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# ATZ extra


# Innovations for a Sustainable and Autonomous Mobility





## SECTIONS | SERVICE



## ENERGY CHAIN



## DRIVELINE-SOLUTIONS



## AUTONOMOUS DRIVING



## URBAN MOBILITY




**ACKNOWLEDGEMENT**

This special issue was produced with the kind support of Schaeffler AG.

# Focused on Sustainable Solutions

*Dear reader,*

the automotive industry is currently undergoing the greatest upheavals since the introduction of the first fully functional automobile in 1886. Ever more pressing environmental problems, global population growth and increasing urbanization are determining the mobility of tomorrow. In addition, new opportunities and challenges are emerging as a result of increases in digitization and data networking. Traditional structures and cooperation models within the industry are put to the test, new players are entering the market and flexibility is an increasingly important attribute for businesses success.

Thanks to a high level of innovative strength based on in-house research and development, combined with smart acquisitions, Schaeffler is playing a decisive role in shaping change in the automotive industry with new components and systems. The company pursues a holistic approach based on cross-industry thinking and activities geared towards implementing sustainable solutions. This applies in particular to the urgent issue of climate change. Schaeffler is striving for comprehensive consideration of all environmental impacts along the entire energy chain and open competition between the various drive concepts instead of restricting it by legislative measures or arbitrary frames for $CO_2$ approaches. Only in this way can the advantages of individual drive and energy systems be optimally utilized to achieve a minimal overall $CO_2$ footprint for mobility. For Schaeffler, this means investing not only in the various drive forms such as electric mobility with batteries and fuel cells, hybridization and the further development of the classic internal combustion engine, but also in energy generation and storage and in innovative urban mobility concepts such as the autonomous Schaeffler Mover and the Bio-Hybrid. The following is an overview of the company's focus areas and innovations. I hope you will enjoy the read.

Richard Backhaus

**Richard Backhaus**
Correspondent ATZ/MTZ

Interview

# Uwe Wagner: ”We think, there are excellent oppor-tunities for us here.“

Today, Schaeffler is already making an essential contribution to ”Mobility for tomorrow“ with its pronounced innovative strength and high manufacturing competence for both automotive and a multitude of industrial applications. In the interview, Uwe Wagner, Head of Research and Development and the future Chief Technology Officer, explains the priorities of the company regarding component and system development.

**Currently, a lot of work is being done concurrently in vehicle development – various drive concepts on the one hand and autonomous driving functions on the other. How does Schaeffler manage these multiple efforts?**
The efforts we have to make to increase the potential of classic drive concepts on the one hand and to develop new technologies in the field of electro-mobility and drive-by-wire on the other are indeed substantial. In addition, there are development studies in the fields of new mobility concepts such as the Schaeffler Mover, which will play a decisive role when it comes to mobility in the future. Both effectiveness and efficiency are necessary in order to achieve the desired goals with the available resources. First, we use scenarios to try to identify the fields of innovation that will play a key role in the future and that fit our DNA. This is how we ensure effectiveness. We then achieve the necessary efficiency by appropriately prioritizing the topics and utilizing synergies between appropriate centers of excellence. This is a very demanding process in which senior management is very actively involved.

**What opportunities does this entail for Schaeffler?**
As a technology-oriented company we actually see this as an opportunity. We never just limited our know-how on the range of our products, but tried to manage system integration through the understanding of the overriding system and thus being able to offer our customers system-optimized products as well as the necessary support for their integration. As a result, we now see excellent opportunities for us being able to offer system solutions such as complete e-axles or rear axle steering systems in the context of electrification and automation.

**Are you going to maintain the high pace of innovation of recent years in the future?**
Yes, we will even have to increase that.

**As an automotive supplier building electronics expertise, what advantages do you offer over established electronics players pushing into the automotive business?**
First of all, the topic of mechatronics is not completely new for us. We have been offering actuator solutions in the fields of engines, transmissions, and chassis for many years. Based on this know-how and our competencies in the systems area, we are in a position to develop high-performance system solutions by strengthening our strategic acquisitions in the areas of electric motors, electronics, and software accordingly. We believe that the key competence lies in system integration.

**Vehicle sales are currently down in Europe, among other places, but particularly in China. How do you assess the economic outlook for the next few years?**
The automotive industry is currently subject to a variety of influences, such as various technological transformations or rapidly changing economic conditions. We believe that the basic need for individual mobility will remain high, albeit in a rapidly changing technological environment.

**Is the production of traction batteries for electric vehicles relevant for Schaeffler?**
We look at batteries with regard to possibilities for the use of Schaeffler technologies – the manufacture of complete batteries for electric vehicles is currently not under consideration. However, we believe that there will be a market for the fuel cell in addition to the battery. That is why we are also doing research and development in this area.

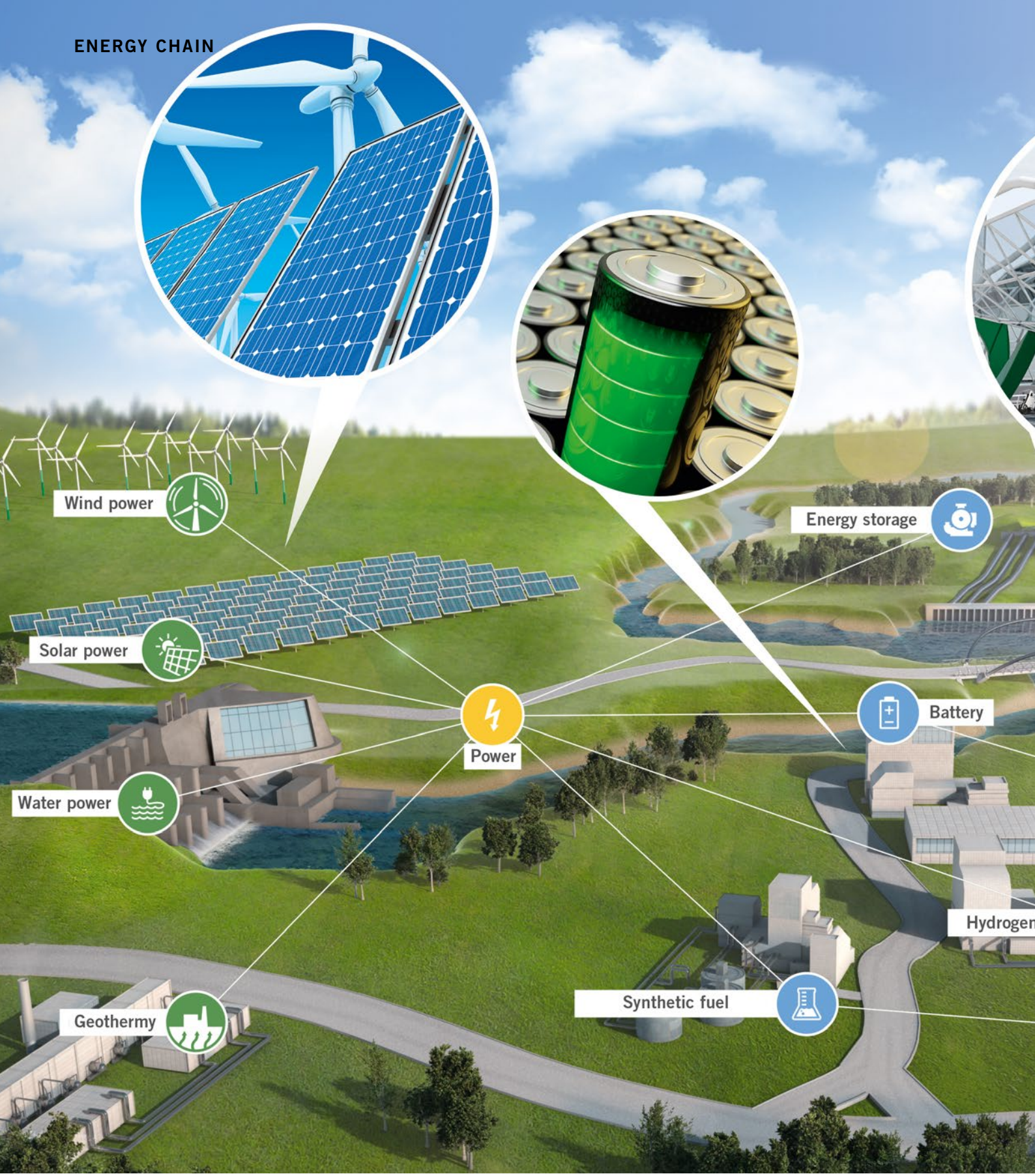
### *RESUME FOR UWE WAGNER*

As of January 1, 2020, Uwe Wagner (54) will take over the position of Chief Technology Officer from Prof. Dr. Ing. Peter Gutzmer, who is retiring.

After studying mechanical engineering at the University of Stuttgart, Wagner began his professional career at LuK in Bühl in the development department for torque converters. From 1995 to 2007 he held leading positions in the following departments: torque converter development, development and production of CVT chains and product line automated transmissions. In 2007 Wagner took over the management of the system house transmission division. In 2014 he took over as Head of Research and Development for the Automotive Division at Schaeffler, and since 2016 he has been Head of Research and Development for Automotive and Industry.

**Thank you very much for the interview, Mr. Wagner**

"System integration is the key competence in the field of electronics", says Uwe Wagner


ENERGY CHAIN
Wind power
Solar power
Water power
Geothermy
Power
Energy storage
Battery
Synthetic fuel
Hydrogen

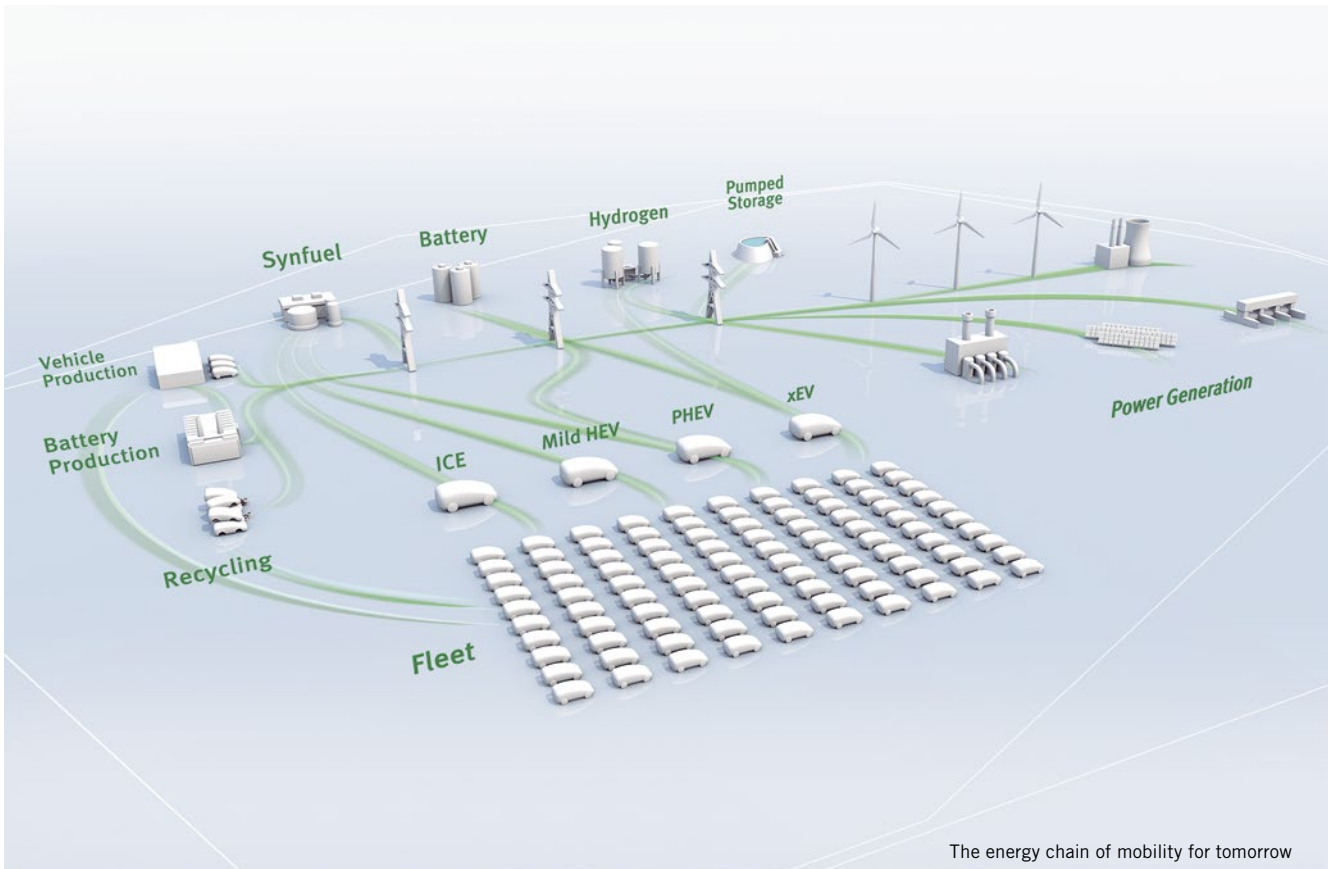

# Looking Beyond the Horizon

The complexity of the mobile world will continue to increase in the future. On the one hand, the range of drive solutions for the various mobility demands will continue to grow; on the other hand, the goals of $CO_2$ and emission reduction requires a comprehensive perspective. Based on extensive experience in both the automotive and industrial sectors, Schaeffler is developing holistic solutions along the entire energy chain.

*A comprehensive cradle-to-grave approach instead of the limiting well-to-wheel perspective*

## REDUCING $CO_2$ ALONG THE PROCESS CHAIN

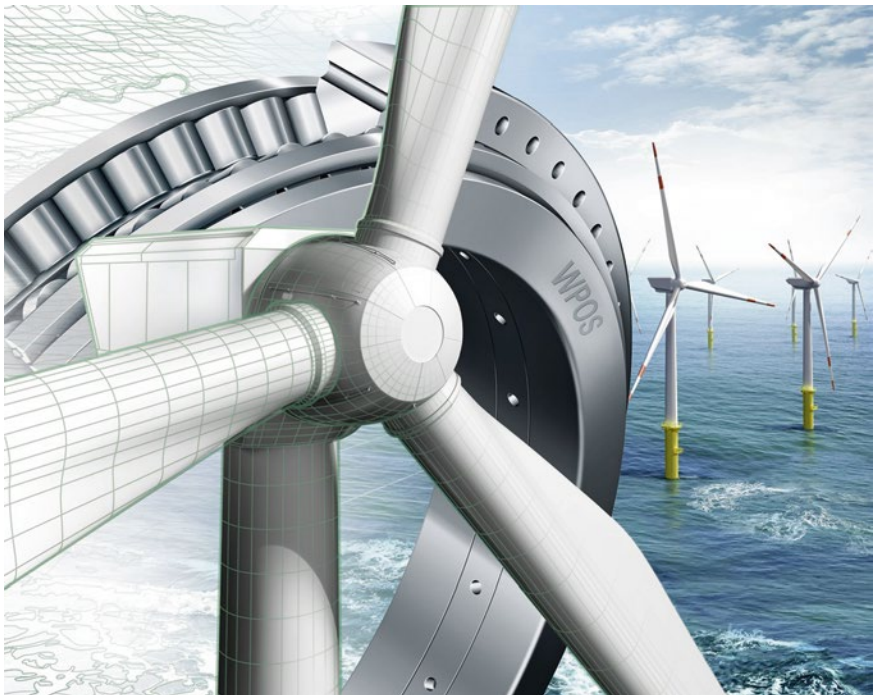
When Lucas di Grassi and Daniel Abt battle for victory in the weekend race, they can be sure that their Audi e-tron FE05, like the racing cars of their rivals, comply with Formula E regulations. The rules specify important benchmarks for the vehicle and drive parameters, which form the framework the developers use to design construction. This is the only way to compare the performance of the teams and to ensure fair competition between the respective technical implementations. A uniform standard is also necessary in other areas of technology in order to be able to correctly compare the efficacy of different solutions. This applies in particular to the urgent issue of reducing $CO_2$ emissions caused by mobility. The decisive factor here is the time frame specified for estimated $CO_2$ emissions – if limits are set improperly, results can be distorted and end up favoring particular technologies. In the so-called tank-to-wheel approach, the fuel tank or, in the case of electric vehicles, the battery and drive wheels become the point of reference for the calculation of emissions and efficiency. With an efficiency of 60 to 80 % under actual driving conditions, the electric drive is clearly ahead of the combustion engine with a maximum of 45 %. Emissions also favor the electric drive because it does not release any $CO_2$, $NO_x$ or particles during operation. The balance is quite different when the concepts are compared from "well to the wheel". In this case, factors like the generation of electric power to operate electric vehicles on an ongoing basis also come to bear and we are a long way from climate-neutral power generation: In 2018, the share of energy generated from renewable sources in the German electricity mix was around 40 % [1]. However, this high figure is partly attributable to the impact of the very hot and dry summer, which was particularly beneficial to solar power generation. On a European scale, rene-




The energy chain of mobility for tomorrow

wable energies accounted for only 32.3 % of total electricity generation [2].

China also covers about 60 % of its electricity needs with environmentally harmful coal [3]. But even this consideration does not include all the relevant factors for balancing total $CO_2$ emissions. The picture is not complete until the extraction and processing of raw materials and disposal at the end of the vehicle's service life are included (cradle-to-grave approach). After all, nature does not care where the $CO_2$ is released in the process chain – whether in the engine, during power generation to recharge the propulsion battery or during the production of the vehicle and its components. Today, the production of lithium-ion traction batteries in particular is the main cause of $CO_2$ emissions from electric vehicles. Depending on the study, the size of the battery under consideration, and the regeneratively generated share of the electricity mix in the calculation, it is assumed that an electric vehicle must run between 70,000 and 150,000 km in order to compensate for this starting load of greenhouse gases compared with an equivalent vehicle with a gasoline or diesel engine. This highlights the fact that electro-mobility and the expansion of renewable energies must go hand in hand if we want to achieve $CO_2$-neutral mobility that will not only begin at the charging station as earliest starting point. Schaeffler is developing cross-sector „cradle-to-grave" solutions along the entire energy chain that further increase efficiency, reduce emissions, and thus support the goal of keeping global warming below 2 °C. To this end, the company places equal focus on all types of drives. Depending on the vehicle's application profile and primary energy structure, the electric drive is not the ideal $CO_2$ solution as such, but regional and market economy aspects must also be taken into account when selecting the drive – even in the future, not every consumer in the world will be able to afford an electric vehicle. Against this background, Schaeffler predicts that by 2030 only 30 % of all new vehicles will be battery-powered, 40 % hybridized, and 30 % will be powered purely by internal combustion engines. Electric vehicles with fuel cells will still play a subordinate role in 2030 but will gain in importance in the years to come.




As one of the world's leading roller bearing manufacturers and development partners in the industry, Schaeffler has been producing bearing supports for wind power stations for over 30 years

**SOLUTIONS FOR WIND POWER STATIONS**

Schaeffler offers specific technologies and comprehensive product know-how in the field of renewable energy generation using wind power, solar energy, hydro power, or geothermal energy. For example, Schaeffler develops high-performance, low-friction components for the bearing support of the drive train for manufacturers of wind power stations. Services that enable remote diagnosis and predictive maintenance improve efficiency because friction-increasing wear in the bearings can be detected earlier. In addition, operators can plan necessary maintenance work in advance and schedule it at times when the wind turbine is not connected to the grid anyway, for example during calm periods.

*Electric mobility and the expansion of renewable energies must go hand in hand.*

*As stationary energy storage devices, Organic Flow batteries cushion peak loads in power plants.*

This optimizes the economic efficiency of the system and increases the reliability of the power supply. In order to develop further energy sources, Schaeffler and its partners are also researching completely new approaches – for example, how sustainable and above all reliable electricity can be generated economically with wave and tidal power plants. One of the main problems in the expansion of renewable energies is dependability of supply. While the capacities of conventional power plants can be controlled on the basis of current demand, the renewable generation of electricity, for example by wind and solar power, depends on nature. Under certain circumstances, the plants may produce too little energy when there is no wind or sunlight, while at other times they could deliver more than currently needed. This limits the efficiency of the systems and leads to a situation in which conventional power plants powered by fossil fuels must be operated as a safety reserve.

## STATIONARY BUFFER BATTERY

Intermediate storage solutions have to be developed to balance the time between production and demand of renewably generated electrical energy. Together with CMBlu, Schaeffler is advancing the industrialization of the renewable battery technology „Organic Flow“. As a stationary energy buffer in the power grid, organic flow batteries cushion overproduction or peak loads in power plants and industrial plants on the one hand and support the expansion of the charging infrastructure for electro-mobility on the other.

For electric vehicle drivers to be able to use a charging station, the electrical energy must first be transported there.

Due to the high current loads, this is usually done via the so-called medium-voltage power grid. Organic Flow batteries arranged in a decentralized way act as energy storage units, helping to relieve this grid, which does not have to be upgraded for additional capacity requirements from new charging stations. In addition, access to the medium-voltage grid is not available everywhere.

In order to be able to install charging stations at these locations as well, Organic Flow batteries can be used as intermediate storage directly at the charging station. Then the stationary accumulator is continuously charged with low energy via the available grid connection and delivers it with high power density if the batteries of several electric cars are to be charged simultaneously.

The Organic Flow accumulator functions similarly to the well-known liquid batteries, i.e. the reaction partners for the chemical storage of electrical energy are present in liquid form as electrolytes. In contrast to conventional, metal-based systems, however, organic molecules of lignin are used for storage in the organic flow solution. The natural substance lignin is contained in every plant, for example in trees or grasses. It is a renewable source of raw materials and is produced as a waste product on a scale of millions of tons in cellulose and paper production. Consequently, a permanently available source for large-scale energy storage is ensured. Practically the entire value chain for the batteries can be covered locally, so that there is no import dependency from individual regions. In addition, the accumulators do not require rare earths or heavy metals, are non-combustible and very safe to operate. Pilot projects with several reference customers are planned within the next two years. By 2021, the first commercial systems will be available.

Organic Flow batteries can be used flexibly in the power grid as stationary energy storage devices and help balance generation and consumption.


Eco-friendly drives by Schaeffler

## FUEL CELL TECHNOLOGY

Another way of storing electrical energy from renewable sources is to convert it into hydrogen using electrolysis processes, which can then be used to power electric vehicles based on fuel cells. The technical structure of a fuel cell is based on two electrodes and a separating layer arranged between them. If the energy carrier hits an electrode, a catalyst causes the division into electrons and ions. The electrons then travel via an electrical conductor to the second electrode, generating electrical energy. In addition to the classic traction battery, the hydrogen fuel cell is a good option for providing energy for emission-free e-mobility along the entire energy chain. The favorable features of the fuel cell are already evident today, especially for future electric commercial vehicles in long-distance traffic. Technologies such as hydrogen-based intra-logistics open up additional paths to climate neutrality in industrial production.

The advantage of fuel cells over battery-powered electric vehicles is the longer range and the very short refueling time for refilling the hydrogen pressurized container. Current challenges are the inadequate network of hydrogen filling stations and a market-oriented cost reduction that can be achieved through mass production. The implementation of fuel cell technology will therefore most probably initially take place via fleets such as municipal bus lines for public transport or delivery services, and later via heavy goods vehicles. Schaeffler does not see any opportunities for further expansion of the concept in the passenger vehicle sector until the next step is taken in 2030. Schaeffler is currently looking into getting involved in this technology and is conducting pre-development activities for fuel cell components using our traditional core competencies in materials, forming, and surface technology.

From wind power station to the wheel: Schaeffler know-how along the entire energy chain

*Regeneratively produced designer fuels also offer a way to reduce $CO_2$ emissions in marine and aviation traffic.*

## COMBUSTION ENGINE OFFERS OPPORTUNITIES

Due to their widespread use, vehicles with combustion engines will continue to offer considerable leverage for $CO_2$ reduction in the future. According to Schaeffler's forecasts, 70 % of new vehicles in 2030 will still be equipped with a conventional engine, either as the sole drive with light electrical support or in the form of full or plug-in hybridization. For these vehicles, Schaeffler is further developing both the engine and the transmission as well as hybridization in the overall system. The aim is to optimize drive and vehicle via the interaction of mechanics, electronics, and thermodynamics for maximum efficiency and minimum $CO_2$ emissions. Further $CO_2$ reduction potential results from the use of synthetic fuels instead of fossil fuels. Their production initially involves the generation of synthesis gases using electrical energy, which are then converted into fuels in several process steps. If green electricity is used for their production, they are almost carbon neutral. The renewable energy sources can be sold via the existing network of gas stations and do not require a separate, cost-intensive infrastructure. Depending on the chemical properties of the synthetic energy source, an admixture with conventional fossil fuels is conceivable, which would further reduce $CO_2$ emissions for the entire vehicle fleet in the field. In addition to passenger cars and commercial vehicles with combustion engines, regeneratively produced designer fuels also offer a way of reducing $CO_2$ emissions in marine and aviation traffic.

**REFERENCES**

**[1]** https://www.spiegel.de/wirtschaft/unternehmen/strom-2018-gab-es-erstmals-mehr-als-40-prozent-oekostrom-a-1246124.html
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**[3]** https://de.reuters.com/article/china-kohle-idDEKCN1QH$_1$7T

## 2 QUESTIONS TO …

**ATZextra _ When it comes to energy chains, is the political world currently providing the right impetus?**

**MATTHIAS ZINK** _ At the moment the focus is very much on electric mobility, which actually makes a lot of sense because it is emission free at the local level. However, $CO_2$ emissions do not stem from cars alone – they are generated throughout the entire energy chain. We are not going to save the world by just shifting $CO_2$ balances. We have to look at the entire energy chain. In order, for example, to make use of the increasingly widespread production of volatile renewable electrical energy, various forms of intermediate storage must be established, including hydrogen. In the future, we must also build a comprehensive hydrogen economy – both for direct use in fuel cells and for further processing into synthetic fuels. We have 1.3 billion vehicles in the world, the majority of which are powered by internal combustion engines. If we add only 20 % of synthetic fuel to their supply, we will have taken a major first step towards solving the $CO_2$ problem. In order to keep Germany at the forefront as a leading site for mobility, we need to be open to new technologies – including infrastructures and supply solutions. With a sole focus on electro-mobility, I am concerned that this will ultimately disappoint people, especially in rural regions in Germany. The consequence is that people have to change their mobility habits drastically and have to bear a disproportionate share of rising costs.

**To what extent does Schaeffler benefit from synergies between automotive and industrial know-how regarding development projects in the field of energy chain?**

Schaeffler certainly benefits from its broad positioning in the „industry“ and „automotive“ sectors and is therefore intrinsically involved in the entire range of the energy chain. Wind energy, for example, continues to be a growth sector, and gradually we also notice efforts by wind farm operators in the area of energy storage. The decisions taken at the Paris Climate Conference in 2015 are significantly more far-reaching than just the „transport“ or „automotive“ sector – they also include industry, buildings, and the energy sector. For this reason, new business potential arises for us in both sectors, but completely new ideas and fields of activity are also emerging.

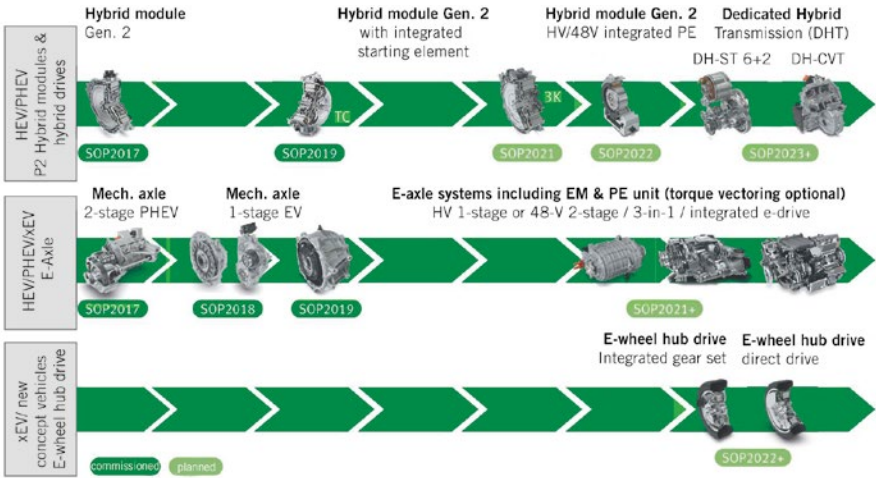
**Matthias Zink**
CEO Automotive OEM

Schaeffler understands the entire energy chain, from energy generation and storage, through to energy use in mobility


Power
electronics
P2-hybrid-module
Battery
Power electronics
E-Wheel Drive


# Solutions for all Drive Concepts

In 2030, around 30 % of all newly registered passenger cars are expected to be powered exclusively by electricity, 40 % by a hybrid system, and 30 % by pure combustion engines. Schaeffler is further developing all three drive concepts simultaneously in order to minimize $CO_2$ emissions. The focus is on electrification as one of the most important drivers of future innovation.

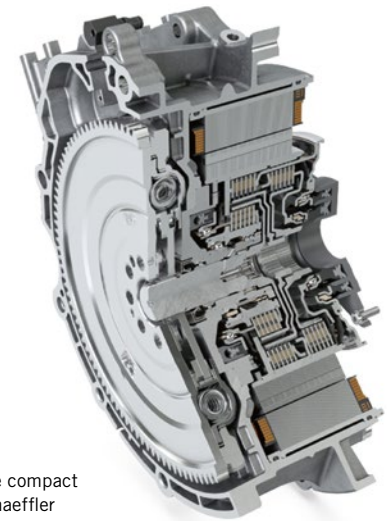



Product roadmap for electric drives

## DIVERSITY INCREASES COMPLEXITY

Germany is aiming to achieve virtually carbon-neutral mobility by 2050, most of which will probably be powered by battery electric drives. This goal will be pursued in stages and that transition phase is characterized by a wide range of different drive solutions that are available on the market concurrently. When it comes to combustion engines, fuels from regenerative sources (e-fuels) can significantly reduce the $CO_2$ footprint.

Schaeffler has analyzed numerous market studies and compared the findings to our own research, in order to gauge the relative passenger car market share of various drives by 2030. The most likely scenario is a 30-40-30 split: 30 % of new passenger cars worldwide will be entirely powered by electricity. Hybrid vehicles will account for 40 % of the total and 30 % of passenger cars will be powered by a combustion engine exclusively. The diversity of concurrent forms of motorization increases the effort involved in and complexity of research and development, since all drive types must be optimized in parallel and improved in terms of sustainability and customer benefit. Classical development approaches and structures are reaching their limits here. Instead of developing the engine, transmission and electrification systems separately, Schaeffler is pursuing the concept of optimizing the drive as a complete system.



The compact Schaeffler P2-Hyrid-Module enhances existing drive concepts and sustainably reduces $CO_2$ emissions

## PLATFORM CONCEPT

Schaeffler began developing electric drives as part of the overall system at an early stage and has gradually expanded its expertise regarding combustion engines and transmissions to include expertise in this area. The new products are based on a platform concept, which allows variations of the engine, mechatronics, thermal management, power electronics, and control software and hardware for the various hybrid configurations to be generated from one basic design.

## P2-HYBRID-MODULE

Since 2017, Schaeffler has been mass producing complete second-generation hybrid modules with high-voltage technology for the Chinese market. The system is designed for hybridization in the so-called P2 arrangement, in which the electrical power between the combustion engine and transmission is fed into the driveline. A modular system creates a high degree of flexibility that takes application-specific requirements into account. The electric motor output can be scaled between 20 and 125 kW, allowing both full and plug-in hybrid vehicles to be equipped with the system. Schaeffler‘s experience in the field of conventional drives led to a highly integrated and compact hybrid module. For example, the separator clutch is accommodated in the engine rotor to save space in order not to increase the module‘s overall length. While this is designed for torques of up to 300 Nm, the starting clutch can transmit up to 800 Nm and is therefore also suitable for electrifying heavy vehicles with high-torque combustion engines. Further advantages of the system are reduced drag losses in hybrid mode due to the decoupling of the combustion engine and a comfortable and quick restart from electric driving.

The third generation of the P2-Hybrid-Module will soon go into series production. It is even more compact and can therefore be more easily integrated into the vehicle’s driveline. For example, the starting element, previously designed as an add-on part, was integrated into the module for this purpose.

As with conventional drives, there also are regional differences in customer preferences for hybrid systems. The US market continues to be dominated by large and heavy vehicles with torque converter automatic transmissions. In conjunction

with a P2-Hybrid-Module, this results in an installation length that is not feasible for all vehicle concepts. Schaeffler has therefore developed two highly integrated systems with customer-specific starting elements for the new generation of hybrid modules, one with an integrated triple clutch and the other with an integrated torque converter. While the system with clutch will be ready for series production in 2021, production of the converter version has already started in 2019. One challenge in integrating the torque converter was its dimensions, because conventional components of the required performance class are actually too large for the module housing. With the aid of a separate vibration damper, which supports the converter in compensating torsional vibrations in the drive, we were able to reduce it by the required amount. Another optimization of the system concerns the electric motor. It is now produced in-house and is designed for high continuous outputs of up to 70 kW. Instead of conventional water cooling, it is equipped with active oil cooling for both rotor and stator.

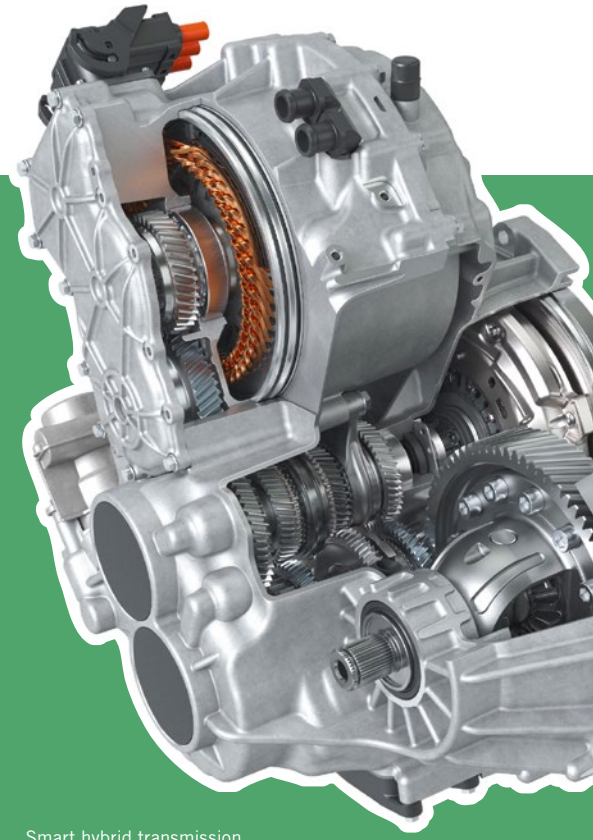
In the future, hybrid drives will become more and more popular. As the number of units increases, so do the possibilities for system integration. If, for example, the hybrid components are used directly in the transmission, this results in lower weight and space requirements as well as a simplified transmission structure. Schaeffler is currently developing various concepts for dedicated hybrid drives to production maturity.

## E-AXLE DRIVES AND TRANSMISSIONS

With electrified axle systems, the drive motor is mounted directly on the front and/or rear axle. They are suitable both for hybrid concepts and for vehicles driven entirely by electric power. Similar to the modules for P2 hybridization, the development of e-axles is based on a cost-saving platform concept. The specific customer demands for all-electric vehicles and for full and plug-in hybridizations can be met with a range of technical solutions. In 2017, Schaeffler started series production of e-axles for plug-in hybrid drives in China. The module, which weighs only 25 kg, delivers a maximum output of 88 kW and a maximum torque of 195 Nm. The design objective of having compact dimensions was achieved through the use of an offset axle arrangement with intermediate shaft. Thanks to the integrated two-speed transmission, the e-axle module offers high starting torque on the one hand and covers a wide speed range on the other. In addition, the transmission has a neutral position that decouples the electric motor from the power flow when its power is not required. This results in efficiency advantages due to lower drag losses and non-existent zero load losses of the electric motor.

In addition to complete drive systems, Schaeffler develops separate transmission modules for electric axles. In 2018, transmission units in both axially parallel and coaxial designs went into series production with the Audi e-tron. In this application, the coaxial variant provides the rear-wheel drive, while the parallel-axle variant on the front axle enables all-wheel drive. The central element of the highly integrated transmission units is the multi-stage planetary gear set developed by Schaeffler in combination with an innovative spur gear differential. The small dimensions of the gearboxes benefit the limited space available at the front and rear axles. Despite an axial length of only 150 mm, the coaxial transmission enables an input torque of 400 Nm at a weight of only 16 kg. With a torque density of 230 Nm/kg, it offers the best performance in the industry. The next development stage of Schaeffler‘s e-axles is expected in 2021. The new system combines the experience from previous development projects for e-axles and e-transmission in a single design. This includes the highly integrated axle drive system, a single or twin-speed transmission as well as highly efficient electric motors from our own production. Different models for 48- and high-voltage applications cover a power range of up to 150 kW (peak) at 360 V.

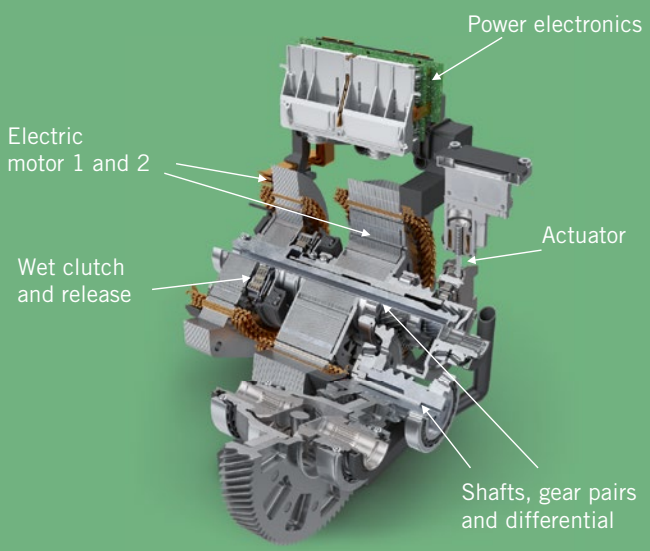
The e-axle from Schaeffler meets the requirements of both hybrid and fully electric vehicle drives



Smart hybrid transmission (DH-ST 6+2) for plug-in hybrid vehicles

## *DEDICATED HYBRID TRANSMISSION*

The current hybridization strategy of automobile manufacturers is generally based on a platform concept in which various configurations for combustion engine, transmission, and electrification are combined in a flexible way from a modular drive system depending on the degree of electrification. The hybrid module is often placed between the combustion engine and the transmission in a P2 arrangement as an add-on solution. This gives automobile manufacturers freedom with regard to the development and production of hybridized vehicle models, as even smaller quantities can be economically viable. However, hybridization will soon become more or less standard in many vehicle segments. With increasing production volumes, the demands on hybrid design are changing. Based on this approach, Scheffler is developing the so-called Dedicated Hybrid Transmission (DHT). The electric drive and transmission are combined in such a way that a self-contained construction and functional unit is created. This makes it possible to simplify the mechanical part of the transmission, for example by eliminating the reverse gear, the function of which can be performed using one of the electric machines in the transmission. Schaeffler has examined various DHT concepts in benchmark analyses and evaluated the main advantages and disadvantages. In addition to the DHT with CVT (continuously variable transmission), the so-called Schaeffler MultiMode and the DH-ST 6+2 were particularly effective. Both approaches cover the entire driving spectrum of the vehicle with a relatively simple transmission structure. The DH-ST 6+2 is based on an automated manual transmission and offers two electric and six mechanical gears. The electric motor, which works in parallel with the combustion engine, has two transmission ratios allowing it to be operated very efficiently even at high driving speeds. There are also two transmission ratios available for the combustion engine. A type of multiplication gear between the two partial transmissions ensures that the combustion engine also uses the partial transmission of the electric path, so that four additional gears are available. This saves a considerable amount of effort, as only five gear levels are required for the six gears due to the dual use of one gear level. Compared to a dual-clutch transmission with a P2 hybrid arrangement, the separation clutch between the P2 e-machine and the crankshaft, one of the two dual clutches, and a complete transmission shaft including bearings and gears are no longer required. Simulations done by Schaeffler show that sporting performance as well as very low fuel consumption of around 4.5 l/100 km can be achieved in the WLTC with the DH-ST 6+2 and a system output of 220 kW.
The MultiMode hybrid transmission has an even simpler design. It impressively com-




**Main features of the MultiMode:**

- Innovative transmission concept for full and plug-in hybrid applications
- Excellent driving comfort and performance (2500 Nm/125 kW)
- Extremely compact design and reduced complexity
- High e-range and efficiency
- Very good cost potential

Hybrid transmission concept MultiMode

bines a minimum number of components – the transmission only needs a fixed ratio – and an extremely efficient and comfortable e-drive mode without gearshifts or traction interruption. The concept is based on two electric machines (one serving as a generator and one as a traction motor). The combustion engine and the first electric motor (generator) of the hybrid transmission are mechanically coupled in a fixed manner via the transmission input stage. The 125-kW electric drive motor is also rigidly connected to the drive wheels via two spur gear stages and the differential. With the aid of a separating clutch between the two electric machines, different hybrid operating modes can be selected. When driving fully on electric power with the separating clutch open, the e-traction motor drives the vehicle. The combustion engine and electric generator are decoupled from the power flow in order to minimize drag losses. This operating mode is particularly suitable for low and medium driving speeds with low power requirements. If speeds are still low, but power consumption is high, or if the vehicle's battery is to be charged by the combustion engine, it switches to serial hybrid operation. This also applies to the so-called State-of-Charge (SoC) mode, in which the total energy content of the battery is kept at a constant level. When the separating clutch is open, i.e. without a mechanical connection to the wheel, the combustion engine drives the generator. The electrical energy from the generator is converted into drive power by the e-traction motor and/or stored temporarily in the vehicle battery, depending on demand. A parallel hybrid mode is available for high driving speeds. The power of the combustion engine is transmitted directly to the drive wheels by the closed separation clutch. The connectable electric motor enables increased overall performance and longitudinal dynamics via the boost function.

## 2 QUESTIONS TO ...

**Dr. Jochen Schröder**
President of Schaeffler's E-Mobility business division

**ATZextra _ Which role does 48-V hybridization play in your development strategy?**
**DR. JOCHEN SCHRÖDER** _ At Schaeffler, we see 48-V hybridization as an attractive and cost-effective way of electrifying conventional drivelines with peak outputs of up to 20 kW without fundamental adjustments to the overall architecture. The energy recovered in the deceleration phases in particular means that such a system can lead to considerable consumption and $CO_2$ reductions of up to 15 % in the WLTC. In addition, 48-V hybridization can further improve the efficiency, performance, and emission behavior of the combustion engine. We at Schaeffler have focused our development strategy for 48-V solutions on P2 hybrid applications with the electric motor between K0 and starting clutch and on 48-V e-axles. For example, if a mechanical all-wheel drive is replaced by a 48-V electric axle, $CO_2$ savings of up to 24 % are possible in the WLTC.

**The concept of a dedicated hybrid transmission only makes sense when high unit numbers are expected. How do your customers, the automobile manufacturers, react to this approach?**
Compared to other hybrid architectures, the complexity of a dedicated hybrid transmission can be significantly reduced by reducing the number of components. This allows for enormous cost advantages, especially with large volumes. In order to achieve the very ambitious $CO_2$ targets (EU: car fleet average for new registrations 59 g/km by 2030) and to avoid substantial fines, our customers only have the option of increasingly opting for plug-in hybrids and all-electric vehicles with batteries or hydrogen fuel cells. Many of our customers are consistently forging ahead with driveline electrification and expect a significant increase in the volume of plug-in hybrids and battery-powered electric vehicles by 2030. We at Schaeffler are therefore actively pushing ahead with the development of dedicated hybrid transmissions and are confident that this technology will make a decisive contribution to enabling our customers to achieve their ambitious fleet targets for $CO_2$ emissions.

Stator with flat wire for high-performance drives such as alternators, electric, and hybrid vehicles

## *DEVELOPMENT AND PRODUCTION OF ELECTRIC MOTORS*

A key component of electrification is the drive motor. Its key parameters significantly determine the performance, package, and cost-effectiveness of the entire drive system. Not every type of electric motor is equally suitable for all electric mobility applications. From the system point of view, it is possible to distinguish between units that run at the speed of the combustion engine or the axle shafts, on the one hand, and fast-rotating electric motors, which are geared back to slow speed before impacting the driveline, on the other. These motor types have to be modeled for voltage levels of 48 and 400 V, and up to 1000 V for the high-performance range. Due to their compact design, Permanently energized Synchronous Motors (PSM) have established themselves throughout the industry as the standard solution for passenger car applications and light transporters up to 3.5 t – regardless of the performance requirements. Schaeffler has set up a project program for the production-ready development and in-house production of electric motors in order to accelerate the further development of electric motors and to improve synergies in the overall system. The product line covers the different requirements for the individual applications using a modular system. The range covers voltage levels between 48 and 800 V and peak performances from 15 to 300 kW. The lower power range is designed for applications with mild hybridization, where the electric motor is usually housed in the transmission of the drive. Full hybrid and plug-in hybrid vehicles require engine outputs of 40 to 130 kW. The high-performance motors of the modular system are suitable for electric axle drives of all-electric vehicles with a characteristic power requirement of between 100 and 200 kW, and up to 300 kW for sports cars or particularly heavy SUVs. Schaeffler uses its extensive knowledge of metal processing to transfer prototype engines into high-volume products. This applies, for example, to production steps such as punching components from strip steel, chipping, or assembly. Further specific skills were integrated into the process via company acquisitions, so that the electric motors can be manufactured entirely within the company. For example, the acquisition of Elmotec Statomat GmbH

**Hybrid Modules**

Dry or wet E-Motors with oil cooling integrated into P2-Hybrid-Modules together with clutches and actuators

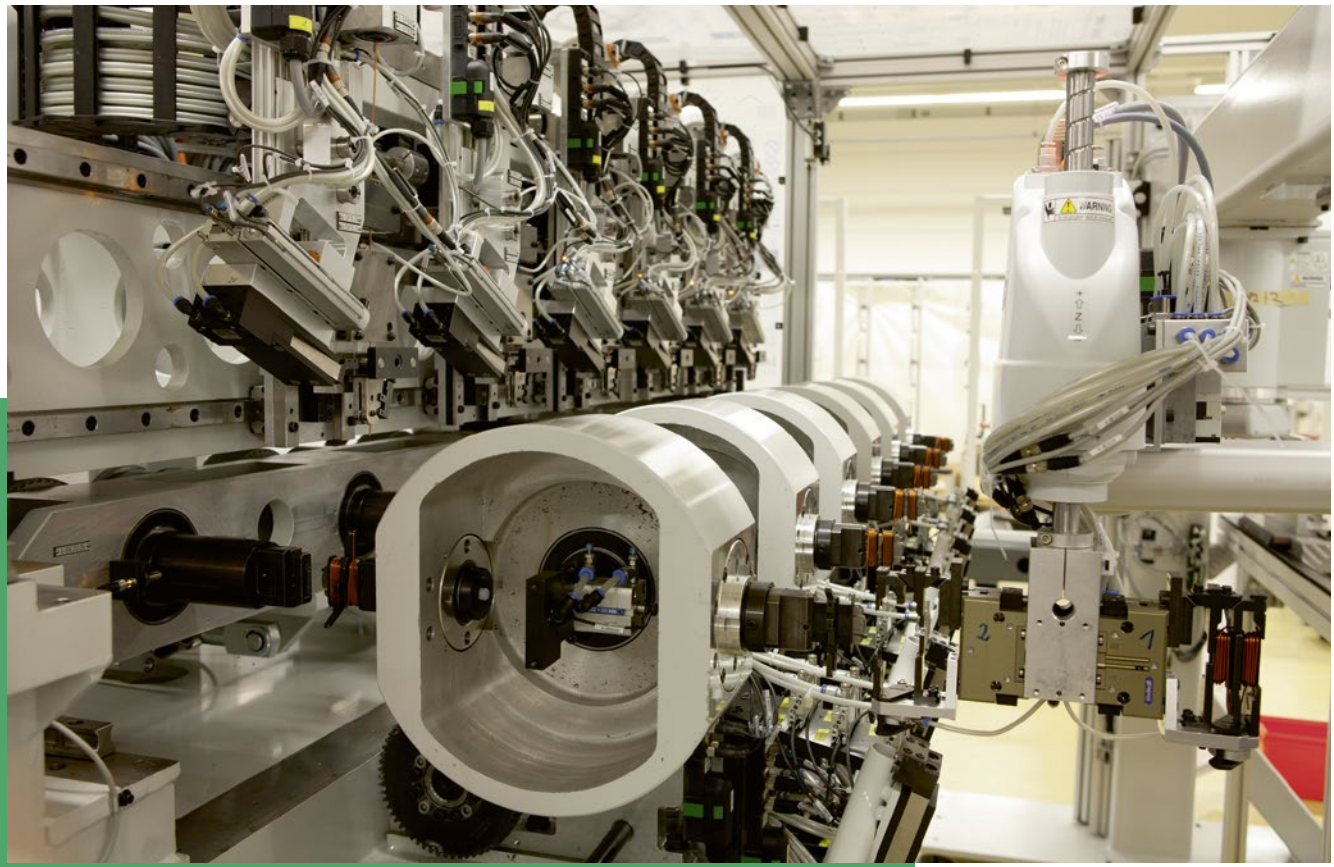
**Dedicated Hybrid Transmissions**

Oil cooled E-Motors integrated into Dedicated Hybrid Transmissions (DHT)

**E-axles**

E-Motor integrated into One- or Two-speed E-axles

Spectrum of applications

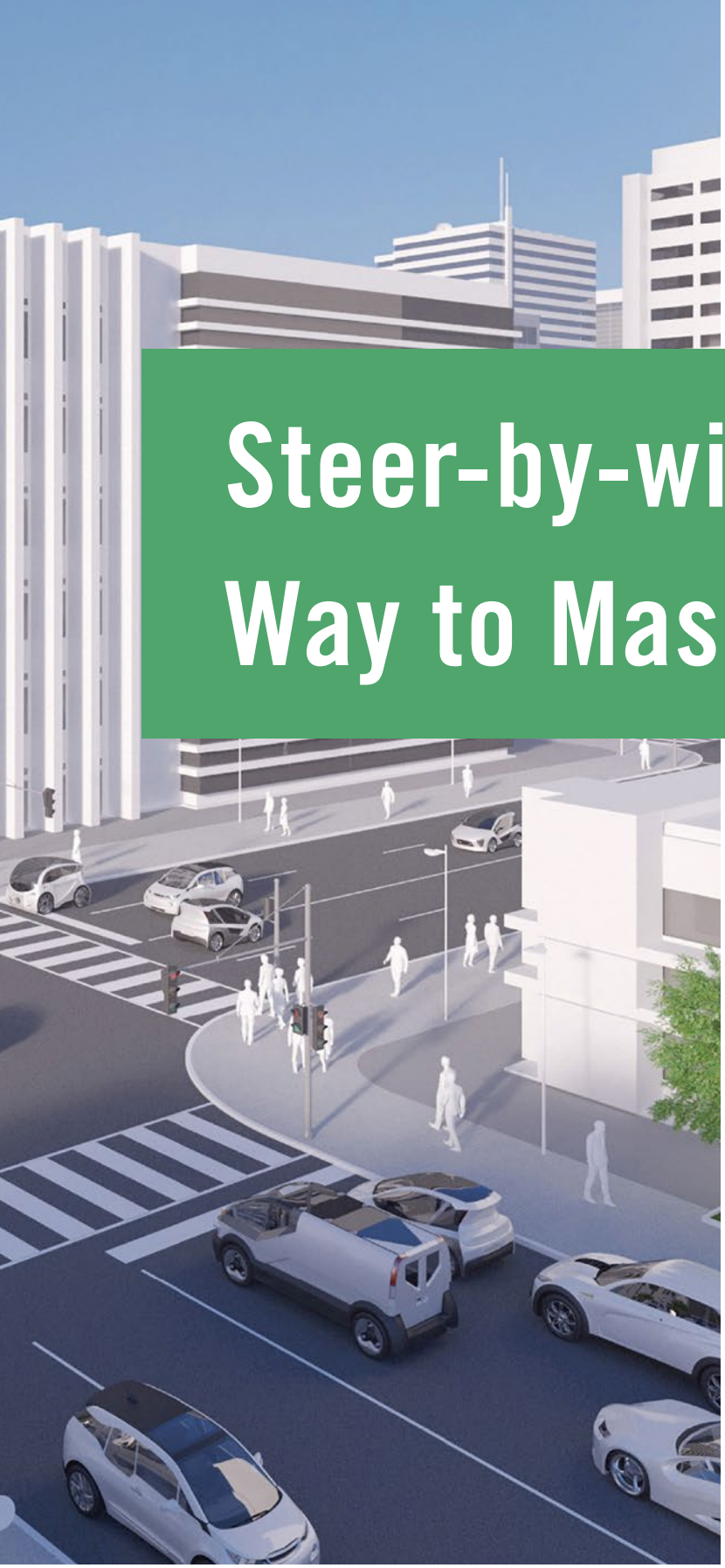


Automatic six-spindle winding machine for large series production – for quantities of up to one million units

at the end of 2018 closed a crucial technological gap with regard to the manufacture of rotors and stators.
This company is the world's leading manufacturer of production machines for the large-scale production of electric motors and has unique expertise in the field of winding technology. The right choice and production of stator winding is part of the core know-how in the production of motors for electric drives. Various concepts are currently being pursued in the automotive sector, such as distributed winding, concentrated winding, and hair pin winding. All concepts offer advantages and disadvantages. High performance density often has to be bought at the expense of more complex production and higher costs. A good alternative is wave winding, in which the distributed winding is made in a kind of braiding process and then fitted into the stator slots. Elmotec Statomat is a technological leader in the field of so-called rod shaft winding. In this process, the winding wire is guided in wave form around the stator. In terms of power density, effectiveness, and efficient mass production, the concept is regarded as the best concept for the future. When designing the motor for the respective application, peripheral conditions such as the expected driving profile, driving resistances of the vehicle, and installation space requirements must be taken into account. Questions such as the dimensioning of the engine, the cooling concept, and the connection to the driveline can only be answered by an overall system analysis that includes the mechanical components, power electronics, and control software. Schaeffler views the electric motor as a component of the overall system and is able to optimally adapt it to customer and system-specific requirements based on our experience with the overall system. Schaeffler is currently creating the technical and organizational prerequisites for mass production of electric motors. Production will start in 2020 with the manufacturing of an electric machine for several electric vehicles for a leading European automobile manufacturer.

## Steer-by-wire for automated driving functions

The steer-by-wire steering system enables the vehicle to be guided reliably and exclusively via electronic control signals. In the future, it will be possible to dispense with a friction-locked mechanical connection between the steering wheel and the running wheels – the steering column. This enables a completely new and flexible interior design. Steer-by-wire is a key technology for autonomous driving, which is particularly dependent on a safe and highly reliable steering function.



# Steer-by-wire on its Way to Mass Production

Fully automated driving functions require new concepts for actuators and sensors as well as for the control system. Instead of mechanical steering systems, mechatronic steer-by-wire systems that do not require a steering column will become increasingly prevalent in the future. Schaeffler recognized this trend early on and consistently broadened its drive-by-wire expertise, including software development, as well as the general electronics know-how through internal growth and strategic acquisitions.

*All-in-one systems for autonomous driving functions of tomorrow*

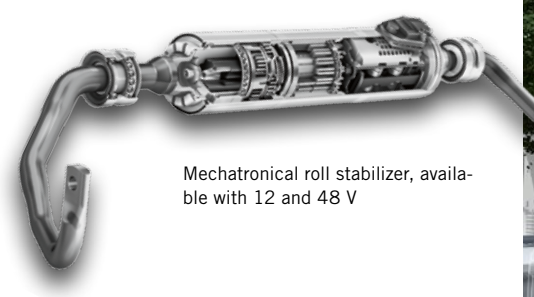
## BY-WIRE FOR ALL VEHICLE CONCEPTS

Smoothly driving through rush hour traffic while watching a film or checking your e-mails – the vision of fully automated driving promises a considerable increase in comfort and quality of life, more safety, better traffic flow, less fuel consumption, and lower emissions. For the autonomous driving functions of tomorrow, Schaeffler is developing turnkey systems consisting of mechatronic actuators and the associated software and hardware controls. The company's efforts are aimed equally at vehicles that drive 100 % autonomously and those that can be controlled either by autopilot or by the driver. At the same time, they are equally relevant for the different drive concepts, whether combustion engine, electric drive, or hybrid system. When developing systems for fully automated driving functions, Schaeffler can draw on its extensive expertise in mechanical components such as bearings and ball screws as well as on experience gained with mechatronic chassis systems. One example of this is the innovative mechatronic roll stabilizer (intelligent Active Roll Control, iARC), which minimizes the rolling movement when cornering or the rocking of the vehicle when crossing obstacles such as potholes or edges on one side. It thus makes a significant contribution to increasing safety and comfort. It also helps to reduce fuel consumption and emissions compared with hydraulic systems. Another advantage of the mechatronic roll stabilizer comes into play when driving fully automated: Since the vehicle occupants concentrate on other things than the actual driving process for a long time while driving, there is a growing risk of developing what is known as travel sickness, which manifests itself as nausea. Especially on winding roads, roll stabilization ensures fewer body movements and thus improves the well-being of vehicle passengers.

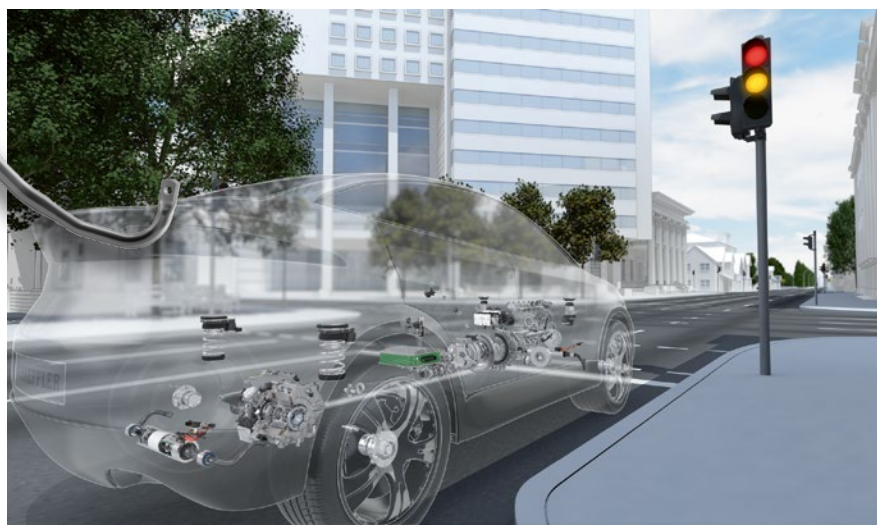
## REAR AXLE STEERING

Schaeffler is developing steering systems specifically for use in autonomous vehicles in which the steering commands are no longer transmitted mechanically by the steering column but within milliseconds via cables as so-called steer-by-wire using electrical signals. A development project for rear axle steering systems was started in 2018. Intelligent Rear Wheel Steering (iRWS) increases driving comfort and handling, and also improves the intervention options of automated lane change assistants.

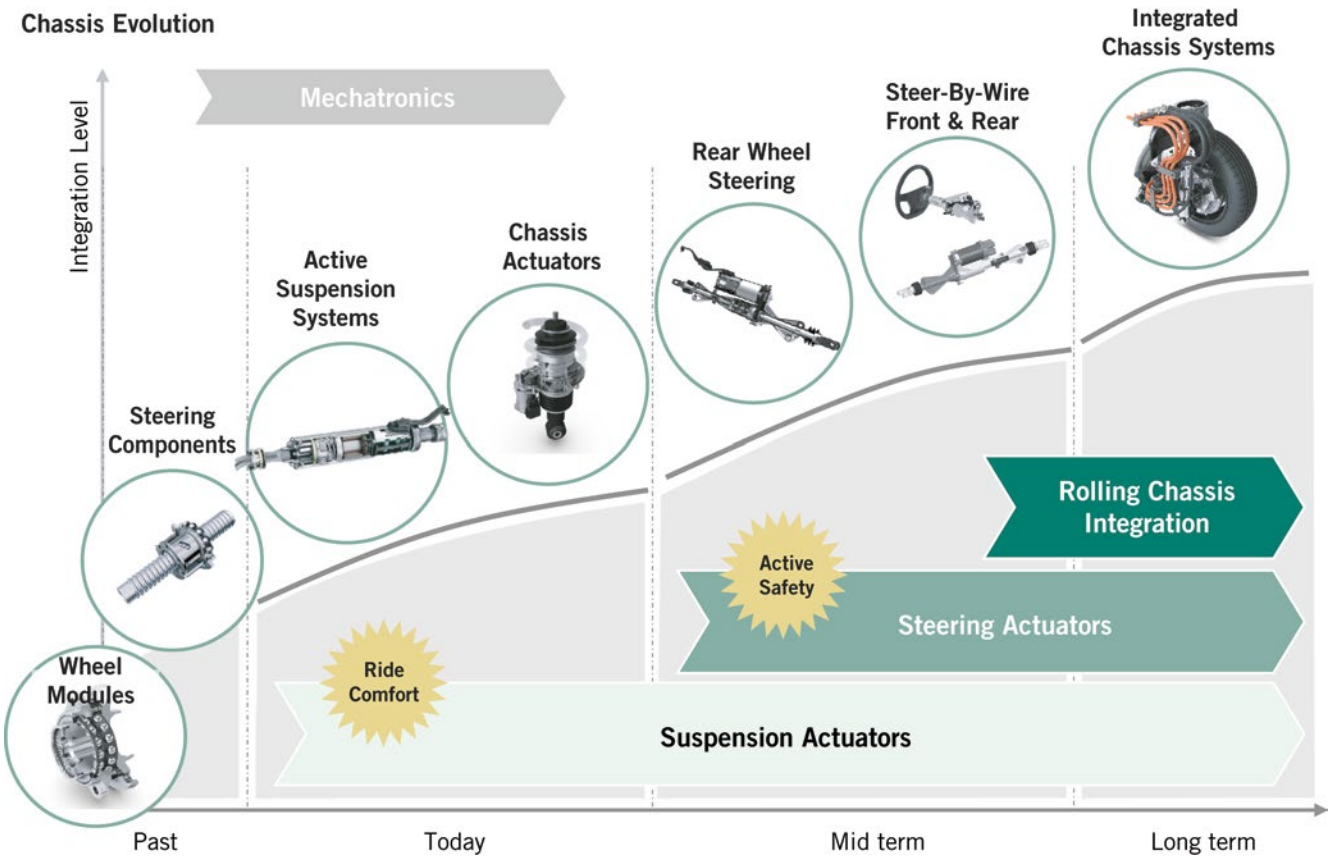
The rear axle steering of electric vehicles also helps to compensate for a frequent design deficiency. If, in these vehicle concepts, the traction battery for the drive is housed in the underbody and is comparatively large due to the high range requirement, the wheelbase



Mechatronical roll stabilizer, available with 12 and 48 V



The mechatronic roll stabilizer can be mounted on both the front and rear axle




Roadmap: development of chassis systems at Schaeffler

inevitably increases sharply. Although this increases driving stability, it also has negative effects on the lateral dynamics of the vehicle. In these cases, the supporting steering movements of the rear axle improve handling while driving. They also reduce the turning circle when maneuvering, which considerably simplifies the search for a parking space in the city, for example. As benchmark studies show, Schaeffler‘s rear axle steering system has a low power requirement thanks to friction-reduced bearing positions in the steering actuators and operates extremely efficiently. In addition, the highly integrated design results in weight advantages over competitor solutions. The system has now reached the B-sample stage of maturity and series production is expected to begin in 2023 depending on customer product launches.

## FRONT AXLE STEERING

Schaeffler is also developing a steer-by-wire system for the front axle. Here, too, both the mechanical components and the mechatronic actuators are produced in-house. The advantages of a steer-by-wire system instead of a conventional mechanical steering system include greater freedom in designing the vehicle interior and the entire vehicle package, greater crash safety, easy integration into different vehicles, and a high degree of customization to suit the needs of the occupants. These advantages also apply to passenger cars that are only driven automatically for a limited period of time. Just by eliminating the steering column, completely new possibilities arise for the conceptual design of vehicles and their interiors.

For example, concepts are conceivable in which the steering wheel in autonomous driving mode disappears into the dashboard allowing for additional space for the passenger in the driver‘s seat.

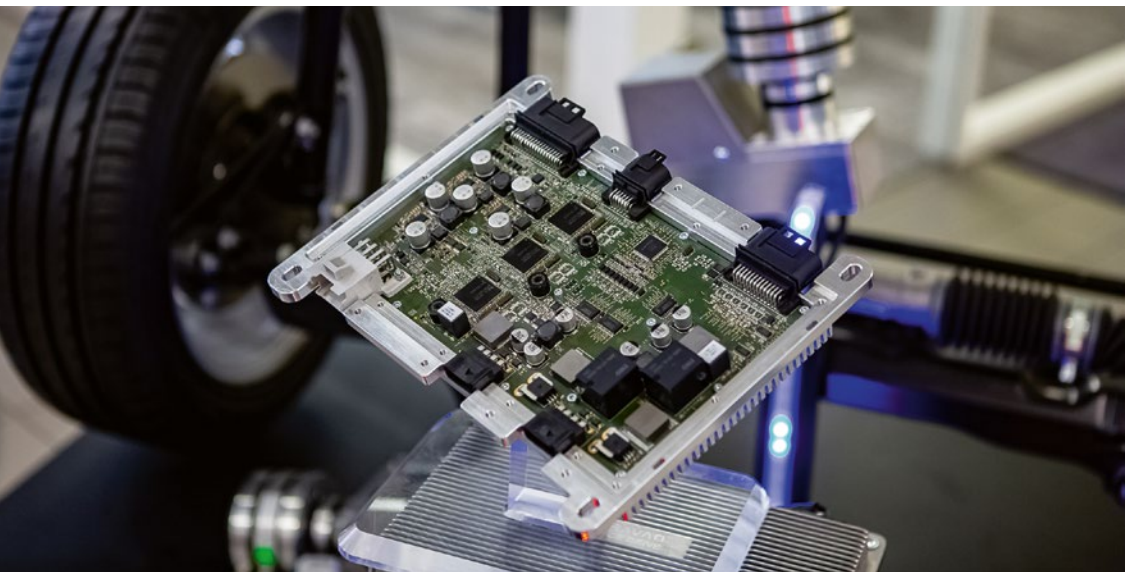
## SPACE DRIVE TECHNOLOGY

In order to make full use of the possibilities offered by steer-by-wire techno-

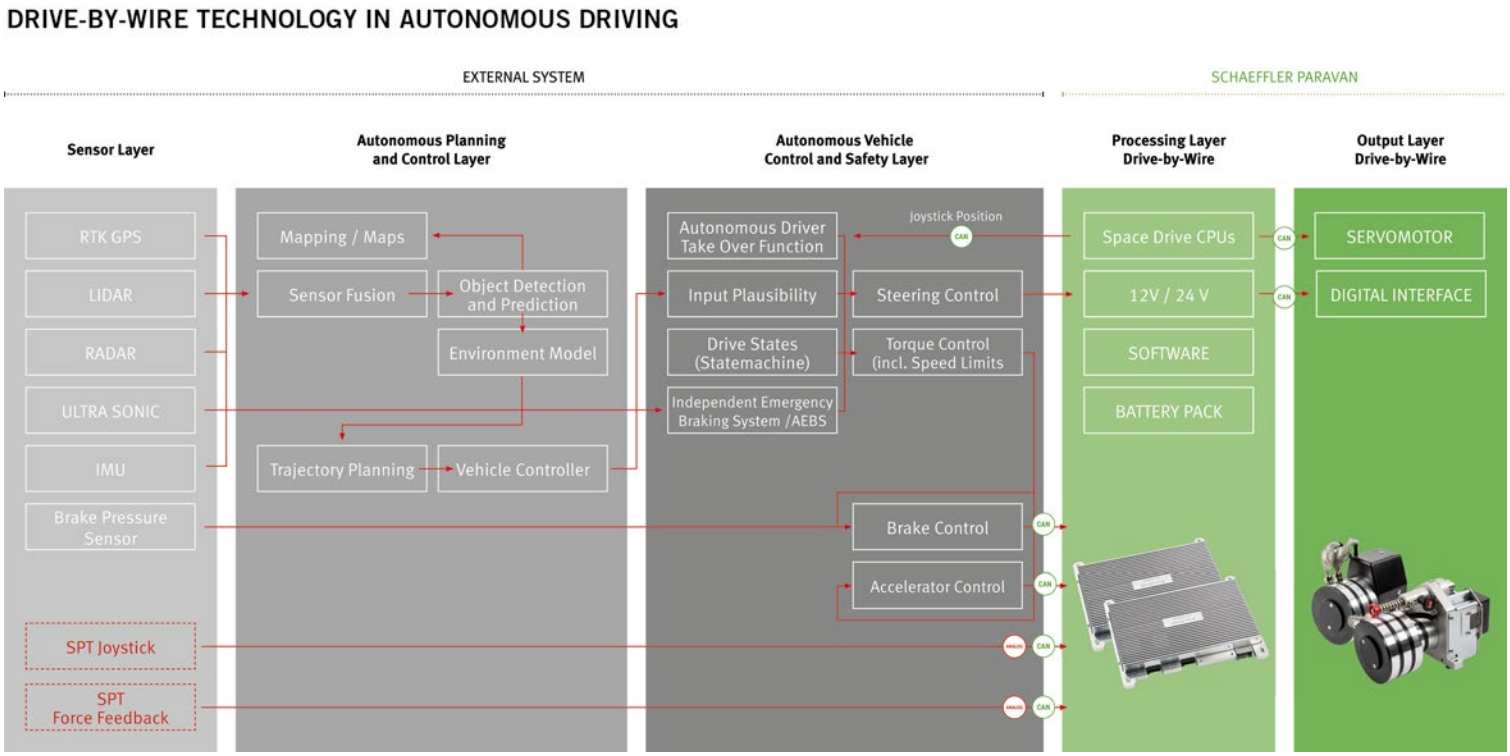
*Triple redundant architecture concept for absolute reliability.*

logy, for example with regard to packaging, the system must, however, be designed in such a way that it does not require any mechanical or hydraulic fallback option at all. The functional safety of the overall system is, therefore, one focus area for developing the steer-by-wire architecture. In the case of safety-relevant functions such as steering or braking, a so-called fail-safe circuit, in which a system switches to a protected state in the event of a problem, is insufficient. Rather, functionality must be maintained until the vehicle comes to a standstill, i.e. it has to work „fail-operationally“, without endangering passengers or others on the road. Therefore, Schaeffler and Roland Arnold, the founder and managing director of Paravan GmbH, established a joint venture called Schaeffler Paravan Technologie GmbH und Co. KG in 2018 to develop innovative drive-by-wire architectures to mass production maturity. The core of the project is the industrialization of Paravan‘s existing and well proven by-wire system called Space Drive, a digital-electronic control system in hardware and software for drive-by-wire functions such as steering, gearshift, throttle or brake. A key component of Space Drive is the open interface management between sensors, driving intelligence and drive-by-wire technology, which makes it truly unique for developers. Originally, Paravan had developed this technology for people with physical disabilities to enable them to control a vehicle with absolute reliability on a completely electronic basis. The architecture is triple redundant: If one processor fails, there are two backup systems that guarantee absolute reliability. In addition, the Electronic Control Unit (ECU) is currently the only functional solution worldwide to meet the highest quality and safety requirements, in particular the demanding functional safety standard ISO 26262 ASIL D. Vehicles equipped and homologated with Space Drive are therefore the only vehicles of their kind to have been approved for the road worldwide. To date, Space Drive has been installed in more than 8,500 vehicles, which have covered more than 1 billion km without any accidents. Among other things, Schaeffler Paravan has proven the high potential of the technology by testing the limits of its driving dynamics in motor sports.

Since 2019, an Audi R8 LMS GT3 with Space Drive is in service in the touring car series DMV GTC in cooperation with Phoenix Racing. The current development stage of Space Drive is designed as a retrofit solution, which is licensed in conjunction with the vehicle via individual homologation. One goal of the joint venture activities is the development of a drive-by-wire system for mass production, which is homologated accordingly and can be integrated into new vehicle concepts without the time-consuming process of individual approvals. Schaeffler Paravan Technolo-



The Space Drive system from Schaeffler Paravan GmbH is a key technology for autonomous driving




Hierarchical system architecture of the drive-by-wire system for autonomous driving

gie GmbH und Co. KG is aiming for series maturity by 2021. With steer-by-wire technology, Schaeffler is taking a decisive step towards becoming a by-wire chassis supplier who develops and markets components, modules, and complete systems right through to the so-called rolling chassis. One example is the Schaeffler Mover concept. One of the special features of the autonomous robotic taxi is its four highly integrated wheel suspension units, the so-called Schaeffler Intelligent Corner Modules (iCorner), which compactly combine all drive and chassis functions including the wheel hub motor.

## COMPETENCE IN ELECTRONICS

The basis for autonomous driving functions and innovative by-wire solutions are new possibilities that arise in the field of software and electronics. The increasing digitalization of vehicle electronics and networking of systems are opening up new functionalities that were previously technically impossible or too expensive to implement.

And with the so-called Internet of Things (IoT), the individual vehicle components such as rolling bearings will be „smart“ in the future, e.g. taking over the function of sensors, being able to report their condition, and make this information available to other components and systems. One of Schaeffler‘s current development projects is a sensor wheel bearing that is able to measure forces, vibrations, and wheel temperatures. Among other things, this information allows for condition analyses of the wheel, tires, and brakes. They provide information on transport

The Schaeffler Intelligent Corner Modules integrated in the Mover ensure maximum maneuverability in the city

safety in commercial vehicles, since they can be used to detect a displaced load, determine the lateral forces on the vehicle during cornering for assistance systems, and provide information on road conditions. In recent years, Schaeffler has successively broadened its in-house electronics know-how and also strengthened its position strategically through acquisitions. One example – in addition to the joint venture Schaeffler Paravan Technologie GmbH und Co. KG for Space Drive – is the acquisition of the electronics expert XTRONIC. The Böblingen-based company specializes in the development of specific software and electronic solutions for automotive applications. Among other things, their portfolio includes developments in the fields of automated driving and electromobility as well as functional safety, methods, tools, and test systems. For example, XTRONIC has developed the proven Space Drive System in close cooperation with Paravan Technologie GmbH und Co. KG.

## 2 QUESTIONS TO ...

**ATZextra _ Why does Schaeffler continue to expand the company's efforts regarding chassis systems?**

**DR. THOMAS FIEBIG** _ One thing is clear: regardless of the type of drive, the chassis will also be needed in the vehicles of the future. This applies to classic components such as our wheel bearings as well as to all the challenges that arise with a changing mobility. The key drivers that we have identified are autonomous driving, the need to reduce $CO_2$ emissions, demographic trends, and the zero-error strategy. If we want to master the challenges associated with these drivers, we must focus increasingly on the more complex mechatronic systems in the chassis area. We have been on the market with the first systems from this sector for several years now. This is now followed by steering systems for the rear and front axles. We foresee only steer-by-wire systems being used in these vehicles in the future. In order to be sufficiently equipped for the challenges in the areas of mechatronics, software, and functional safety in addition to the already existing high mechanical competence for the development and production of these systems, we have strengthened our position with targeted acquisitions (Paravan and XTRONIC). As a result, we at Schaeffler will successfully launch these systems on the market.

**What obstacles still need to be overcome in order for the Space Drive system to be approved for mass production?**

The Space Drive system, as currently already used in more than 8,500 road legal vehicles, has an „operating experience" of more than one billion kilometers, without a critical situation arising for the respective drivers. The concept behind Space Drive is ideally suited for this application scenario with individual approvals. In addition to all the necessary technical adaptations for mass production, the expansion of this concept for use in high-volume production now requires that the system itself can be homologated and approved regardless of the respective vehicle. The preconditions have to be provided to ensure that no critical situations arise even when the system is used in several million vehicles and that it is functional as a „fail operational" system, i.e. even in the event of faults. In addition to statistical considerations, the system design must therefore be able to achieve this - and thus overcome the hurdle of general approval.

**Dr. Thomas Fiebig**
Senior Vice President R&D Chassis Systems at Schaeffler


The R8 LMS GT3 making history on the track: For the first time a racing car has completed the Nordschleife track completely without a steering column

## *RACING CAR WITH STEER-BY-WIRE TECHNOLOGY*


End of a successful racing kick-off: At the Schaeffler-Paravan-Race-Weekend, the R8 with steer-by-wire made its successful debut and was able to advance to the top positions from behind

As part of the 24-hour race at the Nürburgring 2019, Schaeffler Paravan Technologie GmbH & Co. KG, in cooperation with Phoenix Racing, presented the first racing car with a Space Drive steer-by-wire system approved by the German Motor Sport Association (DMSB). The Audi R8 LMS GT3 is equipped with a special force feedback steering wheel. The steering commands are transmitted within milliseconds „by wire“ using electrical signals via the triple redundant drive-by-wire system. This means that there is no mechanical connection between the steering wheel and the steering axle. In the future, the vehicle will participate in the DMV GTC touring car series. The modified Audi R8 LMS GT3 already performed impressively when it entered the series. Even outside the competition, driver Markus Winkelhock was able to advance to fifth place in both DMV GTC races at the Schaeffler Paravan Race Weekend. „You have to act faster in the racing car than in a road vehicle“, says race driver Markus Winkelhock. „If the vehicle breaks out, you have to be able to make very fast steering movements to the right and left. At the beginning I had my doubts whether the engines would be able to meet these requirements. But that was not a problem: Steering is incredibly fast and incredibly precise.“

The extreme demands in motorsport offer an ideal testing ground for the further development of the drive- or steer-by-wire system based on Space Drive. For Schaeffler Paravan Technologie GmbH & Co. KG, too, testing under racing conditions is a crucial precondition for bringing such solutions into series production.

# Redefining Mobility

Urbanization continues to increase worldwide. Existing metropolises are becoming ever larger and grow into gigantic cities, sometimes with ten million or more inhabitants. While at the same time new megacities are emerging, especially in Asia. Climate change and environmental protection are playing an increasingly important role in public perception and are changing traditional social patterns of behavior.

## UTILIZING SCARCE SPACE FOR MOBILITY

Digitization creates new possibilities for communication and sharing data that will change the mobility behavior of city dwellers permanently. Urban planners of the future will have to find new solutions to these issues. They are faced with the challenge of making optimum use of the limited amount of space available for traffic in order to ensure the transportation of people and goods, even in the event of impending traffic collapse due to rising population numbers, and also to keep air pollution to a minimum. The answer lies in new mobility concepts that offer maximum transport performance with minimum space requirements. New and interconnected mobility solutions enable fast and highly automated transportation within the city. Instead of conventional cars and vans, electrified and automated robotic taxis and delivery vehicles as well as small vehicles will shape the future road landscape of metropolitan areas. They do not produce emissions locally, which increases the quality of life in the city, and the regeneratively produced energy for charging their batteries protects the climate [1]. With the Bio-Hybrid and the Schaeffler Mover, Schaeffler is developing two very differently positioned concepts as building blocks for future urban mobility.

**REFERENCE**

**[1]** Gutzmer, P.; Wagner, U.; Zink, M.: Mobility for Tomorrow. In: Documentation Schaeffler Symposium 2018

**Dr. Dirk Kesselgruber**
President of Schaeffler's Chassis Systems Division

## 2 QUESTIONS TO ...

**ATZextra _ Why is Schaeffler working on new mobility concepts?**

**DR. DIRK KESSELGRUBER** _ The mobility of tomorrow will change dramatically and we want to play an active role in shaping it. One of the major future trends, especially in urban regions, is the rise of the sharing economy. Other trends such as autonomous driving and electrification also require technological progress. That is why it is only logical for us to deal with these megatrends. We regard ourselves as a system partner for mobility providers and are therefore developing concepts such as the Schaeffler Mover, the Schaeffler Bio-Hybrid, and the Schaeffler Kickboard. Our Mover shows the scope of the product range of our Automotive OEM division. Furthermore, it can be seen as a first step towards becoming a chassis integrator and overall system supplier. Schaeffler aims to remain the preferred and innovative partner for future mobility solutions. However, the core competence of Schaeffler products remains in the areas of engine systems, chassis systems, e-mobility, and transmission systems – therefore operating such transportation concepts is not our primary focus.

**How are the prospects for the Schaeffler Mover regarding series production?**

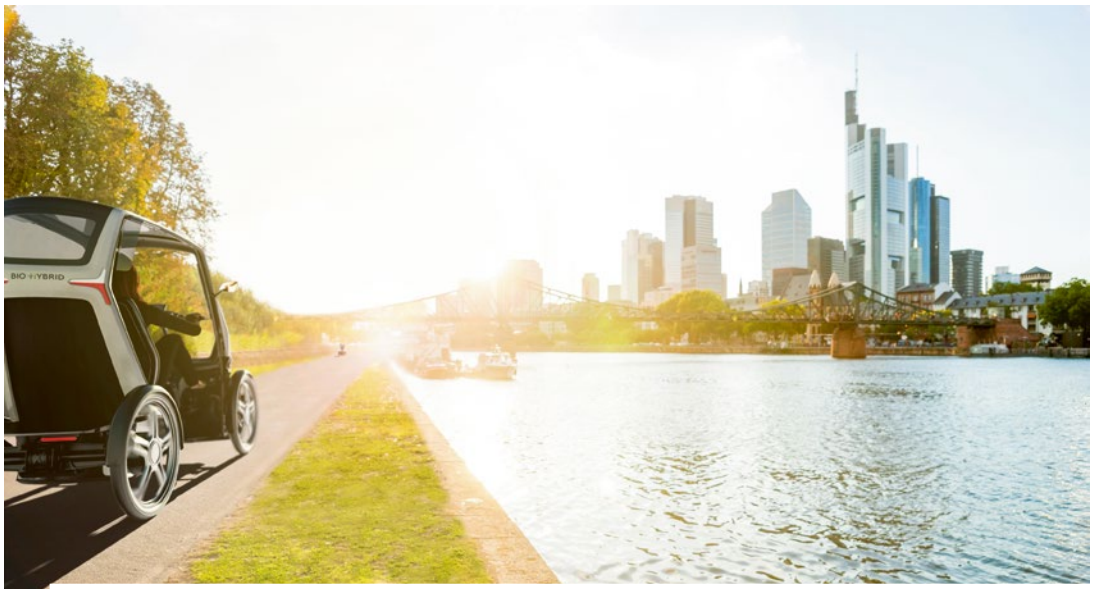
First and foremost, our Schaeffler Mover is a development platform for us. When you approach the subject of brakes, steering, and drive, you first have to position yourself one level above to understand everything. That's why it is important for us to participate in test projects outside Schaeffler as early as possible. This enables us to learn how this plays out in the context of an application, which performance requirements are necessary and where the difficulties are. We are well equipped to respond accordingly with products such as the compact drive module Intelligent Corner Module and Space Drive.


## *SCHAEFFLER MOVER*

People or Cargo Movers bridge the gap between urban electric mobility and autonomous driving. The driverless, electrically driven transportation systems allow fast and environmentally friendly transportation of people and goods. Currently, infrastructures for their use are being developed all over the world, so it is to be expected that they will complement local public transport in the near future and could perhaps replace it completely at a later date. The Schaeffler Mover is setting new standards in the field of autonomous transport systems with a bundle of innovative solutions. Schaeffler's concept is based on a vehicle platform that incorporates all relevant components for the driving functions, i.e. drive, battery, brake, and steering, in a compact unit known as a rolling chassis. Various vehicle variants – from robotic taxis to autonomous delivery vehicles – can be flexibly mounted on the supporting platform. The body can be separated from the platform and replaced by another so that the vehicle can be converted for a different purpose. At the heart of the platform are four Schaeffler Intelligent Corner Modules (iCorner), which are fully controlled „by-wire“ and integrate all drive and chassis components in a single space-saving unit: Wheel hub motor, wheel mounting including suspension, and the actuator for electromechanical steering. Depending on customer demand, all four modules of the vehicle can be equipped with traction motors in a four-wheel drive configuration or just the modules of one axle in a front-wheel or rear-wheel drive configuration. The Schaeffler Intelligent Corner Module offers a wheel angle of up to 90 degrees. This allows the vehicle to be easily maneuvered in narrow streets and even parked sideways to allow passengers to get in and out of the vehicle. Turning on the spot is also possible. One premise in the development of the Corner Modules was a high level of functional safety. In the event of a technical defect, steering and traction are maintained even if one or two wheel Modules are defective, because the wheel-selective drive and wheel-selective steering offer a high degree of redundancy. Schaeffler Paravan Technologie GmbH & Co. KG continues to develop the proven Space Drive technology for controlling the drive-by-wire functions of the Schaeffler Mover. The system forms the link between the control level for automated vehicle steering and the Intelligent Corner modules. In combination with GPS and environment sensors, Space Drive already offers a functionally secure basis for fully automated driving at autonomy levels 4 and 5, i.e. fully automated and driverless vehicle operation. A key topic of autonomous vehicle concepts is interconnection with the data cloud, for example in order to obtain information about traffic events or vehicles in front at an early stage while driving. In the future, Schaeffler will utilize the possibilities of sharing data with a central computer network as a digital twin. A simulation running parallel to the driving operation is to be continuously fed with current operating and status data. In addition to direct operational support, such as searching for the optimal route, the system will in future provide fleet operators with valuable information to support decision making, for example by providing information on upcoming routine vehicle maintenance. The current version of the Schaeffler Mover has a cockpit with display instruments, joystick, and physical operating buttons. Since the vehicle does not require any operating elements for autonomous driving mode – they will then only be available for service work – the interior can be developed in future development stages to provide maximum space for passengers in compact external dimensions. The current prototype of the Schaeffler Mover is designed as a four-seated robotic taxi. The fully functional, automated vehicle can be seen in action at the International Motor Show (IAA) at the outdoor driving area. The next stage of development is an extended ten- to 14-seater version. In this particularly efficient long version, for example, the corner modules have to be designed for the higher loads and weights.

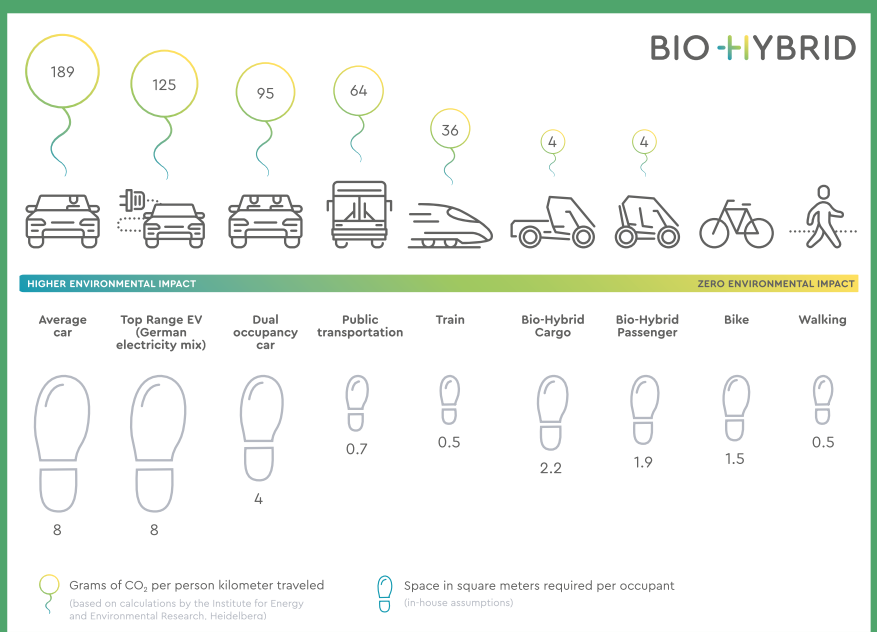
The Schaeffler wheel module

The body can be flexibly adapted to different transportation requirements



## *THE BIO-HYBRID*

With the Bio-Hybrid, Schaeffler presented a groundbreaking approach to individual mobility for urban traffic as early as 2016. The idea was further pursued by Schaeffler Bio-Hybrid GmbH, which was founded specifically for development, sales, and communication. The team behind Schaeffler's first spin-off company has the task of tailoring the Bio-Hybrid for series production. In addition to Schaeffler's own drive concept, the revisions also included the complete operating structure including dashboard and vehicle design. The Bio-Hybrid concept expands the advantages of the successful pedelec bicycles – high range thanks to electrical support of muscle power, little need for parking space and great maneuverability even in heavy traffic – to include safety, comfort, and transport performance of a light and compact four-wheeled vehicle. In addition to the roof as weather protection and the electric reverse gear, the new mobility concept offers high driving stability and good road grip. With its width of less than 90 cm and its locally emission-free 250-W electric drive, it is approved for normal cycling lanes and requires only one third of the parking space of a passenger car. The battery capacity is around 1.2 kWh but can be doubled to 2.4 kWh with a second battery. The electric starting aid works up to a speed of 6 km/h, the electric support reaches up to 25 km/h in the current configuration, in accordance with current legislation. Schaeffler Bio-Hybrid GmbH is developing the Bio-Hybrid in two body variants, both of which are based on the same technical platform. As a passenger variant for individual transportation, the vehicle is equipped with a continuous roof under which two passengers can be seated in a row one behind the other. For most applications, this capacity is perfectly sufficient, because on average each passenger car in Germany is occupied by only 1.4 people. A box available as an accessory for the rear offers a luggage volume of approx. 60 l, supplemented by additional storage space (approx. 10 l) in the rear (under the rear passenger seat). In the version for urban goods transport, the cabin ends behind the driver so that the rear structure can be flexibly adapted to the respective requirements. In addition to an open loading area (dimensions 1074 mm × 660 mm), cooling or box modules are also conceivable. Interconnectivity will play a central role in future urban mobility, especially if the concept is to appeal to a young target group. WiFi and Bluetooth connectivity as well as connection to 4G and GPS integrate the Bio-Hybrid into the digital information world. In addition, vehicle-specific additional functions can in future be easily and conveniently controlled via a smartphone or smart watch using a separate app. At the CES in Las Vegas at the beginning of 2019, Schaeffler Bio-Hybrid GmbH presented near-series prototypes of the Bio-Hybrid, which were put to the test over the course of the year. Market launch is planned for 2020. Further information on the Bio-Hybrid can be found at www.bio-hybrid.de




Comparison of the $CO_2$ footprint

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