers working on the brake, for example, will have to confer more closely with their colleagues working on transmission in the future, for example, because recuperation also involves the electric motor and therefore the transmission (the Taycan has a two-speed transmission on the rear axle). This creates new demands on its load-bearing capacity—but also offers new opportunities, as Reichenecker points out: “Developers have completely new degrees of freedom.” The potential ability to make the distribution of braking force between the front and rear axles variable is the best example of this, he says. Reichenecker expects that technology for the chassis and drive components will continue to merge. “In future architectures, most software functions will presumably be united in a single control unit.”

When it comes to driving, some manufacturers of electric vehicles are concentrating on what is known as one-pedal driving. The principle is that when the driver takes his or her foot off the pedal, the vehicle starts recuperating energy right away—and in extreme cases brakes so hard that the brake lights come on. This means that in most situations, the car can actually be driven with one pedal.

Porsche, on the other hand, makes use of coasting, which is the more natural process of allowing the vehicle to continue to roll unpowered. Recuperation only starts when the brake pedal is stepped on. “This is a more efficient way of driving, because it keeps the kinetic energy in the vehicle,” says Reichenecker. One-pedal driving, on the other hand, recuperates first, and only then converts the recovered energy back into propulsion. “That results in twice the losses.”

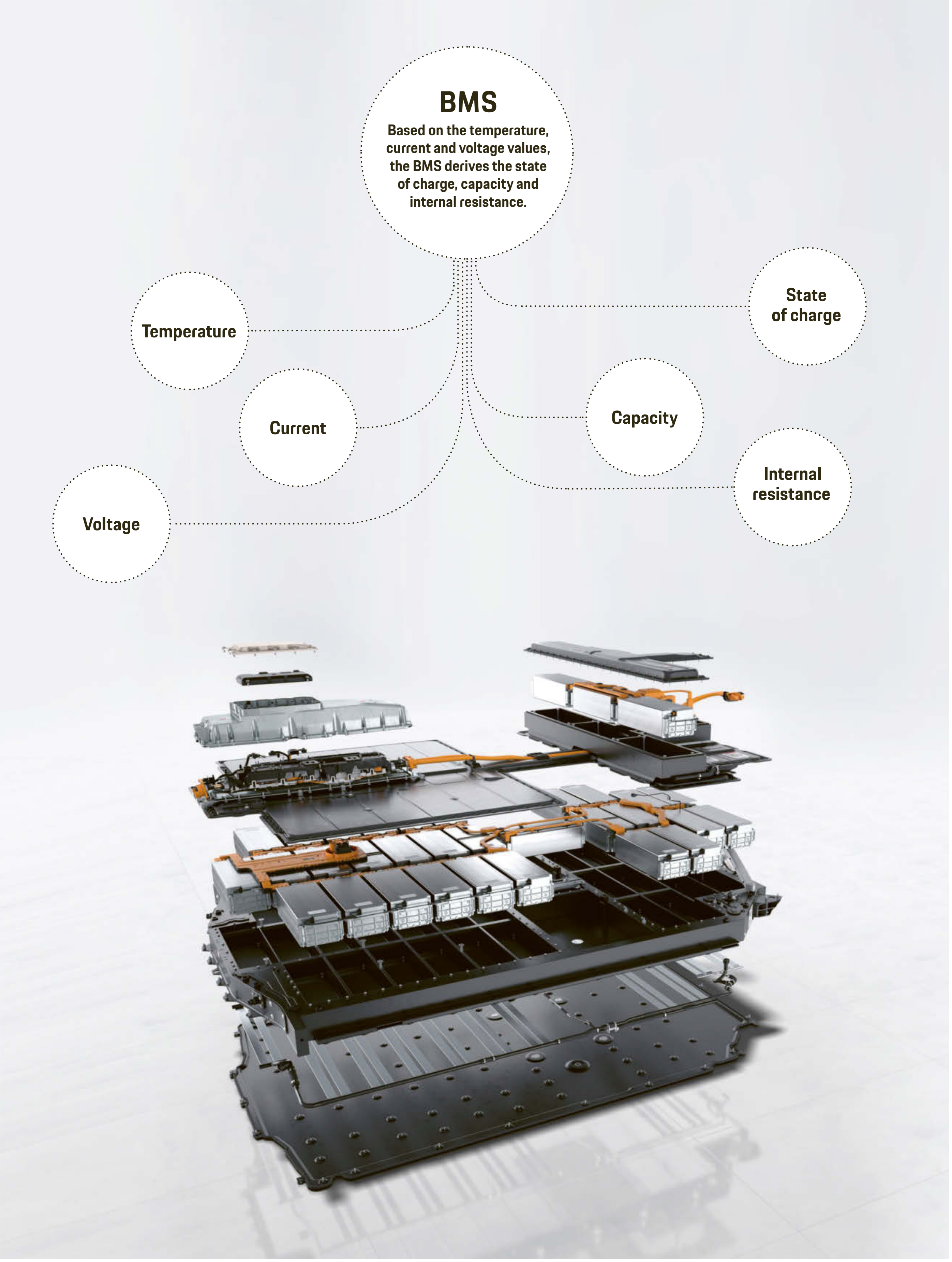
REDUCED BRAKE WEAR

Another positive effect of recuperation is that there is less wear on the hydraulic brakes. “We expect that brake pads will have to be replaced due to aging in the future rather than wear,” as Traut surmises. A feature has been developed for the Taycan to keep the brake discs clean, now that they are being used less often: The vehicle brakes at regular intervals using the hydraulic system only, and without the electric motors, to remove dirt from the discs. This could be a considerable advantage in the future, because the EU is planning for brakes to emit fewer particulates in the future. The new Euro 7 emissions standard, which is due to come into effect in 2025, will be the first time that limits are set for brake abrasion. This will then put electric vehicles like the Taycan, which only uses electricity nine out of each ten times it brakes, in a good starting position.

Up to

30%

more range can be gained in the Porsche Taycan by using recuperation.



Monitoring: The BMS is constantly determining operating parameters to enable maximum performance without negatively impacting battery life.

In feel-good mode

Porsche Engineering has been developing high-performance battery system solutions for motor racing and series production for more than 20 years. The battery management system (BMS) has the task of assessing the condition of the battery, defining the current operating limits and ensuring operation within those limits.

Text: Christian Buck

In battery electric vehicles (BEVs), the battery management system (BMS) plays a central role. It consists of the battery management controller (BMC) and cell module controllers (CMCs). The CMCs are integrated directly into the modules of the high-voltage battery and supply the BMC with measured values such as cell voltage and temperature. They are also responsible for cell balancing: High-voltage batteries consist of a large number of individual low-voltage battery cells. However, tolerances result in the cells having their own individual physical properties, which can cause problems when using the system. To prevent this, the CMCs balance the state of charge of the cells—either passively by means of resistors connected in parallel, or actively by transferring charge from weaker to stronger cells.

The BMC is the central element of the BMS and uses its own current sensors in addition to the measured values from the CMCs. One of its functions is to ensure that the battery operates safely. After all, battery systems contain large amounts of energy and are capable of releasing this energy very quickly. Any uncontrolled or unintended release must be prevented at all costs. In addition, the BMC must find an optimal compromise between battery life and performance, because operation outside the specified parameters can cause damage to the system. Typical causes include excessively high currents; excessively high or low temperatures, which damage the electrolyte or lead to higher current sensitivity; and overvoltage or undervoltage, which can damage the electrolyte or the active materials.

To prevent this, the BMS is used to change current limits, restrict operating modes or adjust the cooling according to the battery condition. “Based on the measured values from numerous temperature, current, and voltage sensors, the BMS derives three crucial battery parameters: The state of charge (SoC) and the capacity, which determine the remaining range, and the internal resistance, which limits performance,” explains Lukas Mäurer, Project Leader High-Voltage Battery Functions at Porsche Engineering. “It is also responsible for safety functions such as overcurrent shutdown and crash detection, as well as for communication with the other controllers in the vehicle.”

OVER 20 YEARS OF EXPERIENCE

Porsche Engineering has already developed diverse BMSs on behalf of customers, and can take on all tasks that arise in connection with the V-model—from requirements surveys to vehicle testing. “As a company, we have been active in this field for more than 20 years, and I have personally been involved with battery management systems for six years,” says Mäurer.

Despite all the experience gained over the course of numerous projects, developing a BMS remains a challenging task even for experienced developers: The software is exceptionally complex, which poses a number of challenges for both engineering and project management. Porsche Engineering therefore attaches great importance to a stringent and transparent process. It begins with requirements management, something that the experts pay particular attention to. "And it's not just about laying the technical foundations—this is also where the further course of the project is decided," emphasizes Achim Olpp, Project Leader at Porsche Engineering.

CHECKING THE SPECIFICATIONS

Potential problems need to be identified and eliminated by checking a new set of specifications as soon as it has been drafted. Olpp refers to the 'rule of ten'. With each stage of software development, the costs of rectifying errors increase by a factor of 10. The effort it involves increases with each process step, since work that has already been done must be checked and redone from the point at which the error arose. Subsequent errors also have to be 'caught' again. This almost automatically jeopardizes what are often tight schedules, especially in the case of software that exists in different versions customized for multiple customers.

"We have gained a lot of experience in BMS development, from motor racing to large-scale production."

Lukas Mäurer
Project Leader High-Voltage Battery Functions at Porsche Engineering

In order to prevent this kind of additional work, having the author of the software requirements specifications, working under the direction of the requirements engineer, call together all project participants for a 'review' of the specifications supplied by the customer has proved a good approach. "Everyone then gathers around the table, including the software architects and developers as well as the testers and the customer," Olpp explains. "It's a much better way to understand the requirements that arise from the specifications and to define the potential solutions for the specifications more systematically. When there are multiple customers, the review provides the opportunity to harmonize different interests." Although this increases the workload somewhat at the beginning, it brings significant time savings in the long run.

Planning of the work scopes builds up on this solid foundation. "We hold a capacity workshop two weeks before each software release cycle to match the customer's needs with the available resources," Olpp reports. "This way, we know exactly what can be accomplished in the time available. And the customer can prioritize work packages where applicable."

CLEAR PICTURE OF CAPACITIES

Precise capacity management can also help prevent the dreaded 'scope creep'. This is when the requirements for a product change continuously and spontaneously during its development, which often results in delays. "If you clearly identify your capacities, you can also better understand and coordinate the effects of requirement dynamics like this," says Olpp. When using software carry-over parts for multiple models and brands in particular, a lot of care needs to be taken during this step. Incorrectly integrated scopes can simultaneously jeopardize several vehicle series due to the modular schedule.

Software architects are also confronted by a number of challenges during BMS development. Among other things, they have to make allowance for the fact that cell chemistry and battery design are constantly evolving (see the article on page 42). "A modified battery cooling system has an impact on thermal management, among other things," explains Mäurer. "The temperature of the individual battery cells cannot be completely determined using sensors. For example, if 60 sensors are used to determine the temperature for 200 cells, the software architecture must support different sensor installation positions and different cooling concepts such as multi-sided cooling plates."

This is why BMS functions must be developed that are easy to adapt to such changes, he says. When it comes to software architecture, the use of software carry-over parts also leads to additional challenges. They necessitate modular structures that meet the requirements of a specific vehicle, but do not result in disadvantages in other models.

ADAPTING TO RESOURCES

The software development step follows the definition of the software architecture and aims to make solutions from predevelopment suitable for series production. A typical task, for example, is to adapt algorithms to the limited resources in terms of processing power and memory capacity of the control units in vehicles—without compromising the quality of the results. "In predevelopment, usually only a single cell is monitored with sensors; in the vehicle, there are several dozen," says Mäurer. "But you can't simply run the algorithm used for a prototype dozens of times in succession in series production, because that would make the required processing power too high."

BEVs also make use of many innovative functions, for example for fast charging. They often operate at the limit of what is currently technically feasible. During the transition from prototype to production status, these functions must be made robust enough to run without problems in all conditions. "In the case of fast charging, this could be achieved by implementing control algorithms that limit the charging current in the event of imminent overheating or voltage overshoot," says Mäurer. If the customer is also pursuing a software carry-over part strategy, developers must also ensure a high degree of adaptability of their functions, for example to adapt to different cell chemistries or hardware concepts.

"Software development for series production is a transfer service for which Porsche Engineering, among others, is particularly well suited," as Mäurer sums up. "We have gained a lot of experience in BMS development, from motor racing to large-scale production. Our solutions are present in all brands within the Volkswagen Group, but also in the 919 Hybrid, Porsche's Le Mans winner." In addition, Porsche Engineering also has its own cell and battery expertise, as well as experience with new technologies such as 800-volt networks in vehicles.

"Without solid processes, a BMS project is like a skyscraper without a stable foundation."

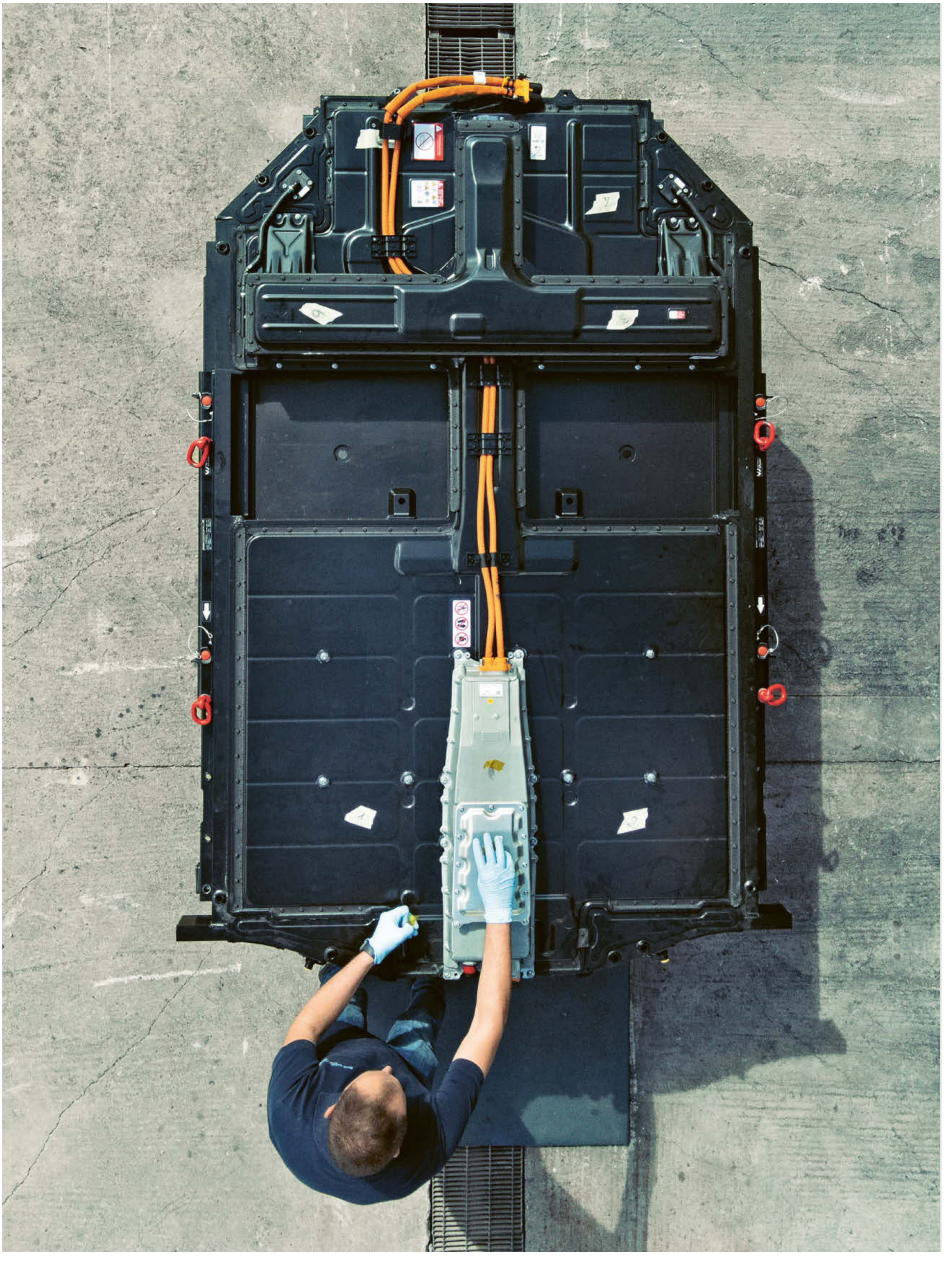
Achim Olpp
Project Leader at Porsche Engineering

The experts evaluate how well the software that was developed meets the requirements for the first time during the module test. In this test, the smallest units of the programs—for example, for calculating residual capacity—are fed with defined input values. If they deliver the expected results, the algorithm is, basically, working correctly. Otherwise, the software developers have to edit the program code. "As the first verification step, the module test offers a lot of potential to save time and money," says Mäurer. "After all, anything found here would require significantly more effort to fix later in the project."

DUAL CONTROL PRINCIPLE DURING TESTING

At Porsche Engineering, the dual control principle applies for module testing: Programming and testing are carried out by different employees. At the very end, a representative from quality assurance joins in who, in addition to the result, also validates the development processes completed beforehand. This ensures that the next steps in the V-model—integration, software and vehicle testing—can build on a good foundation. After all, Project Manager Olpp's advice applies to the entire development process: "Without solid processes, a BMS project is like a skyscraper without a stable foundation."

Comprehensive service: Over the past two years, Porsche Engineering has set up a complete test facility at the NTC for 'misuse tests' on high-voltage batteries in accordance with GB/T and ECE.



High-voltage batteries on the test bench

Porsche Engineering uses state-of-the-art testing procedures for the development of electric drives, which include both real-life tests and tests conducted in a virtual environment. Their use can significantly shorten the development time and reduce the number of test vehicles needed.

Text: Richard Backhaus
Photos: Rafael Kroetz; Luca Santini

To continue to increase efficiency in the development of new components and systems for electric drives, Porsche Engineering uses test methods specifically adapted to the requirements of high-voltage technology. As an example, high-voltage batteries are tested on vehicle and component test benches at the Bietigheim-Bissingen and Nardò locations, while hardware-in-the-loop simulation environments are available for testing the software for pulse inverters (PIs). This involves testing the real hardware in a virtual vehicle system.

The PI plays a key role in electric vehicles because it converts the DC voltage from the battery into the multiphase AC voltage and the associated rotating field for the electric drive motor. When energy recovery is active in overrun mode, the PI works in the opposite direction and converts the motor's AC voltage into a DC voltage that is used to charge the battery. "Precise PI control for the various performance and comfort requirements in different driving situations requires highly complex control algorithms and safety functions that have to be tested before the drive is put into operation," explains Rafael Banzhaf, Technical Project Leader at Porsche Engineering. "This involves, for example, ensuring the drive system enters a safe state in exceptional situations such as a crash with airbag deployment."

Prior to development of the PI-HiL system, the tests had to be carried out in the vehicle or on a real test bench, with there always being a risk that something could be damaged in the event of software errors in the control unit. Porsche Engineering has therefore developed a test bench concept for testing the PI software, in which the real PI ECU is integrated as hardware-in-the-loop (HiL). "The ECU is exactly the same as the version in the vehicle, so we can draw reliable conclusions about the function of the software that has been installed," says Thomas Füchtenhans, Development Engineer at Porsche Engineering. "The only modification is a disconnection of the high-voltage components from the low-voltage components such as the PI control board in the ECU. This is necessary for both functional and safety reasons but has no impact on the tests."

CALCULATIONS IN NANOSECONDS

When the HiL tests are conducted, the PI control board does not activate real hardware, but rather a simulation of the PI power unit. This, in turn, is linked to simulations of the high-voltage battery, the electric drive motor, the bus system and the rest of the vehicle in order to factor in the impact on the PI control caused by vehicle systems such as airbags or the brake control system, and the driver, on the PI control. Conversely, the simulation delivers virtual sensor data such as phase currents and temperatures back to the PI control unit, thereby closing the control loop. Due to the high demands on the real-time capability, the simulations for the battery and the rest of the vehicle are carried out on a real-time computer (RTPC), while even faster FPGAs (field programmable gate arrays), which allow simulation times within the nanosecond range, are used for the power electronics and the electric motor.

"With tests on the PI-HiL, we can lighten the load on the real test benches, reduce costs and increase safety."

Rafael Banzhaf
Technical Project Leader at Porsche Engineering

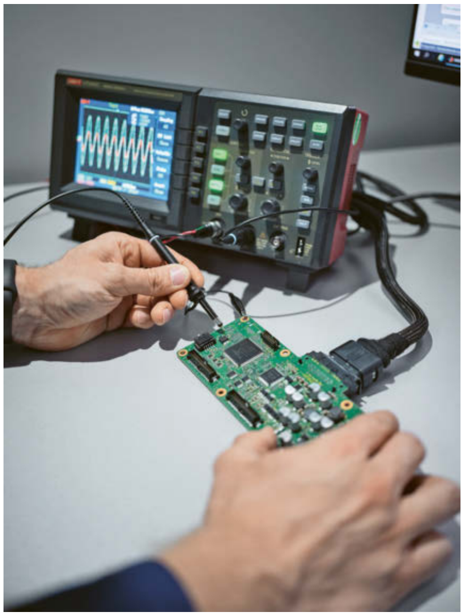
The test scopes possible on the HiL test bench primarily include functional tests according to specification requirements, but also flash tests of new software, validation tests as a safety step before further analyses are conducted in the vehicle, and tests of the interfaces, diagnostic functions, execution times and of cybersecurity and virtual endurance testing. “While we cannot completely replace tests on real test benches or in the vehicle with the PI-HiL, we can significantly reduce their scope, thereby lightening the load on the real test benches and reducing costs significantly while increasing safety as well,” reports Banzhaf.

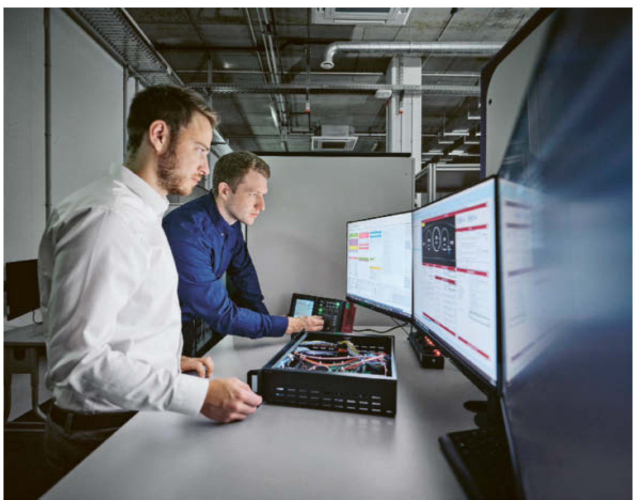
The development of the PI-HiL test bench is the result of close cooperation between different Porsche Engineering locations. Six PI-HiL systems are currently in use, and there are plans for this capacity to increase. “A special feature of our approach is full remote access to control the test benches,” says Füchtenhans. “This allows, for example, application engineers running tests in Sweden or the US to control the simulations from their location. Because all test benches are connected to each other, and to the archiving system, the data can be made available on the servers to all participants with immediate effect. The Shanghai location in particular offers great

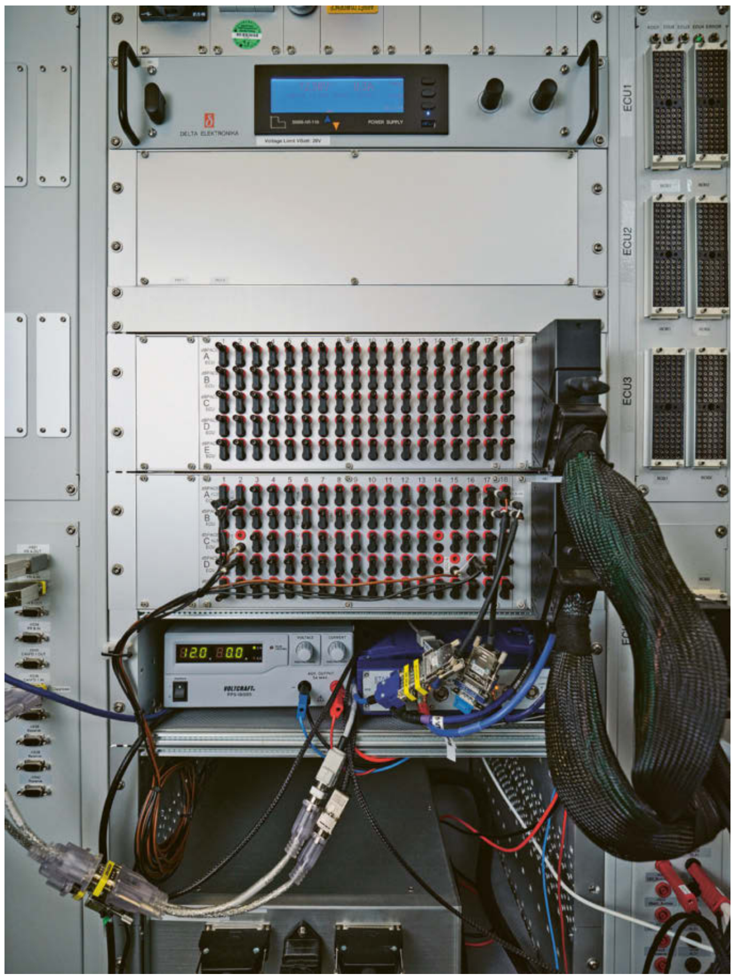
“A special feature of our approach is the complete remote control of the test benches.”

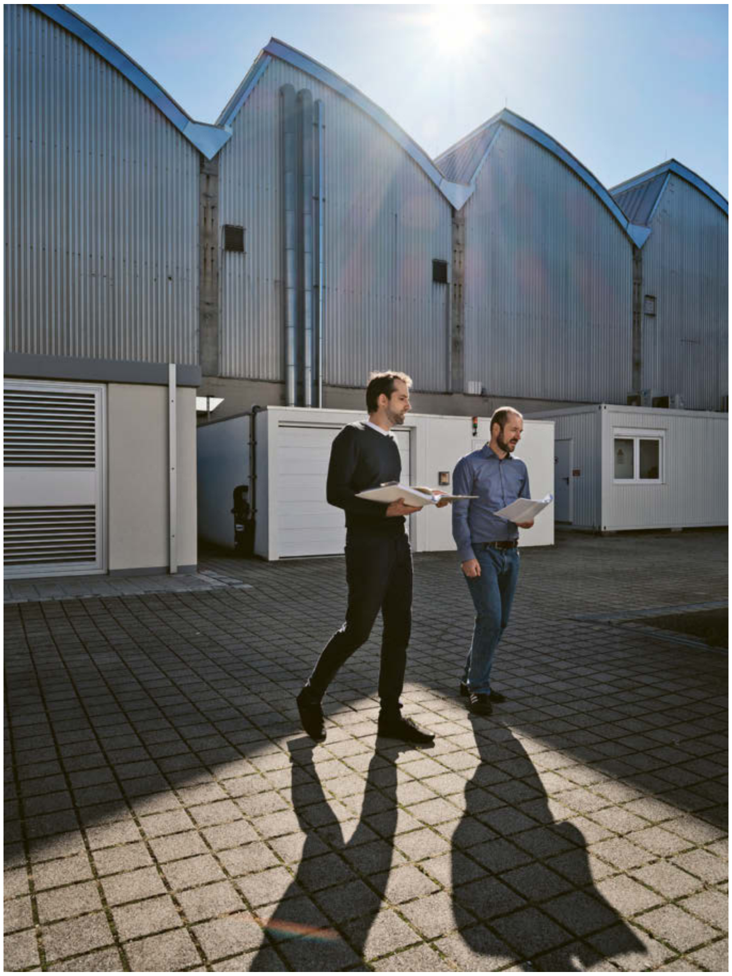
Thomas Füchtenhans
Development Engineer
at Porsche Engineering

Virtual testing: The PI controller (top left) is tested on the HiL test bench (right). Rafael Banzhaf (bottom left) and Thomas Füchtenhans (bottom right) can control and follow the test live.









Real tests on cell and system level: Dirk Pilling (top left) in front of a climate chamber at the test center in which a cell is being measured. In the picture at the bottom left, he is examining a cell stack with Dr. Ulrich Lange.

opportunities for high testing efficiency in this regard, as it allows round-the-clock test implementation and evaluation in the international network of teams due to the time difference between Europe and China."

GENERATING TEST CASES USING AI

Another advantage of Porsche Engineering's PI-HiL is its high level of automation. The requirements documentation for the PI control system supplied by customers is automatically imported. The test specifications are then automatically derived from the customer specifications and used to generate a variety of test cases and trials that can be implemented. "The closed automation chain increases efficiency throughout the test process. Instead of spending several weeks creating the more than 1,000 test cases for a PI test series manually, we only need about a few hours," says Banzhaf.

In the future, there are also plans to employ artificial intelligence (AI) methods: Using natural language processing (NLP), AI is expected to correctly interpret requirements specifications delivered as a simple text document and convert them into machine-readable code. This is used as a basis to automatically generate the test sequences. Today, this activity is performed by experts who must have comprehensive overall system expertise. "Our approach transfers expert knowledge into the digital world, helping to save development time and costs. Initial

"The turn-around time for tests is only about 48 hours for us."

Dirk Pilling
Development Engineer
High-Voltage Batteries
at Porsche Engineering

Misuse test at the NTC: Antonio Toma (top left) and Andrea Casaluce (top right) equip the test object with sensors. It is stored in a heat-insulated enclosure (left) before the test takes place in the battery test building (bottom right).

validations have been very successful. Therefore, I am convinced that we will also use AI in the regular testing process in the medium term," explains Banzhaf.

Even though virtual test procedures are covering more and more areas, they still cannot completely replace real-life trials of high-voltage batteries. For this reason, Porsche Engineering maintains an extensive infrastructure in Bietigheim-Bissingen, with vehicle as well as system and cell test benches. The former is used to analyze batteries more precisely at component level, while the latter even allow conclusions to be drawn at cell chemistry level. By means of a flexible adaptation of driving profiles and load spectrums, the driving situations relevant for the test can be simulated. Depending on the objective of the test, the battery's charge and discharge behavior, its capacity, internal resistances, and temperature behavior are captured and recorded.

Batteries can be tested in their installed state on the vehicle test benches, for example for measurements of battery capacity and currents in the WLTP driving cycle. This is particularly important for endurance test vehicles, where testing the battery every 20,000 kilometers is part of the mandatory scope of testing. "Removing the battery for the tests would take too much time. Instead of taking around a week with removal, the turnaround time from delivery of the vehicle and test preparation to testing and data evaluation is only around 48 hours for us," says Dirk Pilling, Development Engineer High-Voltage Batteries at Porsche Engineering. He also points to another aspect: "Work on the battery could falsify the vehicle endurance test, for example because screws connecting it to the vehicle body are undone and then reconnected during subsequent reinstallation."

Leak tests can be conducted on battery housings on another test bench. "Leaks are caused by corrosion or vibration damage, among other things. If water then penetrates the battery system, this can lead to short circuits," explains Dr. Ulrich Lange, Project Leader High-Voltage Batteries at Porsche Engineering.

PROTOTYPES FOR TESTS

The integrated workshop plays a key role in all battery tests in Bietigheim-Bissingen. "The batteries are prepared for measurements and equipped with the necessary sensor technology there, however entire battery packs and modules are also set up as prototypes for the tests, and the batteries are disassembled for evaluation after the test," says Lange. In some cases, the workshop also handles the preparation of batteries destined for testing at the Nardò Technical Center (NTC).

Over the past two years, Porsche Engineering has set up a complete test facility at the NTC for 'misuse tests' on high-voltage batteries in accordance with GB/T and ECE. This involves examining how the battery responds in the event of a 'thermal runaway' of a battery cell, which might, for example, be caused by overheating.

"We have a background in automotive development and can work with customers with that shared foundation."

Antonio Toma
BEV Coordinator at the Nardò Technical Center

At the NTC, these misuse tests are conducted in a building. "Thermal runaway tests in enclosed buildings place stringent demands on the way measurements are conducted to ensure that the fire burning in the battery remains under control and does not lead to any damage," says Antonio Toma, BEV Coordinator at the Nardò Technical Center.

Therefore, the engineering team in Nardò joined forces with the safety experts and firefighters at the NTC to develop a sophisticated safety concept. After delivery, the batteries are prepared for examination before undergoing testing. Fire extinguishing systems that are triggered automatically ensure a high level of safety. The battery status is assessed after the test. If critical, the battery must rest for 24 hours in a locked box equipped with fire detectors until the NTC experts can begin analyzing the damage and making their findings. After the examination, the battery is stored in a shelter that is also equipped with a fire protection system to await disposal.

This is the basis on which the NTC offers a comprehensive service that not only includes overheating and spontaneous combustion tests of the cells, but also misuse tests of the battery specifically adapted to customer requirements, as well as analyses of the fire resistance of the battery housing. The scope of services ranges from storage, preparation and test execution to post-mortem analysis and detailed reporting. "The great advantage of testing in the test building is that we work under laboratory conditions. In addition, we have a background in automotive development, so we know the specific requirements and can work with customers with that shared foundation," says Toma.

With its combination of real and virtual processes, Porsche Engineering can offer customized testing services. In either case, customers benefit from expert knowledge, methods, and services at the cutting edge of technology.

SUMMARY

Porsche Engineering uses test methods specifically adapted to the requirements of high-voltage technology. These include conventional test benches, but also HiL test benches for virtual testing of PI controllers. Artificial intelligence will help to save development time and costs there in the future.

ANY QUESTIONS?

Some questions just have to be asked. We have the answers—delivered with an amusing twist. This time:

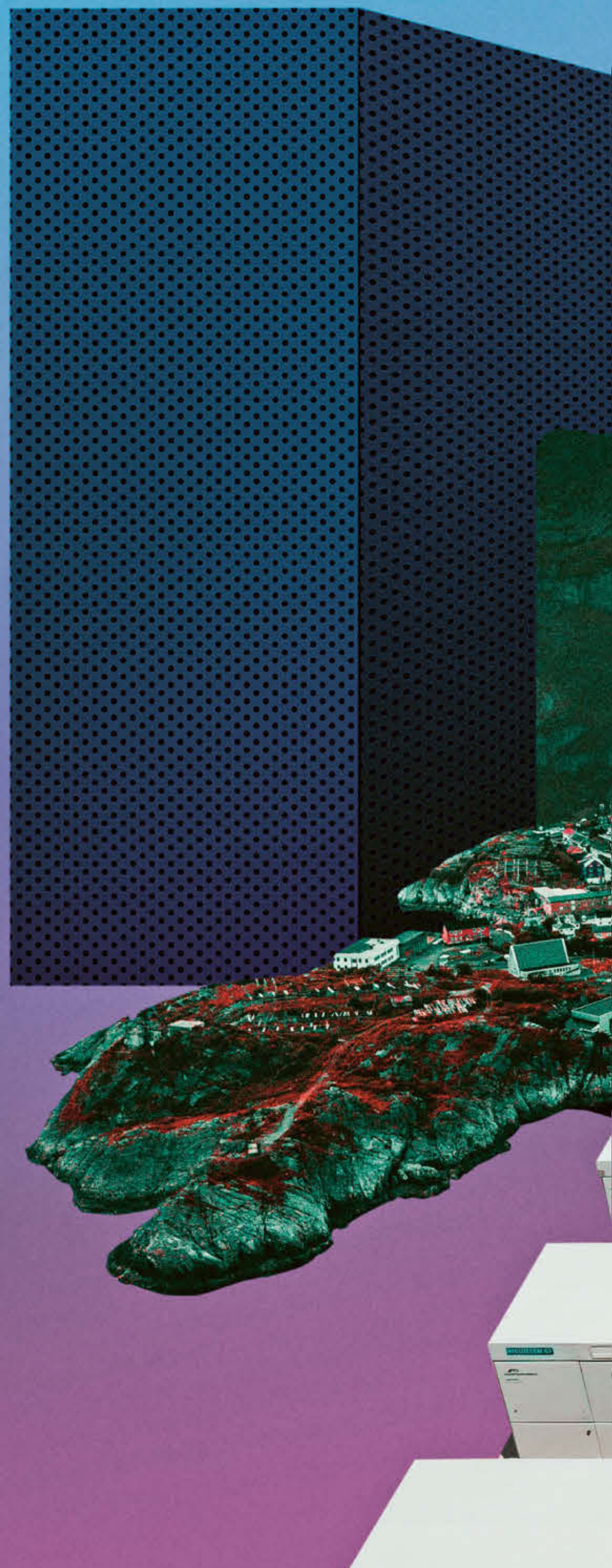
Just how big are the biggest batteries in the world?

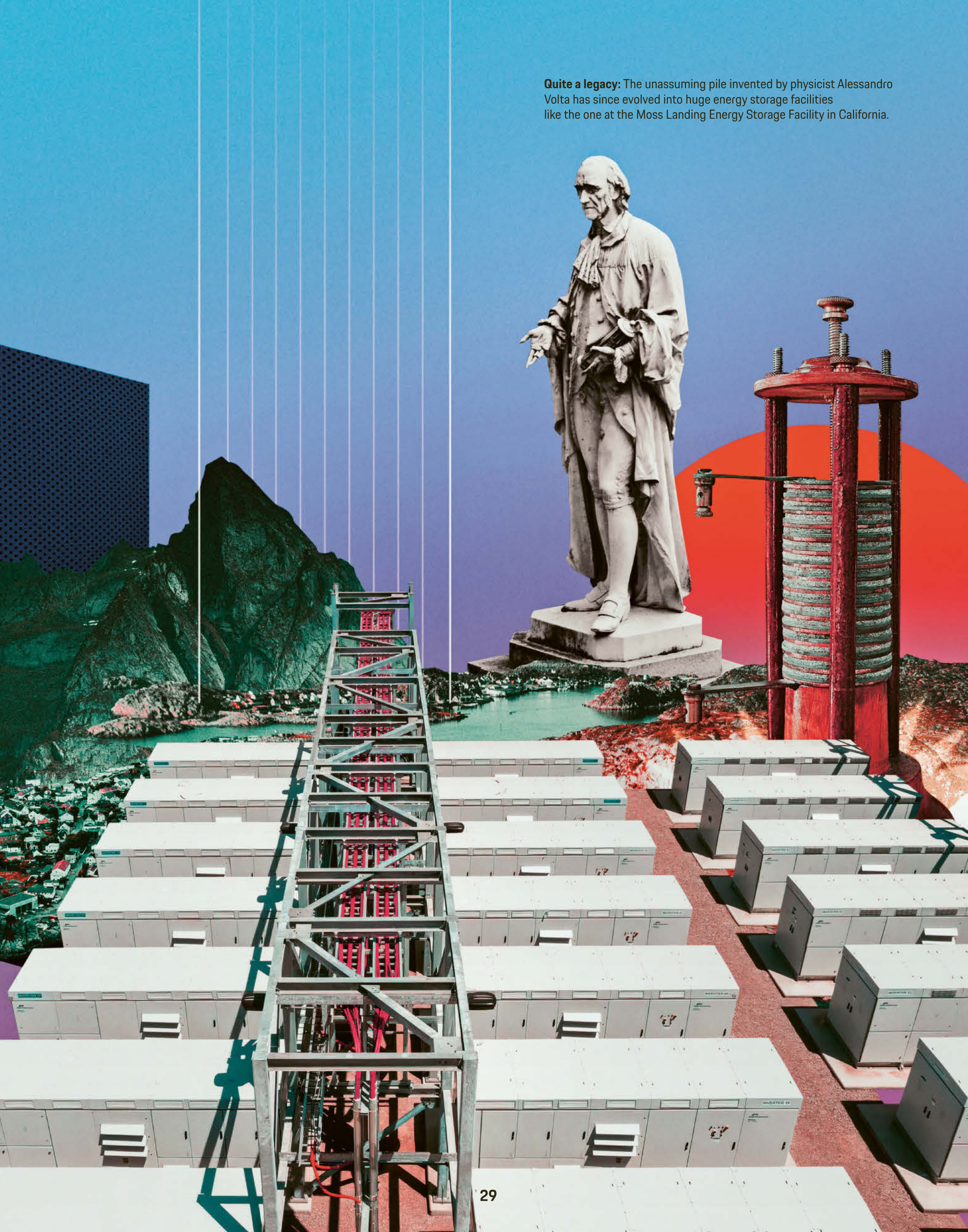
Text: Christian Buck
Illustration: Julien Pacaud

It all began very modestly. In 1800, the Italian physicist Alessandro Volta presented an invention to the venerable Royal Society in London which made an unassuming impression at first, but would quickly make name for itself all around the world: the Voltaic pile, the forerunner of today's batteries. The structure of the cylindrical object was typical of the era and consisted largely of wood—with plastic as an insulating material for the housing having not yet been invented at the time. The functional principle of first power source, however, was actually very modern: Plates made of different metals such as copper and zinc were separated from each other by pieces of cardboard or leather that were saturated with an electrolyte (for example, salt water or lye). Today's batteries use the same basic principle for operation.

But while these early sources of power developed in the 19th century were primarily used as aids in the laboratory, today's batteries play a key role in electronic devices and electric vehicles. And that's not all: In the future, they are supposed to also help bring the fluctuating production of renewable energies into line with effective power consumption levels. One example of how this will be achieved is a 'grid booster' made of lithium-ion batteries currently being put together in Kupferzell, Baden-Württemberg, covering an area the size of four-and-a-half soccer fields. From 2025 on, it will be able to deliver a maximum of 250 megawatts of power—for one hour, amounting to a capacity of 250 megawatt-hours (MWh).

Not, however, that this puts the grid booster in Kupferzell anywhere near the top of the list of the world's largest batteries. That honor is taken by the Moss Landing Energy Storage Facility in Landing Harbor, California, which has a capacity of 1,200 MWh and is also based on lithium-ion batteries. Also in California—in Lancaster near Los Angeles—is the Luna LAB Energy Storage Facility, comprised of lithium-ion batteries that boast a storage capacity of 908 MWh. It can supply 170,000 households in the US state with clean electricity for four hours. Not bad for a technology that first saw the light of day 200 years ago as a concoction of wood and metal.

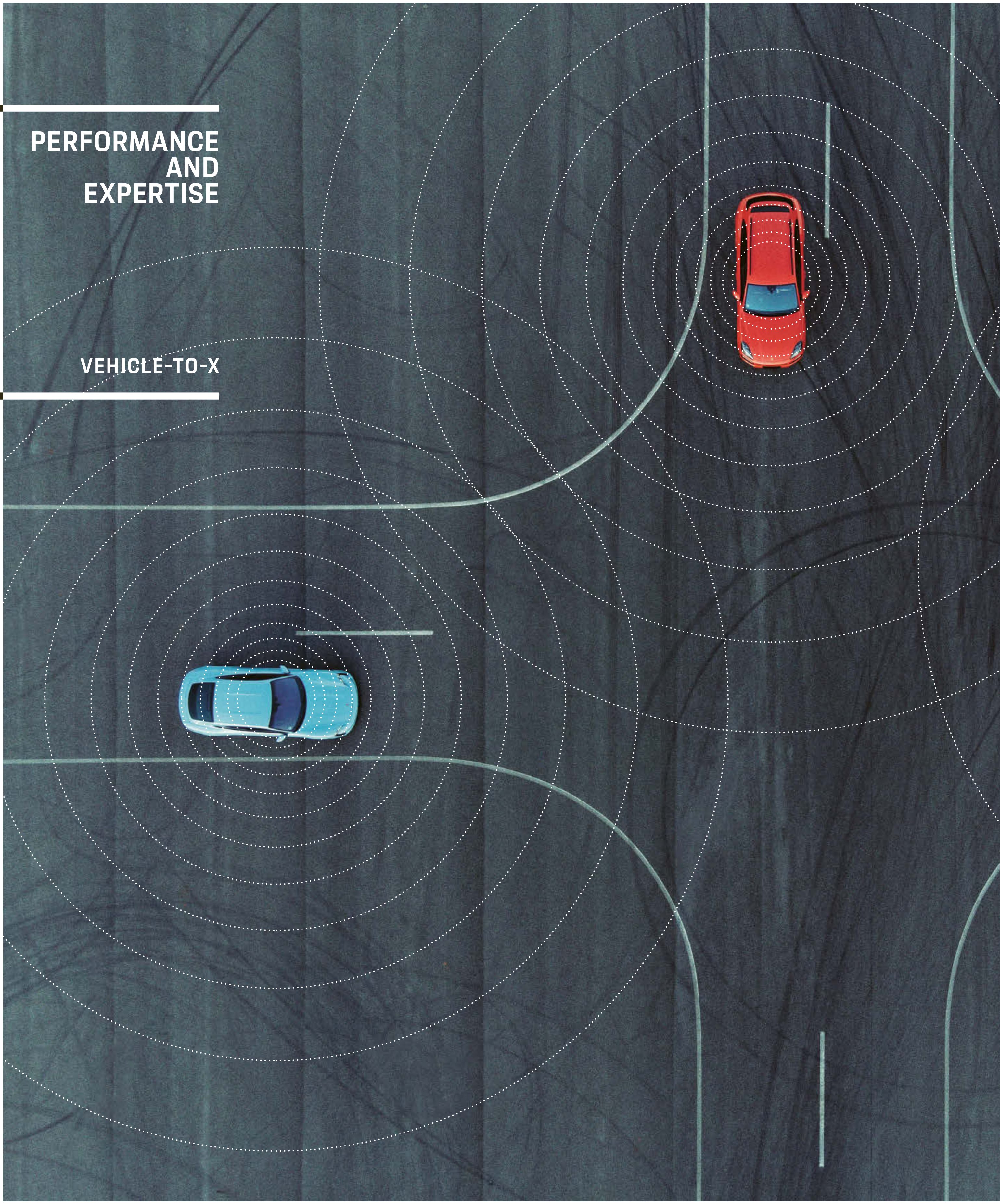




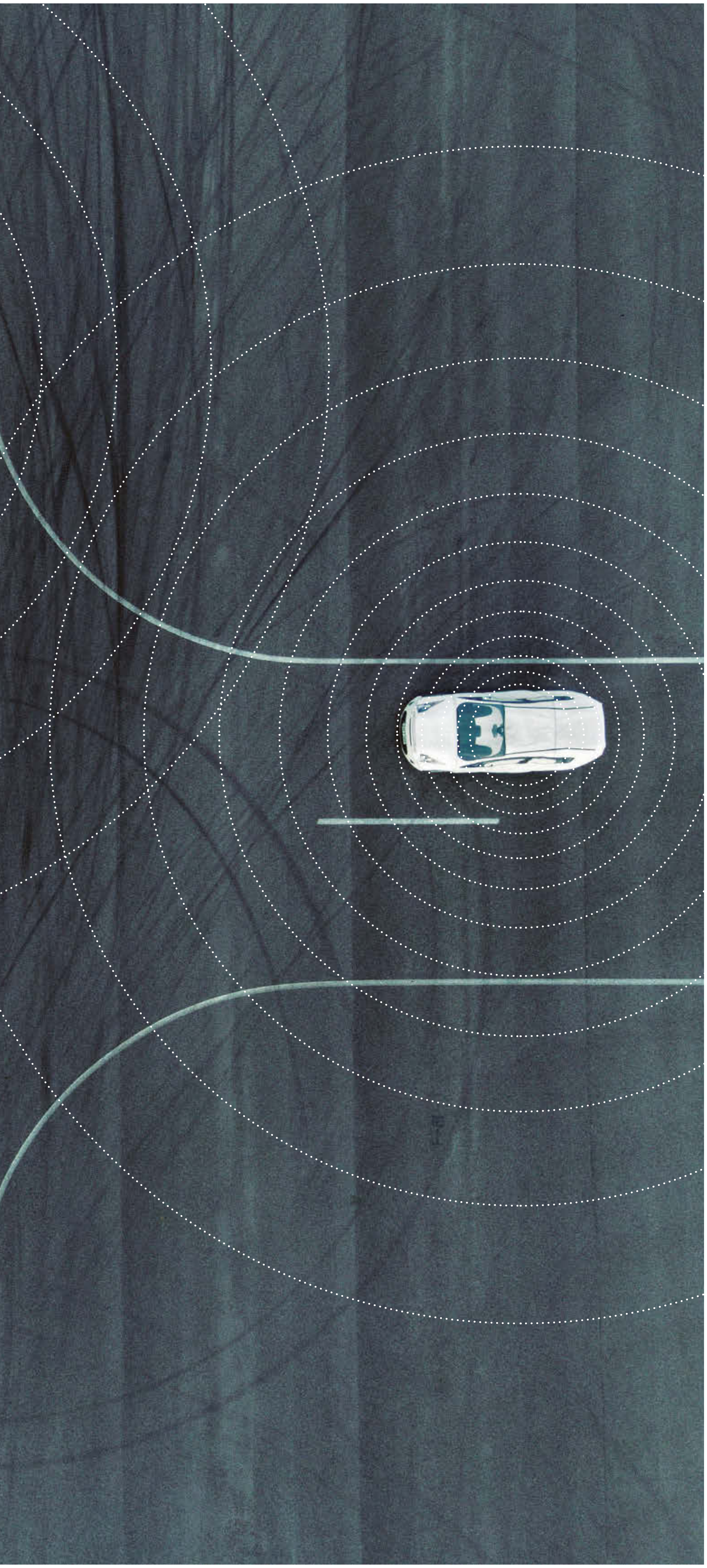
Quite a legacy: The unassuming pile invented by physicist Alessandro Volta has since evolved into huge energy storage facilities like the one at the Moss Landing Energy Storage Facility in California.

PERFORMANCE AND EXPERTISE

VEHICLE-TO-X



Data exchange for greater safety: V2X is supposed to help prevent accidents and improve the flow of traffic. Communication between vehicles can take place using 5G mobile communications or Wi-Fi.



The Cayenne GTS

Consumption data in the NEDC:
Fuel consumption (city) 15.3–14.7 l/100 km
Fuel consumption (highway) 9.1–9.1 l/100 km
Fuel consumption (combined) 11.4–11.2 l/100 km
Combined CO_2 emissions (model series): 260–255 g/km

Consumption data in the WLTP:
Fuel consumption (combined) 14.1–13.3 l/100 km
Combined CO_2 emissions 319–301 g/km

The Taycan

Consumption data in the NEDC:
Power consumption (combined)
(Performance battery) 26.4 kWh/100 km;
Power consumption (combined)
(Performance battery Plus) 27.0 kWh/100 km;
Combined CO_2 emissions 0 g/km

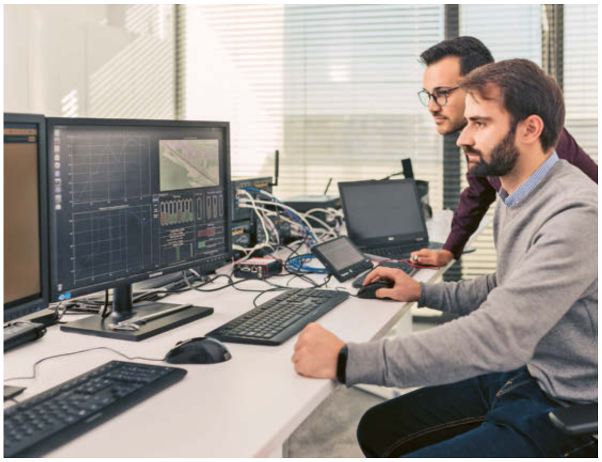
Consumption data in the WLTP:
Power consumption (combined)
(Performance battery) 23.5–19.6 kWh/100 km;
Power consumption (combined)
(Performance battery Plus) 23.9–20.4 kWh/100 km;
Combined CO_2 emissions 0–0 g/km

As of: 10/2022

CONNECTED. EFFICIENT. SAFE.

Tomorrow's vehicles will communicate with each other and their environment. This vehicle-to-X communication (V2X) helps prevent accidents and traffic jams—and advance autonomous driving. Porsche Engineering develops V2X functions ready for series production and is already working on the AI-based functions of tomorrow.

Text: Constantin Gillies
Photos: Luca Santini; Chris Nemes



Development

The Car Data Box was developed by a team led by Adrian Timiș (front) and Dumitru Coteț (back) at the Porsche Engineering sites in Cluj-Napoca and Timișoara, Romania.

The obstacle is directly behind a curve: A large branch blocking the road. A vehicle turns into the corner—and immediately unleashes a digital cascade. The front camera detects the obstacle and the evaluation algorithm connected to it sounds the alarm. It classifies the branch as a hazard and initiates braking. At the same time, it reports the position and the type of obstacle to a cloud server using the mobile network. Other drivers who are also approaching the hazard area now see the 'Obstacle' warning message on their dashboard, including the distance to the branch on the roadway. This enables them to prepare for the hazard well in advance.

This scenario is supposed to soon be a reality, as vehicle-to-X (V2X) communication is making rapid advances. In just a few years' time, vehicles should remain in constant contact with each other and their environment. They will then be able to exchange information with pedestrians' smartphones or with a set of traffic lights. V2X is supposed to help prevent accidents, improve the flow of traffic and make advanced driver assistance systems (ADAS) more effective. "The vehicle of tomorrow will not only use its own sensor technology, but also other road users' sensor systems," explains Pasqual Boehmsdorff, Project Leader for V2X Function at Porsche Engineering. "This makes V2X an important step forward on the road to fully autonomous driving."

China is currently a pioneer when it comes to V2X. In the metropolis Wuxi, many sets of traffic lights are connected to a traffic control center that tells drivers when the next run of green lights is coming. What's more, the networking of road users is being trialed in the metropolitan area: If the vehicle's on-board sensors register, for example, that the road surface is slippery, it can send this information to a central server that relays it on to other vehicles. Porsche Engineering is also already conducting intensive real-world tests with V2X technology at its development center in Anting near Shanghai.

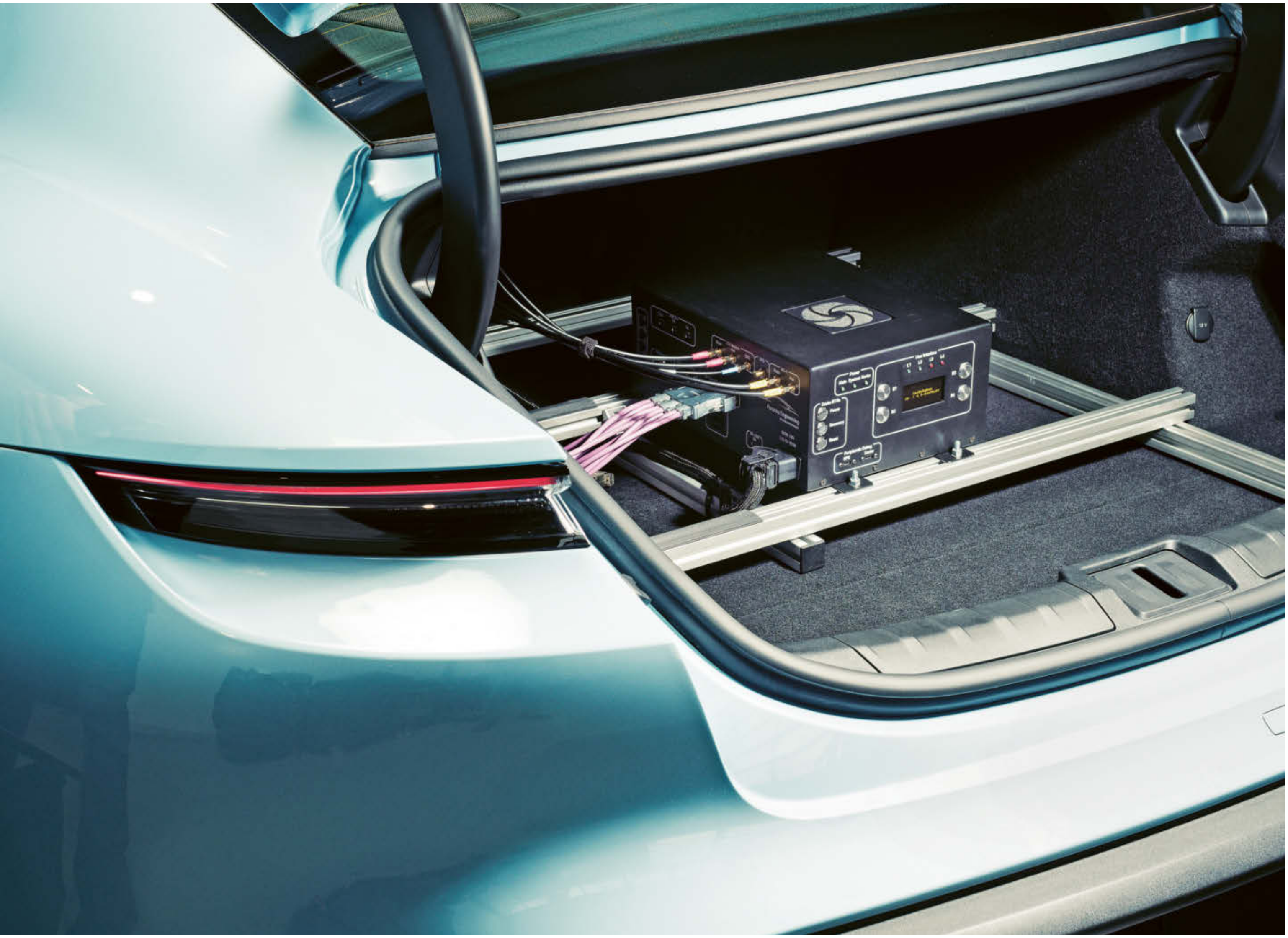
A LARGE NUMBER OF NEW FUNCTIONS

The new technology that is also being used in these parts could make a large number of helpful functions possible: A live traffic light information function, for one, could be connected to the distance cruise control and thereby modify the speed so that the driver only has to wait at the traffic lights for the shortest time possible, and would thereby be able to drive more efficiently. A digital extension of the warning triangle would also be possible: If the vehicle stopped with its hazard warning lights on, nearby road users would be informed by direct short-range communication. This hazard warning could also be forwarded to a central server so that road users who are not in the immediate vicinity could also access it.

In principle, there are two technical concepts that are used for connecting vehicles. One is the 802.11p standard, a variant of Wi-Fi. It allows vehicles to communicate with each other directly. If they are more than 200 to 300 meters apart, roadside units (RSUs) are needed along the road to relay the signals.

"The vehicle of tomorrow will not only use its own sensor technology, but also that of other road users' sensor systems."

Pasqual Boehmsdorff
Project Leader V2X Functions at Porsche Engineering



Installing these routers is costly, but this said, Wi-Fi is considered a fully developed technology. The second option is to use the existing cellular network. The corresponding standard is called C-V2X (the 'C' stands for 'cellular'). It was initially based on the 4G/LTE cellular standard, and all data had to be sent using a base station. The latest, 5G-based version also makes direct communication between vehicles possible (using what is called a sidelink/PC5 interface).

Europe and the US had initially opted for 802.11p, however two years ago the US regulator FCC withdrew the radio frequencies necessary from the standard. For its part, China is pushing ahead with 5G-based networking: By 2025, every second new car in the People's Republic is expected to be permanently online. "This is why I am assuming that a system based on mobile communications will prevail for V2X," says

THE CAR DATA BOX

The Car Data Box (CDB) is a development computer connected to the data bus and sensor technology of a test vehicle. It is ideally suited for implementing new driver assistance systems for which standard ECUs are not powerful enough. The core of the CDB is a Graphics Processing Unit (GPU) from the manufacturer NVIDIA, which is particularly good at machine learning applications.

The test computer is a project being pursued by the Porsche Engineering locations in Cluj-Napoca and Timișoara (Romania), which also developed the requisite software. Engineers at the Prague location were responsible for the hardware side of things. The first version of the CDB was unveiled in June 2020, and it has been in continuous development ever since. A 5G module, for example, has been improving the cloud connection since 2021. Integration of the Robotic Operating System (ROS) also facilitates development work: ROS converts the data from cameras, radar or lidar sensors into a format that does not depend on the specific technology. For example, if a new camera with a higher resolution is installed in the test vehicle, the existing evaluation algorithms can continue to be used. This obviates the need for new development.

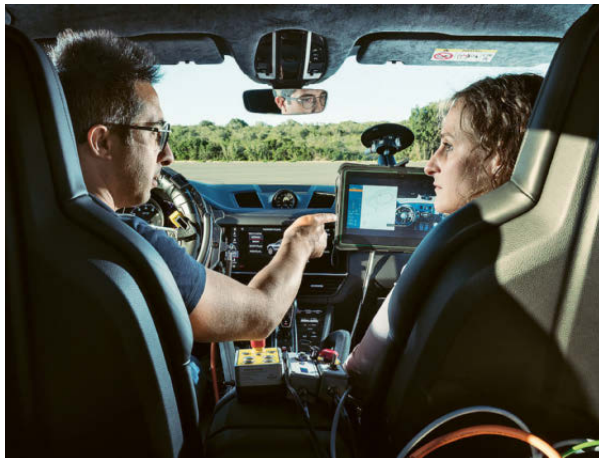
5G IN NARDÒ

The Nardò Technical Center (NTC) has been equipped with a mobile private 5G network since May 2022. Nine base stations provide cellular reception across the 700-hectare site. The bandwidth of the private network totals more than one gigabit per second—twice as high as it is off-site. "Of course, a public 5G network is also available together with the private 5G network," emphasizes Pierpaolo Positano, Senior Manager Engineering at NTC. In addition, road side units (RSUs) are also installed along the test track, which allow data communication according to the 802.11p standard. "Data can be analyzed in real time in the RSUs and the results sent from there to the cloud," says Positano.

At the moment, engineers in southern Italy are focusing on work to prepare existing test equipment for networking using 5G. "Many data loggers that are connected to the vehicle by CAN or FlexRay only feature an ethernet connection," explains Luigi Mazzarella, telecommunications expert at the NTC. They are now being equipped with wireless modules to enable wireless evaluation in the future. The low latency of 5G—less than 10 milliseconds at the NTC–would even make it possible to perform test drives completely remotely. This has particularly benefits when certain driving maneuvers have to be performed the same way several times. Five 'robot vehicles' like this are already on standby at the Nardò Technical Center.

Thomas Pretsch, Senior Manager Connectivity at Porsche Engineering.
The implementation of a new V2X function starts with software development. In the case of the obstacle warning that was described at the beginning of this article, this involves the use of artificial intelligence (AI): A neural network is trained using recordings of real driving situations to allow it to recognize and classify obstacles—and this continues until it can distinguish real hazards (for example, pedestrians, or branches) from harmless objects (leaves, plastic bags) with one hundred percent certainty.

Since there is often little real-life training material for dangerous situations in particular, it is supplemented with synthetic data. "We vary the actual driving situation virtually," explains Dr. Joachim Schaper, Senior Manager AI and Big Data at Porsche Engineering. The tool used for this is called PEVATeC (Porsche Engineering Virtual ADAS Testing Center). It



Application

Luigi Mazzarella (top left) and Marina Bovino set up an automated driving system. Then Davide Palermo (below) can control it remotely using the 5G network.

replicates a physical environment exactly—not only the visible surroundings with roads and vehicles, but also the sensor data that would be available in the vehicle bus in the corresponding situation. This makes it possible to run through the 'branch on the roadway' hazard situation in countless variations: With the glare of the sun in the background, when it is dark, or when heavy rain is falling. After all, AI has to classify the object correctly in all conditions.

TIERED COUNTERMEASURES

After training, the engineers copy the neural network to the component called the Car Data Box (CDB, see box). This development computer, which was developed at the Porsche Engineering location in Cluj-Napoca and Timișoara, Romania, is installed in the test vehicle and can run any ADAS program. The CDB uses the neural network to evaluate real camera and sensor data for the obstacle warning. A special algorithm determines whether an object exceeds a hazard threshold and initiates countermeasures according to a tiered system: From a mere message on the dashboard to an acoustic warning signal or, ultimately, autonomous braking.

In the final step, the function is tested in real conditions. The Nardò Technical Center (NTC) offers ideal conditions for this, as the entire 700-hectare site is equipped with a private 5G network. This is where engineers can check whether a warning message, once issued, reliably reaches its recipients in real-life conditions as well. "The correlation between vehicle speed and data throughput is crucial in this case," explains Luigi Mazzarella, a telecommunications expert at the NTC.

Engineers tested how fast data travels at high driving speeds in the summer of 2022. Several vehicles completed laps of the 12.6-kilometer high-speed circuit while their Car Data Boxes were sending data. The result: At speeds of up to 100 km/h, data rates remain almost constant—1 gigabit per second for downloads and around 150 megabits per second for uploads. At speeds above 200 km/h, the upload speed decreases slightly to 120 megabits per second, while there is no change to reception rates. The bandwidth only decreases at significantly higher speeds, but still remains sufficient at 90 megabits per second for data upload.

The tests showed that both the bandwidth and the latency in the 5G network are sufficient for automotive applications. Handover, this being the transition from one base station to the next, was also intensively tested. In earlier wireless generations the connection could break off, however 5G ensures the handover succeeds reliably even at high speeds.

For the development of V2X functions, the specialists at Porsche Engineering no longer have to travel to the test track in Apulia. The current version of the Car Data Box is equipped with a 5G module, which makes it possible to install test programs remotely. After or during the test drive, the Car Data Box uses 5G to send all data back to the cloud, where it can be analyzed and enriched. "Driving on the one hand, and evaluation and implementation on the other, are therefore independent of time and location," says Schaper approvingly. Remote access will allow new functions—including those for connected driving—to literally make it to the road faster in the future. ●

"We vary the actual driving situation virtually."

Dr. Joachim Schaper
Senior Manager AI and Big Data at Porsche Engineering

SUMMARY

In just a few years' time, vehicles are supposed to remain in constant contact with each other and their environment (V2X). To develop V2X functions, Porsche Engineering uses virtual development methods that make it possible to play out situations in countless variants. An important development tool here is the Car Data Box, which can execute any V2X function. Tests are also carried out on the 5G network at the NTC, which was set up specifically for this purpose.

Interview: Christian Buck
Photos: Robertino Nikolic

The transformation of the automotive industry will also change the role of procurement. **Barbara Frenkel**, Member of the Executive Board for Procurement at Porsche AG, explains in an interview with **Dr. Peter Schäfer**, CEO of Porsche Engineering, the role that collaboration with development plays and how supply chains should become more resilient.

“Procurement and development working hand in hand”

“Porsche Engineering is a proven partner. And we want to work together in the future as well, for example in the development of complete functions and variants. We rely on the innovation expertise of Porsche Engineering.”

Barbara Frenkel
Member of the Executive Board
for Procurement at Porsche AG

Barbara Frenkel
has been the Member of the Executive Board for Procurement at Dr. Ing. h.c. F. Porsche AG since 2021. Previously, the chemistry graduate served as Vice President of Sales Region Europe, Vice President of Sales Network Management and Development, and Head of Central Training for the company. Before joining Porsche, Barbara Frenkel worked for TRW Automotive, Thermal Systems and the Helas plants.

Dr. Peter Schäfer
has been the CEO of Porsche Engineering since 2019. Previously, the mechanical engineering graduate served as Vice President Complete Vehicle Development, Vice President of Chassis Design, and Director of Development Special Projects at Dr. Ing. h.c. F. Porsche AG. Before joining Porsche, Peter Schäfer worked for Volkswagen AG and Ford-Werke AG.

The automotive industry is in the midst of the greatest transformation in its history. What does that mean for procurement?

— **FRENKEL:** Make no mistake: We in procurement are helping shape the transformation. Many of our traditional suppliers are currently changing their portfolios. We’re right with them, providing impetus for strategy and long-term planning. We also advise on financing. But that’s just one aspect. We are finding completely new suppliers, especially for electromobility. One example of this is when we equipped our all-electric Taycan sports car with the highly innovative 800-volt technology. We are also increasingly entering into partnerships and investments. Agile startups are particularly attractive to us. This is why we’re active in scouting formats such as the Startup Autobahn, and we connect with founders through our incubator Forward 31. In addition to the commercial factors, the way our components are manufactured is very important to us. Sustainability is a must! To make the supply chain transparent and to verify this, we also use artificial intelligence. Overall, our purchasers are building up a lot of expertise as the transformation proceeds.

What does electrification of the powertrain mean for procurement?

— **FRENKEL:** We have a broad foundation, working with renowned suppliers in different regions. The important thing is that our battery manufacturers can guarantee long-term access to the relevant raw materials. But we’re constantly analyzing the market.

You’ve already mentioned the role of partners. What will Porsche be doing itself in the future, and what will be handled by strategic partners or a broader network of specialists?

— **FRENKEL:** We’ll decide that within the team. I head a committee, our Strategic Value Creation Management. All key stakeholders in the company are represented there—developers, production experts, procurement specialists and colleagues from the fields of sustainability and investment management. Together, we will analyze what makes the

most sense for Porsche. It's a dynamic process. We're taking a close look at the core competencies that we want to retain in the company in the future as well.

What role will Porsche Engineering play in that?

— **FRENKEL:** Porsche Engineering is a proven partner. And we want to work together in the future as well, for example in the development of complete functions and variants. We rely on the innovation expertise of Porsche Engineering.

— **SCHÄFER:** Our standard has always been to act as a strategic technology partner to our customers. So a strategic orientation of partnerships is consistent

"Our standard has always been to act as a strategic technology partner to our customers."

Dr. Peter Schäfer
CEO of Porsche Engineering

with our desire to create value over the long term and in defined areas related to capabilities and innovation. Today, the focus is on the development of the intelligent and connected vehicle. In this regard, we are focusing on a systems approach, because a function today consists of hardware plus software, with the focus increasingly shifting towards the software. We have developed a long-term strategy to further expand our capabilities in the areas of functional development and systems engineering, especially at our international tech locations. We are seeing strong growth there, particularly in new areas such as automated driving, cloud technology and big data, as well as AI.

Software is a central topic in the automotive industry. How much do you do yourself in this area, and how much do you outsource?

— **FRENKEL:** Software is becoming ever more important. We are well positioned. Within the Volkswagen Group, CARIAD is pushing ahead with the major software architectures. At Porsche, however, we are currently focusing primarily on the architecture for the ‘E^3 1.2’ platform, which is set to be used in the new Macan.

— **SCHÄFER:** Software is a central pillar of our development work—across all departments. For years, for example, we have been responsible for developing the battery core software for the entire group, analyzing performance at battery level in the field for Porsche with the aid of AI, developing predictive thermal management and also brand-specific functions for autonomous driving. However, development is only one side—you also have to test, integrate and put software into operation. We have also developed a strategy for this and are implementing it worldwide, for example with hardware-in-the-loop testing. And of course, we also conduct vehicle tests. In Nardò we have the ideal conditions to allow us to test future driving functions as well. Among other things, we use the combination of virtual and real testing because complex autonomous driving functions can no longer be tested exclusively in driving scenarios.

How does interaction between development and procurement work today? And how will it develop in the future?

— **FRENKEL:** My office is in Weissach for good reason. In the heart of our development center, I work practically next door to my board colleague Michael Steiner. Development and procurement are as close as can be. One example of this is our ‘forward sourcing’, for example in the case of semiconductors. We’ve developed a lot of expertise in this area. Here’s an example: We know today that the use of the latest chips significantly improves the performance and fast charging capacity of batteries. And all that without changes to the cell chemistry. We pass this expertise on in order to spur development. Together, we then decide on partners with whom we will bring our innovations to fruition.

— **SCHÄFER:** We have to work together to define the pathways to the fields of technology that will be critical for our success. This is the great opportunity and potential that a very good and close collaboration between procurement and development brings. This is particularly important because the transformation of our industry is in full swing, and this is the only way to ensure that we are able to plan strategically for the long term and remain agile and flexible at the same time.

You have already touched on the topic of semiconductors. How did you manage during the chip crisis?

— **FRENKEL:** The shortage of semiconductors has really tested us—like it has all manufacturers. So far, thanks to a strong team performance, we’ve managed it well. I stay focused on what’s ahead: You can learn from every problem. We now have direct relationships with the major semiconductor manufacturers. We now have a better understanding of the complex supply chains and the logic of this industry. One thing is clear: The automotive industry only has a share of around 12 percent of the global semiconductor market. We are not exactly at the top of the list of priorities for many of the chip manufacturers. In the future, we intend to expand our contact with manufacturers. The idea is to deepen mutual understanding, to achieve more dependability in the relationships. We also want to work together on new technologies.

“The entire value-added network will have to be even more forward-thinking in the future. We want a supply chain that is as resilient as possible without any one-sided dependencies.”

Barbara Frenkel
Member of the Executive Board
for Procurement at Porsche AG

Sustainability is another key topic. What are you doing in this area?

— **FRENKEL:** Sustainability is a matter close to my heart. Porsche has a clear and ambitious sustainability strategy that we are implementing together with our suppliers. We provide the impetus within the supply chain. One example of this is the green electricity requirement for our suppliers that has been in force since 2021. The share of reusable raw materials will continue to rise in future vehicle projects. Sustainable materials are already being used, in particular for the interior of our vehicles. The plastic parts, for instance. They consist to a large extent of recycled plastic granulate. Our customers want to see and feel sustainability in the vehicle. We have the knowledge and the experts to find and procure the materials and innovations necessary for this.

“We will continue to do everything we can to drive innovation, shape technology and thereby provide support to Porsche and our other customers.”

Dr. Peter Schäfer
CEO of Porsche Engineering

— **SCHÄFER:** We have firmly anchored sustainability in our corporate strategy. For our test site in southern Italy, for example, there is an action plan to reduce the carbon footprint. The topic of diversity also plays a major role in our company. We want to increase the number of females among our engineers and, as an international group, harvest the full potential of our different nationalities—as a family.

Let’s conclude by looking to 2030 and beyond. What will the procurement ecosystem at Porsche look like then?

— **FRENKEL:** I don’t have a crystal ball (laughing). But seriously, the entire value-added network will have to be even more forward-thinking in the future. We want a supply chain that is as resilient as possible without any one-sided dependencies. To do that, we need innovative partners in the world’s regions. Especially the ones where we sell our vehicles.

— **SCHÄFER:** We will continue to do everything we can to drive innovation, shape technology and thereby provide support to Porsche and our other customers. I am also firmly convinced that our partnership with Porsche will continue to grow in the future.

— **FRENKEL:** We’re on the same page there.

TRENDS AND TECHNOLOGIES

BATTERY TECHNOLOGIES

An all-rounder: Silicon can be used not only for computer chips, but also to manufacture anodes with a significantly higher storage capacity compared to graphite-based ones.

THE FUTURE OF THE CELL

Powerful batteries are the central element of electric vehicles. The technology continues to evolve and is expected to make further progress when it comes to capacity, charging capacity, safety, and service life. Porsche is directly involved in current developments through the Cellforce Group and Group 14 Technologies.

Text: Chris Löwer

High energy content, high performance, long service life, maximum safety—all at the lowest possible cost: Batteries in electric vehicles have to meet many requirements, which the dominant lithium-ion technology is already succeeding at quite well. Further improvements can, however, be made to almost all of its parameters, and researchers and industry are currently working intensively on doing just that. At the same time, potential successors are already lining up.

It is no coincidence that lithium-ion batteries dominate today's market: Lithium atoms are particularly keen to emit one of their three electrons, and lithium is also the lightest metal. This makes the element a popular raw material for batteries. "Pure lithium is the ideal active anode material in terms of energy density," says Dr. Stefanie Edelberg, Specialist Engineer Battery Cell at Porsche Engineering. "For safety reasons, however, graphites are currently used primarily as active anode materials that can absorb lithium ions." In addition, the charging capacity of the batteries is very high and their price is relatively low.

Added to this is their long service life: "1,500 to 3,000 full charge cycles until a residual capacity of 80 percent is reached does not present a problem," says Dr. Falko Schappacher, Commercial and Technical Director of MEET Battery Research Center at the University of Münster (WWU). Car battery service lives of up to one million kilometers are now being predicted.

ANODE OPTIMIZATION

Because lithium-ion technology is a multi-component system, there are many ways to optimize it further. Take, for example, the anode: Graphite is currently used as an active anode material. Silicon is an interesting alternative to this because it offers a storage capacity that is ten times higher. "Silicon anodes would significantly increase the total capacity of the lithium-ion battery," as Schappacher underscores.

Edelberg also points out the advantages: “Silicon is of particular interest because it exhibits the second-highest storage capacity in terms of weight after lithium, which allows for cells with very high energy densities. What’s more, it is the second most common element in the earth’s crust.” Cells with a high fast-charging capability and which can be charged from five to 80 percent in less than 15 minutes are indeed feasible.

“However, when lithium is absorbed, the silicon particles expand by 300 percent, resulting in mechanical stress in the material and electrode,” says Schappacher. If this were to damage the electrode surfaces, the service life of the battery would also be impaired. “The biggest leverage in terms of energy density is attained by using pure silicon active material, but then you also have to contend with the worst downsides in terms of service life,” says Edelberg. Nevertheless, intensive work is being carried out on anodes with a very high proportion of silicon of up to 80 percent. This is the path that Cellforce (see box), for example, is following in conjunction with Porsche.

MORE NICKEL IN THE CATHODE

Intensive work is also underway on optimizing the active materials for the cathode. The important thing in this case is a combination of a large charging capacity and a high electrochemical potential of the material. At present, lithium-nickel-cobalt-manganese-oxide (NCM) in a ratio of 6:2:2—in terms of the parts nickel, cobalt, and manganese—is most frequently used in electromobility in Europe. In the future, nickel’s share is likely to increase, while cobalt and manganese will be used to a lesser extent.

“The biggest leverage is attained by using pure silicon active material.”

Dr. Stefanie Edelberg,
Specialist Engineer Battery Cell at Porsche Engineering

Less than

15 minutes

from a five to an 80 percent charge: Silicon anodes could make this a reality in the future.

The growing share accounted for by nickel promises higher charging capacities.

Further optimization potential is offered by the separator, which consists of very thin (10 to 20-micrometer) films, mostly comprised of polyethylene or polypropylene. This separator costs space and weight. “The separator can indirectly contribute to the energy content of a battery cell,” says Edelberg. “The thinner it is, the more layers or coils on electrodes fit into a cell. This increases the cell capacity and the energy content of a battery cell.”

COMPACT SOLID-STATE BATTERIES

Solid batteries, an area into which intensive research is being conducted, could need significantly less installation space than conventional lithium-ion batteries. They do not use an electrolyte solution, but a solid supporting electrolyte. “The plan for solid cells is that the classic separator will be completely replaced by a thin layer of solid electrolytes,” explains Edelberg. “The solid electrolyte is then both electrolyte and separator in one.” By eliminating electrolyte solutions and using lithium-metal anodes at the same time, researchers hope to achieve an increase in energy density of up to 50 percent, and possibly significantly faster charging times as well as a low flammability of the solid electrolyte.

Compared to other developments such as lithium-air batteries, Schappacher sees lithium-based solid-state batteries (SSB) as “a serious alternative to lithium-ion batteries”. Sodium-ion batteries (see box) are of particular interest for local storage applications due to their lower energy density. Lithium-air technology still poses many challenges and, as things stand, promises very few advantages. “Currently and for the foreseeable future as well, lithium-air cells are definitely still a topic for basic research,” says Edelberg.

Cell chemistry, however, is not the only way to optimize batteries. Cell sensors and packaging offer further potential. Battery charge levels, for one, can be detected more precisely and quickly by sensors in the cells. This allows the charging time to be shortened—for example, by allowing fast charging in special voltage ranges. Cell cooling can also be controlled more precisely, which is a boon to battery longevity.

In the future, packaging and cell design will also play a major role in making batteries more powerful. Cell-to-pack technology, for example, integrates the cells directly into the battery pack. “This eliminates the small-scale parts in current batteries,” says Prof. Maximilian Fichtner, Director of the Helmholtz Institute Ulm (HIU) and Head of the Energy Storage Systems research unit at the Karlsruhe Institute of Technology (KIT). “Instead of connecting chocolate-bar-sized cells individually, cells up to 1.20 meters in length are now tightly packed when installed

BATTERIES OF THE FUTURE: IT'S THE MATERIAL THAT MATTERS

The future of sodium-ion batteries

In principle, a sodium-ion cell functions the same way as a lithium-ion cell. Instead of lithium ions, sodium ions migrate between the anode and cathode within the cell. Sodium-ion batteries are a potential alternative to lithium-ion batteries because their price will be significantly lower than the level of lithium-ion cells—a 50-percent reduction seems feasible. In addition, deposits of sodium are widely found throughout the world, making the raw material easier to access than lithium. What's more: The materials used in sodium-ion cells also have benefits in terms of sustainability. Sodium-ion cells also allow for high charging and discharging speeds. Sodium-ion cells have significant advantages over lithium-ion cells, especially at low temperatures due to their superior cold-starting capability. At minus 20 degrees Celsius, capacities that are 20 to 30 percent higher are achieved than with lithium-ion cells. That means that sodium-ion cells may also be used as starter batteries instead of lead-acid batteries in vehicles.

Anode materials in comparison

Lithium has the lowest molar mass (because it is the lightest solid element), the highest potential, and the highest specific capacity. This makes the alkali metal an attractive candidate for use in anodes. There are, however, alternatives: In terms of capacity, silicon ranks only slightly behind lithium, which also makes cells with high energy density a possibility. It is also the second most common element in the earth's crust. Sodium is also widely available, cost-effective, and sustainable.

Material	Molar mass	Number of charge carriers	Theoretical capacity
Lithium	6.94 g/mol	1	3,862 mAh/g
Silicon	28.09 g/mol	3.75	3,578 mAh/g
Sodium	23.0 g/mol	1	1,165 mAh/g
Graphite	12.01 g/mol	0.167	372 mAh/g

High-performance cells for high-performance sports cars

The Tübingen-based Cellforce Group, in which Porsche holds a 72.7 percent stake, has chosen silicon as an anode material. "With silicon, we can achieve energy densities that are up to 30 percent higher, which means greater ranges or lower weight and shorter fast charging times," says Chief Operating Officer Markus Gräf. The battery also fits into a more compact space while retaining the same energy content. Apart from that, the battery's innovative chemistry reduces its internal resistance, allowing it to capture more energy during recuperation. The Cellforce cell is also considered to be more resistant to high temperatures. "The use of silicon also contributes to a reduction of the carbon footprint compared to graphite," adds Gräf. Cellforce purchases the anode material from the US company Group14 Technologies, in which Porsche also holds a stake. Cellforce will initially develop high-performance lithium-ion pouch cells for special automotive applications and will manufacture them in Germany from 2024 on.

crosswise into a frame, just like the slatted frame of a bed." This results in more storage capacity and better cooling in less space.

FURTHER POTENTIAL

"In the medium term, we can expect the combination of new anode chemistry and dense packaging of the cells to allow a vehicle range of 1,300 km," says Fichtner. Schappacher is also optimistic—even if it is difficult to predict the impact of technological advances such as the solid-state battery. "I think that we will see 30 to 50 percent increases in range in premium vehicles in the future," the expert expects, stressing: "More important than simply increasing the range is the fast-charging capability." Schappacher expects that, one day, fast charging to 80 percent of the vehicle's range won't take much longer than a fuel stop.

"In today's Taycan, a charging time of 22.5 minutes was able to be achieved when charging from five to 80 percent," explains Markus Gräf, Chief Operating Officer of the Cellforce Group (also see box). "With silicon as an anode material, values of less than 15 minutes can be attained in the medium term, and significantly lower ones in the longer term." This said, new and more powerful charging stations would also have to be developed for this purpose. In addition, charging sockets will need active cooling in the future so that high charging capacities of more than 500 kW can be reliably conducted.

Optimized lithium-ion batteries and new technologies such as solid state batteries: Thanks to intensive research and development, electrical energy storage systems are set to become much more efficient in the coming years—making electric mobility even more attractive. ●

Chips à la carte

Modular principle: More and more companies are turning to modular chip solutions to replace monolithic systems.

In the future, chips will be built from smaller units. These chiplets, as they are called, promise a higher yield in production and more flexibility in system configuration. The automotive industry can also benefit from this development, as highly automated and autonomous driving requires powerful and flexible solutions.

Text: Christian Buck

The number of transistors on semiconductor chips will grow exponentially in the coming decades—this 1965 forecast made future Intel co-founder Gordon Moore famous. Far less attention was paid to another statement that could also be found in his article for the magazine *Electronics*: "It may prove to be more economical to build large systems out of smaller functions, which are separately packaged and interconnected."

Researchers and semiconductor manufacturers around the world are currently moving forward with this idea. They intend to distribute the numerous functions in the increasingly complex chips to smaller integrated circuits (ICs) that operate in concert. Experts call them chiplets—mini-ICs that can be connected to a complete system much like building blocks. They can each perform sub-functions of an overall system and can, for example, be used as a central processing unit (CPU), graphics processor (GPU), memory, digital interface to the outside world, or Wi-Fi transmitter and receiver.

REVERSING THE TREND IN CHIP SIZE

Until recently, the trend was heading in the opposite direction: For decades, semiconductor manufacturers have integrated more and more functions on one and the same semiconductor board (known as a die) into highly complex systems-on-a-chip (SoC)—all thanks to Moore's Law. However, companies are now encountering their limits, because the probability of defects increases as the dies get bigger, thereby greatly reducing the yield of functioning chips in production. That makes it very difficult to produce large SoCs economically—especially if the very latest manufacturing processes involving immense investment costs are being used to obtain a yield that is already relatively low to begin with.

Die

The term describes semiconductor boards before they are installed in a housing. They are produced by cutting the round semiconductor wafers containing dozens of dies into individual pieces.

Yield

The term stands for the return achieved in chip production. The figure is calculated as the ratio between the usable dies and the total number of dies produced.

"That's why about 15 years ago we started looking for new approaches," says Dr. Michael Schiffer, Head of the Wafer Level System Integration department at the Fraunhofer Institute for Reliability and Microintegration IZM in Berlin. "The issue has been gaining momentum for several years now because today, we have the technologies needed to connect chiplets to each other and because semiconductor manufacturers are now reaching their limits in terms of scrap costs." Chiplets can solve the problem: If the functions of an SoC are distributed to smaller units, the yield on functioning ICs increases again.

Chiplets have other advantages too. If each of them specializes in a single function, the optimum technology can be used for the production of each and every one: For example, you could use state-of-the-art manufacturing processes with the smallest transistors for the high-performance CPU and GPU chiplets, while simpler digital interface chiplets could be produced using older—and cheaper—processes. The same applies to the materials used: Silicon is the best choice for CPU and GPU dies, while gallium arsenide, silicon-germanium, or silicon carbide is the best choice for high-frequency and high-performance chiplets; indium phosphide is most suited to optoelectronic components. "This maximizes the performance of the individual chiplets and improves their efficiency," says Schiffer.

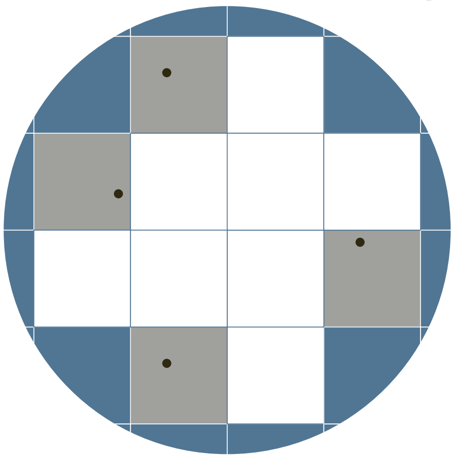
However, the specialized mini-chips must be connected to form a complete system. For this purpose, a silicon interposer, as it is known, is generally used as a location for the chiplets. Either the interposer is a thin silicon plate, into which only copper tracks are inserted for the electrical connection of the chips, or the silicon interposer itself can contain an electronic circuit that actively conducts the chiplet signals, thereby significantly reducing lag times. "Glass is also a potential material for high-frequency applications

CHIPLETS:
HIGHER YIELD AND TAILOR-MADE SYSTEMS

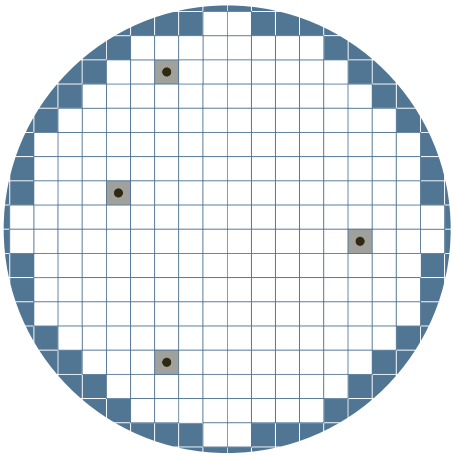
Smaller die areas reduce scrap in semiconductor production

A round semiconductor wafer contains many dies of the same size and shape. A single defect (black dot) is often enough to make the complete die useless and therefore unsaleable. With the chip surface growing—while the number of defects on the wafer remains the same—the scrap rate will also grow sharply. In this example, the wafer exhibits the same four defects in both cases. In the case shown at the top (system on a chip, large die area) the yield drops to 67 percent. In the case shown at the bottom (chiplet, small die surface), however, the defects have a much less significant effect: The yield in this case is 98 percent. Thanks to their small footprint, chiplets generate higher yield rates compared to complete systems on a chip. They also allow for the use of the optimum production technology for each module.

67% yield



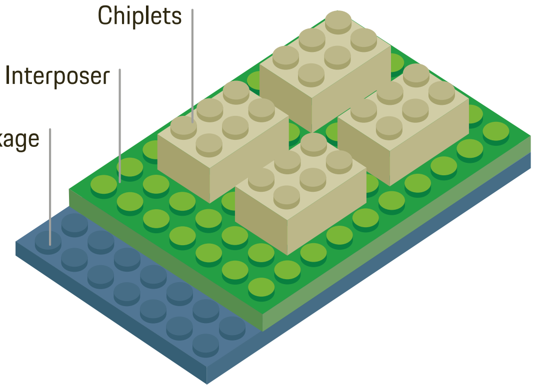
● Defect
■ Defective die
□ Intact die



98% yield

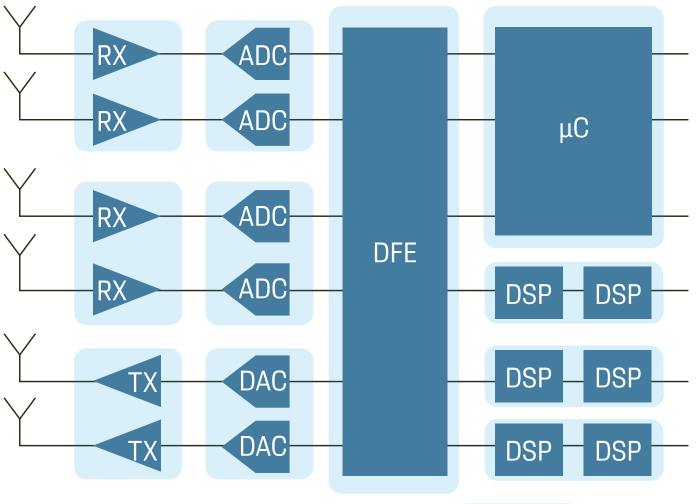
Chiplets can be assembled as required

The individual chiplets are linked by the interposer, similar to connecting various peripherals on a PC to the computer's chip set. In order to fully exploit the potential of the chiplet idea, the industry is working on standards for communication. The complete system consisting of several chiplets is ultimately inserted into a normal chip housing and soldered onto a printed circuit board.



77 GHz radar for autonomous driving

This electronic system developed by the University of Bremen consists of various chiplets for analog (oscillator, transmitter, receiver) and digital (microprocessor, digital signal processor, digital front end) functions. Depending on the specific requirements, individual blocks can be added or omitted, creating a tailor-made system.



ADC - Analog Digital Converter
RX - Receiver
TX - Transmitter
µC - Microcontroller
DFE - Digital Front End
DSP - Digital Signal Processor

while organic substances are also conceivable as a material for the interposer, but these cannot compete with silicon interposers in terms of structure sizes," explains Schiffer.

However, the potential of the chiplet idea can only be fully exploited if the components made by different manufacturers can be combined into a complete system without any problems. In the future, the Universal Chiplet Interconnect Express (UCIe) communication standard plans to make this possible—similar to Peripheral Component Interconnect Express (PCIe), which today is used to connect diverse peripheral devices such as hard disks or graphics cards to the chip set of a processor in a PC. UCIe is backed by chip developers such as AMD, ARM, Intel, Google Cloud, Meta, Microsoft, Qualcomm, and Samsung, as well as TSMC, which is the world's largest contract manufacturer of semiconductors. As an alternative, the Open Compute Project (OCP) has introduced the Bunch of Wires (BoW) standard. Members of the OPC include operators of large data centers such as Google, Meta, and Microsoft.

CHIPLET STANDARD FOR VEHICLES

"Both standards are designed for the exchange of very large amounts of data," says Andy Heinig, Group Manager System Integration at the Fraunhofer Institute for Integrated Circuits IIS in Dresden. "For automotive applications, however, additional analog interfaces would be needed in order to be able to assemble, say, a radar from different chiplets." Together with OEMs and suppliers, the researchers at IIS intend to develop a standard that is tailor-made for use in vehicles.

Although a standard has yet to be established, it is clear to Heinig that chiplets will play an important role in vehicles in the future: "Autonomous driving in particular needs a huge amount of processing power, although the exact requirements will depend largely on the level of automation being aimed for. In the future, OEMs could design the electronics optimally for their individual models or for the different equipment variants by using chiplets." This scalable modular system also caters perfectly to the car manufacturers' platform concept.

"Additional analog interfaces are needed for automotive applications."

Andy Heinig, Group Manager System Integration at the Fraunhofer Institute for Integrated Circuits

"The issue of chiplets has been gaining momentum for several years now."

Dr. Michael Schiffer, Head of the Wafer Level System Integration department at the Fraunhofer Institute for Reliability and Microintegration IZM

Prof. Steffen Paul, head of the Communication Electronics Working Group at the University of Bremen, is investigating how such a vehicle system might look in tandem with industrial and academic project partners. As he, too, stresses: "Chiplets mean that system configurations can be flexibly adapted to the requirements of vehicles." His team demonstrates this using the example of a 77-gigahertz radar for autonomous driving. The analog part is divided into several chiplets, which work both as an oscillator and as a transmitter/receiver, and are housed on a silicon interposer. Depending on the required number of antennas, two or four transceiver chiplets are integrated into the system. The digital part that processes the signals can consist of up to eight chiplets—depending on the complexity of the evaluation algorithms used.

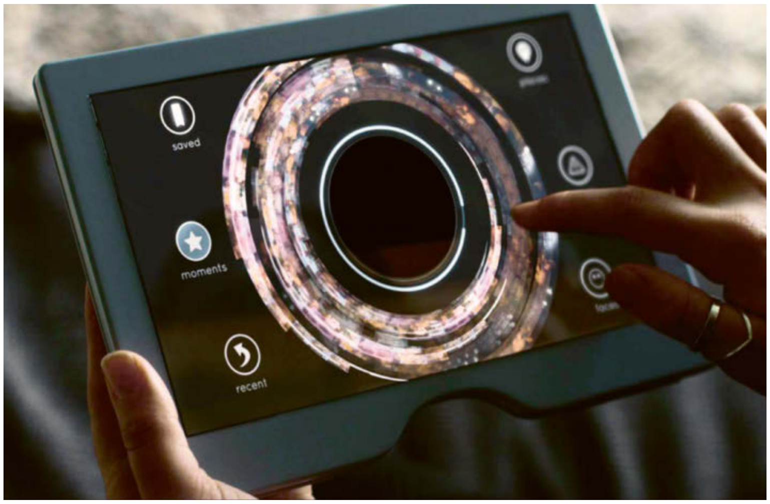
In addition to the greater flexibility attained by combining different calculation engines, Professor Paul sees another advantage in the chiplet approach: Improved protection of intellectual property. "Partitioning the functions into smaller units makes it much more difficult for competitors to determine how the overall system works. In addition, critical functions such as encryption can be developed separately on a chiplet – in a high-security area and kept separate from the development of the remaining logic," explains the expert.

KEY FACTOR FOR THE FUTURE

"Chiplets are currently used in markets such as data centers, mobile devices, networks, and storage," says Tom Hackenberg, Principal Analyst for Computing and Software at technology consulting firm Yole Intelligence. "With the emergence of powerful heterogeneous processors in driver assistance systems, however, they are becoming a key factor in future electronic systems in vehicles. That's why many car chip manufacturers support the standardization of the chiplet." Once more, one of Gordon Moore's predictions may have hit the bullseye.

Visions in film: In science fiction classics such as 'Minority Report' (top right) and the Netflix series 'Black Mirror' (bottom) the heroes can immerse themselves in virtual worlds. In the future, XR could make this possible for everyone.

Dreaming with your eyes open



In the future, XR—a fusion of virtual, augmented and mixed reality—will blur the lines between the virtual and the real worlds. Our guest authors describe what this means both for individuals and society as a whole. The text is based on excerpts from the book 'AI 2041' (Publisher: Campus).

XR means much more than just expanding to a larger screen. In the words of Dr. Brennan Spiegel, XR "is like dreaming with your eyes open." These technologies generate an intense experience known as "presence." Virtual scenes, objects, and characters are lifelike and magical. The technology takes you into an immersive experience that feels like a parallel reality. In the next twenty years, XR will revolutionize entertainment, training, retail, healthcare, sports, and travel.

An immersive experience should be one in which the user experiences the same sensations he or she would in a real-life environment and is unable to distinguish between what is real and synthesized. In order for such a sensory experience to be realistic, we must fool our most acute sense, our sight.

Beyond XR glasses, I believe XR contact lenses may be the first XR technology to achieve the milestone of mass acceptance. Several start-ups are already working to develop XR contact lenses. Their prototypes show that displays and sensors can be embedded in contact lenses, making text and images visible. These contact lenses still require external CPU for processing, which can be done on a mobile phone. By 2041, we anticipate the "invisibility" of contact lenses will truly cause the market to accept the product, and that challenges such as cost, privacy, and regulations will be overcome.

If visual input will be provided by glasses and contact lenses, audio input can be achieved through ear sets, which have improved with every year. By 2030, good ear sets should be almost invisible, through bone-conducting, omni-binaural immersive sound and other technologies, perhaps to the extent that they could be comfortably worn all day.

This combination above is likely to become sufficient to evolve into an "invisible smartstream" (or the smartphone of 2041). When you summon your smartstream, the visual display covers your field of view, perhaps semi-transparently. You could manipulate the smartstream content and apps using gestures, like Tom Cruise's character in the movie Minority Report. The smartstream sound will be heard by your "invisible earsets," and operated by voice, gestures, and fingers typing "in air." This ever-present XR smartstream can do more than a smartstream (or mobile phone) with a screen. It can remind you of the name of an acquaintance you ran into, alert you when a nearby store has what you want to buy, translate for you when you travel abroad, and guide you to escape from a natural disaster. Beyond the usual "six senses," our body can "feel" sensations such as wind and an embrace, as well as warmth, cold, vibration, and pain. Haptic gloves will allow you to virtually pick up objects and feel them. And somatosensory (sometimes also called haptic) suits can make you feel cold or hot, or even that you're getting punched or caressed.

The analysis above pertains to devices stimulating our perception, but how do we provide input, or control XR? Today, the input device for XR is a handheld controller similar to the Xbox controller but usually one-handed. These are easy to learn and to use, but feel unnatural as the rest of the experience becomes immersive and lifelike. The ideal future input should be purely natural. Eye tracking, movement tracking, gesture recognition, and speech understanding will be integrated to become the primary inputs.

One major obstacle to achieving these experiences is content creation. Content creation in an XR environment is similar to creating a complex 3D game; it must encompass all permutations of user choices, model the physics of real and virtual objects, simulate the effects of light and weather, and deliver lifelike renderings. This level of complexity is much greater than what's needed for making video games and developing apps.

If we wear devices like glasses or contact glasses all day long, then we are capturing the world every day. On the one hand, it is wonderful to have this "infinite memory repository." If a customer wants to renege on a commitment, we will be able to search and find the video of his or her promise. But do we really want every word we say to be stored? What if this data falls into the wrong hands? Or is used by an application we trust but has an unknown externality?

The bottom line is that by 2041, much of our work and play will involve the use of virtual technologies. We should orient ourselves to this inevitability. There will be giant XR breakthroughs, probably starting in entertainment. All industries will eventually embrace as well as struggle with how to use XR, just like they do with AI today. If AI turns data into intelligence, XR will collect a greater quantity of data from humans at a higher quality—from our eyes, ears, limbs, and eventually our brains. Together, AI and XR will complete our dream to understand and amplify ourselves—and, in the process, expand the possibilities of the human experience.

"An immersive experience should be one in which the user experiences the same sensations he or she would in a real-life environment and is unable to distinguish between what is real and synthesized."

Kai-Fu Lee, Qiufan Chen

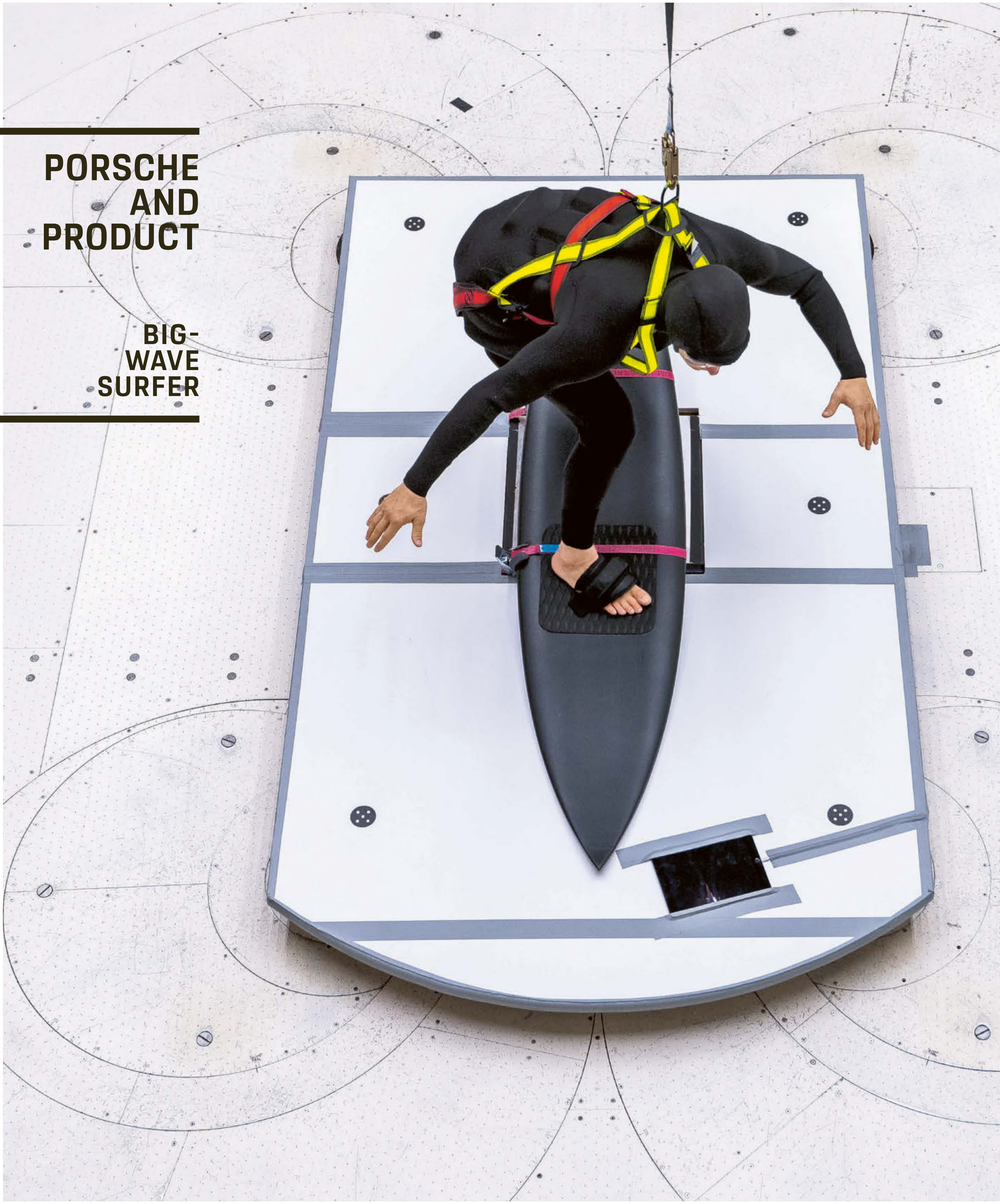
THE AUTHORS

Kai-Fu Lee is the CEO of venture capital firm Sinovation Ventures and Co-chair of the Artificial Intelligence Council at the World Economic Forum.

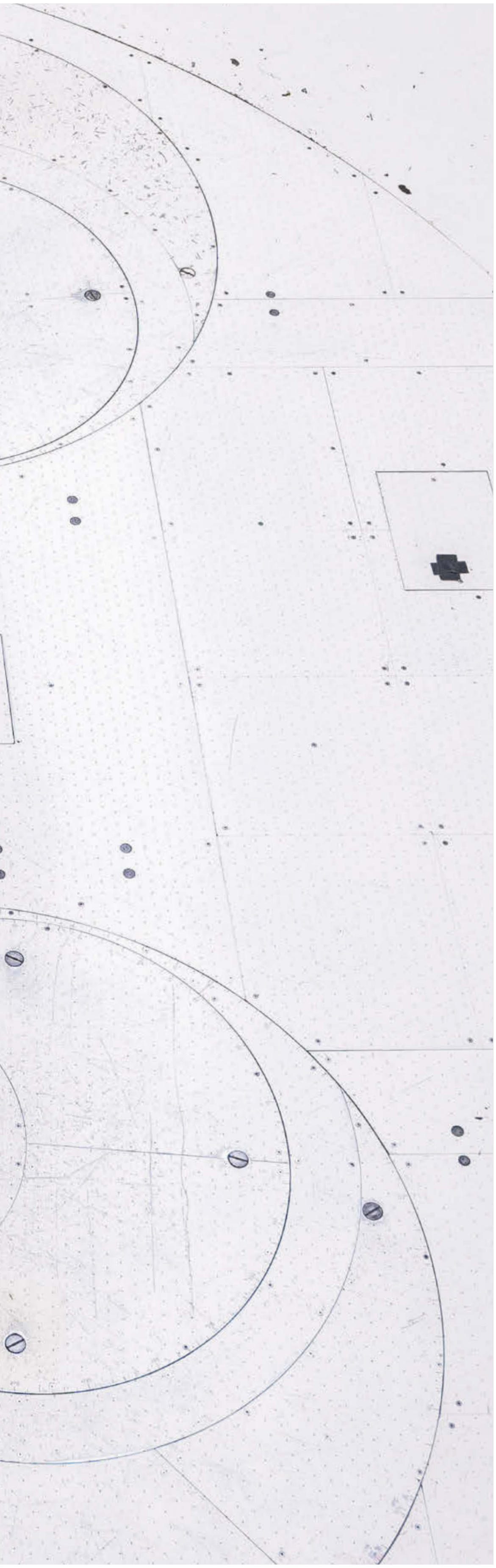
Qiufan Chen is an award-winning author, translator, creative producer, curator, and president of the World Chinese Science Fiction Association.

PORSCHE AND PRODUCT

BIG-WAVE SURFER



Artificial headwinds: Sebastian Steudtner optimizes his stance in Porsche's wind tunnel at the Development Center Weissach.



“It was fascinating to see how much untapped potential there still is.”

Sebastian Steudtner
Big-wave surfer

READY FOR THE PERFECT WAVE

Big-wave world champion Sebastian Steudtner has high ambitions. The 30-year-old surfer already holds the world record. Now, as part of his long-term partnership with Porsche, he is aiming to take his sport to a whole new level together with Porsche Engineering.

Text: Claudius Lüder
Photos: Joerg Mitter, Jorge Neal

Taking a scientific approach: Simulations and wind tunnel validations are used to improve the performance of the surfboard in the water as well as the aerodynamics of the board and surfer.

"Our kinematics model allows us to analyze the influence of different components."

Dr. Jin Gong
Development Engineer
at Porsche Engineering

With intense focus, Sebastian Steudtner faces forward as he stands on his surfboard. A fierce wind is blasting his face. He uses his right leg to correct his stance, and his left arm moves forward, almost as if to hold off an approaching wave. "Thanks, we've got everything we need now," a voice suddenly says. The wind dies down, Steudtner straightens up, and a light illuminates the scene.

The big-wave surfing world champion wasn't riding the waves in the Atlantic, but rather standing on his board in Porsche's wind tunnel in Weissach. Here, a team led by Marcus Schmelz, Marcel Straub, and Dr. Jin Gong from Porsche Engineering is working on an ambitious project: They intend to optimize Steudtner's equipment as well as his posture on the board. The aim is to improve his performance even further.

Porsche Engineering and Steudtner have been working together to achieve this goal since the end of last year as part of a long-term partnership between the big-wave world champion and Porsche. The latest simulation methods and wind tunnel validations, for example, will be used to enhance the performance of the surfboard in the water and the aerodynamics of the board and surfer. "We are bringing together our experience in flow and structural optimization with the practical expertise of a world-renowned surfer to create an optimized board for surfing particularly high waves," says Project Manager Schmelz.

THE LIMIT HAD BEEN REACHED

One key goal is to become faster in the water. World record holder Steudtner currently reaches speeds of 70 to 80 km/h on his surfboard. However, that's still not enough to be able to ride significantly higher waves—because the higher a wave

is, the faster the surfer has to be to keep it from crashing down over him. “My previous boards had definitely reached the technical limits,” says Steudtner.
The Porsche Engineering team is focusing on two areas that will help speed up the world champion: hydrodynamics and aerodynamics. Improving aerodynamics involves figuring out how to modify the surfer’s position on the board to achieve a noticeable reduction in drag. Hydrodynamics involves reducing pressure and skin-friction drag—by means of the position of the fins underwater, for example—and using special coatings for the board. “Everything that is in the air, we study in the wind tunnel. Everything in the water we analyze using a CFD simulation,” Gong explains.

For the wind tunnel tests, a special frame was built to be able to simulate the board’s position on a wave. Special features such as lateral currents could be recreated

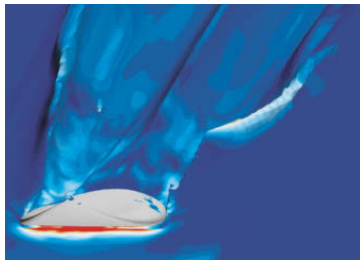
When it comes to improving aerodynamics in particular, we can apply methods from automotive development.”

Marcel Straub
Project Leader Complete Vehicle Aerodynamics and Thermal Management at Porsche Engineering

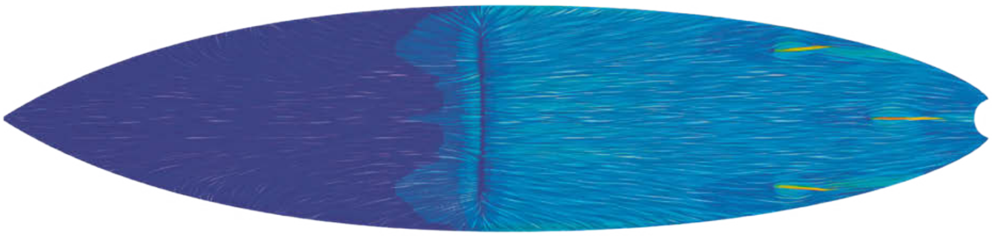
Faster means higher: Steudtner currently reaches speeds of 70 to 80 km/h in the water. The higher the waves, the faster he has to be to keep them from crashing down over him.

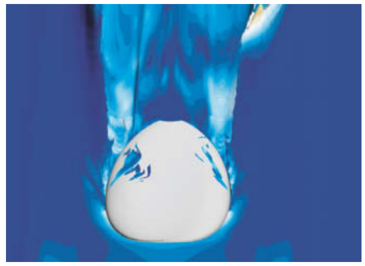
Basis for optimizing the geometry

To optimize the board geometry, the experts had to start by creating a validated reference. To do this, the performance of Sebastian Steudtner's original surfboard was evaluated using a CFD simulation. The large image below shows the shear stress distribution in the boundary layer—a good measure of the flow direction and velocity in wall proximity as well as a reliable indicator of flow separation. The images on the right show the structures of the board in the water surface. The more pronounced they are, the more water resistance is acting on the board.



Simulation of the shear stress distribution





Simulation of water surfaces

Optimized body position: The right arm leans against the side of the front lower thigh, while the upper body, arms and thighs are held close together.

The Taycan Cross Turismo models

Consumption data in the NEDC:
Power consumption (combined):
26.5–26.2 kWh/100 km
CO_2 emissions (combined): 0 g/km

Consumption data in the WLTP:
Power consumption (combined):
24.8–21.2 kWh/100 km
CO_2 emissions (combined): 0 g/km

As of 11/2022

with the aid of a turntable. "We ran tests with the body in different positions in two test series, and also examined optimizations made to the equipment, such as the use of a head spoiler. The potential and reproducibility were confirmed," as Gong explains.

17 PERCENT IMPROVEMENT

Changes to Steudtner's posture allowed significantly lower drag to be achieved. A position in which his right arm leans against the side of his front lower thigh and his upper body, arms and thighs are held as close together as possible proved to be optimal. With these adaptations, engineers achieved a reduction in wind resistance of almost 17 percent. On a display on the frame for the surfboard, the world champion was able to see how the wind resistance changed each time he changed position. "It was fascinating to see how much untapped potential there still is, especially by making aerodynamic improvements," says Steudtner.

Overall, the engineers estimate that the reduction potential in terms of aerodynamic drag totals up to 25 percent. "That is a very high value. In vehicle construction, we normally talk about three to four percent," says Straub. In addition to the 17 percent gained by optimizing the surfer's posture, another four percent could be achieved using measures such as an optimized helmet. And the surfboard also offers plenty of potential for improvement. "In this case, we were able to improve drag by another four percent by adding a cap to the nose, and this both in a straight inflow and with a crosswind," Straub explains. This is comparable, he says, to the effect of wheel profiles on a vehicle's underbody. "In both cases, it's a matter of optimizing the wake and improving the flow to downstream 'components'," Straub continues. And the idea of a 'head spoiler' on the board is also based on insights from vehicle development. "By generating a defined tear-off edge at the head, we can make improvements in the wake area. This can be compared to tear-off edges at the rear of the vehicle, such as the C-pillar flaps on the Taycan Cross Turismo," says Straub.

"We created a kinematics model as a basis for calculations for the wind tunnel test, this being a physical model to describe the aerodynamic and hydrodynamic system in big-wave surfing," Gong explains. The background to this is that when the surfer enters the wave, only some of the available potential energy can be converted into speed due to losses caused by air and water resistance. "Our kinematics model allows us to analyze the influence of different components." It provides the basis for deducing that optimizing air and water resistance plays a crucial role in surfing a giant wave," says Gong.

"We are bringing together our experience with the expertise of a world-renowned surfer."

Marcus Schmelz
Subject Specialist Complete Vehicle Testing at Porsche Engineering

OPTIMIZING THE BOARD WITH CFD

At the same time as the wind tunnel tests, the surfboard was optimized using computational fluid dynamics (CFD) simulations. "They allow us to replicate and visualize flows and flow patterns," says Gong. "This helps us discover critical points and define countermeasures." The next step would be to verify them in a real test on the water.

For all optimizations, the team draws on Porsche Engineering's many years of expertise in vehicle development. "When it comes to improving aerodynamics in particular, we can apply methods from automotive development—in the case of the board, just to a completely new 'vehicle'," says Straub. While the modeling is different, the questions ultimately remain the same: Where and how can resistance be reduced?

Steudtner is confident that he can now ride much higher waves with the help of Porsche's engineers: "Up to now, it has been an ongoing process with constant improvements based on my feel for the sport. Being able to use scientific data as well now is something I find very interesting. I'm curious to see how well the theory functions in practice." As a result of the wind tunnel tests and CFD simulations, four modified boards were built that incorporate all the findings and which the big wave surfing world champion is now testing in the water. "What decides is how rideable the board is. Sebastian gives us regular feedback," reports Straub. Steudtner spends most of his time on the water these days. He has spent every winter in Nazaré in Portugal, about an hour north of Lisbon, since 2012. The cliff there, with its immense underwater canyon, has long since superseded Hawaii as the surfing locale with the highest waves in the world. This is where the biggest waves tower to more than 20 meters in height. Steudtner's current world record is 26.21 meters. With the right equipment, he aims to head even higher in the future. Just how high that will be is yet another factor that the support of Porsche Engineering will help to ascertain more precisely in the future: Porsche engineers are developing a new system to replace the imprecise measurement of wave heights using video footage and still images—ensuring that Steudtner's ascent into new dimensions can be precisely documented.

SUMMARY

In order to ride higher waves, Sebastian Steudtner has to reach greater speeds in the water. The Porsche Engineering team is using hydrodynamics and aerodynamics as a basis for this. It also involves the use of tried-and-tested methods from automotive development. Steudtner tests the modified boards in Portugal after optimization.

Designed for performance

Text and photos: Dr. Ing. h.c. F. Porsche Aktiengesellschaft

Motorsport genes: The Porsche 911 GT3 RS cuts a fine figure on any race track.

The new Porsche 911 GT3 RS makes no secret of its intentions: It is uncompromisingly designed for maximum performance. The road-legal high-performance sports car takes full advantage of technology and concepts from motorsport. Even beyond the high-revving naturally aspirated engine with racing DNA and intelligent lightweight construction, it is above all, the cooling and aerodynamic systems of the 911 GT3 RS that connect it most directly with its motorsport brother, the 911 GT3 R.

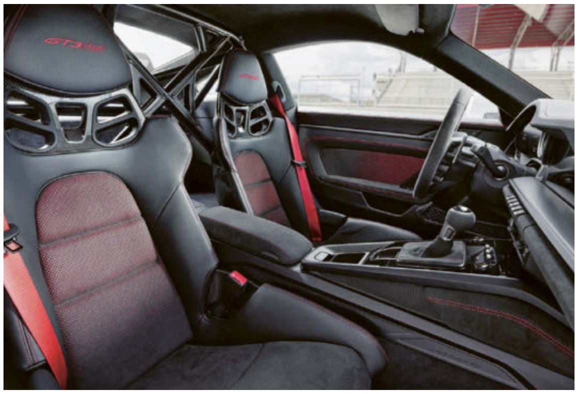
The 911 GT3 RS

Consumption data in the NEDC:
Fuel consumption (city): 17.6 l/100 km
Fuel consumption (highway): 9.8 l/100 km
Fuel consumption (combined): 12.7 l/100 km
CO_2 emissions (combined): 289 g/km

Consumption data in the WLTP:
Fuel consumption (combined): 13.4 l/100 km
CO_2 emissions (combined): 305 g/km

As of 08/2022

→ **High downforce:** Continuously adjustable wing elements at the front contribute to generating a total of 409 kg of downforce at 200 km/h.
↓ **Typical RS:** Black leather, Racetex and visible carbon characterize the interior.



The basis for a significant performance boost is the concept of a central radiator – an idea that was first used in the Le Mans class-winning 911 RSR and subsequently in the 911 GT3 R. Instead of the three-radiator layout seen in previous cars, the new 911 GT3 RS relies on a large, angled center radiator in the car's nose, positioned where the luggage compartment is located on other 911 models. This has made it possible to use the space freed up on the sides to integrate active aerodynamic elements.

Continuously adjustable wing elements in the front and on the two-part rear wing, in combination with a number of other aerodynamic measures, provide 409 kg of total downforce at 200 km/h. This means that the new 911 GT3 RS generates twice as much downforce as its 991.2-generation predecessor and three times as much as a current 911 GT3. At 285 km/h, there is a total downforce of 860 kg. A drag reduction system (DRS) has been fitted in a production Porsche for the first time. To achieve low drag and higher speeds on straight sections of the track, the DRS allows the wings to be flattened out at the push of a button, within a specific operating range. The airbrake function is activated during emergency braking at high speeds: The wing elements at the front and rear are set to maximum, creating an aerodynamic deceleration effect that provides significant support for the wheel brakes. The look of the new 911 GT3 RS is characterized by a large number of functional aerodynamic elements. The most prominent feature of the GT sports car is the swan-neck-supported rear wing, which is significantly larger in all dimensions. The rear wing consists of a fixed main wing and an upper, hydraulically adjustable wing element.

A FRONT SPLITTER INSTEAD OF A FRONT SPOILER

For the first time on a Porsche production vehicle, the upper edge of the rear wing is higher than the car's roof. In addition, the front end of the 911 GT3 RS no longer has a front spoiler, but instead features a front splitter that divides the air flowing over and underneath. Sideblades systematically direct the air outwards. Front wheel arch ventilation is provided via louvred openings in the front wings.

Inlets behind the front wheels in the style of the iconic Le Mans-winning 911 GT1, reduce the dynamic pressure in the wheel arches. Sideblades behind the intake ensure that the air is directed to the side of the vehicle. Air from the centrally positioned radiator flows out through large nostrils on the front lid. Fins on the roof direct the air outwards, ensuring cooler intake temperatures in the rear.

In the new 911 GT3 RS, the openings in the rear side panel are exclusively used for improving the aerodynamics, and not for drawing in process air. The rear wheel arch also features an intake and a sideblade for optimized airflow. The rear diffuser comes from the 911 GT3 and has been slightly adapted.

Even the suspension comes in for aerodynamic attention. Because the wheel arches of the new 911 GT3 RS are subject to powerful airflows, the components of the double-wishbone front axle are designed with teardrop-shaped profiles. These aerodynamically efficient links increase downforce on the front axle by around 40 kg at top speed and are otherwise only used in high-end motorsport applications. Because of the wider track (29 millimeters wider than the 911 GT3), the double-wishbone front axle links are also correspondingly longer.

Premiere: For the first time on a Porsche production vehicle, the upper edge of the rear wing is higher than the roof.

The brother to the 911 GT3 R motorsport car makes an impression with more power and optimized aerodynamics.

To ensure that the downforce balance between the front and rear axles is maintained even when braking from high speeds, the suspension engineers have significantly reduced pitching under braking. On the new 911 GT3 RS, the front ball joint of the lower trailing arm has been set lower on the front axle. The multi-link rear axle has also been adjusted, with modified spring rates. The driver assistance systems and rear-axle steering have also have an even more dynamic set-up here.

THREE DRIVING MODES TO CHOOSE FROM

The 911 GT3 RS offers three driving modes: Normal, Sport and Track. In Track mode, the basic settings can be individually adjusted. Among other settings, the rebound and compression damping of the front and rear axles can be adjusted separately and in several stages. The rear differential lock can also be adjusted via rotary controls on the steering wheel. This is done quickly and intuitively with an operating and display concept also borrowed from motorsport.

Four individual rotary controls and a button for the Drag Reduction System (DRS) are located on the steering wheel. The rotary controls are clearly displayed via graphics in the instrument cluster during the adjustment process. The

Porsche 911 GT3 RS does 6:49.328 on the Nordschleife
The new Porsche 911 GT3 RS posted a lap time of 6:49.328 minutes on the Nürburgring's 20.8-km Nordschleife—10.6 seconds faster than the current 911 GT3. Behind the wheel was Porsche brand ambassador Jörg Bergmeister, who was intensively involved in the development of the new top model in the 911 series.

Engine performance

386 kW

↓

Weight

1,450 kg

↓

Acceleration 0–60 mph (0–100 km/h)

3.2 seconds

A fine sprinter: A powerful engine and intelligent lightweight construction make the Porsche 911 GT3 RS quick off the blocks.

← **Unmistakable:** The most prominent feature of the GT sports car is the significantly enlarged rear wing with swan-neck supports.
↓ **Everything under control:** Four rotary controls and a button for the Drag Reduction System (DRS) are located on the steering wheel.

911 GT3 RS also features the track screen already familiar from the 911 GT3. At the touch of a button, the driver can reduce the digital displays on the two seven-inch side displays to the essential information. The gearshift indicators to the left and right of the analog tachometer have also been taken from the GT3.

The 4.0-liter high-revving naturally aspirated engine has been further optimized compared with the 911 GT3. The increase in power to 386 kW (525 PS) is primarily achieved via new camshafts with modified cam profiles. The single-throttle intake system and the rigid valve drive are derived from motorsport. The seven-speed Porsche Doppelkupplung (PDK) has a shorter overall gear ratio than the 911 GT3. Air intakes on the underbody ensure that the transmission can withstand even extreme loads during frequent use on the track. The 911 GT3 RS accelerates from zero to 100 km/h in 3.2 seconds and reaches a top speed of 296 km/h in seventh gear.

INTELLIGENT LIGHTWEIGHT CONSTRUCTION USING CFRP

Aluminum monobloc fixed-caliper brakes with six pistons each and brake discs with a diameter of 408 mm are used on the front axle. Compared with the 911 GT3, the piston diameters have increased from 30 to 32 mm. In addition, the thickness of the discs has been increased from 34 to 36 mm. The rear axle still features 380-mm brake discs and four-piston fixed-caliper brakes.

The optionally available Porsche Ceramic Composite Brake (PCCB) has 410-mm discs on the front axle and 390-mm discs on the rear axle. The new 911 GT3 RS comes standard with forged light-alloy center lock wheels. Road-legal sports tires measuring 275/35 R 20 at the front and 335/30 R 21 at the rear ensure a high level of mechanical grip.

Intelligent lightweight construction has been a basic principle of all RS models ever since the legendary 911 Carrera RS 2.7. Thanks to an array of lightweight construction measures such as the extensive use of CFRP, the 911 GT3 RS weighs in at only 1,450 kg (curb weight according to DIN) despite its many larger components. The doors, front wings, roof and front lid, for example, are made of CFRP. Lightweight CFRP is also used in the interior, for example in the standard full bucket seats. When it comes to its interior, the new GT sports car is finished in typical RS style: black leather, Racetex and carbon-weave finish characterize the purist, sporting ambiance. The 911 GT3 RS is available with the Clubsport package at no extra cost. This includes a steel rollover bar, a hand-held fire extinguisher and six-point seat belts for the driver.

The Weissach package, which is available at extra cost, involves considerably more. The front lid, roof, parts of the rear wing and the upper shell of the exterior mirrors feature a carbon-weave finish. The front and rear anti-roll bars, the rear coupling rods and the shear panel on the rear axle are made of CFRP and contribute to a further enhancement of the driving dynamics. The rollover bar, constructed for the first time from CFRP, saves around six kilograms compared with the steel version.

Another highlight of the Weissach package is the PDK shift paddles with motorsport-derived magnet technology. This makes gear changes even more dynamic thanks to more precise pressure point and a clearly perceptible click. Optionally available with the Weissach package are magnesium forged wheels, which save another eight kilograms in weight.

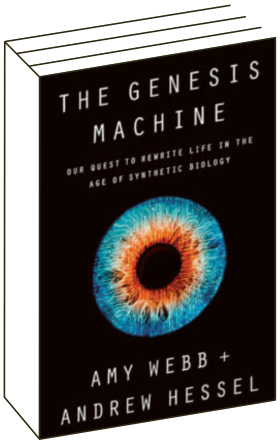
Inspired by the motorsport mindset—where maximum precision is paramount—Porsche's own watchmaking operation in Solothurn, Switzerland, has developed the 911 GT3 RS chronograph. This mechanical watch is reserved for owners of the car. It is based on a glass-bead blasted case made from either natural or black titanium with a screw-down crown. Inside the watch is the mechanical Porsche Design chronograph caliber WERK 01.200, which has been COSC-certified for its high accuracy.

The flyback function allows the wearer to start, stop and reset the second hand with a single action. The chronograph pushers with their 'Start/Stop' and 'Next Lap' laser engravings declare that this chronograph is not just about telling the time. In addition to innovations such as the pulsometer scale on the bezel, many design features and materials from the GT3 RS are also found.

SUMMARY

The new Porsche 911 GT3 RS clearly draws its inspiration from the realm of motor sport. Its four-liter, six-cylinder boxer engine with a high engine speed concept, combined with intelligent lightweight construction, raise the track performance of the road-approved high-performance sports car to a new level.

Deeper knowledge

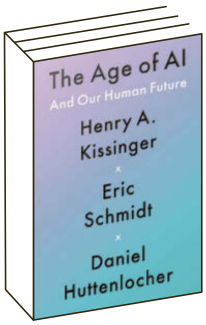


BOOK

Creation from the lab

Synthetic biology aims to create cells or organisms that do not occur in nature. This book describes the scientific and ethical issues surrounding this development.

The Genesis Machine
Amy Webb, Andrew Hessel
Plassen



BOOK

Dawn of the AI age

This book looks at the impact of artificial intelligence (AI) on our society. The three high-profile authors describe where AI will have the greatest impact.

The Age of AI
Henry Kissinger, Eric Schmidt, Daniel Huttenlocher
Hodder And Stoughton

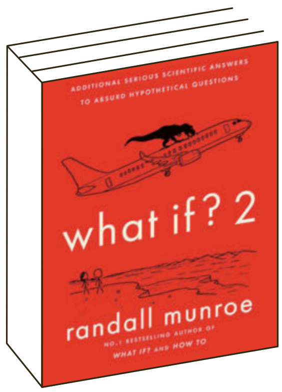
The big picture

BOOK

Where did the future go?

In the 1960s, there was boundless optimism when it came to technology. Flying cars and vacations on Mars seemed to be only a matter of time. Reality, as we know, has proved different. This book explains why this is so and how we can build a better future with new technologies.

Where Is My Flying Car?
J. Storrs Hall
Stripe Press



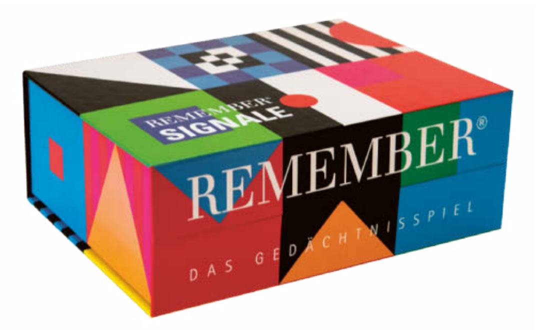
BOOK

Soup all the way to Jupiter

In tried-and-true fashion, Randall Munroe provides scientific answers to absurd questions. For example, this one: What would happen if the solar system were filled with soup all the way to Jupiter?

What If? 2
Randall Munroe
Hodder And Stoughton

For the child in all of us



GAME

Memory training made fun

The object of this game is to search for and find 44 pairs of matching images full of colors and shapes. Along the way, the game also makes for a fun way of training your memory while searching for the pairs.

Remember: The memory game
www.remember.de

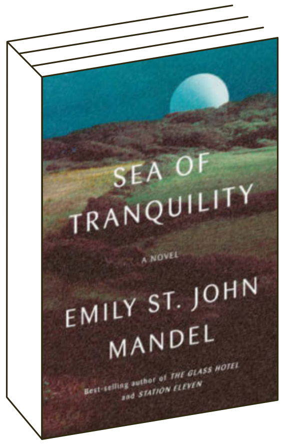
VIDEO GAME

Become a legend

An exhilarating racing experience combined with a great variety of races: Players can become motorsport legends. Single-seaters, touring cars and trucks are just a few of the available options.

Grid Legends
Electronic Arts

Intelligent entertainment



BOOK

Journey through time

In her latest novel, best-selling Canadian author Emily St. John Mandel explores the flow of time, the nature of reality, and the meaning of memories.

Sea of Tranquility
Emily St. John Mandel
Knopf

PODCAST

A world in flux

Each week, this podcast by Antony Funnell takes a critical look at our ever-more-quickly changing world and explains how we can adapt to coming developments. Topics include tiny ‘xenobots’ and the return of airships.

Future Tense
www.abc.net.au/radionational/programs/futuretense

2003
OPTIMIZATION IN A LAKE

Cayago Seabob F5 SR

Motor output
4.5 kW

Maximum thrust
745 N

Maximum speed (over/under water)
22 km/h / 20 km/h

It's not often that a developer gets to launch a completely new vehicle category. Ralf Bauer was presented with this opportunity in 2003: "A customer wanted to launch a water scooter that would be propelled through the water by a turbine using the recoil principle—similar to a jet airplane in the air," reports the current Senior Manager System Development discipline at Porsche Engineering. "Previously, only propellers had been used to propel watercraft like this."

Bauer developed the software module for the central control unit for the new scooter. In 2005, the watercraft named 'Seabob' was presented to the public by Cayago AG at the 'Boot' trade fair in Düsseldorf. The collaboration with Porsche Engineering was, however, far from over: In 2007, the engineers improved the battery manager, the motor control system and the control panel with a graphic display. For the required electronics and software to meet the objectives, they had to push the limits of the available technology. "Back then, microcontrollers were nowhere near as powerful as they are today," recalls Ulf Schlieben, Project Leader Electronics at Porsche Engineering. "This made it a real challenge to accommodate all of the scooter's functions in the control unit—and yet not make any compromises in terms of safety." Porsche Engineering's expertise was, in fact, also in demand for the industrialization of the water scooter. Much like in vehicle development, the aim in this case was to turn a prototype into a product ready for series production. This included testing—often in the water, of course. "For the calibration process, we repeatedly went to lakes to optimize the performance of the scooter," says Schlieben. Porsche Engineering also used a special test bench with a water basin and counter-current system for endurance testing.

Over the years, the Seabob has been continually refined by Cayago and Porsche Engineering and a succession of new generations of the water scooter have been brought to the market. Controlled by shifting the user's body weight, water sports enthusiasts can now cruise the ocean blue or the local lake at speeds of up to 22 kilometers per hour—largely silently and without emissions—thanks to the up to 4.5 kW (6 PS) provided by the electric jet drive. The watercraft, which weighs around 30 kg, can also dive to depths of up to 40 meters. Thanks to the color display, the driver can keep an eye on information such as the battery charge or water temperature while underway.

"It's exciting to develop a new product completely from scratch," says Schlieben, who has also developed battery management control units for Porsche's Le Mans-winning car. "And of course I was particularly pleased to see a lot of Seabobs on the beach last summer between Saint Tropez and Cannes."

"It's exciting to develop a new product completely from scratch."

Ulf Schlieben
Project Leader Electronics at Porsche Engineering

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