Porsche Engineering Magazine

Issue
1/2020

www.porsche-engineering.com

AUTOMOTIVE DEVELOPMENT OF THE FUTURE

Inside China

Started off for a drive.
Returned home with an epic story.

The new 911 Turbo S.

The 911 Turbo S has the potential to turn every drive into an unforgettable story. This is ensured by the power output of 478kW (650PS), Porsche Active Aerodynamics (PAA), PASM sports suspension and an array of intelligent assistance systems. Discover more at www.porsche.com/911Turbo

Fuel consumption (in l/100km) urban 15.5 · extra urban 8.6 · combined 11.1; CO_2 emissions combined 254g/km

PORSCHE

Dr. Peter Schäfer,
Managing Director Porsche Engineering

Dear Reader,

A Chinese proverb says: "One generation builds the road the next will travel." We—as a company, as a society, as individuals—set the course for future generations in the here and now. This applies both to concrete developments we are working on and the ways in which we work together.

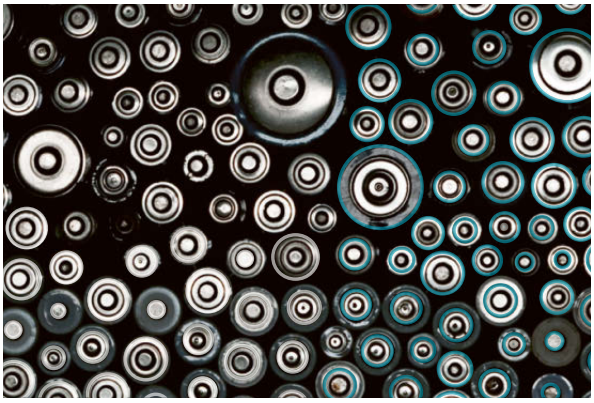
We have been partnering with Chinese companies for decades. And we learn from each other every day. Mobility is in a state of upheaval—and that is nowhere more evident than in China. New drivetrain strategies, highly automated driving functions, and a wide range of connectivity services are shaping the Chinese market. Together with our customers and partners, we are continuing to develop these technologies. In addition to our understanding of the market and our expertise in both traditional and digital disciplines, one thing in particular helps us in this process: the deep conviction that we are successful when our customers are successful.

We are proud to have accompanied the development of the automotive future in China for more than 25 years, as well as to have played a role in shaping it together with Chinese car manufacturers, suppliers, IT companies, and local subsidiaries of international OEMs. A positive culture of cooperation is as important to us as the latest findings from the worlds of business and science, tech players, and universities. So we are working together to build the roads that the next generation will drive on.

I hope you enjoy reading this China issue of our magazine.

Best regards,
Peter Schäfer

ABOUT PORSCHE ENGINEERING: Creating forward-looking solutions was the standard set by Ferdinand Porsche when he started his design office in 1931. In doing so, he laid the foundation for today's Porsche customer developments. We renew our commitment to that example with each new project that we carry out for customers. Porsche Engineering combines expertise from vehicle and system development with the latest innovations from function and software development and validates these using comprehensive simulation and testing facilities.



DOSSIER

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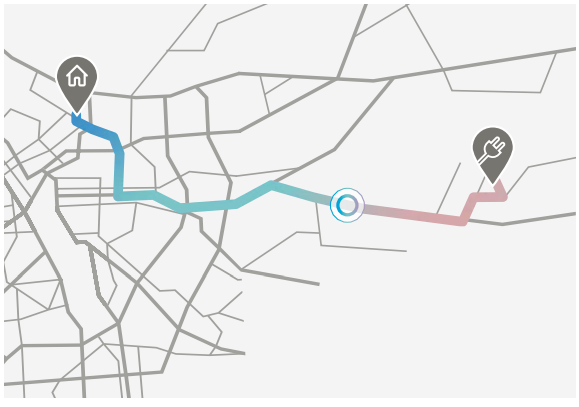

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Authors

24 **Andreas Burkert** is an *ATZ* correspondent and an author. He writes about automotive engineering, electric mobility, and AI.

32 **Valerio Pellegrini** is a communication designer in Milan. Among other things, he deals with data visualization and illustration.

58 **Constantin Gillies** is an economist and business journalist. His subjects include companies, technology, digitalization, and logistics.

News

Porsche Cayenne Coupé

Fuel consumption (urban): 11.7 - 11.6 l/100 km
Fuel consumption (highway): 8.0 - 7.9 l/100 km
Fuel consumption (combined): 9.4 - 9.3 l/100 km
CO_2 emissions (combined): 215 - 212 g/km
Efficiency class: D

Virtual and augmented reality

Fast decisions with the Visual Engineering Tool

Porsche Engineering is increasingly relying on virtual and augmented reality (VR and AR) in development. Using the in-house-developed Visual Engineering Tool (VET), engineers can in many cases reduce complex real models and rebuilds and thereby save time and costs. Among other things, VET was used in the development of the new Porsche Cayenne Coupé, one of the highlights of which is its large glass roof. Instead of constructing different variants in real life, the developers created a virtual model from CAD data. The model could be equipped with numerous realistic glass variants on a daily basis and viewed from different angles in different lighting conditions. This allowed important decisions to be made more quickly. The VET system is being continuously refined by Porsche Engineering. It can be used not only to assess visual aspects or component variants, but also to present technical content. Until now, VET has been used for ergonomics and assembly studies, the representation of dimension data, and as a virtual wind tunnel. In addition to VR, AR is currently being integrated into the VET system as well, for instance for cross-location collaboration.

#Inside Porsche Engineering

Porsche Engineering on Instagram

Porsche Engineering has expanded its social media presence and is now also available on Instagram at @porsche.engineering. In addition to news and information about upcoming events, visitors dive into the world of the company and experience which trends and technologies the engineers of Porsche Engineering are working on.

“We have invested a lot in activities like model-based and web development.”

Marius Mihailovici,
Managing Director of Porsche Engineering Romania

Further expansion of function and software development

More employees and office space in Cluj

Porsche Engineering continues its growth in Cluj, Romania. The location, which specializes in the areas of function and software development, had roughly 200 employees at the end of 2019 as planned and will create additional jobs in the course of this year. Porsche Engineering Romania is also expanding geographically in preparation for further growth. The increasing numbers of personnel and space reflect the many projects under way, particularly in the areas of artificial intelligence and autonomous driving. “We have invested a lot in activities like model-based and web development. As the automotive market is developing in this direction, we will continue to expand our capabilities in both areas,” says Marius Mihailovici, Managing Director of Porsche Engineering Romania. In Cluj, experts work together in national and international teams on the latest technologies to develop, test, and validate the cars of the future.

Porsche Turbo Charging

Porsche Leipzig opens fast charging park and invites the public to try it

Porsche has launched a new public charging park dubbed Porsche Turbo Charging in Leipzig. The Porsche Leipzig Customer Center in the popular trade fair city now features twelve high-power chargers with 350 kW (direct current) and four charging points with 22 kW (alternating current)—seven days a week, around the clock, and for customers of all vehicle brands. The total capacity of the charging park, including six internal fast charging points and a further 22 internal charging points, is around 7 MW. The electricity is derived entirely from renewable energy sources. As part of a charging flash mob, Porsche Leipzig invited the public to fill up on electricity free of charge at the charging park on February 29. The event was quickly fully booked: more than 400 visitors with 170 e-vehicles from almost every vehicle brand took part in the electrifying event. Experts from Porsche Engineering were on hand to answer technical questions and provide support during charging. The fast charging stations, called Porsche Turbo Chargers, were developed by Porsche Engineering and set new standards in terms of charging times. Depending on the vehicle model, energy for a range of up to 100 kilometers can be charged in just five minutes. All vehicles with a Combined Charging System connection (CCS2) can use the fast charging function.

12

public high-power chargers

350 kW

direct current (12 units)

22 kW

alternating current (4 units)

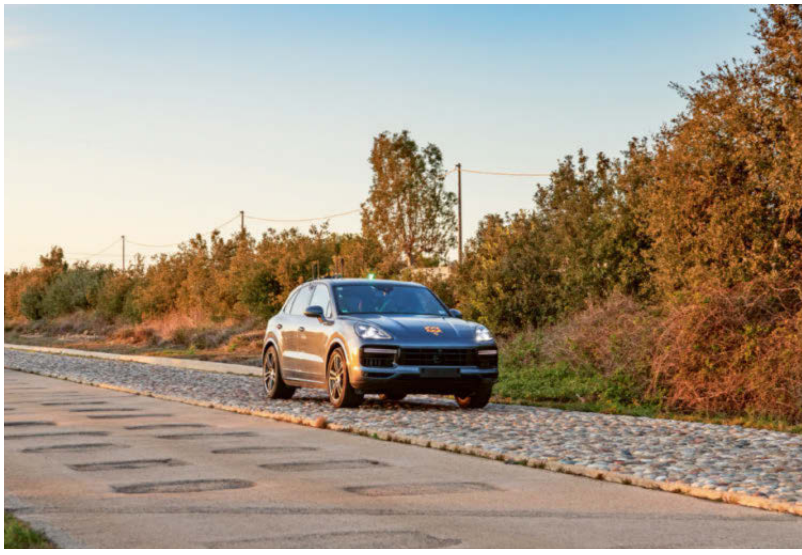
7 MW

of power, including internal charging points

Groundbreaking endurance tests

Driving robots complement test drivers behind the wheel

The engineering team at the Nardò Technical Center (NTC) is not only working on new ways of testing autonomous driving functions, but also the future of automotive endurance tests. In February, a production vehicle covered hundreds of kilometers on the circuit and the neighboring test tracks. There was no human driver behind the wheel; instead, a robot was in command of the steering wheel and pedals. The robot accelerated to up to 130 km/h on the circuit and covered 600 kilometers in a single night shift. During the tests, the sports car was connected to another vehicle via a direct wifi link. This enabled the engineers to observe all parameters in real time as well as to intervene by remote control in case of an emergency. Professional test drivers will remain indispensable for vehicle validation in the future, but robotic drive automation will make it easier to perform similar tests in a more reproducible manner. The margin of error is so small that even the smallest deviations from the target values can be detected. "These driverless tests are groundbreaking," says Davide Palermo, manager of the ADAS Center of Competence at the NTC. "We have made a great leap forward—in terms of the complexity of test automation, vehicle set-up, parameter tuning, and intense activity on the track."



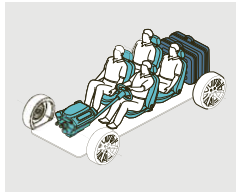
Turbo for Talents

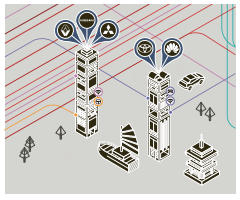
Summer camp for youths in Nardò

The Nardò Technical Center continues its commitment to the local community through its partnership with the A.C. Nardò soccer club. This year, the program focuses on the prevention of bullying and initiatives to spread important educational values such as fitness, fairness, integrity, respect, and trust. The commitment in Nardò is part of the Porsche corporate program Turbo for Talents, which aims to promote the social and personal development of young people through high-quality sports training.

An immensely influential market

China is booming. A middle class with high purchasing power expects first-class vehicles that seamlessly connect with the ubiquitous smartphones. Chinese and Western OEMs are driving forward new and classic vehicle development themes at full steam. Reports from a country that is helping to shape the future of mobility.





Autocity: In Anting, almost everything is about cars. Porsche Engineering maintains a site here tailored to the local customers' specific requirements and with access to one of China's best talent pools.

Highly sought expertise

Text: Thomas Kern Contributor: Kurt Schwaiger Photos: Kai Hartmann

In Anting near Shanghai, around 75 Porsche Engineering staff work for Chinese car manufacturers and customers from the VW Group. The site has cutting-edge test facilities and investigates the latest trends in the automotive industry as well as automated driving and e-mobility.

Not far from the world-famous Formula 1 race track Shanghai International Circuit, we find the town of Anting. Anting was an early bird in becoming a key location for the Chinese automotive industry. Shanghai Automotive Industry Corporation (SAIC) was founded there in 1984, with the joint venture SAIC-VW following in 1988. Today, start-ups like Nio and suppliers like Schaeffler, ZF, and Brose maintain sites here, too. Almost everything else in town is also all about cars. In 2007, an automobile museum opened in Anting, and right next to it we find the Porsche Experience Center. So it makes sense that Porsche Engineering chose Anting to set up its Chinese base.

For more than

25

years,
Porsche Engineering has assisted Chinese customers.

2015

Porsche Engineering opens its Anting site near Shanghai.

The company has pursued engineering projects together with its local customers here since 2015. Key fields of research are suspension systems, high-power charging, and software development. Porsche Engineering's Chinese operations have a fair history: the engineers have been active here for more than 25 years—opening a branch here was the logical thing to do. "Customer projects have always been part and parcel of Porsche," says Kurt Schwaiger, head of the Shanghai branch. "We're simply continuing the history." Besides Chinese OEMs, the key accounts also include companies from the VW Group.

Better response to customer requirements

Kurt Schwaiger plans to use the Anting site to respond more rapidly to customer requirements. For one thing, there's a time difference between China and Germany of six or seven hours—depending on the season. Always a stumbling block in terms of quick project turnaround. Then there also used to be language barriers. Opening a local site eliminated those. Today, Kurt Schwaiger and his team can support Chinese customers in developing vehicles, while filling in western customers on valuable details concerning the Chinese market.

With the Chinese market undergoing major change, Porsche Engineering's expertise is highly sought lately. The times when China was "the world's workshop" have long gone. The country is advancing towards a high-tech economy with a large, well-educated, and affluent middle class. The customers have long been just as demanding here as they are in the traditional markets. And the government has ambitious plans, too: China wants the intelligent and connected vehicle—ICV for short—to be a common sight on its roads by 2025 at the latest. The aim is to have all vehicles communicate in real time and to share data, for example on congested traffic. On top of that, China wants 15 percent of all vehicles in the country to be highly automated and ten percent to be driving entirely by themselves by no later than 2030. This gives the Chinese market tremendous influence on the future of the motor car.

Porsche Engineering in Shanghai deals with more or less every aspect of vehicle design. "It all started off with chassis design," Kurt Schwaiger says. "We made a name for ourselves with that here." Today, this has become entire suspension systems based on highly advanced electronics: all-wheel steering, stabilizers, four-wheel drive, air suspension. "The past two years

Chassis systems for China: Staff fine-tuning and checking the chassis components.

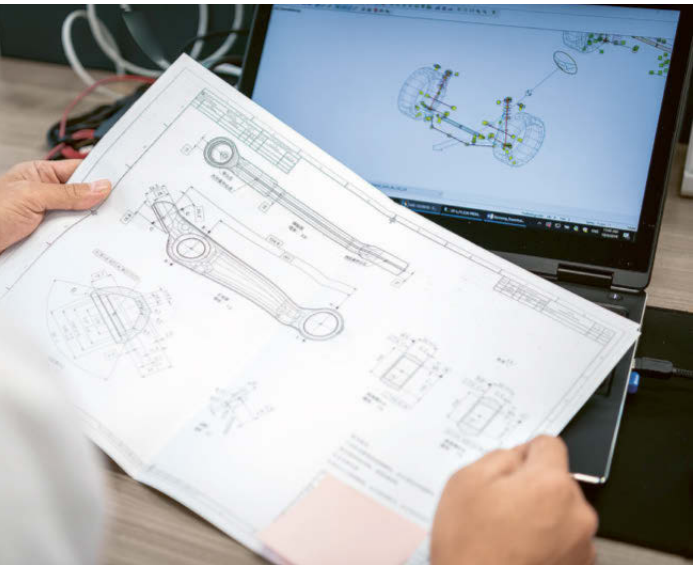
High-power charging: Testing a battery and battery management system for electric vehicles (on left).

Check: Reviewing designs for suspension components (on right).

have seen customer interest in electronic suspension systems rise significantly," Kurt Schwaiger relates.

And then there's the electrical engineering and electronics division (E/E), which is the one that deals with all of the smart control units in a vehicle. The tech specialists at Porsche Engineering in Shanghai always start by developing the software to match their customer's specifications, and in the next step test it on HiL (hardware-in-the-loop) test rigs. The test rigs lead the control units to act just as they would if they were in a real vehicle, enabling trial runs long before any prototypes are available. While before, all tests ran in Germany, Anting now has the necessary equipment on site. "We save so much time now that we can run the important tests right here and right away," says Naikai Du, who is also responsible for HiL test rig development in Anting.

High-power charging for electric vehicles is another major topic in China, where a huge market for electric cars is emerging. Porsche Engineering developed a special charging station that delivers up to 350 kW of charging power to recharge a Porsche Taycan in mere minutes. The major markets, however, all observe different standards. China is subject to the national GB/T standard (GuoBiao), which means that the charging station needs to be adjusted to comply with the Chinese market's specifications. "We and a local enterprise are acting development partner for this. All Porsche dealers in China will be supplied this charging station," Kurt Schwaiger says.



Ben Wang
Manager Software Development

Naikai Du
Senior Manager Electric & Electronics

Estha Li
Senior Manager Connectivity

911 Carrera Cabriolet

Fuel consumption (urban): 12.9 l/100 km
Fuel consumption (highway): 7.6 l/100 km
Fuel consumption (combined): 9.6 l/100 km
CO_2 emissions (combined): 218 g/km
Efficiency class: G

Taycan Turbo S

Electricity consumption (combined): 26.9 kWh/100 km
CO_2 emissions (combined): 0 g/km
Efficiency class: Germany: A+ Switzerland: B

Porsche Engineering's work in Anting is moving steadily more and more into software development. This is due to some extent to the smart chassis systems, but overall is owed to the new electronic driver assistance systems, which lead up to the self-driving cars of the future. These assistance systems require even more than others to be designed on site in China. "Chinese traffic is different to traffic in Europe or the USA. The people have a different way of driving," the expert, Ben Wang, explains. "For instance, the relative number of beginner drivers is much higher in China. Some of the traffic signs are different, too, and automatic parking needs to take into account that underground parking lots in China are designed differently." Ben Wang hails from the neighboring province of Jiangsu. He joined Porsche Engineering two years ago. He considers his job both a challenge and an inspiration: "We're always needing to adapt to new customer requirements. The fields of traffic and traffic control, for example, are massively in flux."

Seamlessly integrated car and phone

Testing and validation are also part of the Shanghai branch's portfolio. Here, infotainment systems and their interconnectivity are a key field of operations. "Chinese drivers consider these things really important," says Kurt Schwaiger. Indeed, smartphones feature in every walk of life here, perhaps more so than anywhere else in the world. Nowadays, almost every day-to-day activity is resolved, optimized, and measured using a mobile phone. With WeChat, for example: on the face of it, the app is the Chinese version of WhatsApp. But it also acts like Instagram, Facebook, Twitter, and—most significantly—as a credit card. Almost all payment transactions in China these days use WeChat Pay, or its competitor service Alipay. "So Chinese drivers all assume there's a seamless integration between car and smartphone," Kurt Schwaiger says.

Network integration goes further yet, pursuing prevention of congestion and immediate detection of accidents. "Plug-in hybrids and fully electric vehicles send related data to the national data center via a corporate server," Estha Li explains. She comes from Beijing and has been on board with Porsche Engineering since 2017. "Our server lets us share data specifically and as needed, which lets us realize all kinds of support for drivers. The corresponding functions have to be developed here in China, indeed they couldn't be developed elsewhere."

Kurt Schwaiger, the branch manager, has lived in Shanghai for the past ten years. When he took on his

Future technology: Working on the intelligent and connected vehicle.

"Chinese traffic is different to traffic in Europe or the USA. People have a different way of driving."

Ben Wang,
Manager Software Development

job in Anting in 2015, the Shanghai branch employed a staff of eight. Today, 75 people work here, and staff will be increased to over 100 by year's end. At the same time, the business premises will grow from 1,500 to 2,100 square meters. Geographically, the premises divide into two locations: the larger of the two lies in the Autocity Innovation Park in Anting. In the months ahead, a second building will be rented to allow for expansion of the team. The first floor will feature a workshop accessible to customers. The branch's second location is in Minhang, a suburban district in Shanghai's southeast.

A regular part of the Shanghai branch's operations is its cooperation with renowned Tongji University. Every two years, the partners jointly host the Tongji Porsche Engineering Symposium, a platform for

>100

staff will be working at the Shanghai branch by late 2020.

Three questions for Kurt Schwaiger "China is setting out on a new path of its own"

1 What do customers in China expect?

A rapid response, most of all. Everything here moves much faster. That's why it's so important to have our branch in Shanghai, in the same time zone as our customers and with the requisite language skills, so that we can react quickly and flexibly to requirements. There's also a keen eye to prices.

2 Is it difficult to find good staff in China?

Generally speaking, China has an abundance of good, skilled workers. But locating them isn't always so easy. Here in Shanghai, our location gives us an edge because a lot of Chinese people want to be here. Our good connections to Tongji University also help us find new junior talent. And there's our strong brand, of course. All this keeps employee turnaround in the low single-digit figures.

3 How does the Chinese automotive market differ from its western counterpart?

Today, Chinese businesses are at a really high level. Highly automated driving is going to be a major thing in China in the years to come. Here, China is treading new paths, as a pioneer. For V2X applications, for instance, they'll be using only mobile comms standards like LTE-V and 5G. Because the Chinese government doesn't permit the export of geo-based data, all the testing needs to be done here in the country.

Kurt Schwaiger

The branch manager has lived in Shanghai for the past ten years. The branch first made a name for itself with chassis design. Today, its portfolio covers a wide range of fields.

top execs to discuss the latest developments in the automotive trade. The cooperation also includes exchanges in the form of internships and thesis programs as well as sponsoring the local Formula Student team, in which students design their own race cars and take part in competitive racing. This provides the branch with ideal connections to one of China's best talent pools—essential for continued growth in one of the world's most important automotive markets.

IN BRIEF

The Chinese market is heavily in flux. Customers expect the best technology and solutions tailored to their requirements—for example when it comes to integrating vehicle and smartphone. In its branch in Anting, Porsche Engineering is right on the market's pulse and responds rapidly to local customers' queries. At the same time, the staff supply western businesses with valuable insights into the Chinese market.

On-site testing: Engineers validating control unit software on HiL test rigs.

Adaptable: Platforms must take into account the requirements of different drive systems and different model variants.

In vehicle development, the concept and package design assumes a central role in the early phase, as this is where the technical foundations for the later products are laid. For a customer from China, Porsche Engineering used an existing vehicle architecture to verify the feasibility of a comprehensive platform concept with different body variants and drive systems in a relatively short time, and gathered valuable information for further development activities in the process.

Text: Richard Backhaus

Contributors: Humberto de Campos do Carmo, Stefan Bender

Illustrations: Florian Müller

When automobile manufacturers develop a new vehicle model, good advance planning is required. At the very outset of the development process, the technical concept and the package (definition of the vehicle geometry, including the ergonomics and usage conditions, as well as the definition and management of the different zones in the vehicle) must be defined so that the final developed vehicle will later correspond to the original ideas. Some projects require a different approach, however, for instance when an OEM has already started a vehicle development and later decides to launch further vehicles and drivetrain variants derived from the original concept.

An increasing number of such requests are coming from car manufacturers in China. "There are currently many new OEMs being founded there that have only been developing cars for a few years," explains Humberto de Campos do Carmo, who as Senior Manager Vehicle Concepts and Package at Porsche Engineering has already implemented a wide range of different projects for customers worldwide. "These companies are therefore turning to us for conceptual platform development that takes into account all drivetrain variants and various model derivatives. They might wish, for example, to expand the existing vehicle concept into a platform by adding further body and drivetrain variants."

One recent example is a platform concept commissioned by a Chinese customer. The aim was to develop various derivatives based on an existing SUV model with an all-electric drive unit: on the one hand an additional sedan, and on the other hand drivetrain variants with internal combustion engines, an electric drive unit with range extender, and a hybrid system. If, as in this case, the concept development is to be based on an existing vehicle, the experts start with a precise analysis of the existing platform. "In each case, we focus on the most critical vehicle derivatives, such as the heaviest or most powerful variant—the worst-case scenario, so to speak," explains de Campos do Carmo.

Studies indicated that the body structure of the front end was too soft for the heaviest derivative of the platform. "In order to improve crash safety, we proposed enlarging front longitudinal members," reports

"We have experts from all vehicle sectors and we use the latest simulation and development tools."

Humberto de Campos do Carmo, Senior Manager Vehicle Concepts and Package

de Campos do Carmo. “We also had to change the suspensions so that different ground clearances and heights could be achieved for SUV and sedan." Using tires with different diameters, springs of different stiffness, and special spacers on the axle carrier, the developers were able to adapt the vehicle height to the varying requirements without having to interfere with the basic axle design. The cooling system also had to be modified: the analysis showed that the heat exchanger was too small for the SUV version with a combustion engine. It was adapted to the new conditions in further vehicle development.

One of the biggest challenges was the package of different sized batteries for the electric model variants. “Together with the customer, we developed the concept for an underbody structure that is identical for all vehicles,” says de Campos do Carmo. “In each case, different mounting points accommodate the different sized batteries of the electric variants, so we were able to avoid cost-intensive modifications in this area.” The battery of the purely electric vehicle fills the entire available package space; in the versions with the range extender and the hybrid drivetrain, the fuel tank for the combustion engine was placed behind the smaller battery pack.

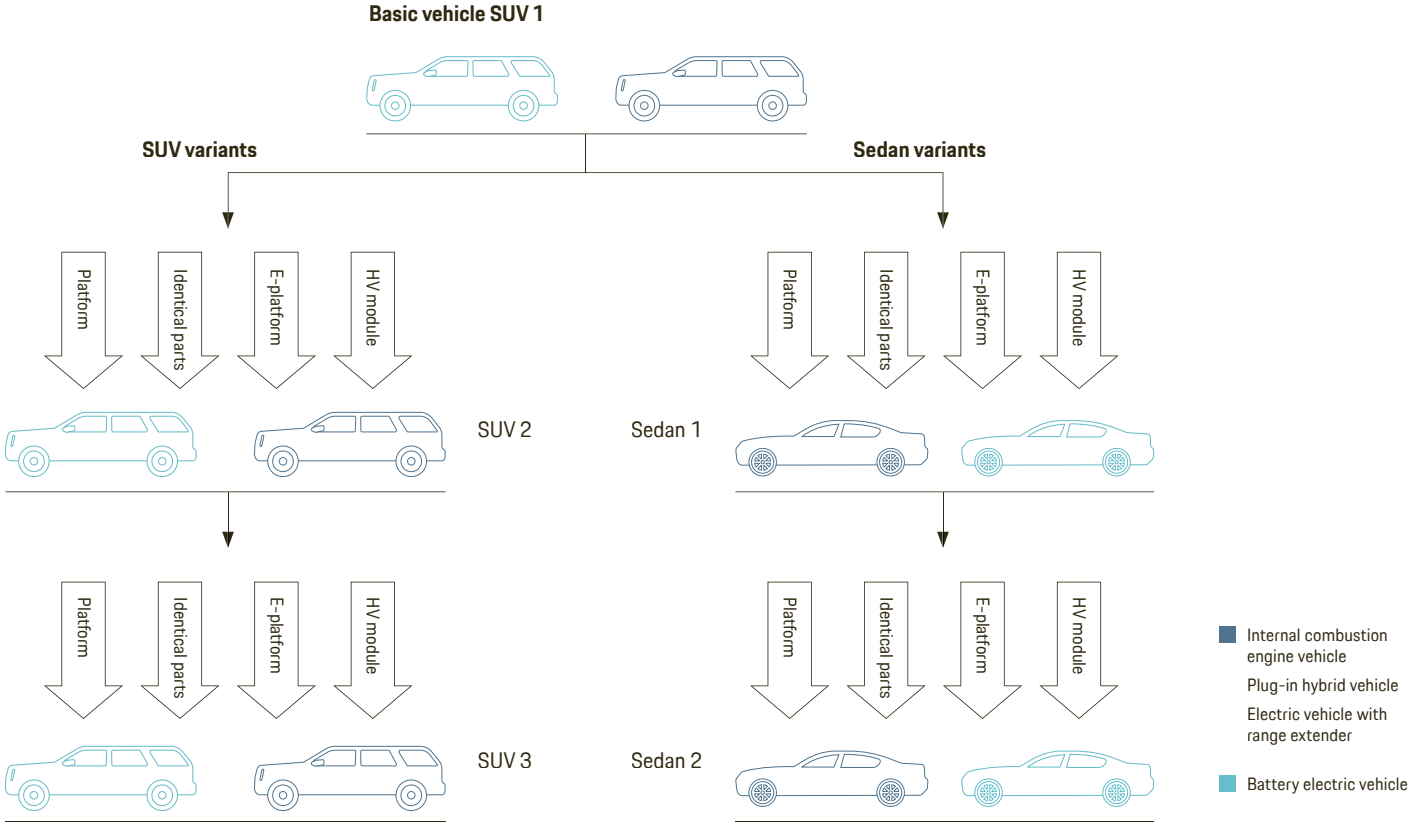
Core elements of the platform

If it becomes apparent during concept development that the effort required to change the existing platform is too high, the customer is faced with a choice: it can either skip its current project in favor of a platform-compliant solution or pursue both approaches in parallel. “From a cost perspective, the focus on the future-proof platform architecture would usually be best,” says de Campos do Carmo. “However, when a vehicle project is already very advanced, customers often decide to develop both concepts to market maturity at the same time and absorb the additional costs as a lesson learned.”

Ideally, a customer should therefore define the desired segments, drivetrain concepts and engine variants to

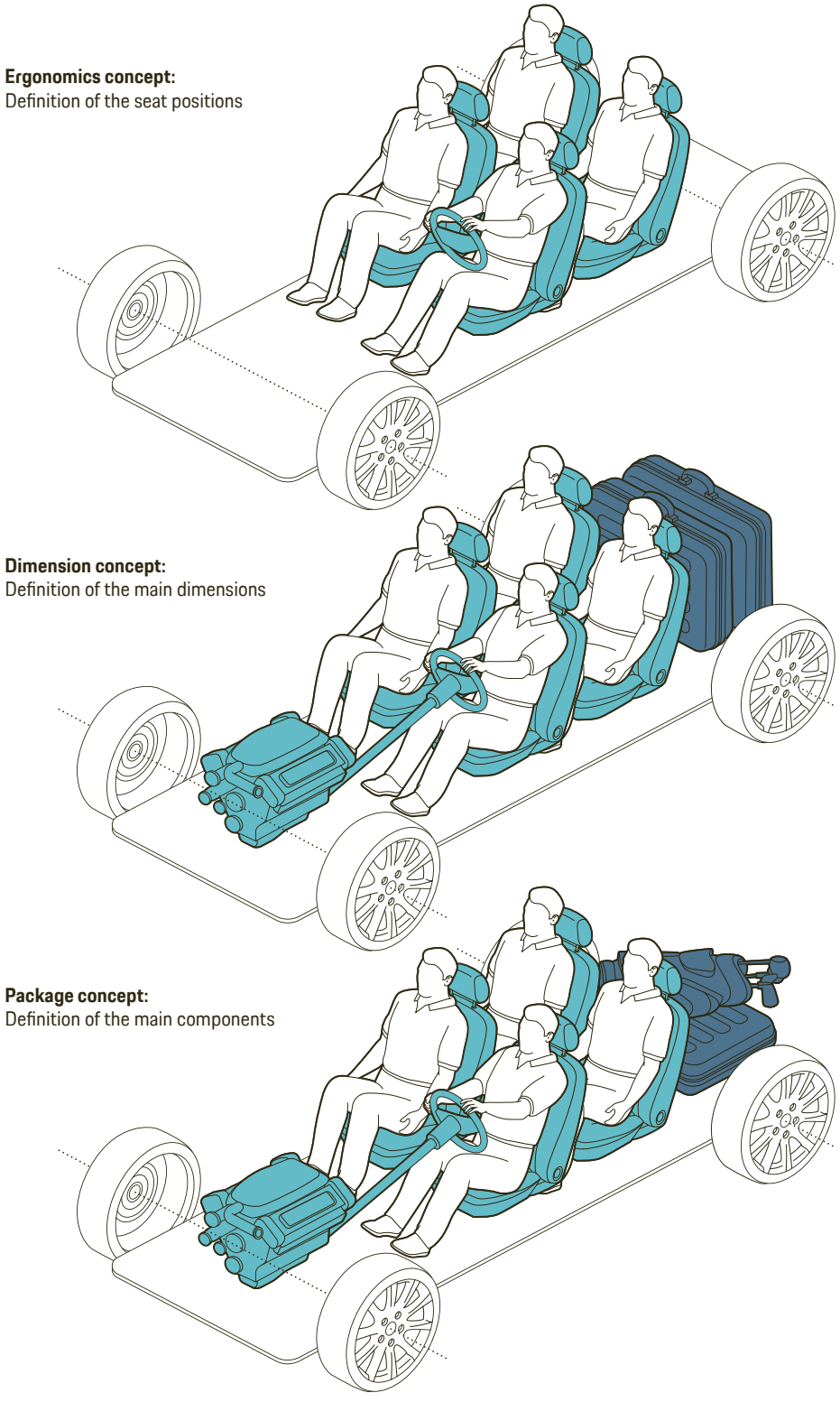
Conceptual platform development

Starting from an existing SUV model with an all-electric drive unit, Porsche Engineering has developed several different variants: an additional sedan and drivetrain variants with internal combustion engines, an electric drive unit with range extender, and a hybrid system.



Step-by-step development

The optimal accommodation for passengers: This is the most important goal of every vehicle concept. The first step is the **ergonomics concept** on the basis of anthropometry (the science of the human body and skeletal characteristics). The **dimension concept** describes the geometric values and interrelationships; it also takes into account legal requirements and the geometry of components. Finally, the **package concept** guarantees that in the end everything is in the right place. The idea of the package concept is to bring the goals of the departments into line with their sometimes contradictory requirements.



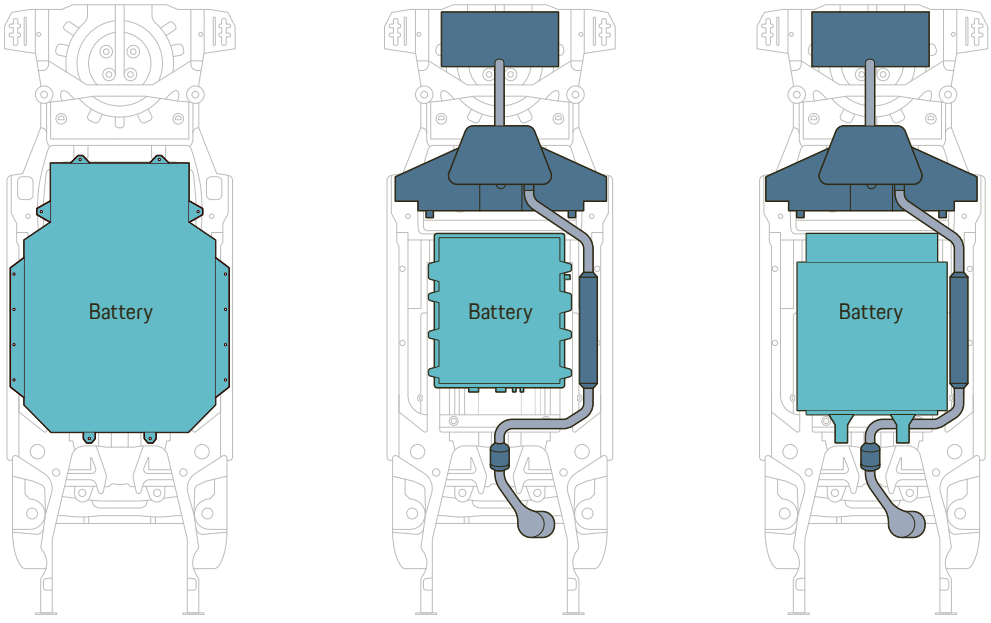
Ergonomics concept:
Definition of the seat positions

Dimension concept:
Definition of the main dimensions

Package concept:
Definition of the main components

Common underbody structure

Different mounting points of the common underbody structure accommodate the differently sized batteries of the electric variants. The battery of the all-electric vehicle fills the entire available package. In the versions with the range extender and hybrid drivetrain, the fuel tank for the combustion engine is located behind the somewhat smaller battery pack.



Battery electric vehicle | **Plug-in hybrid vehicle** | **Electric vehicle with range extender**

be covered by a new platform in advance. This gives the engineers responsible for the concept and package basic conditions as well as maximum freedom and the opportunity to develop the vehicle platform in a targeted manner, while also allowing them to incorporate factors such as the automobile manufacturer's product and brand strategy into their considerations. The customer benefits from an efficient development process that leads to optimal results in a very short time.

Customers from China typically work on a very tight schedule, which is not comparable with the development cycles of European car manufacturers. "In the abovementioned project we had about six weeks from the requirements analysis to the finished result. To avoid communication problems in the coordination process, resident engineers from the customer supported us as a link to the development team in China," says de Campos do Carmo. "This trusting and close cooperation was a decisive factor in successfully completing the project within the specified timeframe."

Defining the concept and package of a new vehicle requires extensive experience at all levels of vehicle development and the development methodology chain. "We have technical experts from all vehicle sectors, and we use the latest simulation and development tools," says de Campos do Carmo. "And then, of course,there is the high degree of flexibility and customer focus with which we handle development projects, which is also appreciated by our partners in China."

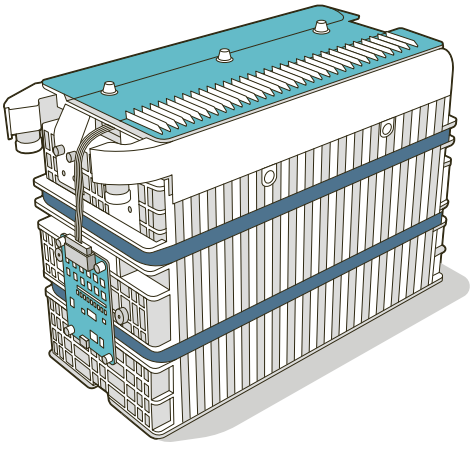
IN BRIEF

Ideally, concept development occurs at the very beginning of a project. But a platform concept for additional drivetrain and model derivatives can also be derived from an existing vehicle. In the case of a Chinese customer, Porsche Engineering has succeeded in doing this by modifying the chassis, cooling system, and underbody, among other things.

Package of high-voltage batteries

China is currently experiencing a real hybrid and electric vehicle boom, which is leading to the development of a large number of new vehicle concepts. "Many of the car manufacturers are start-up companies to whom we can provide technical support in integrating the high-voltage battery into the vehicle," says Stefan Bender, Lead Engineer Battery Package at Porsche Engineering.

In general, the **high-voltage battery** is the largest and heaviest individual module that has to be accommodated in the vehicle as part of the concept and package development process. The requirements for crash safety, the vehicle's center of gravity position, which is important for driving dynamics, the high-voltage wiring of the complete electrical system, and the thermal management of the energy storage system reduce the developers' leeway in the placement of the battery system. "Since with high-voltage batteries, literally every millimeter counts, a precise definition of the technical requirements is the basic prerequisite for package development," says Bender.



Single cell module:
The high-voltage battery has a major impact on crash safety and driving dynamics. Its integration is therefore a special challenge.

Many smaller companies lack this analysis. "The result of this is quite often that, together with the customer, we create a development process tailored to the customer's needs in parallel with the actual battery package project," says Bender. As an example, he cites a customer who wanted to integrate an oversized battery into his vehicle. "Together with the customer, we first determined what performance the vehicle, and thus the battery, had to provide."

In order to be able to meet all the specifications in terms of their mutual interactions, the integration of the battery into the vehicle must be initiated as early as possible in the development process. This applies both to all-electric vehicles and hybrid models based on a conventional vehicle platform designed for combustion engines, where there is no excess construction space for the battery. The aim is always to design the battery module as compactly as possible during the development phase in order to leave plenty of space for placement, and then to accommodate it in the vehicle as required. "If a customer gives us the cell module for the vehicle project, we integrate it in such a way that it meets all requirements in the best possible way," says Bender. "However, overall system solutions in which we can develop the battery unit individually and tailor it to the package are preferable."

"If a customer gives us the cell module for the vehicle project, we integrate it in such a way that it meets all requirements in the best possible way."

Stefan Bender, Lead Engineer
Battery Package

Here, Porsche Engineering can draw on expertise gained over decades in the development and optimization of the electrical, mechanical and thermodynamic properties of batteries. For example, the experts use calculation models that are created and validated in-house—for example for the "heart" of the energy storage system, the battery cell. In addition to the simulation tools, test benches are also available to them.

"In the concept and package of a traction battery, we consider all the details of the vehicle. For example, a sports car, unlike a city car, can be expected to have high instantaneous currents," explains Bender. "We adjust the connection of the individual cells within the battery pack to this, for example, so that the contact resistances and the resulting heat generation over several acceleration processes in quick succession do not increase too much and the engine power does not have to be reduced for component protection reasons."

On skyhooks

Text: Andreas Burkert Contributors: Dr. Martin Braun, Johannes Wüst

For a Chinese customer, Porsche Engineering developed a chassis platform with a variable damper system and skyhook feature. The challenge: to design a smart and cost-optimized chassis for a two-model electric vehicle series—in only 18 months. Mass production kicked off on time in March, 2020.

A vehicle's character is defined by its suspension system. The more tightly wheel suspension, tires, body, and driver interweave, the smoother your control over advanced driving maneuvers. For sporty drivers, this is often key to making a purchase decision. Of course, the chassis also has a major effect on driving safety and ride comfort. With electrified powertrains and the trend toward automated driving, the latter will be even more important in future than it is today. Disruptive progress, like the advances in e-mobility, is among the greatest challenges the international automotive industry faces. To address the greater requirements regarding driving dynamics and ride comfort, automobile manufacturers are seeking to employ advanced design tools.

To understand the possibilities modern suspension systems offer, it's worth taking a look at the sportscars Porsche developed in the past. Besides a driving dynamics control system stabilizing the vehicle in extreme driving maneuvers (Porsche Stability Management, PSM), they also feature smart torque distribution (*Torque Vectoring*). The variable shock absorber system PASM (Porsche Active Suspension Management) is another tried-and-tested element in this kind of semi-active suspension system. It responds to dynamic alterations, such as you might encounter during a sudden evasive maneuver, in the blink of an eye. In only fractions of a second, PASM ramps up shock absorber force on both axles to reduce lateral tilt or body see-sawing. Driving maneuvers of utmost precision become possible—and safe.

Falling back onto its experience with designing sportscar chassis, Porsche Engineering is able to offer its customers cutting-edge solutions. Like it did for a Chinese enterprise: "Our customer wanted us to design the front and rear axles for a model series comprising a number of electric vehicles from scratch and including the software algorithms and controllers for a variable shock absorber system," says Johannes Wüst, Senior Manager Chassis Design. Dr. Martin Braun, Senior Manager Chassis Systems at Porsche Engineering, adds: "The customer specified benchmark vehicles we had to catch or outperform within a tight deadline and budget." The goal was to build

Master of the switchback: The new suspension design guarantees ride comfort and excellent driving dynamics.

a suspension system that could hold its own against established international competitors when it came to ride comfort and driving dynamics.

Though the front and rear axles' mechanical design was conventional, getting it done in time to meet the tight deadline while also integrating the design specs of the overall platform was no minor feat. One of these specs, for example, was a double wishbone axle with alloy arms and pivot bearings. The lower control-arm plane was resolved to optimize scrub radius and Ackermann toe-out. "For the rear axle, we focused heavily on getting a really good shock absorber ratio and longitudinal compliance," Wüst explains with respect to the 5-arm design. "We also aimed for excellent elasto-kinematics and rigidity in both axles." The resulting axle designs are now suitable for both sedans and SUVs in terms of spring travel, maximum axle load, and fatigue limits.

To obtain the specified driving characteristics, the engineers developed a special electronic system architecture for the front and rear axles' damper control system. This system architecture allows the damper controller to adjust perfectly to the control systems in the respective vehicle. On top of that, it supports a variety of sensor layouts, in turn making custom-tailored solutions feasible in short times at little expense. "This kind of software-based control is complex," Braun says. "But it helps us keep production costs down by letting algorithms handle the lion's share of comfort and driving dynamics functions."

"This kind of software-based control system keeps production costs down."

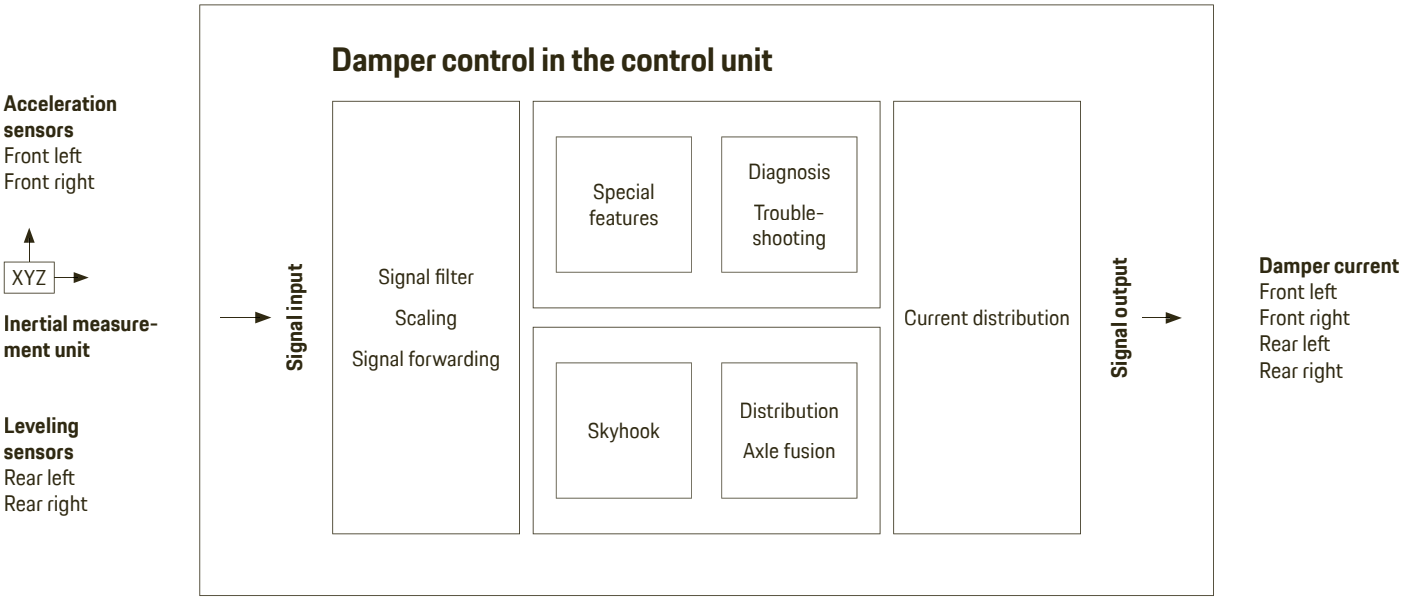
Dr. Martin Braun,
Senior Manager
Chassis Systems

The skyhook function keeps the vehicle body as steady as possible

In the end, this meant using only a small number of sensors and actuators. Instead of four leveling and eight acceleration sensors complementing an inertial measurement unit (IMU), the IMU now interacts with only two acceleration and two leveling sensors. The result is the cost-optimized, smart damper control system (Continuous Damping Control, CDC). The system expands upon the familiar skyhook feature with a whole range of software-based add-ons—among them pothole detection and lane changing. When active, it keeps the vehicle body as steady as possible, irrespective of the present road conditions, almost as if the vehicle were actually attached to skyhooks. While driving, the control system manages to damp or neutralize vibrations across the entire frequency range, especially those in the higher-frequency range from 16 to 30 hertz.

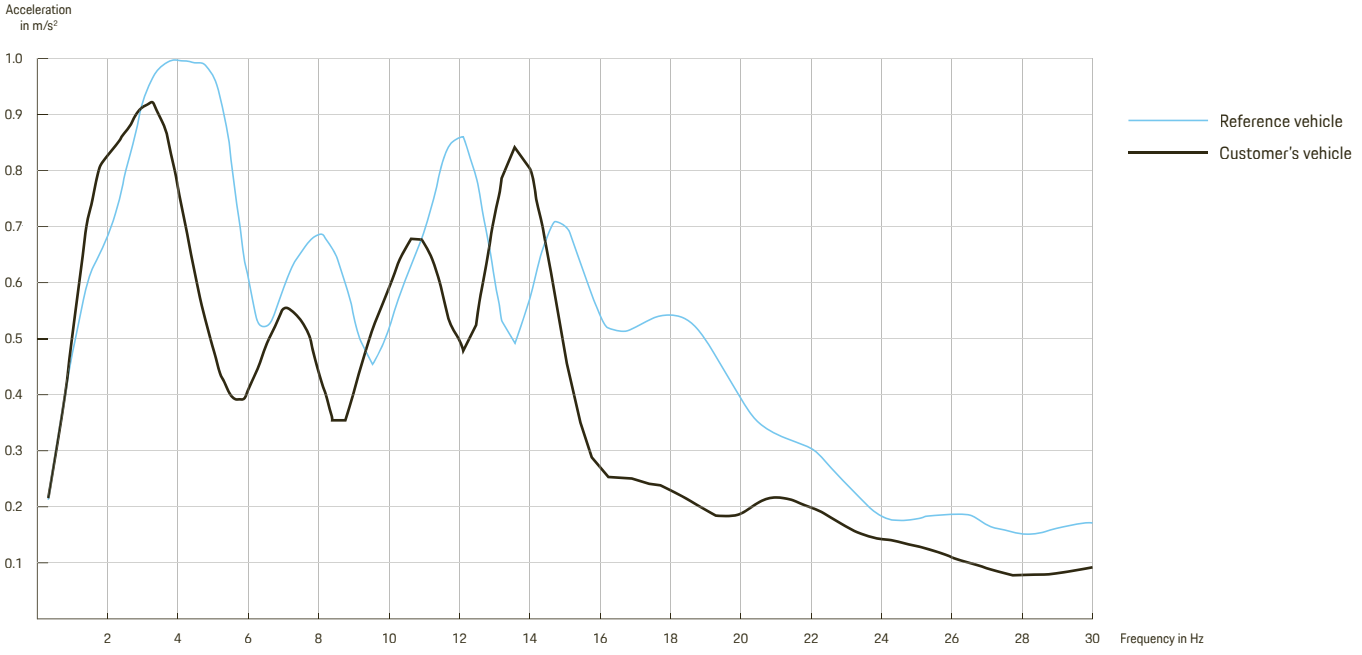
Principle of the damper control system

The controller's architecture supports a variety of sensor layouts. Custom-tailoring takes little time and costs are kept low.



Acceleration along z-axis

The measurements recorded in the vehicle prove that high-frequency vibration in the range from 16 to 30 hertz can be fully neutralized.



Besides first-grade technology solutions, the Chinese OEM also expected close collaboration and support in setting up their capacities. "To begin with, our customer's R&D team was still quite small at less than 400 staff. It grew considerably over the course of the project," Wüst remembers. "An entirely new production infrastructure was set up, alongside designing the vehicle itself." Working closely with the customer's production division, Porsche Engineering's engineers discussed the requirements mass production needed to meet and incorporated the findings in their designs. Experience gained in past projects and on Porsche's production lines in Zuffenhausen and Leipzig proved invaluable, too.

One of the greatest challenges was the customer's tight schedule. Start of production was expected only 18 months after completing the first prototype. To meet this specification, Porsche Engineering began using simulation platforms and rapid prototyping system right from the beginning. "This let us get the first prototypes running for tests really quickly," Braun elaborates. The specifically designed mule vehicles make it possible to quickly draft and fine-tune an axle concept in the early design phase. "This way, we can avoid major change cycles during the trial phase," says Wüst. "So we're not only saving on development time, but also cutting down on test components and prototyping tools and ultimately saving a lot of money."

"An entirely new production infrastructure was set up, alongside designing the vehicle itself."

Johannes Wüst,
Senior Manager
Chassis Design

Another benefit was that working simultaneously on the control system and on the software offered extra potential for optimizing. Wüst is full of praise for the Chinese customer here, lauding that the design targets and vehicle variants were already defined with great precision when the project kicked off. During the project itself, decisions on where to take things were always reached quickly and pragmatically, every time taking into account Porsche Engineering's advice and avoiding delays. "Without these rapid-fire decisions, the short development schedule would have been our undoing," Wüst confides. In the end, the ambitious schedule was met and the model series went into mass production according to plan in March, 2020.

Technology giant: Tencent, based in Shenzhen, is one of China's largest Internet companies.

"We shore up the main capabilities of automobile manufacturers"

Interview: Jost Burger

The Chinese technology group Tencent is driving forward the development of new forms of mobility and services related to vehicles. In an interview, Cham Zhong, Vice President of the company, talks about the automotive market in China and Tencent's collaboration with classic OEMs.

Pioneer: Cham Zhong wants to turn vehicles into data nodes within smart cities.

Why is the automotive market attractive to Tencent?

— **CHAM ZHONG:** The automotive industry is one of the most important efforts of Tencent to embrace the industrial internet. China boasts the world's greatest potential for car consumption, not to mention the high acceptance rate and demand for intelligent products among Chinese consumers. According to a McKinsey survey, 69 percent of Chinese consumers would like to change their car into an "intelligently connected" car. Automotive manufacturers are vying to change their positioning from "automakers" to "mobility service providers."

Over the past few years, we have formed various partnerships with 28 domestic and foreign automotive brands regarding automobile intelligence systems, autonomous driving and shared mobility services. As a digital assistant, Tencent is well positioned to help automotive manufactures gain a better understanding of the Chinese market and its customers.

Tencent

was founded in 1998 and generated a turnover of around 49 billion euros in 2019.

Tencent had

63,000

employees at the end of 2019.

Could you give us some examples?

— **ZHONG:** First of all, we offer integrated automotive intelligence solutions and bring Internet services popular among Chinese consumers into the car, such as WeChat, QQ Music, or Tencent Maps. We also take the lead in developing an in-car light app framework, with cloud update, no need to download, and use-and-go apps. This enables such features as smart parking, car washing, car refueling, car charging or restaurant reservation, all of which are based on the WeChat Unconscious Payment system.

Secondly, we are forging into the new territory of autonomous driving, mainly by focusing our efforts on three basic pillars: a data development cloud platform, a simulation platform, and high-precision mapping. In terms of simulation, Tencent has combined its game engine with industrial-grade vehicle dynamics models and integrated traffic simulations based on virtual-reality, allowing users to test autonomous driving in a highly realistic simulated environment.

We have also rolled out the "Smart 4S" solution to help 4S dealerships—dealerships that pursue a full-service approach by bringing together sales, service, spare parts and surveys—sell cars more efficiently. Through digital tools and platforms like WeChat and mini programs, as well as AI and big data technologies represented by facial recognition, this solution can help 4S dealerships to attract customers more efficiently and accurately. Through its Automotive Cloud platform, Tencent helps automotive manufacturers maintain an efficient grip over the entire product lifecycle from manufacturing, sales to after-sales services. Furthermore, Tencent Keen Security Lab has been working on information security for years where it comes to internet access and over-the-air capability for vehicles.

Talking about over-the-air capabilities, how important is cloud technology in this context?

— **ZHONG:** One cannot talk about digitalization without mentioning the indispensable cloud capability behind it. Tencent's Automobile Cloud provides a full-chain solution ranging from Infrastructure-as-a-Service and Platform-as-a-Service to Software-as-a-Service and Data-as-a-Service.

What exactly are potential applications of this technology?

— **ZHONG:** During the R&D and manufacturing stages, automobile manufacturers are able to cut costs and boost efficiency by employing big data to provide guidelines. Big data is also essential for accu-

rate lead generation and thus enhances marketing and sales efficiency. With respect to after-sales, the Tencent Cloud helps manufacturers set up a comprehensive user management system and provide multi-scenario value-added services, such as ride sharing, which may lead to novel business models. In the meantime, the data-driven services can provide services such as battery life and vehicle lifecycle estimation, part failure analysis and forecast, driver behavior analysis, scenario-based data analysis, and service recommendation.

How can companies like Tencent and classic OEMs benefit from a collaboration?

— **ZHONG:** Automotive manufacturers have developed cutting-edge manufacturing technologies and maintain a sophisticated supply-chain system. In this new era, the automotive industry must embrace the internet to thrive, while internet companies must learn the fundamentals of the automotive industry. Tencent is poised to bridge this gap by offering flexible and modular digital toolboxes and ecological connectors.

By shoring up the four main capabilities of automotive manufacturers, Tencent helps automakers enhance customer experience. First, the capability to recognize and understand users: Intelligent systems will remember seat positions, preferred music or commuter routes. When a customer walks into a 4S dealership, intelligent systems will immediately identify them and anticipate their needs.

Second, the capability to communicate and connect with customers in various ways. Customers interact with their car by voice. Virtual keys can work as a platform for the auto brand to communicate and interact with its customers. Brands can inform their customers of the real-time status and maintenance progress of their cars via WeChat notifications.

Third, the capability to help customers access a wide range of services while driving. Auto brands need to build an all-inclusive service ecosystem by bringing together a vast number of developers and service providers to enrich the in-car app ecosystem.

Fourth, the cloud-powered capabilities accompany a vehicle throughout its entire lifecycle. The lengthy and complex supply chain—from manufacturing to sales and use including vehicle status and after-sales—is a daunting challenge for auto brands that could be eased by cloud-based processes.

"In the coming decade, China will usher in a golden age of the industrial internet."

What role do vehicles play in the overall concept of the "Smart City" of the future?

— **ZHONG:** With new technologies such as big data, cloud computing, AI or 5G, Smart Cities will spring up one after another. Vehicles will become important data nodes in these cities. They can sense the surrounding environment, upload real-time traffic data to the cloud, and assist efforts towards digital traffic and city management. Built on 5G technology and the cooperative vehicle-infrastructure system, the intelligent V2X human-vehicle-road network will become the new urban infrastructure. In addition, self-driving vehicles are more versatile and can function as different spaces, such as con-

Autonomous driving: Tencent is making use of the cloud, a simulation platform, and precise roadmaps.

ference room, cinema, shop, home, etc., increasingly blurring the boundaries between them. They will also increase the use of shared mobility with fewer private cars and more urban space in the future. Vehicles might drive to a suburban parking lot at night by themselves and return in the morning to pick up passengers.

What does Tencent think of the development of Level 4 or Level 5 autonomous driving? Which course still has to be set up—technologically, socially, and legally?

— **ZHONG:** L4/L5 autonomous driving is a necessary precondition for autonomous driving and shared mobility on which it is based. Currently, we have set two parallel courses. First, we are pushing algorithm development and data accumulation for an ideal L4/L5 autonomous driving solution. Second, we are taking into account the needs of customers by promoting applications in specific scenarios. Therefore, we are working towards a solution that combines a highway pilot and a traffic jam pilot, the commercialization of which will provide strong data support for our future R&D efforts.

From a technical perspective, autonomous driving relies on high-precision map data, cloud computing, and simulation techniques. At the policy level, local governments need to gradually relax relevant policies to allow testing on public roads. We need to clarify road safety conditions and ethical judgments. We need support of road network infrastructures such as 5G-based intelligent transportation and traffic systems. With regard to the social aspect, we need to increase public acceptance of autonomous driving, eliminate consumer anxiety, and gain the public's trust.

What do Chinese digital natives value when it comes to in-vehicle infotainment?

— **ZHONG:** Digital natives are currently the main customers of the Chinese automotive industry. They are accustomed to constant real-time connection with the digital world and continuous access to its services. Such expectations are frustrated by the offline state experienced by drivers—it is difficult to check your smart phone while being behind the wheel.

To address this offline anxiety and ensure services are accessible from different terminals and in diverse scenarios, Tencent is providing perfect service continuity between mobile phone and cockpit via Super ID, the uniform identification system. Our Auto Intelligence system (TAI) enables efficient and convenient processing of diverse services through its robust interactive architecture and massive use-and-go light apps. Last year we launched WeChat for Auto, to help drivers communicate more safely through full Voice User Interface (VUI).

Integration: Tencent Auto Intelligence (TAI) enables efficient and convenient processing of various services.

Portfolio

Tencent's product range includes WeChat, one of the most widespread chat and payment services in China. It also offers video games, music, and numerous activities in the field of artificial intelligence.

How does Tencent define "luxury" in the digital age?

— **ZHONG:** Luxury in the digital age must take into account services provided—how to leverage digital means. Traditional brand image campaigns easily lead to uniformity. Therefore, we should shift our focus to services. They can make all the difference and bring a brand closer to its customers.

China is developing rapidly. Where will the country be in the next ten years? In which technology areas will it stand out?

— **ZHONG:** In the coming decade, China will usher in a golden age of the industrial internet. Digital technologies such as 5G, AI, and cloud computing will accelerate the intelligence upgrade of diverse industries. The "digital economy" will become the engine of growth for China and the entire world. Blessed with the fertile soil that allows new technologies to quickly move into the market, China will witness the unprecedentedly large-scale commercialization of substantial cutting-edge technologies.

Cham Zhong joined Tencent in 2004 and is now the company's Vice President. As head of the Intelligence Mobility Business and Intelligent Platform Business, he is responsible for Tencent Maps, Tencent Auto Intelligence, Tencent Autonomous Vehicle, Tencent Location-based Services, Tencent Cloud Xiaowei, and Tencent AI Translation teams.

Closely networked

Research: François Baumgartner Contributor: Martin Stegelmeier Illustration: Valerio Pellegrini

The large Chinese digital companies have discovered the automotive market for themselves. In areas such as autonomous driving, connected cars, and mobility services, they cooperate with established OEMs and other technology companies.

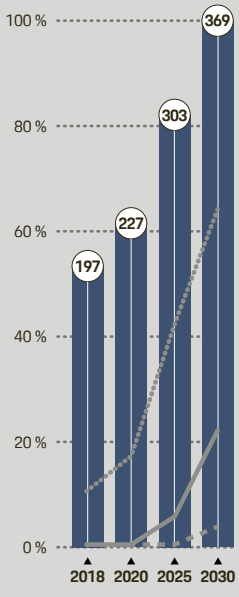
Future trends

New technologies such as connectivity and autonomous driving play an increasingly important role in China. Major local technology companies are driving this development forward.

1 Number of vehicles in China (in millions)

Share (in %)

- Connected cars
- Electric vehicles
- Autonomous vehicles



(Source: PwC)

Baidu

Baidu is a leading search engine and AI company that offers OEMs the fully open Apollo ecosystem for autonomous driving.

Tencent

Tencent is one of the most valuable technology companies in the world, and is in the vanguard of autonomous and networked vehicles.

Alibaba

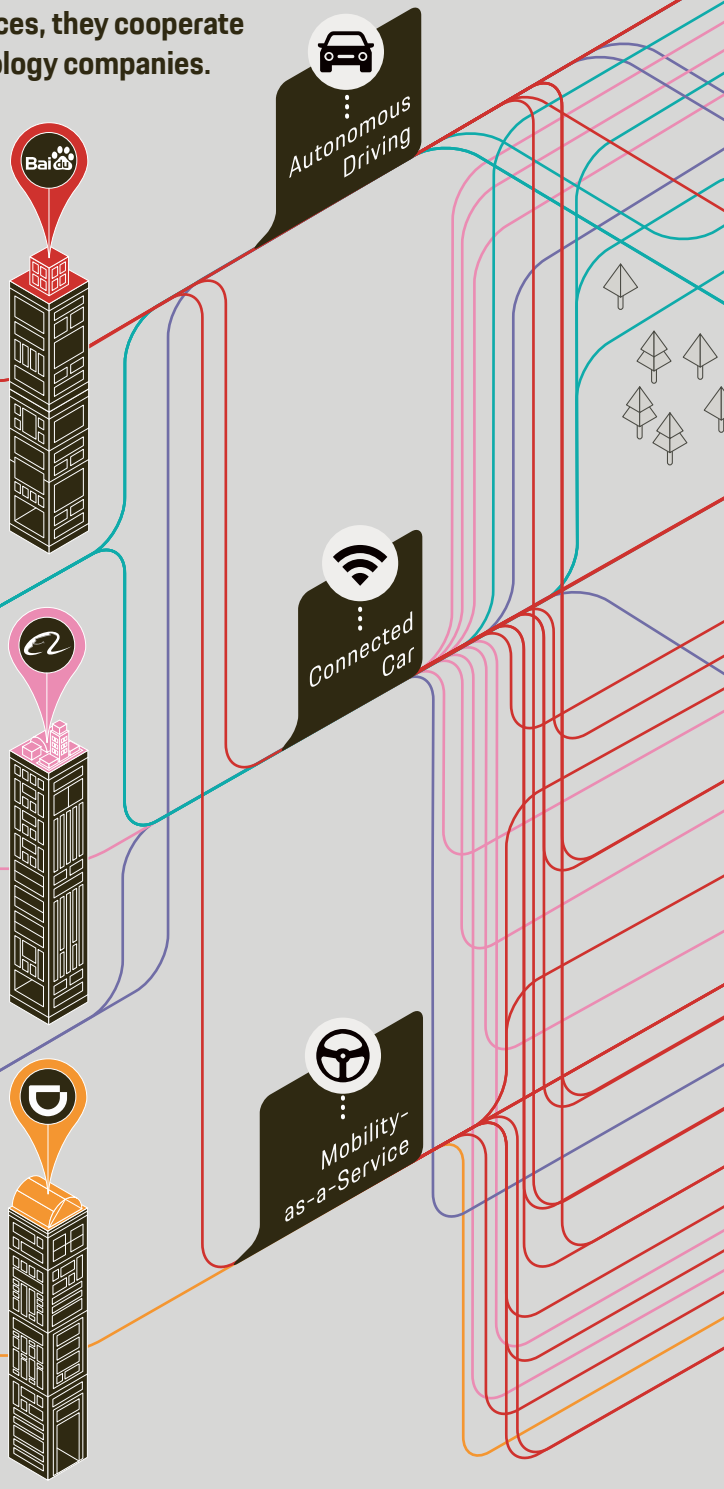
Alibaba operates the B2B platform Alibaba.com and the online auction house Taobao, among other ventures. Its YunOS operating system also runs in cars.

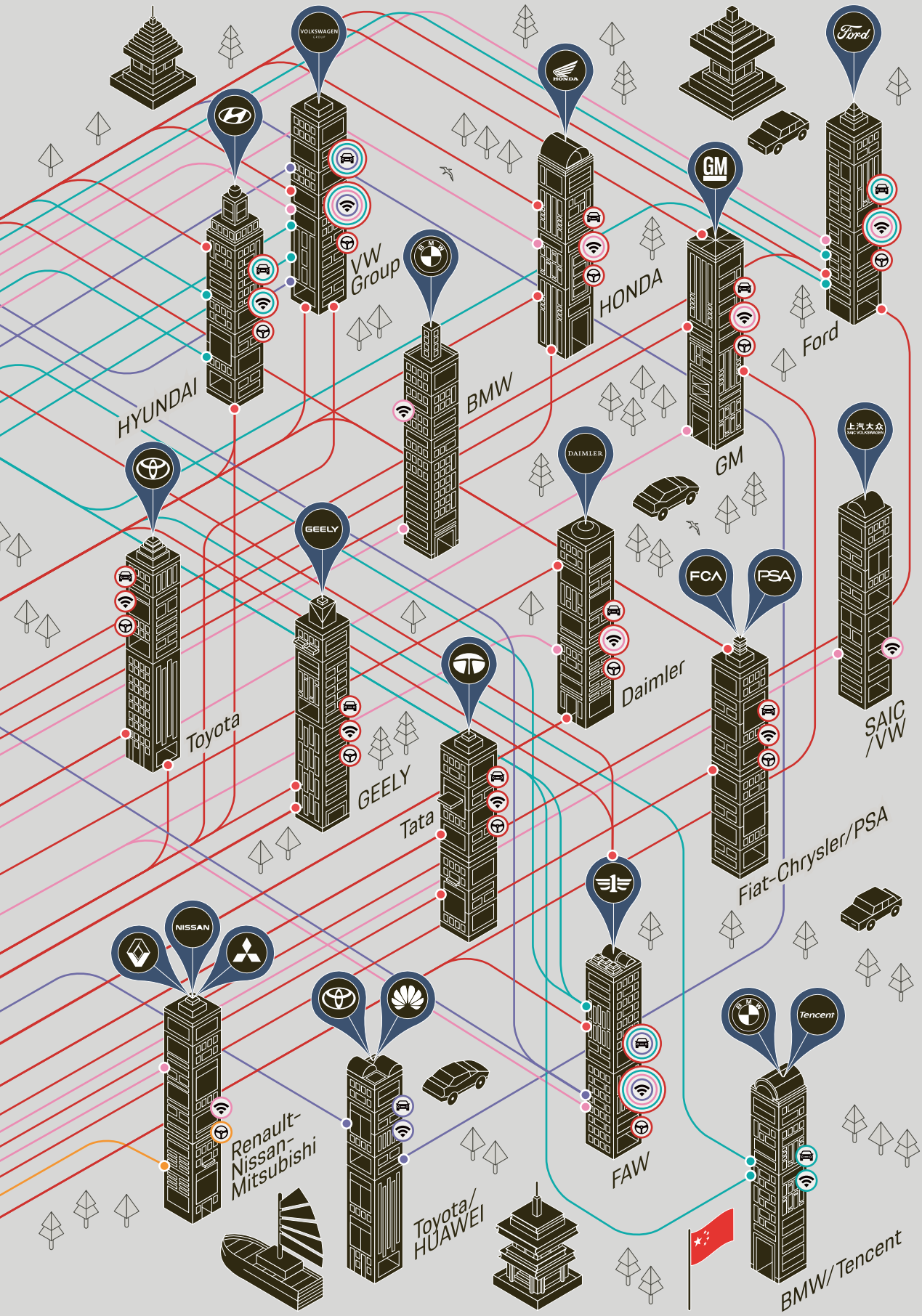
Huawei

The smartphone manufacturer Huawei offers, among other things, HiCar, a proprietary interface for using the phone in a car.

DiDi Auto Alliance

Didi Chuxing ("DiDi") mediates mobility services in a similar manner to its competitor Uber. It arranges for around eight billion trips a year.





Data-driven strategies
Leaders of the automotive industry see many ways to create new value from data.

New experiences
Creating personalized points of contact with customers.

86%

New expertise
Opening up new opportunities with other industries.

84%

New focus
Formulating and testing new business models.

82%

New ways of working
Enabling a responsive organization.

76%

(Source: IBM)

Omnipresent energy stores: Nothing in future mobility will work without batteries—and efforts to develop them further will be accordingly intense.

The perfect cell

Text: Chris Löwer Contributor: Dr. Stefanie Edelberg

Modern vehicle batteries already enable long ranges and convenient charging times. Nevertheless, researchers are working on even better energy storage systems based on proven lithium-ion technology and using new approaches.

The testers from *Auto Bild* were impressed. In around 22 minutes, they were able to charge the almost empty battery of a Porsche Taycan to 80 percent. A record that is almost obligatory in this segment because sporty drivers are not the types to wait for a charge. “For Porsche in particular, high charging performance plays a major role,” says Dr. Stefanie Edelberg, Engineer at Porsche Engineering. “Sporty driving drains the battery faster, and the customer doesn't want to have to wait an hour to fully recharge it.”

Drivers no longer have to. “Battery technology for cars works well in practice, including in terms of performance, charging and service life,” says Dirk Uwe Sauer, Professor of Electrochemical Energy Conversion and Storage System Technology at RWTH Aachen University. “However, several extreme properties cannot be combined. You can't have everything at once.” Ultra-fast charging combined with a high energy density? That's not possible because the service life would suffer from this combination. Sauer is therefore skeptical about media reports about supposed miracle batteries, because usually a single parameter is optimized at the expense of others. “There will be no universal all-rounder battery,” he says.

500 Wh/l

is the energy density of modern lithium-ion battery cells.

Lithium-ion cells: high energy density

Energy storage systems for electric vehicles are getting better all the time, but lithium-ion cells will remain the technology of choice for the foreseeable future. This is because the high reactivity of lithium and the high energy density of the cells make it possible to store a relatively large amount of energy in a small space. They also boast good storability and robustness, which enables them to withstand around 2,000 charging cycles in an all-electric vehicle at a high depth of discharge before losing their utility. However, developers believe that they could last

"Especially for Porsche, high charging performance is key."

Dr. Stefanie Edelberg, Engineer

several times as long. Furthermore, lithium batteries do not have the memory effect that nickel-cadmium batteries suffer from. In the case of frequent partial discharges, they "remember" the typical energy requirement and adjust their capacity to it.

In addition, lithium-ion technology still offers a wealth of development opportunities in terms of cell chemistry and cell design. Energy density, for example, could benefit from this: according to researchers at the Fraunhofer Institute for Systems and Innovation Research (ISI), energy density has almost doubled over the past ten years in large-format lithium-ion battery cells for electric cars—to an average specific energy of 250 Wh/kg (or 500 Wh/l energy density). By 2030, energy density could increase by a factor of two.

Other properties of lithium-ion cells can also be further improved. "The biggest challenges are fast charging and safety," reports Prof. Dr. Stefano Passerini, Director of the Battery Electrochemistry Research Group at the Helmholtz Institute Ulm. "A quick charge to 80 percent in 15 minutes or less would make electric vehicles even more attractive. However, the safety requirements also rise in conjunction with rapid charging."

The capacity and performance of the battery diminish with each excessively fast charge

Rapid charging is a challenge because lithium atoms migrate into the carbon crystals of the electrode during charging. When discharging, they are retrieved from there. "The faster the battery is charged, the greater the risk that the charge carriers will stick to the surface of the crystals, forming a metallic layer and thus damaging the cell," explains Sauer. So capacity and power diminish with each rapid charge. In extreme cases a short circuit can occur. "Unfortunately, it is not easy to say what 'too fast' means exactly," says Sauer. "Intensive research into ways of detecting this in the laboratory, and above all in the vehicle itself, is under way in many places."

C=10

would mean that you can charge a battery in about six minutes. The best systems available today achieve C = 4.

Other technological hurdles also await the developers: The charging plugs, charging cables, and the vehicle infrastructure must also be designed for the high currents. The motto here is "amperes are heavy." In other words: high currents mean thick cables and therefore weight. However, this can be compensated through a higher-voltage battery system. That's why the Porsche Taycan was equipped with a high-voltage battery system of 800 volts instead of the 400 volts common in electric cars.

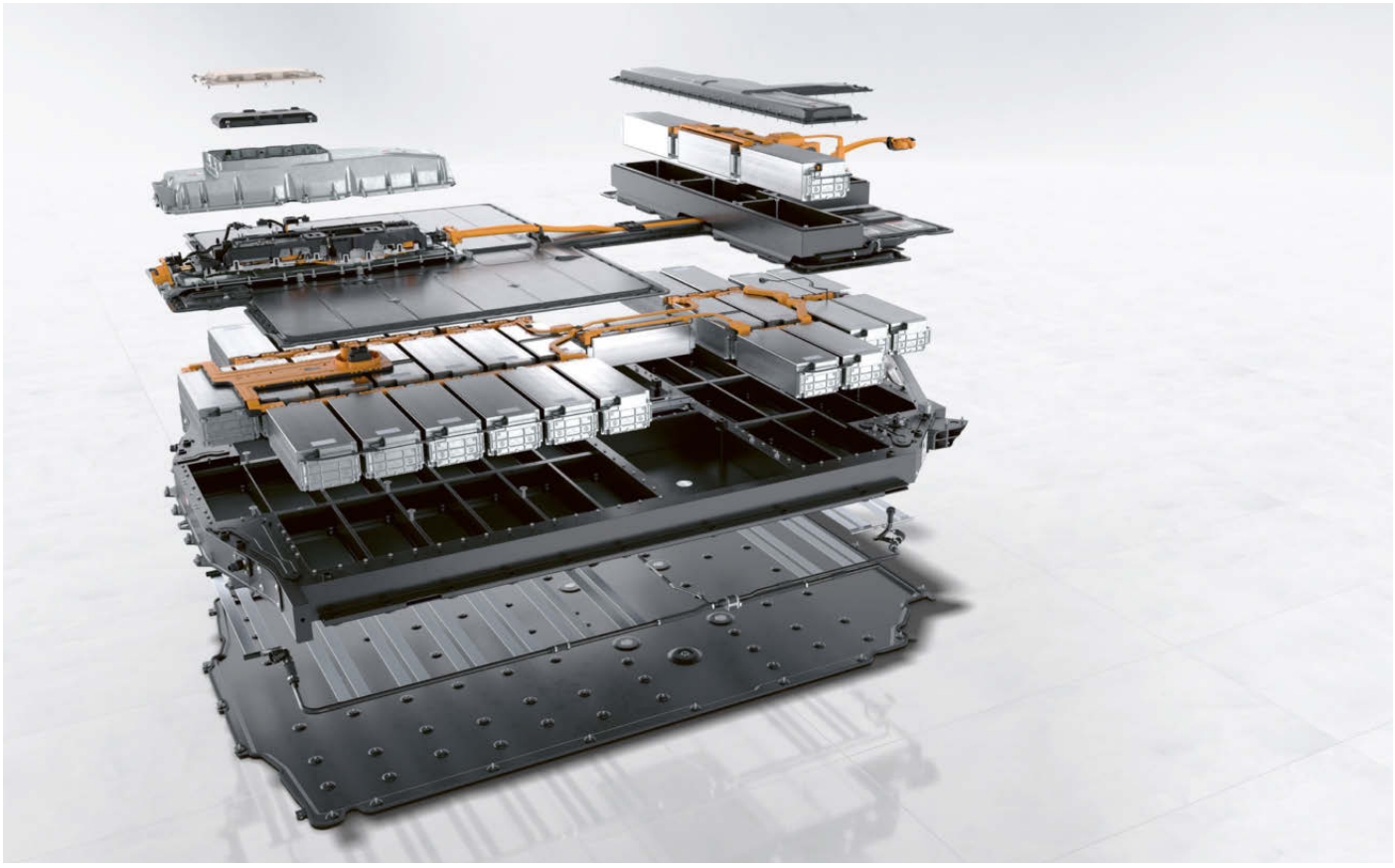
In order to compare the charging times of electric vehicles with different battery capacities, the C-rate (C stands for "capacity") is a useful metric. It indicates the ratio of the charge or discharge current of an electrochemical cell in amperes (A) to the capacity of the cell in ampere-hours (Ah). A value of 1 means that complete recharging takes one hour. 2 stands for half an hour, 3 for 20 minutes.

The developers are aiming for a C rate of 10, which means about six minutes of charging time—similar to refueling. We are still a long way from that today. But in the FastCharge research project, Siemens,

Dr. Stefanie Edelberg works as an engineer at Porsche Engineering in the Electric and Hybrid Vehicle Concepts and Package department. The team deals with the design, packaging, and development of HV batteries.

Prof. Dirk Uwe Sauer is Professor of Electrochemical Energy Conversion and Storage System Technology at RWTH Aachen University. Together with Prof. Martin Winter, he has been the scientific director of the Power Plant Battery conference since 2009.

Prof. Dr. Stefano Passerini is Director of the Battery Electrochemistry Research Group at the Helmholtz Institute Ulm (HIU). His team studies batteries as well as the sustainable use of resources, the environment, and the economy.

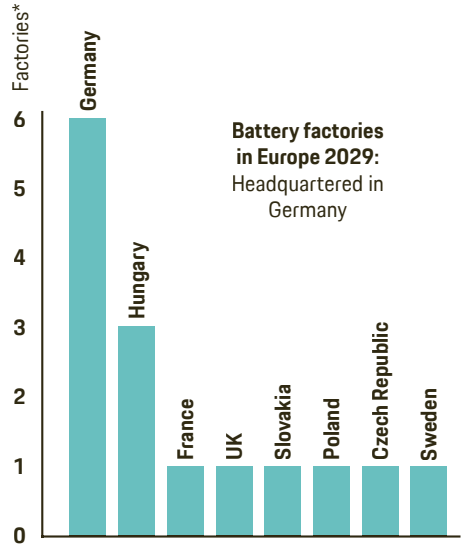


Power pack: Modern lithium-ion batteries could store up to 1,000 Wh/l by 2030.

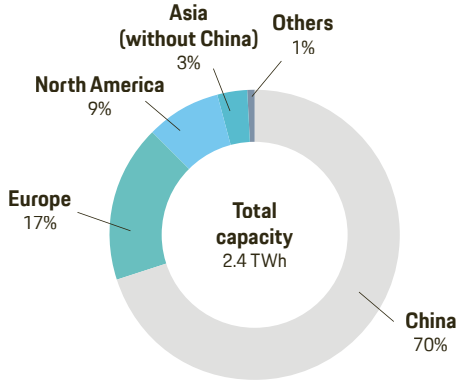
Production capacities of lithium-ion batteries

Although China will continue to have the largest production capacities for lithium-ion batteries by some distance, Europe, and Germany in particular, are catching up. By the end of the decade, factories with an annual capacity of 413.5 GWh and 173 GWh, respectively, are slated to be in place.

According to a study by the Fraunhofer Institute for Systems and Innovation Research, over 7.5 million electric vehicles were on the roads worldwide by early 2020. Their share of global car sales is projected to be between 25 and 75 percent in 2030, depending on the market study. As a result, global demand for lithium-ion batteries is expected to rise sharply: from 500 GWh to 1,500 GWh in 2025 to 1,000 GWh to 6,000 GWh in 2030. According to the Fraunhofer researcher, this demand can probably be met—primarily by suppliers from Asia, who currently have an 80 percent share of the market. But other regions of the world also plan to invest massively in new battery factories by the end of the decade.



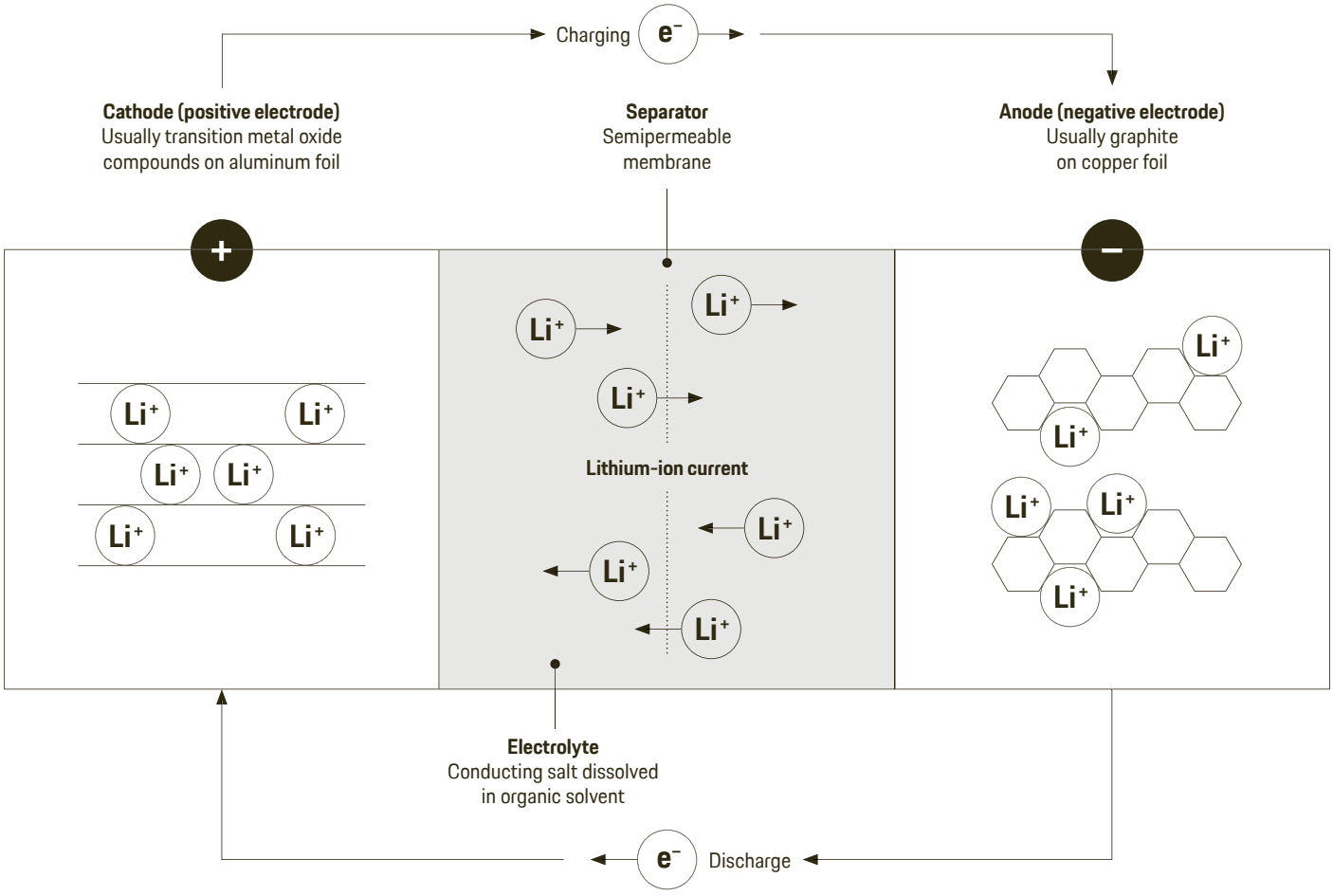
Battery factories in Europe 2029: Headquartered in Germany



Worldwide production capacity 2029: China stays ahead, Europe catches up.

*Factories with more than 5 GWh production capacity per year Source: Benchmark Mineral Intelligence

Charging and discharging a lithium-ion battery



In **lithium-ion batteries**, the negative electrode (usually made of graphite) and the positive electrode (usually made of transition metal layer oxides) are divided by a separator. Positively charged lithium ions can freely pass through it in both directions. When discharging, electrons flow from the **anode** via the outer circuit to the **cathode,** while simultaneously positively charged lithium ions also go through the separator and migrate into the cathode structure. During charging, an external voltage drives the lithium ions back in the direction of the negative electrode. Lithium is particularly well suited for batteries because the lightest metal in the periodic table is very keen to give up one of its three electrons. At the same time, their high **reactivity** also results in lithium atoms easily forming chemical bonds. To prevent this, they must be protected from air and water inside the battery.

The theoretical specific capacity of lithium metal is

3,862

mAh/mg.

Li_1C_6

During the charging process, the active material graphite can be charged up to one lithium atom per six carbon atoms.

"We expect solid-state lithium-ion batteries to reduce safety problems because solid-state electrolytes are less susceptible to fire."

Prof. Dr. Stefano Passerini

Phoenix Contact E-Mobility, and Porsche, among others, are working on improving the energy supply system for electric vehicles. The industrial consortium has already made great progress. A Porsche research vehicle with a battery capacity of around 90 kWh achieved a charging capacity of 400 kW, enabling charging times of less than three minutes for the first 100 kilometers of range. A complete charging process from 10 to 80 percent at the ultra-fast charging station took 15 minutes. C rates of 4 to 5 are therefore feasible. "The decisive factor was an innovative cooling system for the battery, the vehicle and the charging system," Edelberg explains.

The solid state battery is expected to bring progress in terms of fast charging and safety. In this case, a polymer or ceramic is used instead of the liquid electrolyte. Since no liquid is used, the batteries become more compact, which allows their energy density to be increased significantly. At the same time, the cells are less flammable. "We expect solid-state lithium-ion batteries to reduce safety problems because solid-state electrolytes are less susceptible to fire," says Passerini. Theoretically, it could also be charged faster. "But the practical feasibility has yet to be proven," Passerini concludes.

Lightweight alternative: lithium sulfur

However, lithium will remain the basis—as well as with another variant, which is currently being intensively studied: lithium-sulfur batteries. In these cells, the cathode consists of a sulfur mesh that completely replaces the conventional grid structure of cobalt, manganese, and nickel. This makes the batteries significantly lighter than conventional energy storage devices. But at the moment they are also significantly more expensive, which is why they may be more suitable as an option for future air taxis. Their durability is still considered problematic.

Other technologies for increasing energy density that are currently being researched and could be launched now or in the years to come include electrode materials made of silicon-carbon composites, nickel-rich cathode materials, or high-voltage materials that enable cell voltages of around five volts. "Research in these areas is already closer to practical application," says Sauer. Many other approaches, he noted however, were still in the field of basic research, such as sodium ions instead of lithium ions or metal-oxygen combinations.

400 kW

of charging capacity was reached by a Porsche research vehicle. A complete charge was completed in just 15 minutes.

5 volts

of cell voltage is achieved by high-voltage materials, on which practical research is under way.

107 euros

was the price of lithium-ion batteries per kWh of storage capacity in 2019.

Sauer sees one decisive question for all development avenues: costs. "In the end, the range of a vehicle is not limited by the weight of a battery, but by its price." According to the consultants at Horváth & Partners, the price of lithium-ion batteries per kWh has fallen from 400 euros in 2013 to 107 euros in 2019, but the price decline will not continue at this pace due to increasing demand. This is mainly due to the raw materials: "Raw materials account for up to 75 percent of the cost of a battery," says Sauer.

One thing is clear: in the next decade, lithium-ion batteries, with all their further enhancements, will remain the dominant technology. "Progress will be evolutionary, not revolutionary," says Sauer. "I do not expect any great leaps forward as the limits of the laws of nature are already being probed as we speak." Which isn't necessarily a bad thing: "The characteristics of this technology are too good to be replaced by anything else. Electromobility is already working very well with what batteries can deliver today and the potential for further development in the coming years," emphasizes Sauer.

IN BRIEF

Today, lithium-ion batteries already offer long ranges and short charging times for electrically powered vehicles. But development still continues apace. New technologies such as solid state batteries and new electrode materials could further increase energy density in the future and further reduce charging times.

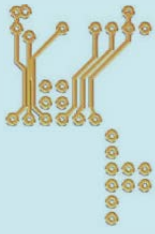
The religion of data

Lateral thinking is the origin of Porsche Engineering. Without an unconventional idea there are no innovations—and no responsible use of new technologies. That's why we like to think outside the box and regularly draw inspiration from other sources. For example from Yuval Noah Harari. The Israeli historian and bestselling author is one of most sought-after thinkers of the present moment. His book *Homo Deus* examines the question of the future of humanity. The following excerpt is about the new "data religion," in which animals, people, and societies are regarded as nothing more than different forms of data processing.

GUEST AUTHOR

Yuval Noah Harari is a bestselling author from Israel and one of the most famous historians in the world. The excerpt comes from his book *Homo Deus* (HarperCollins Publishers). Other works by Harari include: *21 Lessons for the 21st Century* and *Princes in the Cross-Hairs*.

Dataism says that the universe consists of data flows, and the value of any phenomenon or entity is determined by its contribution to data processing. This may strike you as some eccentric fringe notion, but in fact it has already conquered most of the scientific establishment. Dataism was born from the explosive confluence of two scientific tidal waves. In the 150 years since Charles Darwin published *On the Origin of Species*, the life sciences have come to see organisms as biochemical algorithms. Simultaneously, in the eight decades since Alan Turing formulated the idea of a Turing Machine, computer scientists have learned to engineer increasingly sophisticated electronic algorithms. Dataism puts the two together, pointing out that exactly the same mathematical laws apply to both biochemical and electronic algorithms. Dataism thereby collapses the barrier between animals and machines, and expects electronic algorithms to eventually decipher and outperform biochemical algorithms.



For politicians, business people and ordinary consumers, Dataism offers groundbreaking technologies and immense new powers. For scholars and intellectuals it also promises to provide the scientific holy grail that has eluded us for centuries: a single overarching theory that unifies all the scientific disciplines from literature and musicology to economics and biology. According to Dataism, *King Lear* and the flu virus are just two patterns of dataflow that can be analysed using the same basic concepts and tools. This idea is extremely attractive. It gives all scientists a common language, builds bridges over academic rifts and easily exports insights across disciplinary borders. Musicologists, political scientists and cell biologists can finally understand each other.

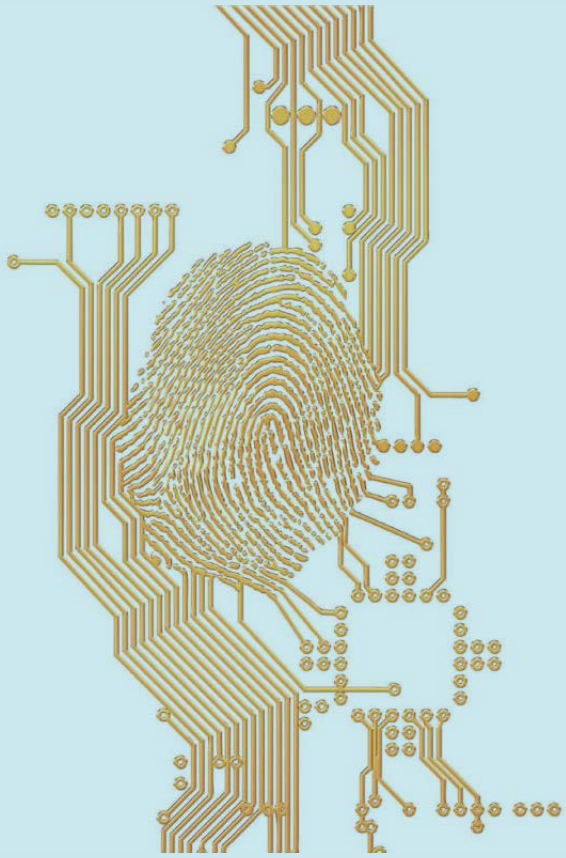
In the process, Dataism inverts the traditional pyramid of learning. Hitherto, data was seen as only the first step in a long chain of intellectual activity. Humans were supposed to distil data into information, information

into knowledge, and knowledge into wisdom. However, Dataists believe that humans can no longer cope with the immense flows of data, hence they cannot distil data into information, let alone into knowledge or wisdom. The work of processing data should therefore be entrusted to electronic algorithms, whose capacity far exceeds that of the human brain. In practice, this means that Dataists are sceptical about human knowledge and wisdom, and prefer to put their trust in Big Data and computer algorithms.

Dataism is most firmly entrenched in its two mother disciplines: computer science and biology. Of the two, biology is the more important. It was the biological embracement of Dataism that turned a limited breakthrough in computer science into a world-shattering cataclysm that may completely transform the very nature of life. You may not agree with the idea that organisms are algorithms, and that giraffes, tomatoes and human beings are just different methods for processing data. But you should know that this is current scientific dogma, and that it is changing our world beyond recognition.

Not only individual organisms are seen today as data processing systems, but also entire societies such as beehives, bacteria colonies, forests and human cities. Economists increasingly interpret the economy, too, as a data-processing system. Laypeople believe that the economy consists of peasants growing wheat, workers manufacturing clothes, and customers buying bread and underpants. Yet experts see the economy as a mechanism for gathering data about desires and abilities, and turning this data into decisions. [...]

Sapiens evolved in the African savannah tens of thousands of years ago, and their algorithms are just not built to handle twenty-first-century data flows. We might try to upgrade the human data-processing system, but this may not be enough. The Internet-of-All-Things may soon create such huge and rapid data flows that even upgraded human algorithms cannot handle it. When the car replaced the horse-drawn carriage, we didn't upgrade the horses – we retired them. Perhaps it is time to do the same with *Homo sapiens*.



Dataism adopts a strictly functional approach to humanity, appraising the value of human experiences according to their function in data-processing mechanisms. If we develop an algorithm that fulfills the same function better, human experiences will lose their value. Thus if we can replace not just taxi drivers and doctors but also lawyers, poets and musicians with superior computer programs, why should we care if these programs have no consciousness and no subjective experiences? If some humanist starts adulating the sacredness of human experience, Dataists would dismiss such sentimental humbug. "The experience you praise is just an outdated biochemical algorithm. In the African savannah 70,000 years ago, that algorithm was state-of-the-art. Even in the twentieth century it was vital for the army and for the economy. But soon we will have much better algorithms." [...]

"Dataism points out that exactly the same mathematical laws apply to both biochemical and electronic algorithms."

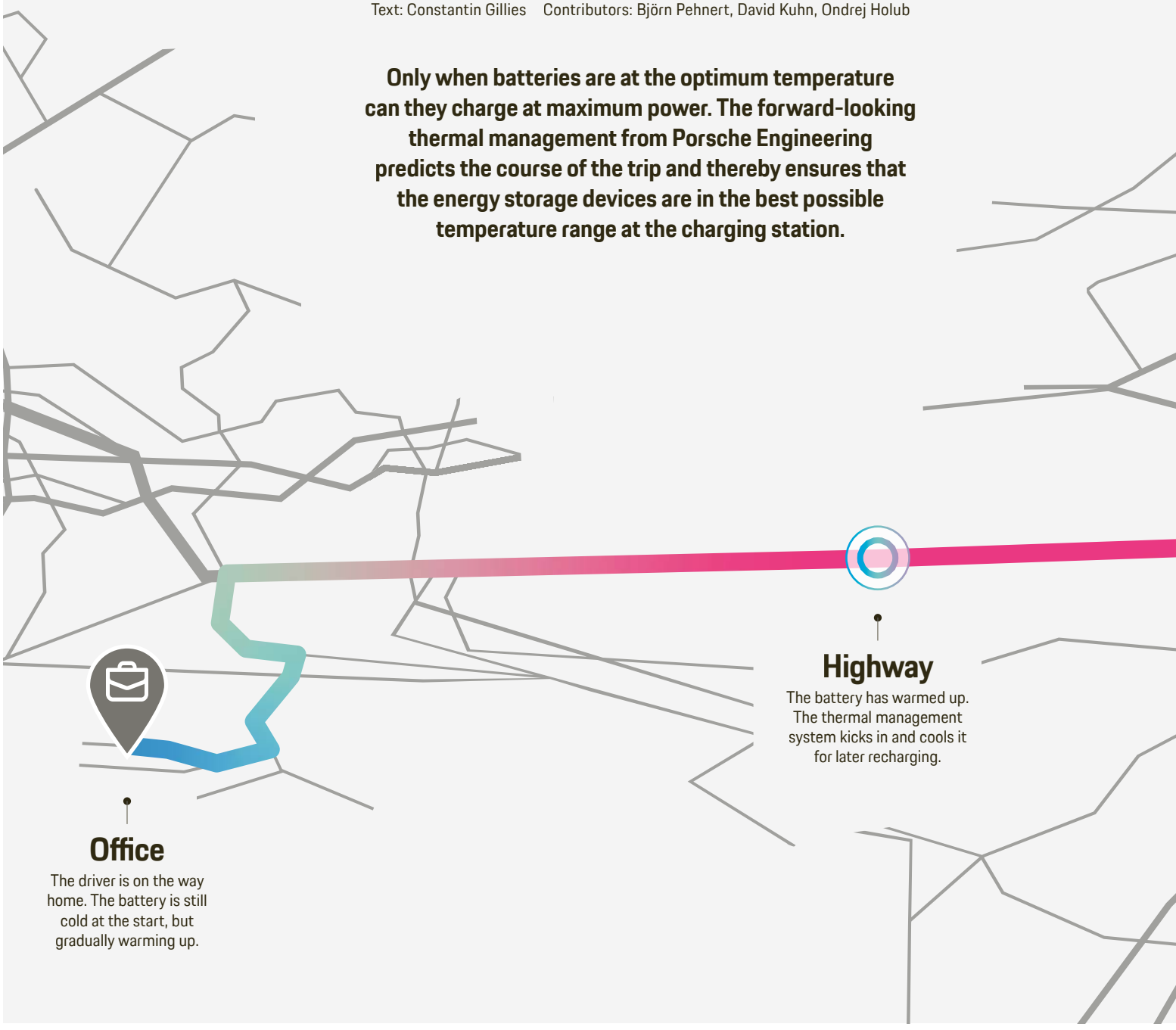
The Dataist revolution will probably take a few decades, if not a century or two. But then the humanist revolution too did not happen overnight. [...]

Excerpts from Ch. 11: "The Data Religion" from Homo Deus by Yuval Noah Harari. Copyright (c) 2017 by Yuval Noah Harari. Used by permission of HarperCollins Publishers.

Algorithm with foresight

Text: Constantin Gillies Contributors: Björn Pehnert, David Kuhn, Ondrej Holub

Only when batteries are at the optimum temperature can they charge at maximum power. The forward-looking thermal management from Porsche Engineering predicts the course of the trip and thereby ensures that the energy storage devices are in the best possible temperature range at the charging station.



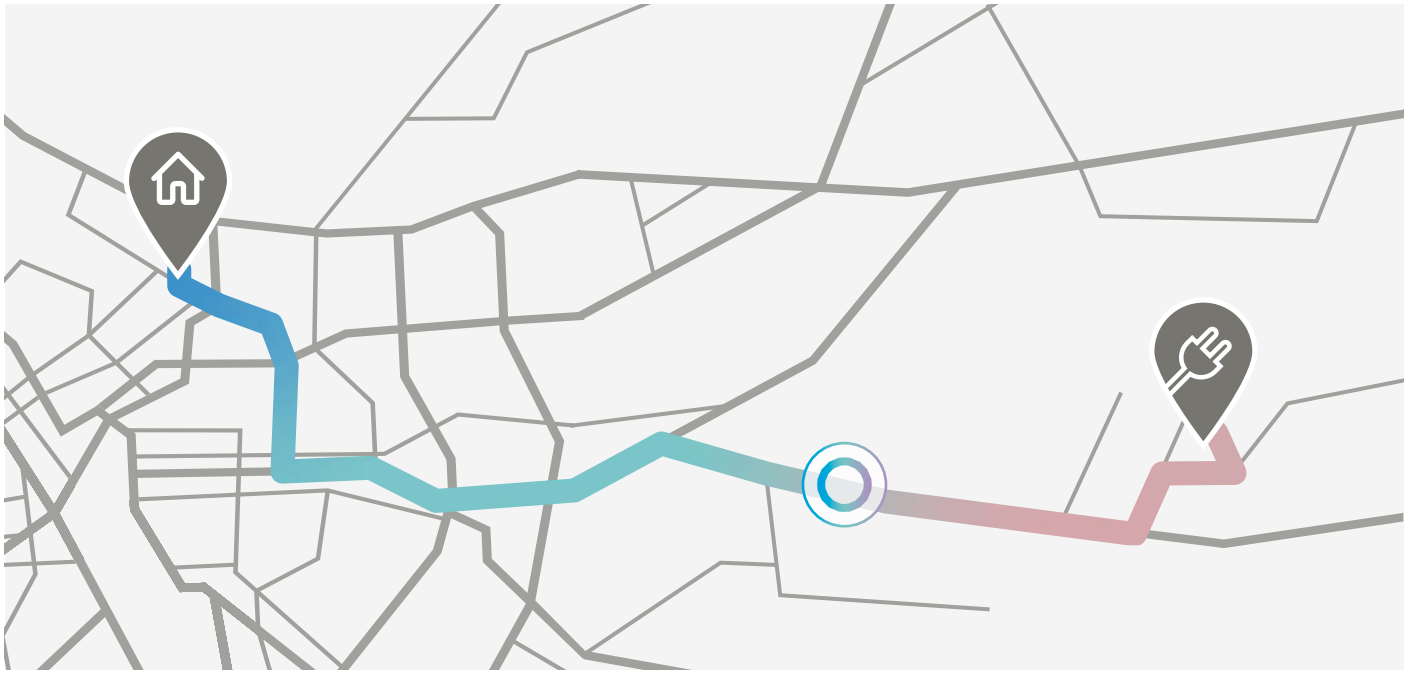
Office

The driver is on the way home. The battery is still cold at the start, but gradually warming up.

Highway

The battery has warmed up. The thermal management system kicks in and cools it for later recharging.


Apartment
The driver arrives at home with a freshly charged battery. It has warmed up a little during the trip.
Charging point
Just in time for arrival at the charging point, the thermal management system has brought the battery to the optimum temperature.



Warming up the energy storage unit: The battery is very cold when starting. By the time it reaches the charging point, the thermal management system has heated it up to the optimal temperature range.

Shorter battery charging times and longer ranges: this is the promise of the predictive thermal management system developed by Porsche Engineering last year as a concept study. The technology ensures that batteries are at the optimal temperature for stopping at the charging station and that fast charging takes only a few minutes. Temperature plays a key role in this: if the cells are too cold or too hot, charging performance drops. Thanks to predictive thermal management, however, this phenomenon could soon be a thing of the past: Software in the car will predict the upcoming course of the trip and control all thermal components so that the battery is at the optimum temperature. This look into the future also prevents unnecessary heating or cooling, which saves energy and increases the range.

This prediction distinguishes the new system from conventional thermal management as it is currently implemented in vehicles. In the simplest form currently on the market, it is a control loop that always keeps the engine temperature within a safe corridor. However, this usually works purely reactively: if the drive unit gets too hot, for example, the air flaps open to lower the temperature. In the case of combustion engines, this ad hoc control works quite well, as an engine block can be cooled down in a few minutes. However, the batteries in electric vehicles, which weigh up to 700 kilograms, have much greater thermal inertia. “With them, the temperature can only be regulated very slowly,” explains Björn Pehnert, Lead Engineer Thermal Management at Porsche Engineering.

In order to bring the large battery in electric vehicles to the right temperature for charging in good time, the vehicle control system must detect potential loads in advance. “It is becoming essential to look further into the future,” Pehnert summarizes. It was precisely this challenge to which the engineers applied themselves. They developed a predictive thermal management system that predicts the battery

“In order to get the battery to the right temperature for charging, the vehicle’s control system has to look further into the future than it does now.”

Björn Pehnert, Lead Engineer Thermal Management

temperatures for the upcoming trip. For example, if the forecasting program notices that the driver is driving towards a fast charging station, the system activates the cooling or heating systems on board with the necessary advance time, so that the battery has the perfect temperature for a fast charging process on arrival. Until recently, powerful mainframe computers were still needed for such complex calculations in real time. Thanks to clever optimization, however, the software runs on a normal control unit.

Simulation of the entire vehicle

In order for the vehicle control system to decide when to intervene for cooling or heating, it must first know how the various components interact. If the cells are cooled, for example, power consumption increases, which in turn decreases the range. A simulation of the entire vehicle therefore forms the basis of thermal management: everything—from the battery and drive unit to the cooling system and air conditioning system—is reproduced in the simulation using models. This digital twin behaves exactly like a real vehicle.

700 kilograms

is how much a battery in the vehicle can weigh. The energy storage units are thermally inert and can only be temperature-controlled slowly.

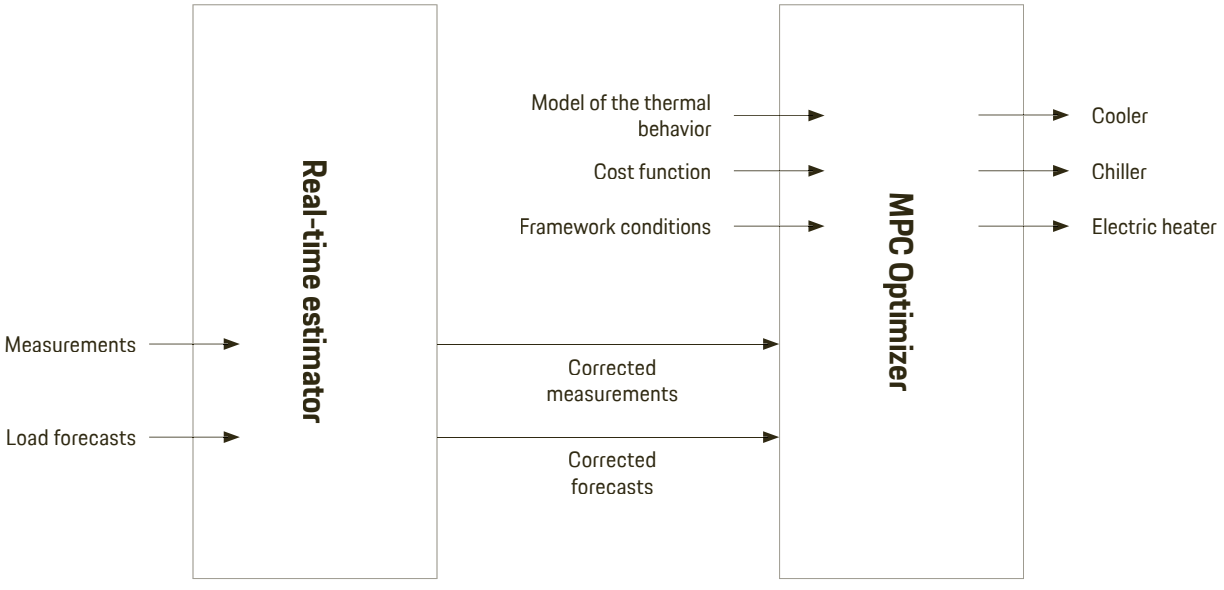
For example, if the heating is turned on, the simulation shows exactly how this will affect the battery's charge state.

However, the car reproduced by the computer only provides a target state. In reality, many other factors, which are often not directly measurable, influence the behavior of a vehicle: driving style, payload, road surface, even dirt on the bodywork, or the color of the paint (in black models, the interior heats up more). For this reason, a special software module (real-time estimator, RTE) ensures that these thermal influences are also taken into account. It compares the actual behavior of the vehicle with the simulation and thus gradually adapts the model to reality.

To be able to look into the future, the vehicle must, of course, know where the trip will take it. But hardly anyone enters every destination into the navigation device. Therefore, the driver can simply allow the car to "learn" the trips. It then tracks the routes via GPS and identifies frequently traveled routes by itself. Based on this experience, the system is later able to

Looking to the future

The real-time estimator (RTE) predicts the thermal load that the vehicle will generate in the future (for example, in 40 minutes). To do this, it combines the current state of the vehicle, externally supplied load predictions, and a model of the vehicle's behavior. The MPC Optimizer (model predictive control) controls the heating and cooling system, taking into account not only RTE calculations but also comfort and efficiency requirements (expressed by the cost function and constraints).



recognize the trip ahead shortly after starting and internally generate a map of the coming route. For example “five kilometers of urban traffic followed by 20 kilometers of highway at 120 km/h.”

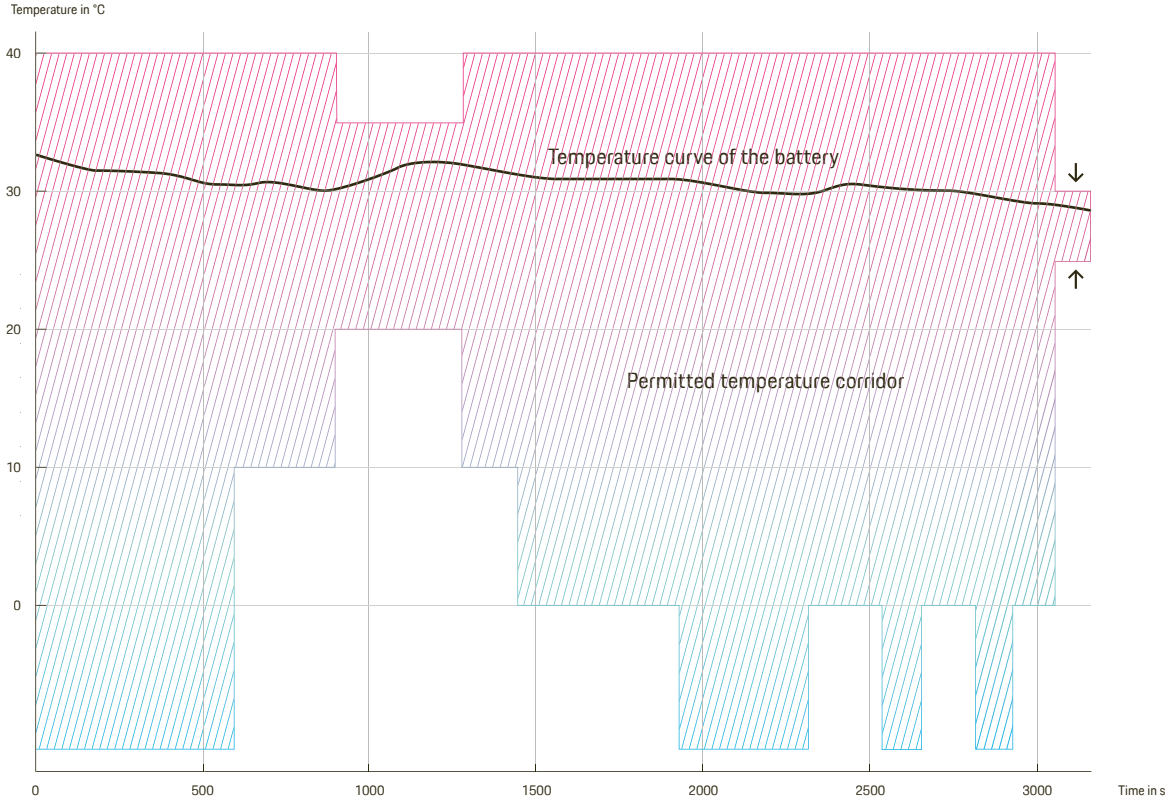
The core of the predictive thermal management is the optimizer. It takes the data from the simulated vehicle plus the route information and uses it to calculate the car’s optimal thermal response. When does the heat pump have to be activated to preheat the battery? When is it advisable to bring it down to a lower temperature with the help of the cooler or air conditioning?

What is referred to as the cost function determines which goal is being pursued. In the default configuration, the algorithm tries to minimize both charging time and energy consumption. Theoretically, however, priority could also be given to performance: in this case, the thermal management system would preheat the battery before reaching a highway access point so that the vehicle can accelerate more quickly. The special capability of the optimizer is that it recalculates its forecast every few seconds and adapts it to reality. For example, if the driver takes off their jacket and turns down the heating, the algorithm would notice this and take the effects into account in its next forecast.

This constant look into the future has several advantages: if an electric car is mainly used for short trips within the city, for example, the control unit learns this pattern and can raise the battery temperature beyond the normal corridor—but still within the safe range. This is because it knows that the journey will soon be over anyway and that the vehicle will

Precisely in the optimal temperature range

The black curve shows how the battery temperature changes over time. On arrival at the charging station, it is precisely in the optimal range between 25 and 30 °C thanks to predictive thermal management. So the battery can be recharged at maximum power in just a few minutes.



Always in the corridor: Even while driving, the battery must be within a certain temperature range. It depends primarily on whether the vehicle is traveling on the highway, on country roads, or in the city.

"We have brought together the best of the academic and automotive worlds."

Prof. Michal Kvasnica,
Czech Technical University in Prague

then cool down by itself when parked. In this way, no energy would be wasted on superfluous cooling. Predictive thermal management can therefore not only shorten charging, but also improve the vehicle's range. "10 to 30 percent energy savings are theoretically possible," says Ondrej Holub, who leads software development at Porsche Engineering Prague.

Compute-intensive method for the control unit

Mathematically, the temperature control system is a model-based predictive system (model predictive control, MPC). It is used wherever multiple factors affect a system and future events must be taken into account. The oil industry uses MPC to control refineries, for example. However, the method also has a disadvantage: it's very compute-intensive. "Traditionally, such optimizations run on extremely powerful computers," explains Professor Michal Kvasnica from the Czech Technical University in Prague, who, together with his team, developed the core of the prediction code.

The greatest challenge for the mathematicians was to modify the highly complex optimization program in such a way that the control unit of a normal car could handle the calculations. This required some tricks, because there is usually less computing power available there than in a smartphone. For this reason, the program works with look-up tables, for example, which contain discrete values, such as the relationship between temperature and battery resistance. This saves computing time. "We also had to create a robust system that never fails," adds Professor Kvasnica. "Making a completely new forecast every few seconds means several hundred thousand forecasts during average driving conditions per year—and each one has to be right."

The development of the forecasting software represented step one. The second step was to make the new technology tangible and implement it in a prototype. "We had to find a solution that would work with existing control units, without any further support from a supplier," says David Kuhn, Complete Vehicle Thermal Management Development at Porsche Engineering. The code was first adapted to the complete vehicle architecture, then tested and calibrated in a Porsche Taycan demonstrator vehicle. The developers selected realistic trips, for example through the city, over country roads, or on the highway, including traffic jams. It would be pointless to try out such a system on a test track as there are few unforeseeable events that would have to be taken into account in a forecast. After six months the implementation was complete. Does the driver sense the software intervention? "No, and that's exactly the goal," says Kuhn. "It's about meeting the customer's expectations at all times."

The project has now been completed. The concept study has shown that predictive thermal management has a high potential for series development and can be installed in a customer vehicle in the future. Although "installed" is actually the wrong word. After all, this is a typical innovation of the 21st century, and therefore consists only of code, not hardware—an algorithm alone is the advancement here, resulting in up to 30 percent less energy consumption. The conclusion of mathematician Kvasnica: "We have brought together the best of the academic and automotive worlds."

Predictive optimization enables

10 to 30%

energy savings on thermal management.

IN BRIEF

What was previously only possible on mainframe computers can now be implemented with a control unit: A software that looks into the future while driving and brings the battery in an electric-vehicle to the optimum temperature in time for charging at the charging station. Test drives have shown that the solution has great potential for series development.

Continuous health check

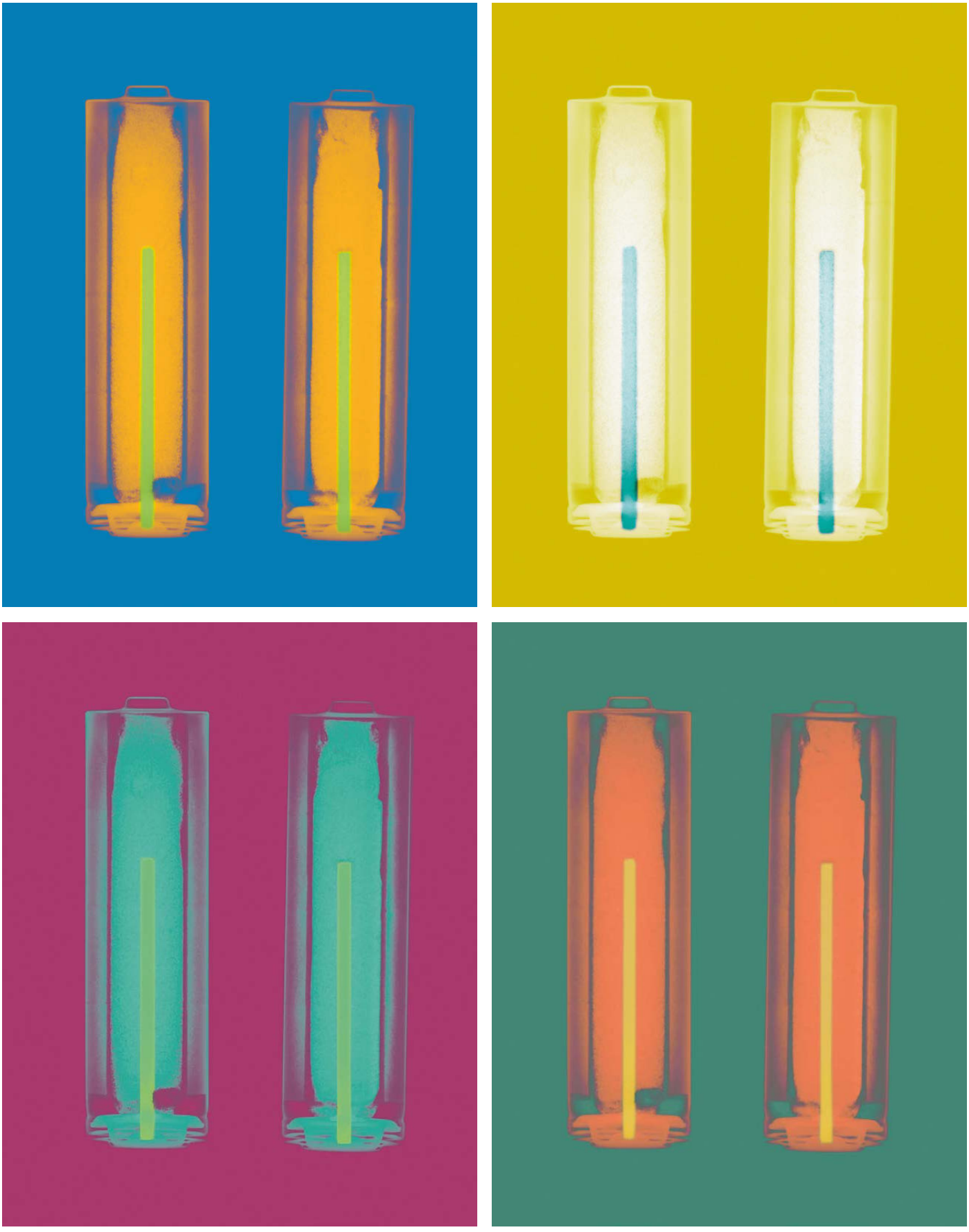
Text: Christian Buck, Contributors: Jiří Valtr, Dr. Joachim Schaper

Porsche Engineering has developed a new method of modeling the current internal resistance of vehicle batteries. The AI-based approach benefits drivers and OEMs in equal measure.

Due to their high energy and power density, lithium-ion batteries are currently the preferred energy storage technology for electric vehicles. However, their properties change in the course of a vehicle's life: aging reduces the storage capacity and the maximum retrievable performance. These effects are also familiar from other applications, such as smartphones or notebooks. They are the result of the chemical processes in the batteries and cannot be entirely avoided (see the box on battery aging processes on page 51).

For drivers of electric vehicles, the current state of the battery is important information. "With that information, the remaining range at a certain state of charge can be estimated very precisely," explains Dr. Joachim Schaper, AI expert at Porsche Engineering. "Vehicle manufacturers can also derive important information from the aging of the batteries, for example the maximum power that can be called up or technical issues that require a visit to the workshop." The objective is to find a method that provides the most reliable information possible about the condition of a battery.

The most important indicator of this is its internal resistance. Due to the irreversible changes within the energy storage system, it rises continuously during the battery's lifetime, so the current value is a good indicator of the battery's "state of health." However, it cannot be determined directly and must be calculated



A look inside: X-rays show what's inside batteries. AI finds out how the energy stores are doing.

from different measured values. For this purpose, the batteries are outfitted with sensors that regularly determine the current intensity, the voltage of individual battery cells, and the temperature of cell groups at short intervals.

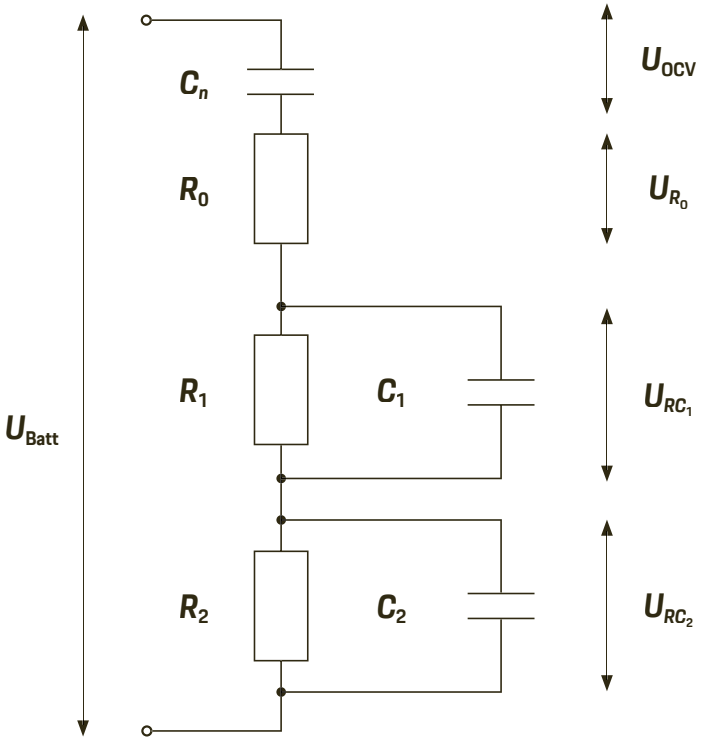
Their measured values are used to calculate the current state of the battery with the help of an equivalent electrical circuit. The behavior of the energy storage system is modeled by the internal resistance and battery capacity as well as two combinations of resistors and capacitors (RC elements). "While driving, the power consumption changes again and again, for example when the driver steps on the accelerator pedal. This leads to jumps in the measured values of current and voltage. From these jumps we can calculate the internal resistance of the battery," explains Jiří Valtr of Porsche Engineering Prague. "The calculation is straightforward: the higher the voltage jumps due to a given current jump, the higher the internal resistance."

"We wanted to replace the conventional model with a more advanced approach to determining the internal resistance."

Jiří Valtr,
Porsche Engineering Prague

Battery equivalent circuit diagram

Real batteries can be modeled as a combination of an ideal voltage source with resistors *(R)* and capacitors *(C)*. This makes it possible to describe their behavior under static and dynamic loads—such as the voltage drop when the current increases.



C_n represents the capacity of the battery, R_0 its internal resistance. U_{Batt} is the voltage measured at the terminals, U_{OCV} indicates the voltage without load (open circuit voltage, OCV), and U_{R_0} the voltage drop at the internal resistance. U_{RC_1} and U_{RC_2} depend on the course of the current flow (with different time scales)

However, the conventional method does have some disadvantages: the values of the resistors and capacitors in the equivalent circuit diagram are not constants, but depend on the temperature and state of charge (SoC) of the battery. And even when all these influences are taken into account, the model still does not represent the actual state of the battery precisely enough. "One reason for this is nonlinearities at low temperatures. When these occur, the battery does not behave like a conventional electrical resistance," explains Valtr. "That's why we wanted to replace the conventional model with a more advanced approach to determining internal resistance." He's part of a team that has been developing battery management software at Porsche Engineering Prague since 2012. The experts were able to base their work on in-depth knowledge and years of experience in the development of series software used by the entire VW Group.

The developers are relying on artificial intelligence (AI) for this. First they measure the internal resistance of the battery under certain boundary conditions on the test bench. In addition, a correction factor is determined during real trips with machine learning, which makes the calculation of the internal resistance of the battery much more precise by taking into account external influences such as temperature and state of charge, among other things. The data used to calculate the correction factor comes from various sources. One of them is long-term test bench

Aging processes in batteries

When batteries age, two effects overlap: **calendar** and **cyclical** aging. Calendar aging does not depend on use and represents an inherent limit on the possible service life of the energy storage device—even without load. It depends primarily on the state of charge (SoC) and the storage temperature.

The higher the battery is charged, the faster its capacity decreases. **High temperatures** also accelerate calendar aging. An increase in temperature of 10 kelvins approximately doubles the rate of aging of its electrochemical components.

When operating batteries, the calendar aging process is additionally overlaid by the cyclic aging. The **depth of discharge** (DoD) plays an important role here. It indicates the ratio of used energy to the total battery energy. A DoD of 80 percent, for example, means that only 80 percent of the total energy is used. The higher the DoD, the faster the battery ages. The state of charge limits must also be considered. A DoD of 80 percent can be achieved by charging 20 percent SoC to 100 percent SoC.

But even a charge of 10 percent to 90 percent SoC results in a DoD of 80 percent. In general, a higher SoC leads to greater cyclic aging.

Current rates (C-rates) also have a major influence on cyclic aging. High C rates and thus high currents accelerate cyclic aging, although high charging currents accelerate cyclic aging much faster than high discharge currents.

During **rapid charging** at high currents, unwanted secondary chemical reactions can be set in motion in the battery cells: metallic lithium can deposit on the anode surface (lithium plating). The metallic lithium reacts with the electrolyte and forms new cover layers, which consumes further lithium ions. This means that fewer lithium ions are available for energy storage, which leads to an irreversible loss of capacity. In order to avoid such secondary reactions, special **fast charging profiles** are developed that are precisely adapted to the respective battery cell.

DoD

The depth of discharge indicates the ratio of used energy to the total battery energy.

10 kelvins

of increased temperature roughly doubles the calendar aging of the battery.

measurements of the internal resistance under different environmental conditions such as temperature, driving cycle and charging behavior. Further valuable input is provided by data from a fleet of test vehicles. “All this data also includes influences that we were previously unable to take into account,” says Valtr. "This includes the outside temperature, the number of charging and discharging cycles already carried out, and driving style, among other things."

More precise forecasts of the remaining range

The new method provides vehicle owners with more precise forecasts of the remaining range. The system learns more and more over time and can, for example, increasingly take the owner's personal driving style into account. It also enables a charging strategy that is adapted to the battery's state of health: if the battery is already showing clear signs of aging, it can be protected by charging it very gently. The new method is tailored to the limited computing capacity of control units in vehicles and a patent application has been filed.

AI

can also take into account influences such as temperature or driving style that have not yet been included in the calculation of the internal resistance.

Even more comprehensive information about the state of health of the battery can be obtained by evaluations in the cloud, because here the computing capacity is practically unlimited. Vehicle manufacturers can, for example, evaluate temperature curves in the batteries and use them to determine the condition of entire vehicle fleets. “From these analyses, the OEMs can identify new relationships,” says Schaper. “Among other things, the question of which factors determine the aging of a battery is interesting. One factor might be the customer's driving style, but it can also be due to problems with the charging software or the cell supplier.” The ultimate goal is to use the data analyses to further improve future electric vehicles.

The new approach to calculating the internal resistance of batteries is already well advanced. Developers can already create models for the aging process using machine learning from test bench data, data from test vehicles, and log files from customer vehicles. The cloud solution is currently in the works. Customers should benefit from the new range calculation function in about two years' time, which will then be gradually integrated into various vehicle models.

High-flier: Company founder Mate Rimac in front of an autoclave his company uses to manufacture composite fiber components.

Crazy about cars

As a kid, Mate Rimac caught horsepower craze. Today, he's head of Rimac Automobili, the only car manufacturer in his home country of Croatia.

Electrified

Text: Christian Buck Photos: Alexander Babic

Mate Rimac builds electrically powered supercars in Croatia. OEMs know him as a supplier of reliable, high-performance battery systems. Porsche, too, holds shares in Rimac Automobili and works on battery technology together with the company.

It was clear early on where his life would take him. "I've been a car nut for forever, from before I could even walk or talk," Mate Rimac remembers. "No idea where I get it from. It's nothing to do with my family, that's for sure." Wherever he caught horsepower craze, cars have been at the heart of almost everything throughout the thirty-two years since he was born. Mate Rimac managed to make his passion his profession: Since 2009, he's been head of Rimac Automobili, the only car manufacturer in his home country of Croatia. The company is based in Sveta Nedelja near the country's capital, Zagreb. Porsche joined as shareholder in 2018.

Rimac's specialty are electrically driven supercars, two of which we can see on display in the company's entry hall. They're both a Concept_One, the company's first model that saw only eight units produced. More than 1,200 hp, 1,600 Nm of torque, 0 to 100 km/h in 2.5 seconds. Top speed 355 km/h. At the 2018 Geneva Motor Show, Rimac Automobili presented the successor model, the C_Two. Its four electric motors—one for each wheel—treat the road to more than 1,900 hp and 2,300 Nm. On racing tires, it makes it from 0 to 100 km/h in under two seconds. Electronic fuel cutoff stops the speedometer needle at 412 km/h. The company plans to build 150 units of the electric sportscar. They'll come in at two million euros apiece.

The C_Two prototype models four and five are in the workshop, Rimac technicians tinkering away at their electronics. A black 198-kilogram carbon monocoque

lies ready for a third prototype in the corridor, only a couple steps away from the two large autoclaves. These cylindrical ovens are where the company produces all their composite fiber components at temperatures of up to 350 °C. A short way across the corridor, Rimac workers are piling CFC mats into molds layer-by-layer, lifting each of them by hand. Around 2,000 hours of work go into each car.

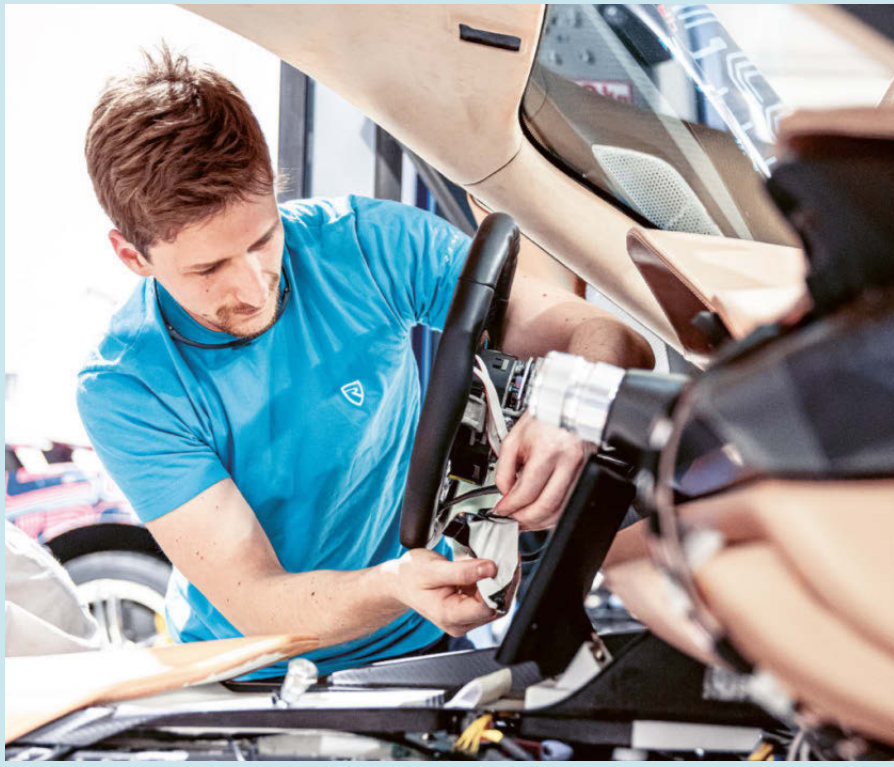
Building success with your own hands

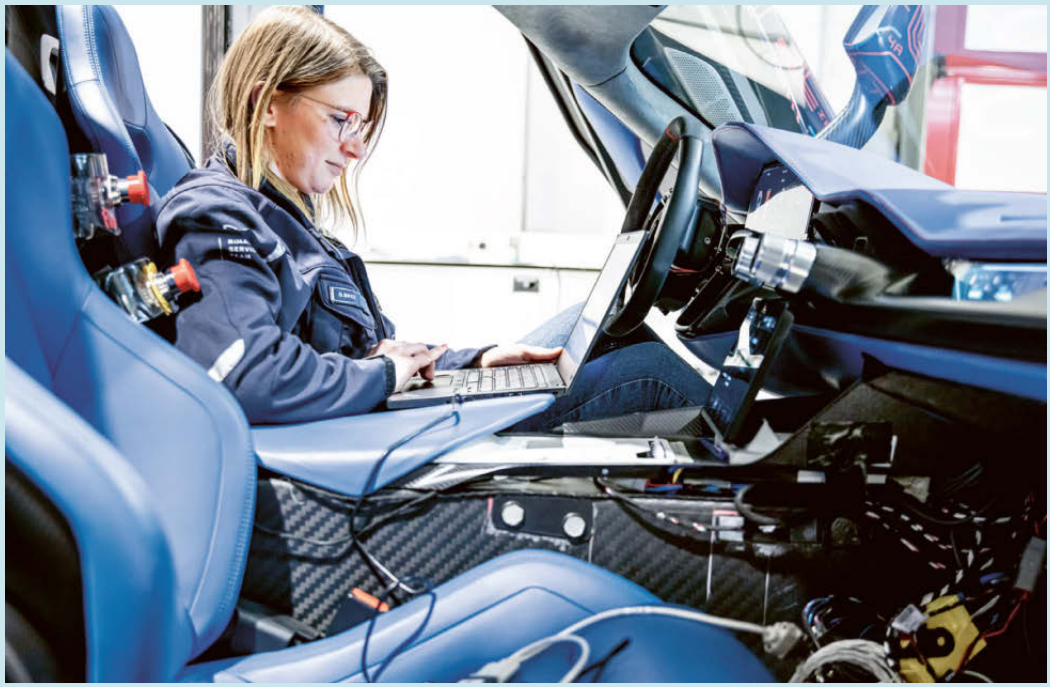
Rimac's story of success also begins with a whole lot of hands-on work. At the age of 18, our young horsepower fan bought himself a BMW 3-series. The car rolled out of the factory in 1984, making it four years older than Mate Rimac. The aging engine blew up on him in only his second drift race. This gave the passionate electronics tinkerer the idea to try out an electric powertrain. He presented at the races again with an electric motor taken from a forklift and some second-hand batteries, and was met with ridicule at first. "Can I charge my cell from your car?" was only one of the mocking questions asked back then.

But Rimac persevered and showed them all in the end. Though it took several conversions, his electric BMW eventually beat the fossil-fueled competitors, his vintage car even breaking all of five FIA acceleration records in 2011. Not surprisingly: thanks to technical improvements, the car was by now putting out 600 hp at 900 Nm of torque, making it from 0 to 100 km/h in 3.3 seconds. Its extreme performance—and because it was painted green—earned the BMW the nickname "Green Monster." We can't find it on a tour of the company grounds, however. "The BMW needs to be restored because a friend of mine drove it into a wall a couple years ago, wrecking it pretty badly," Rimac says.

Another pretty beat-up exhibit shown in a display case on the grounds is a battery system. It was stuck in a fire for two minutes as part of a test to prove that it would withstand even such extremes. This kind of reliable, high-performance electric energy store, along with the matching electronics, are Rimac Automobili's specialty. These, too, are designed and produced in-house, at a secluded site only a few kilometers away from the HQ in Sveta Nedelja. The site is well shielded from prying eyes. By design: Rimac produces components for customers here, too.

"We generate 80 percent of our turnover through component sales," Rimac tells us. "Our own cars make ideal promotion platforms and are a perfect test bed for us to go crazy with new tech." Becoming a supplier was necessity rather than choice. After its founding, the startup business faced financial collapse all the





Where electric supercars are born:
Rimac Automobili staff are currently testing the prototypes for the new model C_Two. Its carbon monocoque weighs only 198 kilograms. The company produces all components in-house, most of them painstakingly by hand. In the showroom, visitors get to see the racecars and high-end e-bikes by Rimac's sister brand Greyp.

"We know how to cram a lot of performance into a tight space."

Mate Rimac

Rimac Automobili has

650

staff.

Porsche AG holds

15.5%

of the shares in Rimac.

Successful businessman: Few only have managed to set up a new automobile manufacturer in recent decades. Mate Rimac is one of them—thanks to his experience as a component supplier. His own products, like the C_Two (below is a wind tunnel model), act as promotions platforms.

time. "They shut off our power and I didn't know how I was going to pay my people's wages," Rimac remembers. "I had to grow up early back then." Just before using up his last reserves in 2011, he drove to the International Motor Show Germany (IAA) to present his first car—and brought home his first work order as a supplier. A customer wanted to build an electric car and asked Rimac to help. "That was how I survived and how I managed to pay the six people I was employing back then, because it was instant sales." From there, the projects just kept rolling in, more and more of them, including entire powertrain systems and prototypes for suppliers and tech firms.

But for Mate Rimac, moving into component supply meant more than just escaping pressing financial difficulties. "Without gaining that customer experience we'd likely have taken it in the wrong direction, burned all our investors' money and wound up dead in the water. Instead, we built a team, built expertise, and made a name for ourselves as a reliable tech company." And so, Rimac pulled off what so many have failed to do: he founded a new automobile manufacturer, one that today employs around 650 people.

His expertise in electric drives attracted not only customers but also brought investors to Croatia. Among them Porsche, who continued investing after their initial buy-in in 2018, now holding 15.5 percent of shares. "We understood early on that Porsche and Rimac could learn a lot from each other," says Lutz Meschke, Deputy Chairman & Member of the Executive Board—Finance and IT at Porsche AG. "We believe in Mate Rimac and his company, that's why we've increased our share now. We're also expanding our collaboration in the field of battery technology."

Battery-powered electric drive systems are the future, of that Mate Rimac is sure: "Fuel cells can't cut it; producing hydrogen requires far too much energy. They'll offer benefits in some niche applications, perhaps, maybe for buses or trucks." The new drive technology does not pose a threat to established OEMs and suppliers, he believes: "Used to be you installed combustion engines in cars. In future, you'll be installing electric motors. There's not much difference, essentially."

Changes in consumer behavior will impact the industry far more severely. "Young people today don't see cars as a mark of status anymore. To them, it's a means to an end. And why should they spend months learning how to drive if self-driving vehicles will soon be a far safer and more efficient option? Today, accidents still kill more than a million people worldwide and cause massive economic damage—because, among other things, humans only feature 'two poor cameras.' Self-driving cars have better cameras and, on top of that, also have radar and lidar sensors. This will make computers the better drivers."

In tomorrow's mobility, personal cars are a collector's piece

That's why Rimac believes most people in future will travel in self-driving, primarily electrically powered cars provided by carsharing or ride-hailing services. "Of course there'll still be privately owned cars, but they'll be like horses are today: a collector's piece. Cars are tomorrow's race horses." The automotive industry's customers in this future of mobility would then no longer be private owners but instead fleet operators with very precise expectations of their vehicles—built from the vast amount of data gained from day-to-day operations. This will include data on regular usage and customer behavior during trips, in turn making it possible to define range or equipment-feature requirements.

Rimac considers his company well equipped to meet the future. "We know how to cram a lot of performance into a tight space. This is why everyone who wants a high-performance electric vehicle or hybrid comes knocking on our door. But we're also capable of delivering fun electric driving to a mass market." The engineers in Croatia are looking into self-driving cars, too, albeit for a more niche application: The modified C_Two will feature a computer-aided "Driver Coach" programmed to help the owner become a better driver at speeds of 300 km/h on a race track. "Bringing driving excitement to self-driving cars," Mate Rimac calls it.

Rimac

Milestones in a success story

1988
Mate Rimac
is born in Livno in what is then still Yugoslavia.

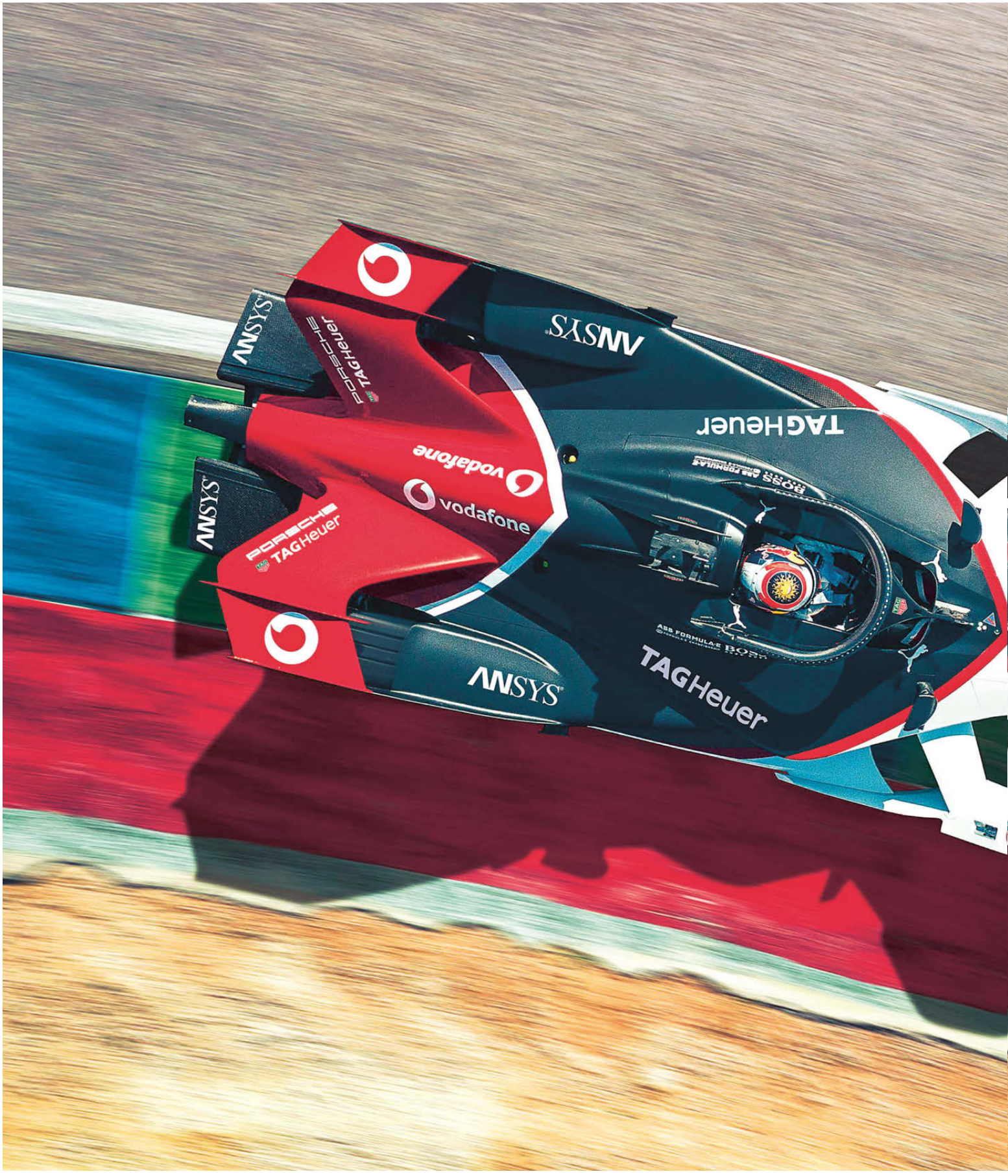
2009
Rimac Automobili
is founded. Mate Rimac had earlier converted a BMW E30 (built 1984) into an electric vehicle. The car was known as the "Green Monster."

2011
Records broken and Concept_One
On April 17, the "Green Monster" breaks five world records, including the one-kilometer (23.26 seconds) and one-mile (35.35 seconds) speed record. The first Concept_One model is presented at the IAA.

2018
C_Two
Rimac Automobili presents the supercar C_Two at the Geneva Motor Show.

IN BRIEF

Rimac Automobili is a firmly established manufacturer of electrically powered supercars and component supplier for high-performance battery systems to OEMs worldwide. Company founder Mate Rimac broke world records with a BMW he converted to electric drive. He believes most people will travel in self-driving cars in the future.

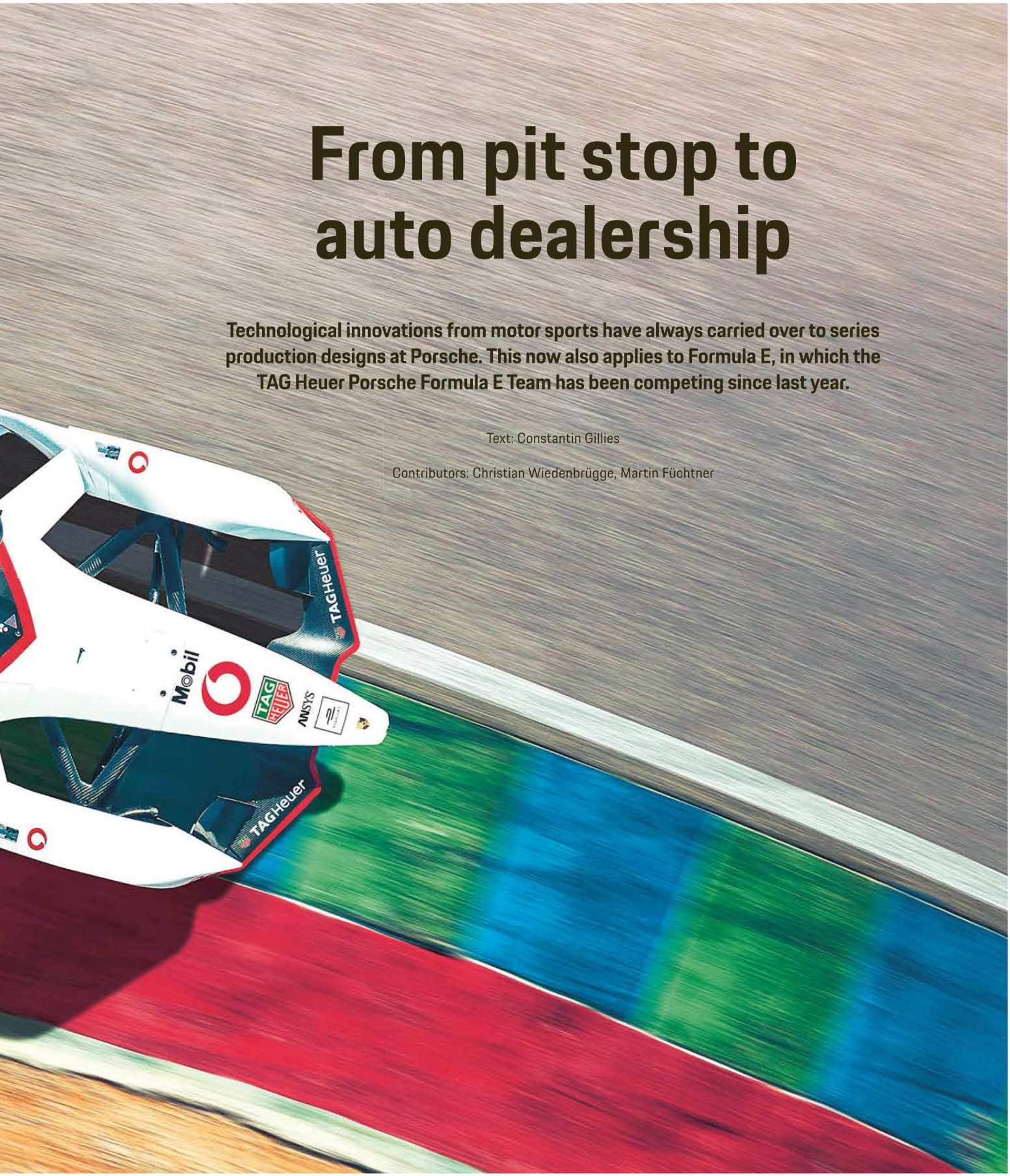

ANSYS
TAGHeuer
vodafone
PORSCHE
TAGHeuer
ANSYS
TAGHeuer

From pit stop to auto dealership

Technological innovations from motor sports have always carried over to series production designs at Porsche. This now also applies to Formula E, in which the TAG Heuer Porsche Formula E Team has been competing since last year.

Text: Constantin Gillies

Contributors: Christian Wiedenbrügge, Martin Füchtner



It's like stepping into a spaceship: the walls are white, the floors are spotless, the light is neon-bright. Orange cabling winds its way along, joining with a machine in the center of the room. The signal color is well-warranted: the cables carry 800 volts. We're in the high-voltage test rig at the Porsche Development Center in Weissach, the place where Porsche tests electric motors. Right now, a special specimen is being put through its motions: the motor driving the Porsche 99X Electric, Porsche's contender in Formula E since last year. The electric mover propels the black-red-and-white race car from 0 to 100 km/h in only 2.8 seconds.

Here on the test rig, the engineers are trying to improve the motor's efficiency further still. To do so, they're taking it through a sheer endless cycle of laps along a virtual race track, always subjecting it to acceleration and braking levels identical to real-world conditions. But the tests are not only meant to take the racer to victory. Porsche also intends to carry over as many innovations from motor racing to their regular production vehicles. "Our mission is to win races. But we're also pursuing a smooth transition to series production," explains Martin Füchtner, Senior Manager High-Voltage Drive Development, motor sports.

Advancing progress in electric mobility overall—a goal shared with the Formula E organizers. The racing formula is not designed to be an exclusive technology reserve, instead it intends to motivate series production innovation. Which makes it a totally different ball game from combustion-engine racing. The key difference is that all the teams have to use largely identical vehicles. Formula E specifies the vehicle chassis and standardized battery. All the powertrain components, on the other hand, are the teams' own designs. This includes the electric motor, inverter, brake-by-wire system, transmission, differential, drive shafts, structural frame, and associated suspension elements on the rear axle as well as the cooling system and control unit. This way, the teams need to design fewer parts themselves, which levels the playing field for teams with lower funding. It also allows the engineers to focus on the actual electric drive instead of investing lots of money in expensive secondary issues like aerodynamics, for example.

Electric-drive expert Füchtner breaks down his mission: "We need to test the limits of what's possible." Right now, that means focusing especially on two components: electric motor and inverter. The electric motor converts alternating current into torque that drives the vehicle. Internal eddy current and conductance losses need to be minimized, and component weight reduced. Here, the team is benefiting from the fundamental research already pursued with the Le-Mans prototype (LMP), which explored new motor topologies and discovered new materials. "It's awe-inspiring to see how massively we've pushed technology over recent years—drive systems with under five liters volume are now capable of producing the same power as a full-blown sportscar engine. And at efficiency rates we only dreamed of."

Reciprocity: The Porsche Taycan Turbo S (on left) and the Porsche 99X Electric are keeping technology transfer between motor racing and series design alive at Porsche.

Taycan Turbo S

Electricity consumption (combined): 26.9 kWh/100 km
CO_2 emissions (combined): 0 g/km
Efficiency class: Germany: A+ Switzerland: B

"Our mission is to win races. But we're also pursuing a smooth transition to series production."

Martin Füchtner, Senior Manager High-Voltage Drive Development, motor sports

"Many on the Taycan team are former members of the team that previously developed the 918 Spyder."

Christian Wiedenbrügge,
Team Lead Software and Calibration

But it's not enough to optimize only a single component. It's how integrated the powertrain is that's key. This means that reducing the electric motor's efficiency may make sense if it leads to benefits for the inverter. Or vice versa. It's the end result that matters. The inverter partners with the electric motor by transforming the battery's direct current into alternating current. It does so using a semiconductor element that switches many thousand times per second, with each switchover producing a small loss. Porsche is trying to reduce these step-by-step, a real high-tech challenge. Their attempts to identify the most efficient semiconductor for the switch lead the engineers to atomic scale. The latest prime contender in terms of material is silicon carbide (SiC), which in its pure form is very expensive.

Another way to leverage electric drive efficiency is by adjusting the inverter's switching pattern, meaning the way and the switching frequency. This pattern is governed by complex mathematical algorithms where even the minutest of changes can mean victory or defeat on the race track. "By going through numerous iterations of semiconductors and algorithms, we now have an exceptionally high system efficiency," Füchtner tells us happily. In its efforts to advance inverter and motor, the team benefits greatly from its close association with the field of science. Many among the staff have just recently graduated from university and possess cutting-edge knowledge. "It never ceases to amaze how easily they handle the most complex subjects." Füchtner is full of praise.

Among the things that appeal to the junior talent is that the Porsche team maintains flat hierarchies. There's a lot of leeway for trying things out, there's next to no red tape getting in the way, and productive mistakes are allowed. At the same time, the junior engineers needn't concern themselves with warranty issues or the advance scheduling involved in industrial realization. Without this kind of culture, major technology progress would be impossible within such short timeframes, Füchtner believes: "We're like a start-up."

2.8 seconds
for the Porsche 99X Electric to accelerate from 0 to 100 km/h.

SiC
The semiconductor compound silicon carbide is a particularly efficient switch—in racing and in series cars.

Decision in favor of 800 volts

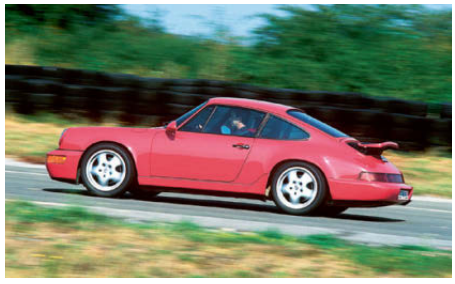
Motor sports innovations regularly benefit series production, too (see box on page 62/63). A recent example: the Porsche Hybrid 919 claimed three constructor world championship titles and won three times at the 24 Hours of Le Mans in 2015, 2016, and 2017. The LMP's crucial advantage was that it is able to store and supply energy very quickly. This was why the engineers chose an internal voltage of 800 volts over the otherwise common 400 volts. The experience gained on the race track—in particular with respect to the high levels of electromagnetic radiation—helped realize the series model. "The LMP supported our choice of 800 volts for the Taycan," Füchtner says.

The greatest overlap can be found in test rig technology. The rigs allow testing individual components under precisely controlled conditions without having to go out to the test track on real test drives. This

Innovations in series production that came from motor sports

Synchronized five-speed transmission (1955)
Porsche designs a synchronized five-speed transmission for the 550 Spyder that allows faster gearshifts. From 1963 onwards, it gets installed in the production-line 911.

Anti-lock braking system (1968)
The Porsche 908 KH acts as a test bed for an early anti-lock braking system (ABS) that allows more stable braking into cornering. ABS is optionally available as of 1983, and a standard feature in the Porsche 928 S from 1986 onward.



Active aerodynamics (1969)
To gain greater downforce when cornering, Porsche installs moving flaps on the rear of the 917 race car for a time. The flaps extend upon entering corners. They mark the first step on the path toward automatic aerodynamics, which become standard equipment with the automatic rear wing on the 911 model generation 964.

saves a huge amount of time. “Completing the legally required test cycles using a real vehicle takes ten days. On the test rig, it takes us one day of work plus a night shift,” Christian Wiedenbrügge explains. He is team lead for software and calibration of battery electric vehicles.

Obviously, the various teams are all pursuing their own goals on the test rig. The racing team, for example, would simulate the Nürburgring’s Nordschleife to tailor a component for best lap time. Series designers, on the other hand, might choose a virtual day trip through the Black Forest in their quest to extend range. “But the methods are still the same,” Wiedenbrügge stresses. Both partners are also pushing the technology of the test benches forward. For instance, the racing team ended up refining specimen temperature adjustment because every tenth of a degree makes a difference in an electric drive. Series design contributed advances in automating test sequences.

One day
on the test rig is enough to complete all required test cycles.

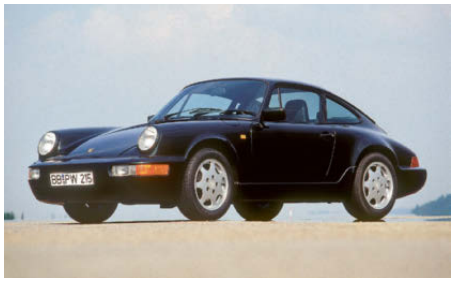
Expert committees for internal exchange between racing and series production

But the test rig isn’t the only point of crossover in joint development of the electric drive. Porsche has set up in-house expert committees for certain components and has them meet every eight weeks or so. They provide a panel for inverter specialists, for example, from series development and from motor racing to speak. It paid off. When the tech heads meet, many of them start off by saying: “We’ve something here you might want to see…” which is exactly what the idea was. Racing and series designers are meant to recognize their own struggles in what their counterparts are doing and to explore possible solutions together.

But perhaps even more significant is how technology transfers through the minds of people. “Many on the Taycan team are former members of the team that previously developed the 918 Spyder,” Wiedenbrügge

Porsche dual-clutch transmission (1983)

To enable gearshifting without traction loss, Porsche merges two transmissions with one another in the 956 race car. Progress in control technology finally allow this dual-clutch transmission to be installed in a production-line vehicle for model year 2009, when it gets used in the Porsche 911 Carrera 4.



Controlled all-wheel drive (1986)

Porsche make their breakthrough in rally racing in the early 1980s with the 959, managing to win the classic Paris-Dakar. The success is owed to the program-controlled all-wheel drive, which adaptively distributes torque between the axles. The system becomes a standard feature with the 911 Carrera 4 from model 964 onwards.

800-volt technology (2014)

Following a 16-year hiatus, Porsche returns to Le Mans in 2014 with its revolutionary 919 Hybrid. For the batteries to supply their energy more rapidly, the engineers design the electrical systems for 800 volts—whereas 400 volts were commonly used till then. Three consecutive overall victories prove them right. The designs are adopted in the 2019 Taycan.

shares. Team transfers like this are common practice at Porsche. This way, an expert in noise vibration harshness engineering working in series development helped the motor racers get a handle on the electric race car's vibrations. And that's only one example. Being in the same area also plays an important part: Porsche's Development Center is only about 1,000 meters away from the motor sports headquarters. "We all come in through the same gate, and we share meals meet for lunch," Füchtner says and laughs. He knows that many a neat idea for winning the first Formula E race could be born in Weissach's cafeteria.

Ideas for improvement are already piling up—not all of them, however, are viable just yet. "It would be great if the Formula E teams were also allowed to design their own batteries, too." Füchtner firmly believes: "This is where we still have huge potential for advancing electric vehicles. We're already in a pretty good place in terms of the drivetrain. But competing over batteries may hurt Formula E, because costs are very high. This would skew competition. We have therefore developed a lot of ideas to prevent that while still opening up the door for the development of cell technology by making it last an entire season. This way, it is usable for road car production and we have been able to further push the technology for our road cars."

Taycan Turbo S

Electricity consumption (combined): 26.9 kWh/100 km
CO_2 emissions (combined): 0 g/km
Efficiency class: Germany: A+ Switzerland: B

Porsche 911 Carrera 4

Fuel consumption (urban): 12.6 l/100 km
Fuel consumption (highway): 7.8 l/100 km
Fuel consumption (combined): 9.6 l/100 km
CO_2 emissions (combined): 218 g/km
Efficiency class: G

IN BRIEF

Motor racing and series production: crossing over between the two fields has a long tradition at Porsche. Electric vehicles are no exception. The Taycan thus benefits from experience gained with the Porsche 919 Hybrid. Joint expert committees guarantee that new ideas will continue to cross over between racing and series production teams in future.

The power of evolution

Text: Hans Oberländer

Stronger, more dynamic, more comfortable: with the new 911 Turbo S and 911 Turbo S Cabriolet, Porsche is once again setting emphatic new standards in the ranks of the sports cars. Numerous improvements make driving a safe pleasure suitable for everyday use.

The new 911 Turbo S is once again a top athlete and feels most in its element while sprinting. That is when it can show its full power and phenomenal acceleration: Shifted by an eight-speed Porsche dual-clutch transmission, the 911 Turbo S takes just 2.7 seconds to go from 0 to 100 km/h. It reaches 200 km/h in 8.9 seconds—a full second faster than its predecessor from the 991 model series. And the latest top-of-the-line 911 doesn't max out until it hits 330 km/h.

Another novelty is the six-cylinder boxer engine with two VTG superchargers. The Biturbo has 650 hp and 800 Nm of torque—a boost of 70 hp and 50 Nm over its predecessor. The new power unit is based on the 3.0-liter biturbo from the 992 Carrera. Other features include a completely redesigned intercooler, larger and symmetrically designed VTG turbochargers with electrically adjustable wastegate flaps, and piezo injectors. They improve responsiveness, revving ability, and performance. And gasoline particulate filters optimize emissions.

2.7 seconds
is all the new 911 Turbo S needs for the sprint from 0 to 100 km/h.

330 km/h
is its top speed.

The enhanced dynamic response of the Porsche 911 Turbo S is plain to see: Never has a 911 been wider. It's added 45 millimeters in the front for a stately total of 1.84 meters, while across the rear axle it has grown by 20 millimeters to 1.90 meters For the first time, the Turbo S has wheels of different sizes and mixed tires. In the front it features 255/35 tires on 20-inch wheels, while in the rear it has impressive 315/30 tires on 21-inch wheels. This individual dimensioning of wheels and tires further improves the driving dynamics of the 911 Turbo S.

Porsche Active Suspension Management (PASM) electronically controls the shock absorber system for each individual wheel, depending on road conditions and driving style, thus reducing body movements. In the standard PASM adaptive chassis of the Turbo S, the shock absorbers now work even faster and more precisely: special software and a control valve that can be continuously adjusted by magnetic force adjust the wheel-specific damping force depending on the driving situation, with precision and in fractions of a

911 Turbo S Cabriolet

Fuel consumption (urban):
15.9 l/100 km
Fuel consumption (highway):
8.6 l/100 km
Fuel consumption (combined):
11.3 l/100 km
CO_2 emissions (combined):
257 g/km
Efficiency class: G

Optimized driving dynamics: For the first time, the 911 Turbo S has different wheel sizes as well as mixed front and rear tires (above). Porsche Communication Management (bottom left) recognizes handwriting and can be controlled by voice. The rear spoiler (bottom right) is part of the adaptive aerodynamics and ensures sufficient downforce and safety.

second. And it does so much more softly, or tightly, as the case may be, than the previous system—with considerable advantages in terms of roll stability, road grip, steering response, and possible cornering speeds. For those who like it particularly sporty: for the first time, a PASM sports suspension with ten-millimeter lowering can be ordered.

Greater safety on wet roads

All-wheel drive and all-wheel steering ensure reliable grip, while further refined adaptive aerodynamics, introduced as a world-first in the predecessor model, guarantee additional safety. The newly shaped, pneumatically extendible front spoiler and the enlarged rear wing create 15 percent more downforce. New features include the "Wet Mode" and "air brake" functions. When the road is wet, the contact pressure on the rear axle and the frictional connection between the tires and the road are enhanced. During emergency braking at high speeds, air brake moves the front spoiler and rear wing to the performance position. The higher drag and increased downforce shorten the braking distance and improve driving stability. And the enhanced ceramic brake system, with its brake discs of up to 420 millimeters in diameter, is also more powerful than ever before.

In 1974, the first Porsche 911 Turbo was a revolution in the automotive sector. 46 years later, the 911 Turbo S is a prime example of the creative power of evolution. Take, for example, the lithium-iron-

Technical data of the 911 Turbo S

300 lux
of illumination are provided by the matrix headlights with 84 pixels.

15%
more downforce is generated by the new front spoiler and enlarged rear wing.

10.9-inch
center screen for the Porsche Communication Management system.

570 watts
are delivered by the standard BOSE® surround sound system with twelve speakers.

911 Turbo S
Fuel consumption (urban): 15.5 l/100 km
Fuel consumption (highway): 8.6 l/100 km
Fuel consumption (combined): 11.1 l/100 km
CO_2 emissions (combined): 254 g/km
Efficiency class: G

There's never been a wider 911. Also new are the mixed tires.

1,840 millimeters
Front width

20-inch
Ø front wheels

1,900 millimeters
Rear width

21-inch
Ø rear wheels

The newly developed engine is based on the current 911 Carrera engine generation and offers a significant leap in performance.

650 hp

800 Nm

1974
Porsche presents a high-performance sports car that sets standards in terms of performance and luxury: the 911 Turbo 3.0 delivers 260 hp from three liters of engine capacity and reaches a top speed of 250 km/h, making it the fastest street-legal car in Germany for a long time.

1995
The 911 Turbo of the 993 generation, a new highlight in sports car design: with 408 hp and now standard four-wheel drive, the 3.6-liter engine accelerates from 0 to 100 km/h in 4.5 seconds and tops out at 290 km/h.

2009
The first completely new turbo engine with 500 hp features direct fuel injection and reduces consumption over its predecessor by up to 16 percent.

phosphate battery, which comes as standard in the 911 Turbo S for the first time. Compared with a conventional lead battery, it is significantly lighter, boasts higher voltage stability, and achieves significantly lower internal resistance. For the driver, this means shorter reaction times and the possibility of activating the fuel-saving start-stop function more frequently. The higher-performance power storage unit allows considerably longer operation of energy-intensive and electrical on-board systems, such as the sound system, when the combustion engine is switched off.

Standard LED matrix headlights with dark interior trim, which are optionally available in an even darker version, underline the striking appearance of the Turbo S. The module allows illumination at over 300 lux and numerous different functions. Headlight range and curve illumination can be controlled individually and dynamically. Highway lights, fog lights, and bad-weather lights illuminate the field of vision in an adaptive manner, while targeted dimming prevents dazzling reflections on signs.

Twelve speakers turn the cabin into a concert hall

Evolutionary progress can also be felt in the interior of the 911 Turbo S. Porsche Communication Management (PCM) with online navigation combines intuitive control with a wide range of infotainment options.

12.75 kilograms
is the weight of the battery in the Porsche 911 Turbo S. For the first time, a lithium-iron-phosphate battery is used, which more than halves the weight of the on-board battery.

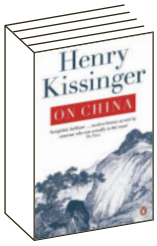
Simple wiping movements, zooming in, out, or rotating the display with two fingers—all no problem for the PCM. The display also recognizes handwriting and many functions can be used conveniently via voice control. A new type of optional soundproof glazing lives up to its name and enhances enjoyment when the cab transforms into a concert hall: the BOSE® surround sound system, with a total output of 570 watts, delivers acoustic finesse through twelve speakers. Extreme sportiness and luxurious comfort: in the Porsche 911 Turbo S, opposites complement each other. Sound system, GT sports steering wheel, carbon deco, Sport Chrono Package—all ex-works, as are the comfortable leather seats, suitable for the long haul. With their special quilting, they are reminiscent of the first 911 Turbo.

As with the current 911 Carrera models, the new 911 Turbo S Cabriolet's climate control function has been significantly improved when the top is open. New features include automatic adjustment and control of the automatic climate control system after the top has been opened. Fan control, temperature regulation, and air distribution in the interior adapt to the respective situation, taking into account the outside temperature, solar radiation, and many other parameters.

Of course, the Porsche 911 Turbo S is also absolutely suitable for everyday use. But even more than that, it's the ideal car in which to leave everyday life behind.

Outside the box

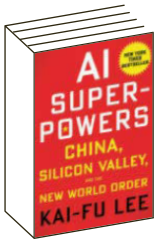
Deeper knowledge



Tradition and challenges

Former US Secretary of State Henry Kissinger is an undisputed expert on China. In this book, he traces the country's history from the early dynasties to the present—based in part on his own experiences with the political leaders of today's superpower.

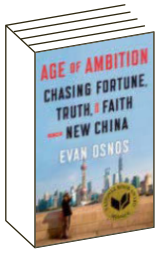
On China
Henry Kissinger
Penguin



Arms race of the AI superpowers

In his bestseller, AI expert and investor Kai-Fu Lee takes a look at the future of artificial intelligence (AI) and the AI arms race between the two "AI superpowers," China and the US. A fascinating book about technology and our life in the 21st century.

AI Superpowers
Kai-Fu Lee
Houghton Mifflin Harcourt

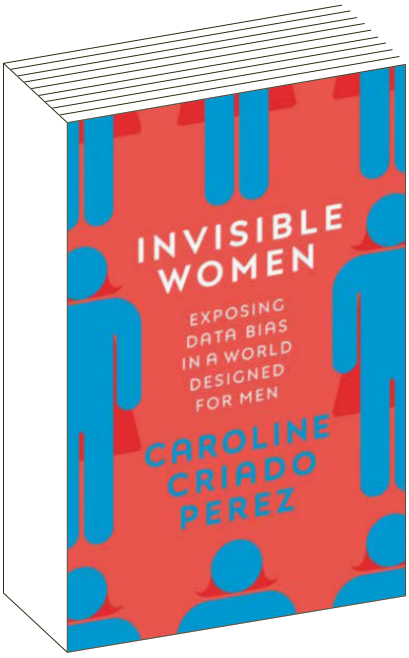


China's boundless dream

Journalist Evan Osnos is considered one of the top experts on today's China. For this book, he spoke to many people about their hopes and expectations. He met adventurers in pursuit of wealth and spent time with some famous personalities.

Age of Ambition
Evan Osnos
Farrar, Straus and Giroux

The big picture



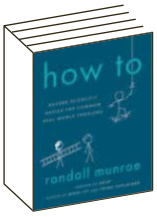
The ignored half of humanity

Author Caroline Criado-Perez's thesis: Our world is made by men, for men, and tends to ignore half of the population—for instance through gender differences in the collection of scientific data.

Invisible Women
Caroline Criado-Perez
Harry N. Abrams

"A book about the whole world—and essential reading for the whole world."

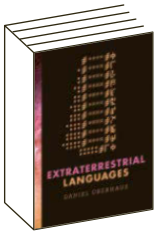
Austrian Broadcasting Corporation



How to get it done

This book promises "absurd scientific advice for common real-world problems." According to Randall Munroe, in the search for a solution to problems, there is the right way, the wrong way—and the obviously absurd way. Munroe's new bestseller examines this approach.

how to
Randall Munroe
Riverhead Books

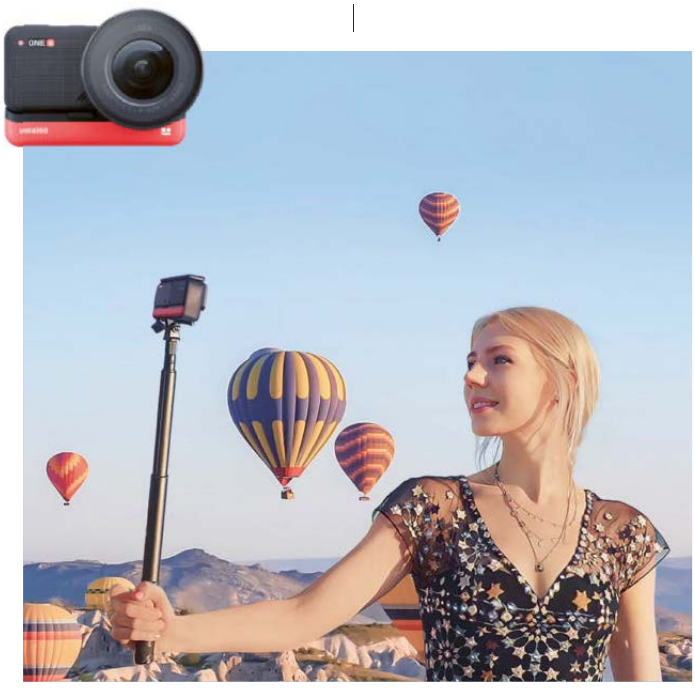


Chatting with the aliens

How would we talk to aliens if we actually encountered them one day? In his book *WIRED*, author Daniel Oberhaus examines various possibilities, including mathematics and art.

Extraterrestrial Languages
Daniel Oberhaus
The MIT Press

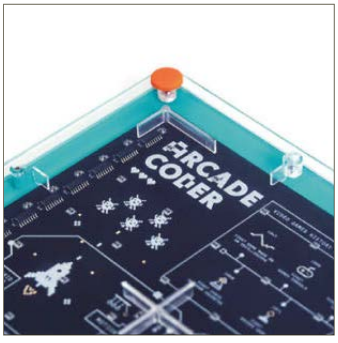
For the child in all of us



Plug-and-go action cam

The modular action camera Insta360 ONE R can be disassembled and reassembled in a few easy steps. The operating module with display and a camera module have space on the battery unit. Depending on the configuration, you can use wide-angle lens or take 360-degree shots (photos and videos). The camera is a hit in China.

Insta360 ONE
www.insta360.com



Introduction to gaming programming

Program simple video games for the iPad yourself: the Arcade Coder makes it possible. Children as young as six years old are introduced to the basics of graphics and game programming by the board with 144 programmable LED buttons.

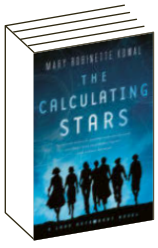
Arcade Coder
www.techwillsaveus.com/shop/arcade-coder

Intelligent entertainment

Unheralded heroines

Nominated for multiple Oscars, this remarkable film centers around three African-American mathematicians, Katherine Johnson, Dorothy Vaughan, and Mary Jackson, who, during the time of racial segregation in the United States, carried out important calculations for NASA's Mercury and Apollo programs in the Colored Computers department (the word "computer" also referred to humans at the time).

Hidden Figures
Theodore Melfi (director), 2016



Against all odds

A meteorite hits the east coast of the United States in the 1950s. In this award-winning novel, mathematician and pilot Elma York recognizes that the resulting climate change will make Earth uninhabitable. She joins the International Aerospace Coalition and wants to become the first female astronaut ever—a break with all the conventions of her time.

The Calculating Stars
Mary Robinette Kowal
Tor Trade

A family car for China: The appearance of the "C88" drew on elements of Chinese culture.

1994

In just four months, Porsche Engineering developed the concept for a family car for the Chinese market. The "C88" was to be built in three versions. Its design and technology were adapted to the requirements of the still young car market. Chinese employees were also involved in the development.

Porsche Engineering can look back on a long tradition of development projects in China. At the invitation of the Chinese government, in November 1994 the company and several international OEMs presented a concept study of a vehicle for the then still relatively young car market at the Family Car Congress in Beijing, among other events.

The "C88" concept car was developed in just four months. The aim was to bring the vehicle to the Chinese market in three different versions. The inexpensive entry-level version with four seats had two doors, a four-cylinder gasoline engine with 35 kW output, a four-speed transmission, and an estimated cost of around 45,000 renminbi (approx. 4,000 euros). The standard version had the same engine, was slightly larger, and would cost between 60,000 and 65,000 renminbi (approx. 5,800 euros) depending on the equipment package. The luxury version offered even more space for around 80,000 renminbi (approx. 7,000 euros), had four doors, a more powerful engine with 50 kW of output, and a five-speed transmission. A four-speed automatic transmission was also to be offered as an optional extra.

In their effort to cater to the tastes of Chinese buyers, the developers spoke not only to Chinese experts and journalists, but also engaged a technician and a designer from China in the project.

The result was a car characterized by low-key lines, high safety and quality, and comparatively simple production. A long wheelbase and short overhangs resulted in highly modern proportions, while 15-inch steel wheels ensured comfortable rolling properties. The interior featured ergonomics adapted to the Chinese population. User-friendly material surfaces and the spaciousness of the interior created a cozy and comfortable experience. The aesthetics were based on elements of Chinese culture.

The Porsche logo was not to be found on the show car, however. Instead, the front bore an emblem with three circles on it, meant to symbolize China's one-child policy. The name also had a reference to China: The "C" stood for "China", and the number "88" means "good luck" there. In the end, however, the Chinese government opted not to allow Porsche Engineering or any other contender to build the car. That is why there is only one existing unit of the "C88", which is now in the Porsche Museum in Stuttgart.

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AT THE PUSH OF A BUTTON.

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