

MAHLE

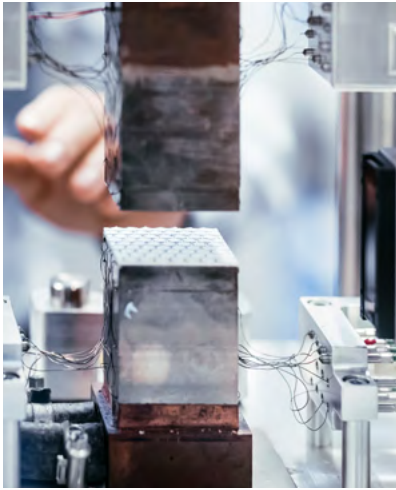


We shape
future mobility

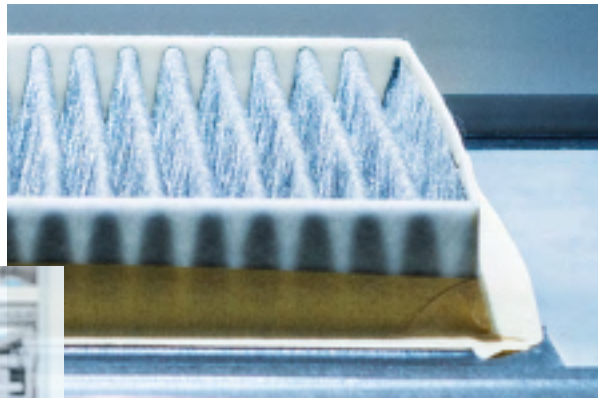




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MAHLE is a leading international development partner and supplier to the automotive industry. The technology group is now broadly positioned in the areas of powertrain technology and thermal management with a clear focus on future topics relating to mobility. As part of its dual strategy, MAHLE is working both on the intelligent combustion engine for the use of hydrogen and other nonfossil fuels and on technologies that will help the fuel cell and e-mobility achieve broad acceptance in the markets. The product portfolio of the company, which was founded in 1920, addresses all the crucial aspects of the powertrain and air conditioning technology. Half of all vehicles in the world now contain MAHLE components.
#weshapefuturemobility

In 2020, MAHLE generated sales of around EUR 9.8 billion and is represented in over 30 countries with more than 72,000 employees in 160 production locations and 12 major research and development centers. (Last revised: 2020-12-31)

**Michael Frick**

Chairman of the MAHLE
Management Board (ad interim)

Dear readers,

when the world came to a standstill in 2020, we realized how important mobility is to us. The ability to bring people together and transport goods is one of the foundations of our global society. At the same time, issues relating to sustainability, climate change, social responsibility, and diversity have come into even sharper focus. Tomorrow's mobility and transportation landscape will encompass a range of climate-friendly solutions.

MAHLE has been a reliable development and technology partner to the automotive industry for decades and, with numerous innovations, has contributed significantly to mobility in the passenger and commercial vehicle sectors in all major markets. Today, MAHLE components are fitted in every second vehicle in the world. Our Group has an important role to play, particularly in view of the targets set out by the Paris Agreement, which we fully support. We are committed to protecting the climate. MAHLE technologies are key components for the world's most efficient, cleanest, and most economical drives. We rank among the global market leaders in this field as well as for thermal management and filter technology. Our e-bike drives are efficiently connected and so slim that they make an e-bike look like a conventional bike. We now supply over 40 e-bike manufacturers worldwide.

Today, MAHLE generates more than 60 percent of its sales from products that are unrelated to the passenger car combustion engine. And this trend is still rising. These products are focused on a triad of sustainable drives consisting of the electric motor, the fuel cell, and the internal combustion engine powered by nonfossil fuels. Our commitment applies not only to our products but also to us as a Group. By 2040, we want to be a climate-neutral business all around the world. MAHLE's production locations in Germany will already be carbon-neutral by the end of 2021.

We have retained the pioneering spirit of the Mahle brothers, who founded MAHLE over 100 years ago. It guides us in developing groundbreaking ideas for environmentally friendly, climate-neutral mobility. You'll find a selection of these ideas in this brochure. I hope you find them inspiring!

Michael Frick

The mobility of the future

How will we travel in the future? How will we transport goods? One thing is clear: our future mobility and transportation landscape will be carbon-neutral. The hot topic, though, is which routes will lead us to that destination. In this interview, Dr. Martin Berger sets out his position. The Vice President Corporate Research and Advanced Engineering at MAHLE strongly believes that there is no single route; instead, we need a variety of technical solutions—because we have a variety of needs.

Dr. Berger, MAHLE is currently causing a stir with a new kind of magnet-free electric motor that doesn't require rare earth elements. Is MAHLE now focusing entirely on e-mobility?

Dr. Martin Berger: Electric motors will be a vital component in the carbon-neutral, future mobility landscape. This is because electric traction motors can be used to drive not only purely battery electric vehicles but also passenger cars, buses, or trucks powered by hydrogen and fuel cells. It's for that reason that we're giving this area of technology a lot of attention. At the same time, however, we also believe that focusing on electric drives alone will not solve all the challenges that lie ahead of us.

What do you mean, exactly?

Firstly, there are many technological fields that need ongoing development, whatever the type of drive. Take thermal management, for example. This isn't just important for combustion engines—it's also vital when it comes to fast charging for electric vehicles. What you need to understand is that fast charging is critical to the success of e-mobility, because it makes even smaller battery sizes more suitable for everyday use. But fast charging also generates a lot of heat. To take

this heat out of the system, MAHLE is working on immersion cooling systems in which the battery cells are stored directly submerged in a nonconductive liquid. But that's just one example. We're also developing new solutions in actuator engineering, filtration, and lightweight construction. At the same



time, we're applying our expertise to new forms of mobility, such as smart mobility in urban areas. And last but not least, we're pursuing the ongoing development of the combustion engine.

Why does it still have an important role to play?

Because there's no way around using synthetic fuels, if we're serious about meeting the climate targets in the transport sector. Even if there are disadvantages in terms of efficiency, vehicles with combustion engines can also be climate-neutral if they are powered by e-fuels produced using renewable electricity. The biggest advantage of synthetically produced gasoline or diesel fuels is that we can add them quickly and directly to the existing fuel system. Thanks to climate-friendly fuels, we're thus effectively reaching the existing fleet via the back door. Incidentally, we can start doing this immediately and reach almost all of the global vehicle population straight-away—with a corresponding strong leverage effect in terms of carbon footprint.

Let's go back to the magnet-free electric motor we mentioned earlier. Why is this a milestone for MAHLE?

Our magnet-free traction motor can certainly be described as a breakthrough, because it delivers several advantages that have not previously been combined in a product of this type. Firstly, it doesn't require rare earth elements. Manufacturing is thus more environmentally friendly; it also offers benefits in terms of costs and resource security. Secondly, the new electric motor enables the inductive and therefore contactless transmission of electrical currents between the rotating and stationary parts inside the motor. In this way, the motor operates wear-free and very efficiently, particularly at high speeds.

Can you put this into figures?

The level of efficiency is over 95 percent in the most common driving conditions in which the drive system is used. This is a value previously only achieved by Formula E race



We're applying our expertise to new forms of mobility, such as smart mobility in urban areas.

Dr. Martin Berger

Vice President Corporate Research and
Advanced Engineering at MAHLE

cars. With the new magnet-free motor, we have succeeded in combining the strengths of various electric motor concepts into one product. And, what's more, this new development is easily scalable, so it can be used in anything from small cars through commercial vehicles.

Speaking of commercial vehicles: the hydrogen fuel cell may be an alternative to the battery, especially on long-haul routes. What is MAHLE's position on this technology?

The fuel cell drive is another key technology pathway en route to a carbon-neutral mobility and transportation landscape. With our hydrogen project house, we also want to contribute to the breakthrough of this future drive. MAHLE's focus is on the system peripherals surrounding the fuel cell stack itself—from thermal management through to filtration and humidification. With the installation of hydrogen testing infrastructure in Stuttgart, we're also putting ourselves forward as a development partner. Incidentally, that is also the case when it comes to the direct combustion of hydrogen in truck engines.

MAHLE on site

*Around 160 production locations
12 major research and development centers
More than 72,000 employees**

Major research and development centers

Europe

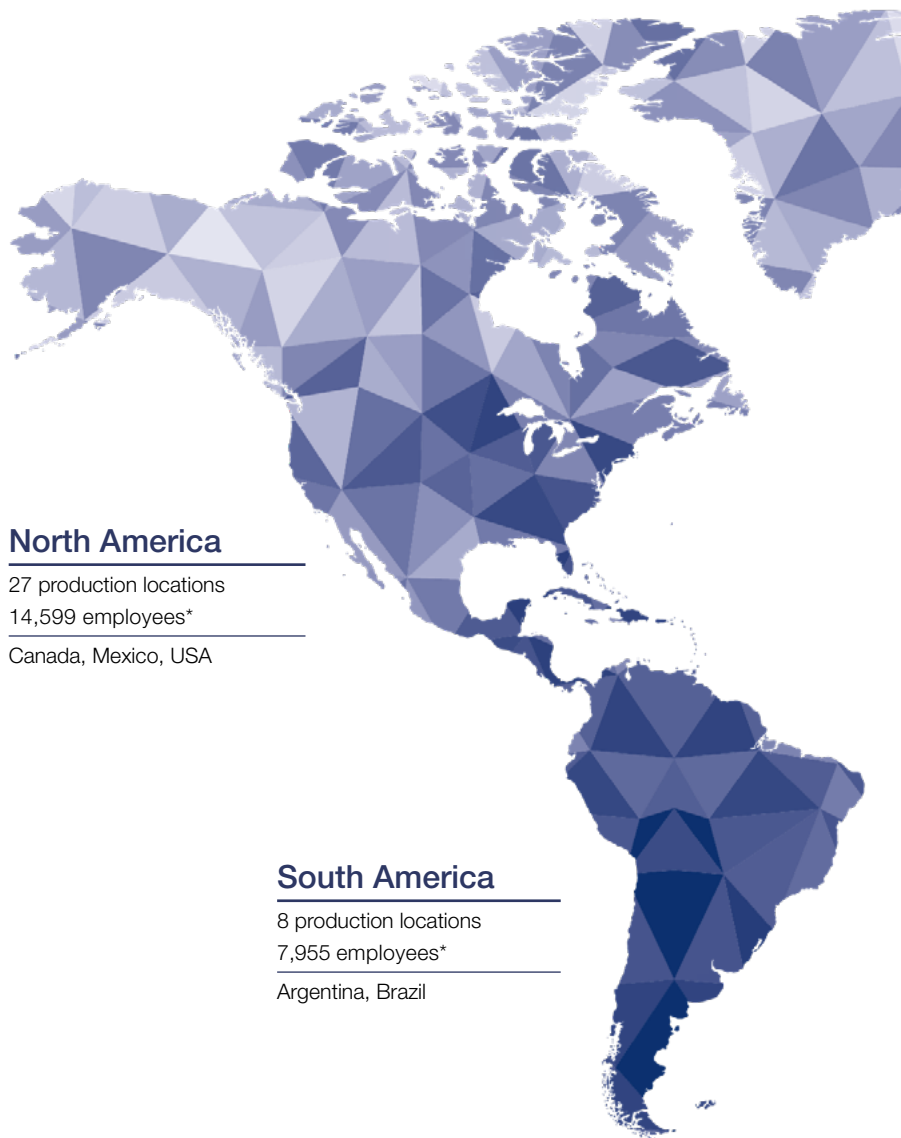
Northampton/Great Britain
Šempeter pri Gorici/Slovenia
Stuttgart, Bad Cannstatt/Germany
Stuttgart, Feuerbach/Germany
Valencia/Spain

North/South America

Buffalo/USA (Amherst, Lockport)
Detroit/USA (Farmington Hills, Troy)
São Paulo, Jundiaí/Brazil

Asia/Pacific

Pune/India
Shanghai/China
Numazu/Japan
Tokyo/Japan (Okegawa, Kawagoe)



North America

27 production locations
14,599 employees*
Canada, Mexico, USA

South America

8 production locations
7,955 employees*
Argentina, Brazil

Europe

65 production locations

33,009 employees*

Austria, Belarus, Bosnia and Herzegovina, Czech Republic, France, Germany, Great Britain, Hungary, Italy, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Turkey

Asia/Pacific

59 production locations

15,694 employees*

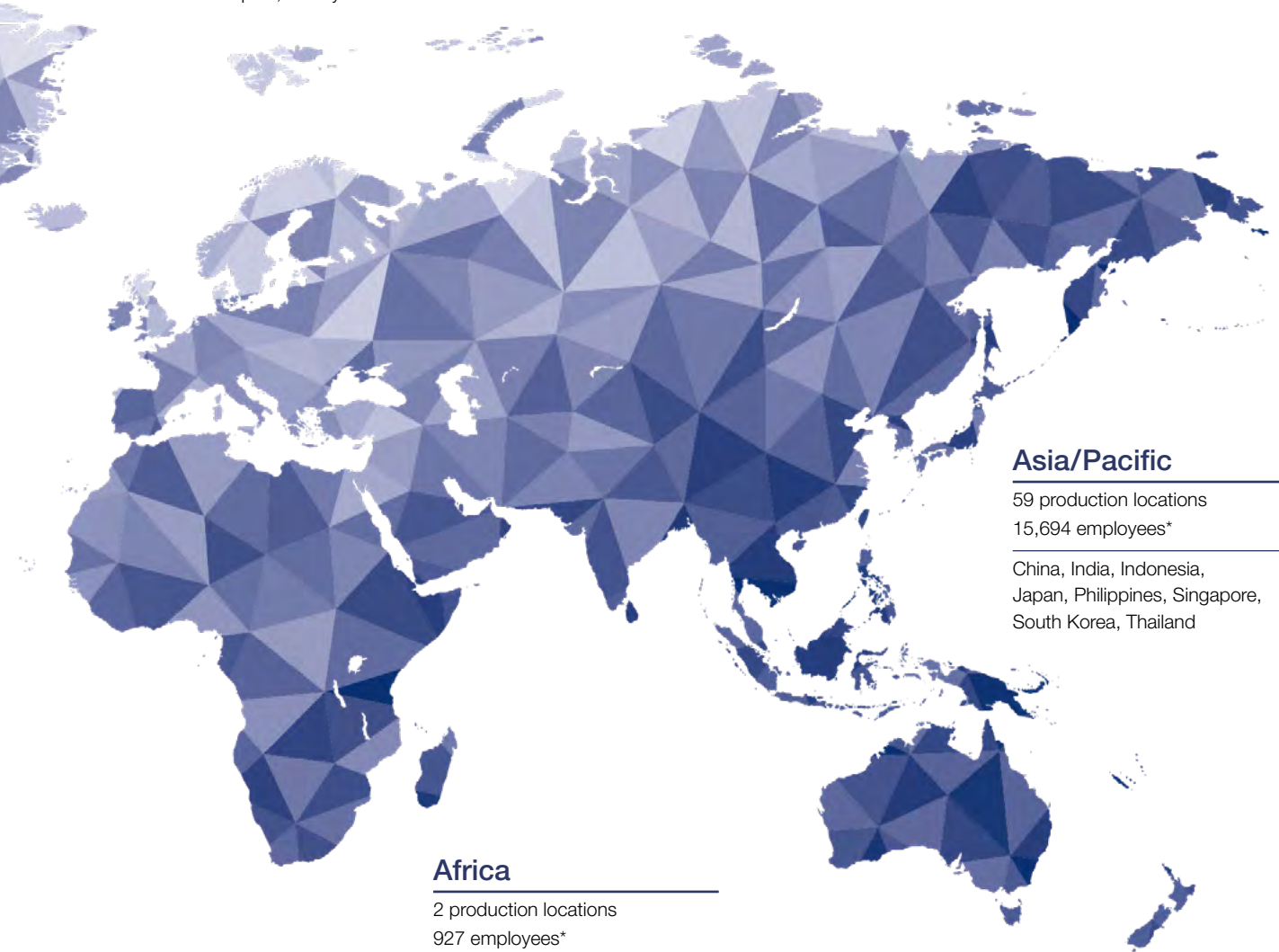
China, India, Indonesia, Japan, Philippines, Singapore, South Korea, Thailand

Africa

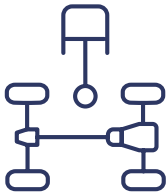
2 production locations

927 employees*

South Africa

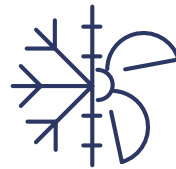


MAHLE's product portfolio



Engine Systems and Components

As a global market leader in our key market segments, we have decades of systems and development expertise as well as extensive production experience to build on. The development of piston systems and cylinder and valve train components has been a core competence at MAHLE since the very beginning. Because we understand how all engine components interact, we can deliver optimal solutions to our customers. Our products are used around the globe in two-wheeled vehicles, passenger cars, commercial vehicles, and large engines. Today, our development work focuses on the combustion of hydrogen and other nonfossil fuels, so that carbon-neutral mobility can also be achieved using the combustion engine.



Thermal Management

The increasing electrification of the automotive and commercial vehicle industry calls for superior innovative strength in the thermal management of the entire powertrain. Innovative products from the Thermal Management business unit for batteries, fuel cells, power electronics, and electric drives are key to extended cruising ranges, high levels of efficiency, and long service lives for components—and are thereby playing a significant role in shaping the shift toward zero-emission powertrains. Thermal management is also essential for the ongoing development of the combustion engine. For instance, increasingly effective and efficient cooling systems are making a substantial contribution toward reducing energy consumption. Air conditioning innovations are enabling new design concepts for the cabin and helping to provide a high degree of thermal comfort in vehicles alongside efficiency improvements.



Filtration and Engine Peripherals

MAHLE has a long-standing tradition in fuel, oil, and air management, and this business unit's specialist knowledge is now of great benefit to the company in the current transformation process. From fluid management and materials expertise to complex filtration tasks—all this is needed for new drive types. Today, we apply our decades of experience with highly complex and safe plastic components to the development of solutions such as battery housings with integrated functions. Air and oil filtration are still necessary in battery electric drives—and vital to ensure the safe operation of fuel cells.



Electronics and Mechatronics

Electronic and mechatronic components play a crucial role in increasing efficiency in the powertrain and in advancing e-mobility. With its electric drive systems, actuators and auxiliaries, and control and power electronics product groups, MAHLE offers relevant solutions in this area today. These activities are founded on our expertise in the development and manufacture of electric motors and electronic and mechatronic systems. Although these are used in a wide variety of applications, their technology is closely interlinked, thus affording synergies and economies of scale—key success factors in the automotive industry.



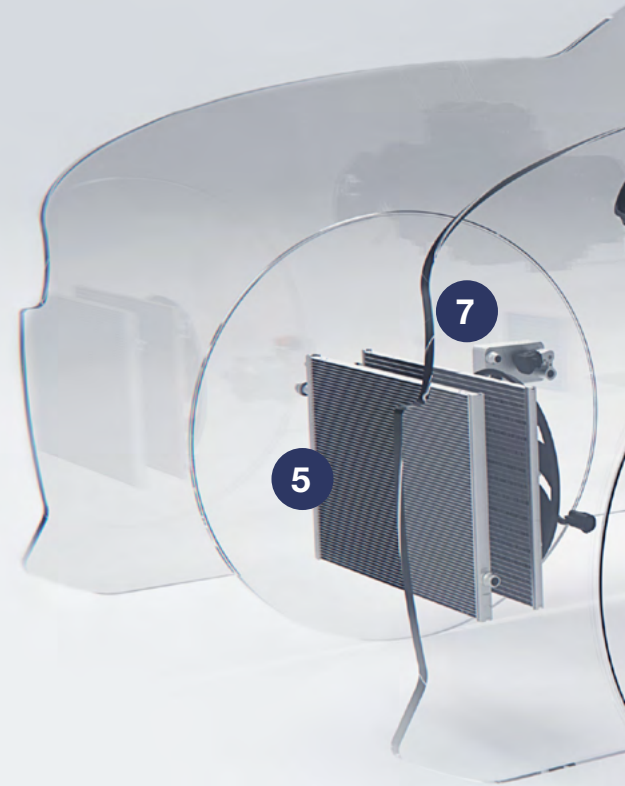
Aftermarket

The Aftermarket business unit supplies wholesalers, automotive workshops, and electronic retail platforms all around the world. Its range includes spare parts in original equipment quality as well as service units and various services. In addition to standard spare parts, such as engine components, filters, turbochargers, and mechatronic components, MAHLE also offers products for thermal management, such as thermostats, radiators, and charge air coolers. The new services offered by the business unit include diagnostic tools, equipment to calibrate advanced driver assistance systems, air conditioning and transmission oil service units, and solutions for hygienically cleaning vehicle cabins. The portfolio is rounded off by technical support provided by MAHLE's worldwide network, customer training, and service information.

System-wide expertise

E-mobility will be a key component of carbon-neutral private transportation over the long term. By contributing its systems solutions, MAHLE aims to be an innovation driver in this field, too, and lay the foundation for the widespread acceptance and worldwide introduction of e-mobility.

Highly efficient: MAHLE is an expert for systems and power electronics in electric powertrains. As a leading international development partner and supplier to the automotive industry, the company is also able to use its extensive know-how in electric and electronic components to develop integrated systems solutions for e-mobility applications. One area of focus is thermal management. The performance, cruising range, and service life of an electric vehicle all depend on the careful management of the heat flows that are produced. MAHLE develops integrated solutions for electric vehicles, both for the cabin and for the powertrain and peripheral systems. MAHLE's expertise and technology are now present in at least every second vehicle worldwide. This diagram of an electric car highlights the components that MAHLE is developing for the future of mobility.



1 High-voltage battery module

Immersion cooling not only makes fast charging possible but also paves the way for smaller batteries and electric vehicles that are cheaper, lighter, and more resource efficient. **> More on p. 17**

2 Fluid management module for electric vehicles

Supplies the drive with clean, temperature-controlled fluid, ensuring greater cruising range and a long service life for the drive.

3 Cabin filter

Conventional cabin filters with and without activated carbon remove dirt particles, gas molecules, and viruses from the air breathed by passengers.

4 Air conditioning (HVAC)

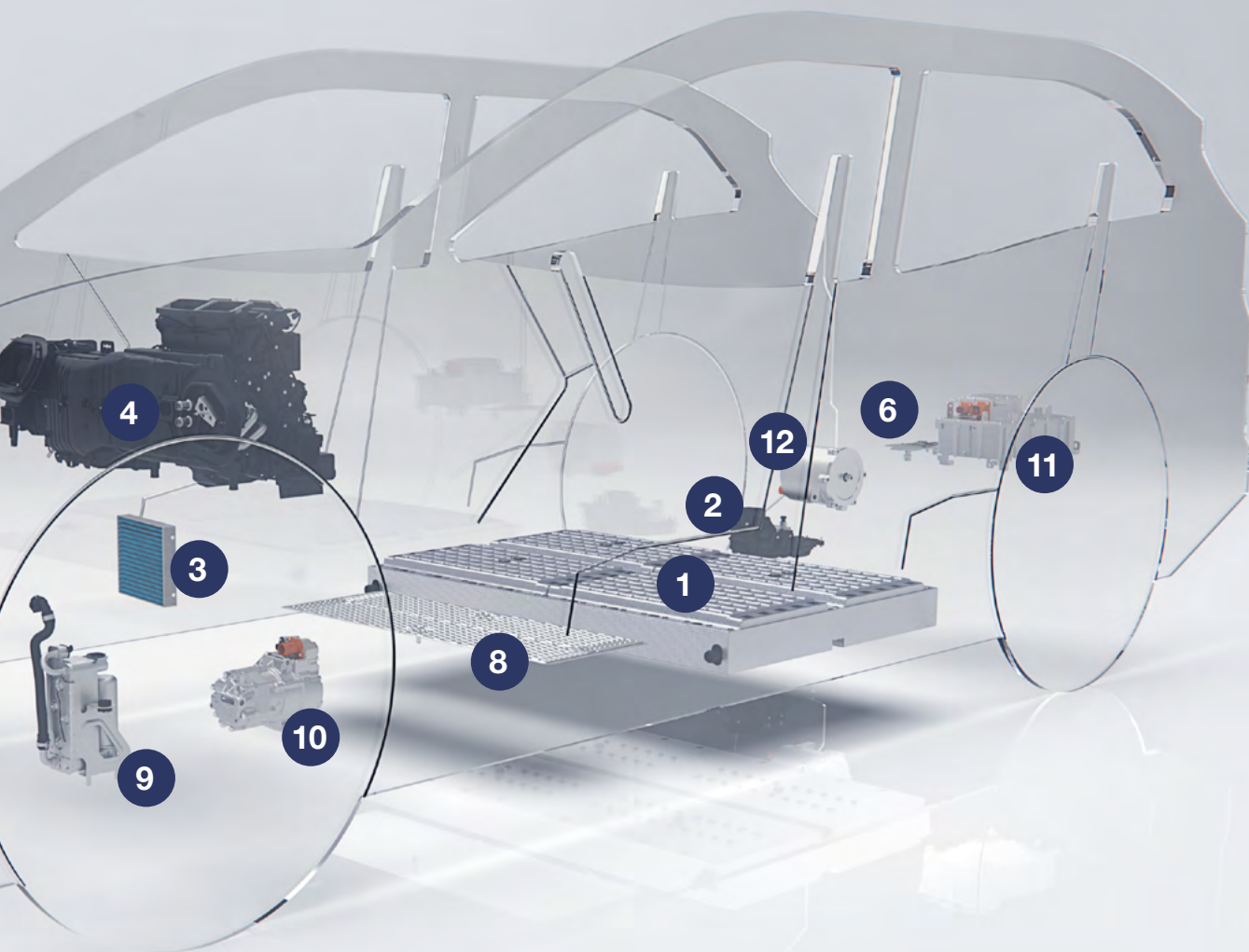
Two- and three-zone temperature regulation and air distribution with variably adjustable footwell temperature and best-in-class acoustics. **> More on p. 35**

5 Cooling module for BEVs

Highly efficient and compact: MAHLE cooling modules maintain optimal temperatures in electric vehicles. **> More on p. 27**

6 Electronics cooling plate

Cooling the power electronics in high-performance systems closer to the component also increases the service life of the electrical components and interfaces. **> More on p. 26**



7 Chiller with MAHLE EXV

The chiller featuring the new electric expansion valve (EXV) from MAHLE transfers cold temperatures between different cooling circuits. > **More on p. 25**

8 Battery cooling plate

Thermal management keeps the battery temperature constantly below 40°C and increases the service life of the battery.

> **More on p. 27**

9 Indirect condenser

An indirect condenser is cooled with water when in air conditioning mode and, conversely, heats coolant for heating purposes when in heat pump mode. > **More on p. 25**

10 Electric compressor

The heart of the air conditioning and refrigerant circuit. Air conditioning compressors are available for all relevant voltage ranges and vehicle classes. > **More on p. 17**

11 OBC

The onboard charging system ensures a safe and efficient charging process with continuous temperature monitoring.

12 High-voltage drive motor

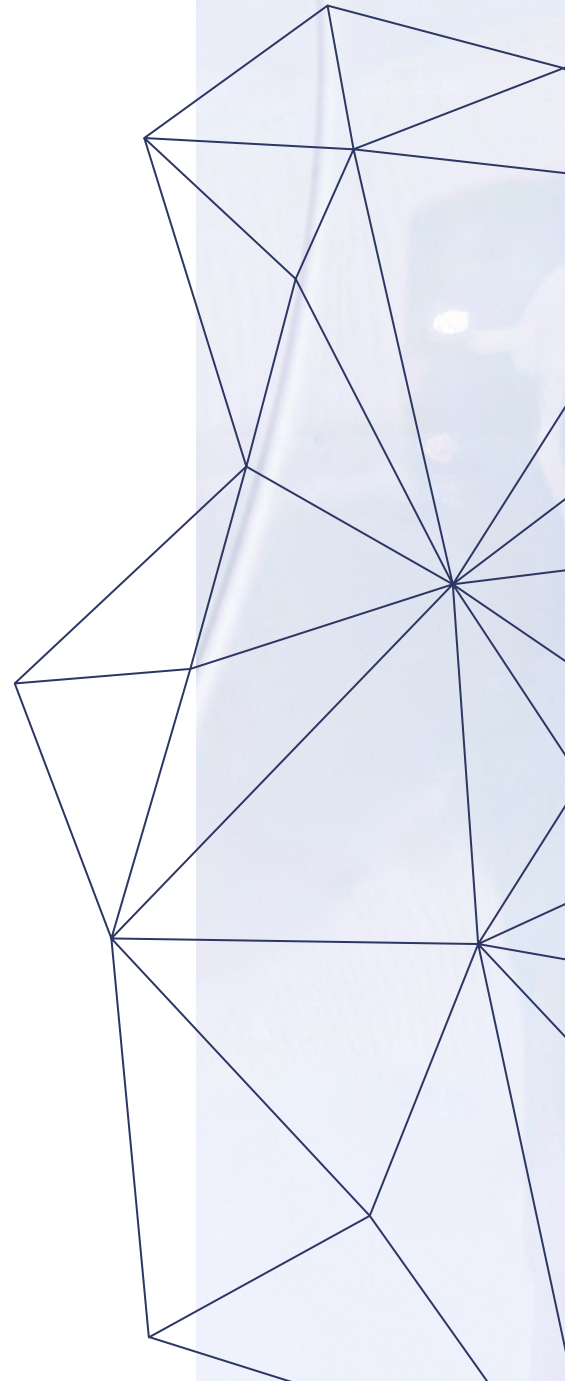
800-volt solution with hairpin winding for battery electric drives. Outstanding motor dynamics combined with high power density in a small housing. > **More on p. 17**

E-MOBILITY

Electrifying diversity

The number of electric vehicles on our roads is growing rapidly. Car manufacturers around the world are making further improvements to the technology this development requires. MAHLE is able to support them thanks to decades of experience with electric, electronic, and mechatronic components from a wide variety of fields.

Whether in passenger cars, commercial vehicles, e-bikes, or forklifts—electric drives of all sizes have become an indispensable part of the mobility landscape. That's why e-drives are already a core part of MAHLE's business. This applies not only to purely battery-powered vehicles but also to hybrid vehicles of all performance levels.





The traction motor and battery are the best-known electrical components of an electric car, but there are many more besides. Auxiliaries and their components relating to assistance systems, thermal management, and oil management also have an important role to play. They ensure that the battery and motor are always at the right temperature. This is important as it reduces wear and allows for higher performance. In electric cars especially, auxiliaries therefore serve particularly vital functions.

Actuators are another group of electric assistants developed by MAHLE. These are usually electric motors, in some cases also electromagnetic valves, which are used in drive control and comfort systems. They are responsible for converting the signals from the control unit into an action. Actuators can be found in power steering or in the park lock system, for example, and are important elements of electronic control systems.

There are many mechatronic components that MAHLE hasn't needed to invent, because similar parts are already found in cars with combustion engines—a field in which MAHLE boasts decades of experience. Thanks to this advanced know-how, the components for electric cars can be adapted to meet constantly changing requirements more quickly and safely.



The tension's rising

There are dozens and dozens of electric devices at work in an automobile. The problem is that they work at very different voltage levels. MAHLE offers the solution with tailored products for every voltage.

The battery in a purely electric car needs to be powerful. Today, most electric vehicles are equipped with a 400-volt battery—and the next generation is on its way. It's already being used by manufacturers of electric sports cars, who like to go one better by installing 800-volt traction battery.

Although ideal for powering vehicles, hundreds of volts are too much to drive smaller motors for window lifts, power steering, or central locking. These devices usually operate at 12 volts. In a vehicle with a combustion engine, these parts receive the power they need via the alternator, which supplies an appropriate voltage.

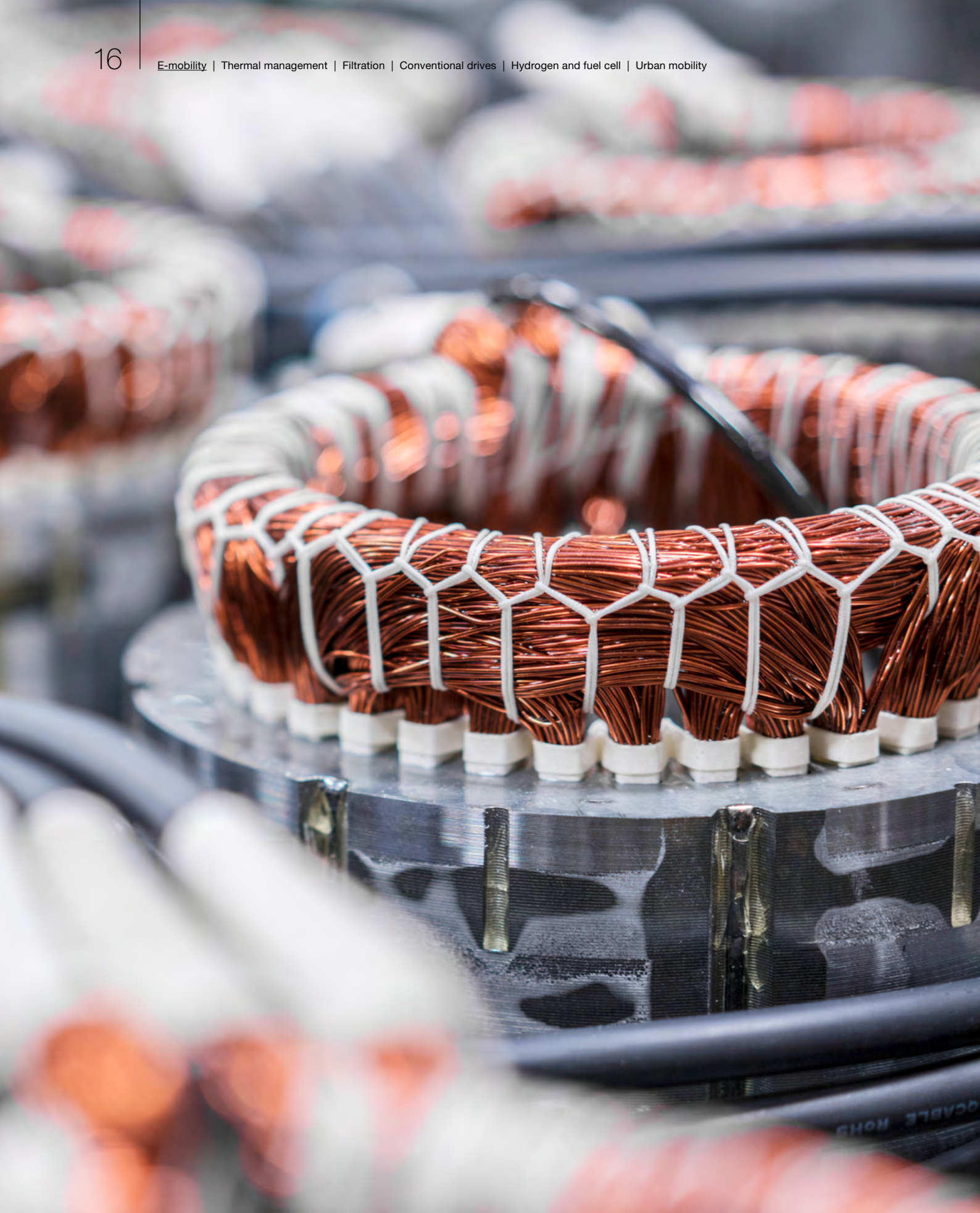
The right voltage for every vehicle

MAHLE's developers are already working on the electrical systems of the future. This is because the 12-volt automobile wiring system is gradually being replaced by a supply system that operates at 48 volts. The main reason is that modern cars contain power-hungry systems that push the conventional 12-volt network to its limits. That's why, in the future, there will be vehicles with two, or sometimes even three, sub-systems supplying different voltages.



The success of hybrid vehicles is intensifying this trend. Their auxiliary motors usually operate at 48 volts and are powered by a battery of the same voltage. MAHLE offers electric motors for mild hybrid cars with 48-volt technology and solutions for high-voltage systems in plug-in hybrid vehicles.

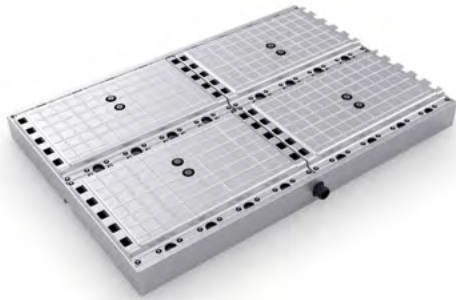
Still other voltage levels are required for electric bicycles. Their batteries and motors generally operate at 36 volts. Here too, MAHLE provides the right technology for every application.



All charged up

HV battery module with integrated immersion cooling

Made of lightweight, fiber-reinforced plastic, the battery housing from MAHLE sets new standards—because the battery cells it contains are surrounded by a special fluid. Known as immersion cooling, this design gives the cells even better protection against overheating, which in turn makes fast charging possible. Another major advantage is that even temperature distribution increases the service life of the battery.



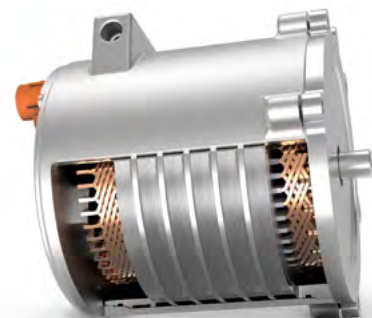
Oil management module

Numerous manufacturers of electric cars use oil to cool their electric drive motors and/or transmission systems. Batteries are increasingly cooled using a fluid (immersion cooling). This means that other functions, such as filtration and oil circulation, must be taken into account in addition to cooling when developing a drive unit or an immersion-cooled battery. MAHLE is successfully combining the filter, oil pump, and thermostat in one compact unit. This solution is thus optimized for drops in performance and pressure, resulting in simpler design, production, and interfaces.



Electric compressor

The e-compressor from MAHLE is the beating heart of the air conditioning and refrigerant circuit in an electric vehicle. Firstly, it takes on the central role of air conditioning the cabin, and secondly, it helps to regulate the temperature of the most important components in the electric vehicle's powertrain, such as the battery and electric motor. The compressor is part of the MAHLE Direct Thermal System.



High-voltage drive motor

Our synchronous motors have been specifically developed for use in purely battery electric vehicles. High power density, efficiency, and a compact design are hallmarks of the unit.

Durable and versatile

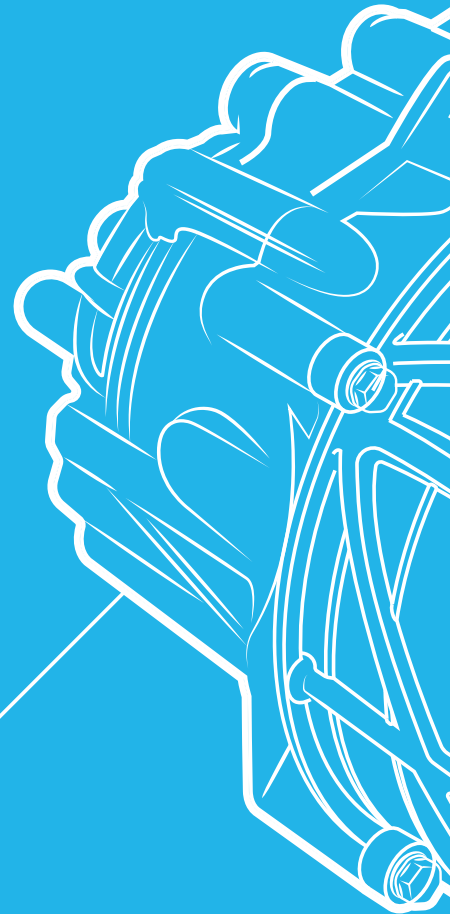
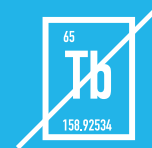
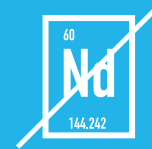
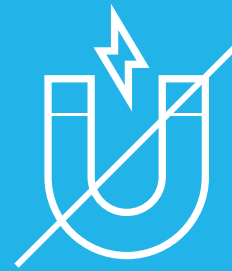
The magnet-free, high-voltage drive from MAHLE is wear-free, highly efficient, and environmentally friendly. Its key feature is the contactless transmission of the electrical currents that flow between the rotating and stationary parts inside the motor. This raises the efficiency of the electric motor above 95 percent.

One thing is clear: Without e-mobility, the ambitious CO₂ reduction targets cannot be met. However, the motors required are not always sustainably manufactured. Take magnets, for example. They are key components in electric drives. Their production requires rare earth elements—but mining these often harms people and the environment.

Contactless power transmission for maximum efficiency

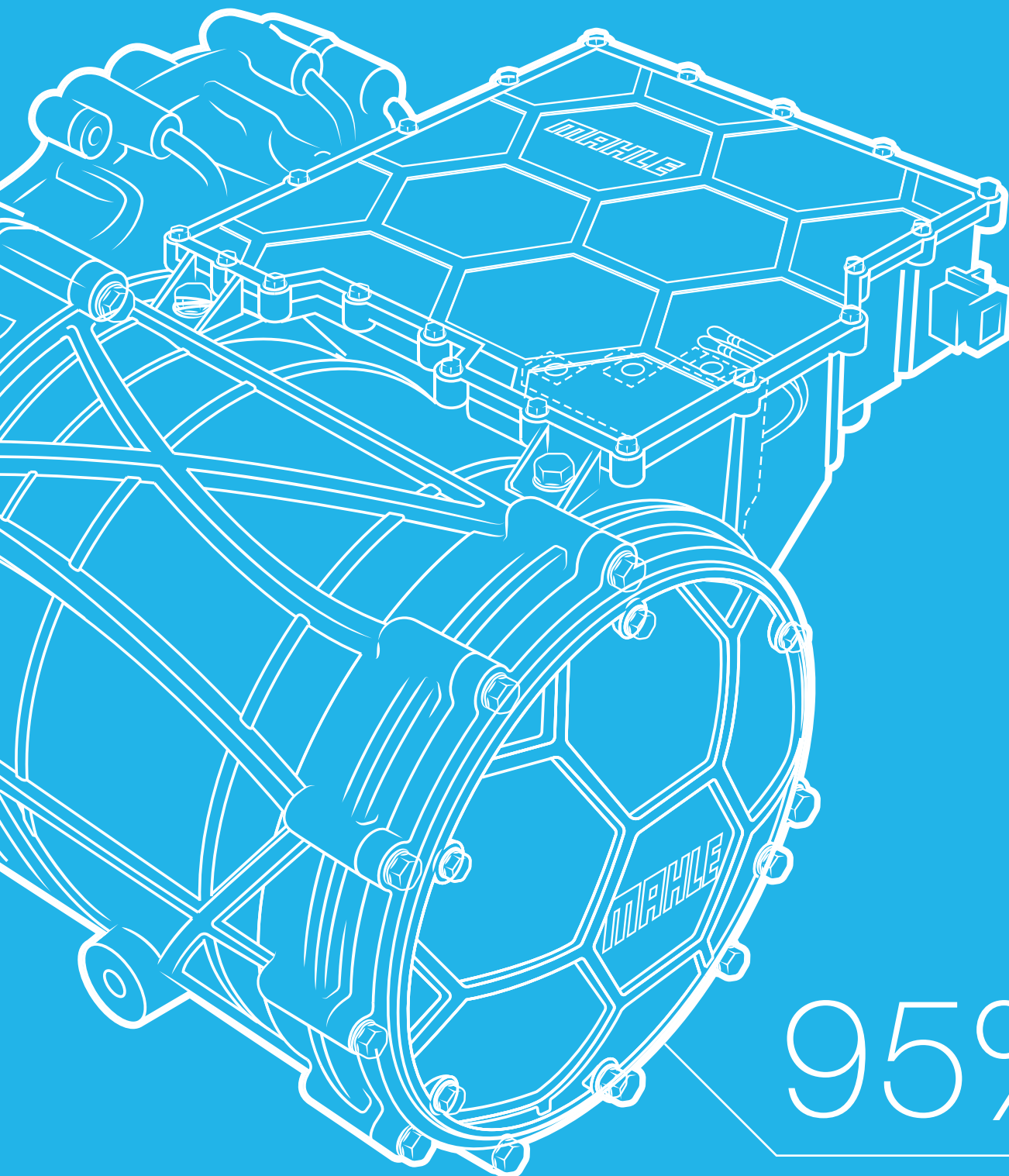
MAHLE has developed an electric motor that doesn't require rare earth elements. Electromagnets act on the rotor instead of magnets. The central feature of the motor is the inductive and thus contactless power transmission to these coils. They allow the motor to operate highly efficiently at all speeds. The drive's efficiency is more than 95 percent—a value previously only achieved by Formula E race cars.

The current is transmitted between the rotating and stationary parts of the motor without them touching each other. As a result, the drive is wear-free, requires no maintenance, and can be used in a variety of applications. "It can be described as a breakthrough, because the highly efficient motor brings



together advantages that have not been combined in a single product before," says Dr. Martin Berger, Vice President Corporate Research and Advanced Engineering at MAHLE.

The innovation was realized in record time. To do so, the developers took advantage of a simulation process that allowed them to test several variants virtually. The result is a motor that's not only highly efficient but also keeps costs in check. With this new drive, MAHLE is making an important contribution to the success of e-mobility.



95%

efficiency—a value previously only achieved by Formula E race cars.

Tiny but mighty— actuators in cars

When something moves or lights up in an automobile, mechatronic actuators are often involved. Actuators translate signals from a control unit into an action and, for this purpose, convert electrical energy into mechanical motion. They are heavily used in the powertrain and in comfort systems, where they control flaps and valves, regulate coolant flow, or open windows. With an annual production of 2.5 million units, MAHLE is currently one of the world's three largest manufacturers of actuators for automotive applications. Here are just two examples from the conventional and future mobility landscape.

Park lock system

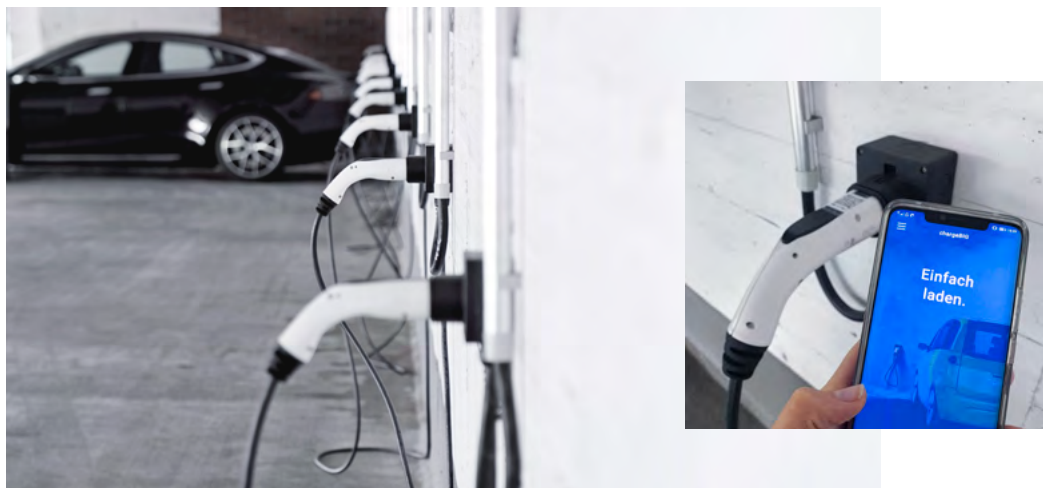
If the control lever of an electric car is in the “Park” position, the vehicle is prevented from moving. This is ensured by a park lock function, which is equipped with an electric actuator. The actuator can be used in various applications, not only in electric vehicles.



Electric wastegate (EWG) actuator

For many years, MAHLE has developed actuators to optimize combustion engines. Applications include downsizing, where reduced displacement cuts fuel consumption, while maintaining performance thanks to a turbocharger. The electric wastegate actuator from MAHLE ensures optimum interaction between the turbocharger and the engine.





chargeBIG — MAHLE's solution for intelligent charging infrastructure

chargeBIG is an intelligent charge management system for long-stay parking and can be integrated into the existing infrastructure at low cost and without lengthy conversion work. The system follows a new approach: charging as quickly as necessary rather than charging as quickly as possible. And it's intended to be used by as many vehicles as possible, among which the amount of electricity available is distributed intelligently. The chargeBIG system is an ideal solution for parking lots where electric vehicles are left for relatively long periods of time—e.g., in company parking garages, at airports, in underground garages for large residential buildings, and at fleet operators.

The chargeBIG charging concept consists of a central control unit with permanently mounted cables and connector plugs instead of charging posts in the parking lot. Thanks to the intelligent charging system and design-

to-cost approach, there is no need to invest in expanding the network connection, thus saving time and money when setting up the charging infrastructure.

A central control unit distributes the available charging power across the parked vehicles using dynamic, phase-specific load management. This prevents unbalanced loads in the power supply. chargeBIG responds flexibly to other consumers on the network and uses the electric vehicles as a controllable load, ensuring optimal utilization of the available power supply. In addition, the chargeBIG solution is more convenient to install and maintain than alternative systems, as the charging points can be serviced very easily via the central electronics. The system offers a further advantage in terms of safety, because the charging points are de-energized when not in use. In addition to intelligent charging

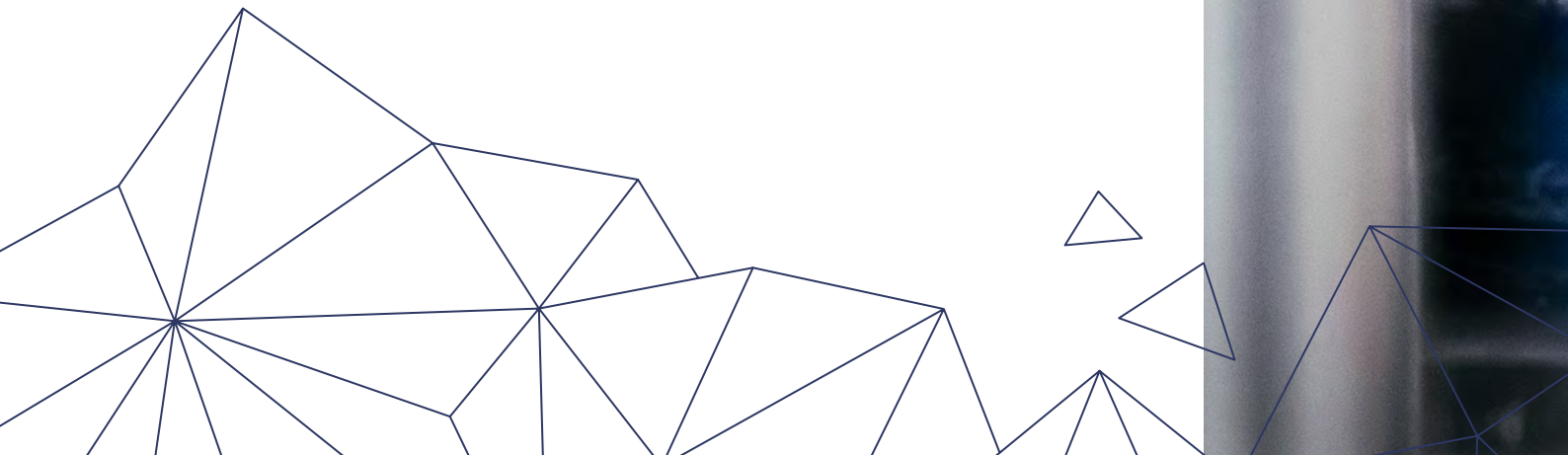
hardware, chargeBIG also offers installation, maintenance, service, operation, and charge billing. Having successfully passed the VDE's certification procedure, chargeBIG is also the first provider of a regulation-compliant charging progress display for smartphones. The chargeBIG app for iOS and Android or the universal web app can be used to activate correspondingly equipped chargeBIG charging points via a QR code scanner or near-field client (NFC). Users pay for their charge on an ad hoc basis using conventional methods such as credit card or PayPal. The app offers repeat customers the option of setting up a user account and storing their preferred means of payment so that fewer clicks are needed to start the charging process. For fleet customers, one-off visitors, or drivers wishing to charge company cars on their employer's premises, chargeBIG also offers access codes for activation and billing to cost centers.

THERMAL MANAGEMENT

Ideal temperature

When electricity flows, it can get hot—the same is true in electric cars. Efficient thermal management is therefore decisive to optimize the cruising range and service life of an electrically driven vehicle.

The batteries in an electric car must not get too hot or too cold. The same applies to the motor and power electronics. And in the cabin, passengers don't want to sweat or freeze. That's why there are numerous devices and control units that ensure the correct temperature is maintained in the various areas of the vehicle. The challenge is that they all draw their electricity from the powertrain battery—at the expense of cruising range. Sophisticated thermal management systems must therefore ensure that the cooling and refrigeration circuit operates as efficiently as possible.





Thermal management begins at the charging station. Especially when charging quickly at high power, heat is generated, which puts strain on the cable and the battery. Effective cooling is the only way to protect the components against damage. Temperature control systems perform this task by compressing a refrigerant to the desired pressure and thereby generating the required temperature.

Heat pumps give greater range

MAHLE offers efficient thermal management for the entire vehicle. In addition to compressors, condensers, evaporators, and cooling plates, solutions also include innovative heating systems for the cabin. The latter harness the waste heat from the electric motor or power electronics using a newly developed heat pump. This protects the batteries and increases the cruising range of the vehicle by up to 20 percent.

Thermal management is also critical in cars with fuel cells. In addition to a generator, they have a backup battery and an electric motor. MAHLE is also developing suitable components for these applications.



Thermal management

is a key prerequisite for the reliable operation of electrically powered vehicles. It has a significant impact on efficiency and thus supports CO₂ reduction.



Temperature regulation from MAHLE— for all drive types

Chiller with MAHLE EXV

Especially in hot weather, the battery cooler alone is not always enough to regulate the temperature. That's why the coolant takes a detour and flows through a so-called chiller, in which refrigerant evaporates from the air conditioning system. This reduces the load on the battery cooler. Valves play an important role in this process. The new electric expansion valve (EXV) from MAHLE is used in the chiller. It supports the thermal management of vehicles of all drive types.

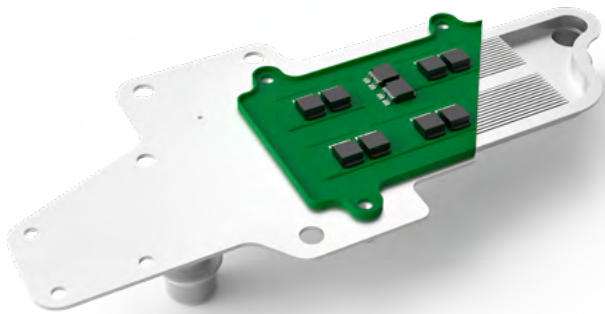


Indirect condenser

A condenser is an integral component of every automotive air conditioning system. Hot, compressed, gaseous refrigerant is cooled until it condenses, making it available for another cooling evaporation process. The condenser can also be fitted with a manifold/drier. This acts as an expansion tank in the refrigerant circuit and also contains additional refrigerant in order to compensate for creeping losses over the operating time. The manifold also contains drying agent to bind water from the refrigerant that would otherwise lead to blockages due to ice formation and corrosion.

Electronics cooling plates

Electronics for high-performance systems, such as inverters in electric motors, heat up considerably under high loads. The cooling plate from MAHLE ensures that the system can continue to operate at all times by efficiently removing heat from the electronic components. At the same time, ongoing cooling safeguards the service life of the electrical components and interfaces.



High-voltage PTC heater

Electric heaters are an indispensable heat source when it comes to heating the cabins of electric vehicles over long periods. MAHLE's innovation does away with temperature sensors and instead uses an intelligent system of hardware and software, which incorporates the heating elements and integrates all of the functions. The built-in electronics continuously analyze the electrical resistance of the PTC elements (positive temperature coefficient) in the heater and thus know and are able to adjust their temperature.



Low-temperature radiator

Low-temperature radiators are available in core depths of 16 and 21 mm, with a 28 mm variant coming soon. In order to meet different customer requirements, there is a wide range of fin-and-tube combinations. All radiators from MAHLE are characterized by their low weight and compact dimensions with a lateral projection of only 2.4 mm. They have a low coolant volume and are easy to recycle.

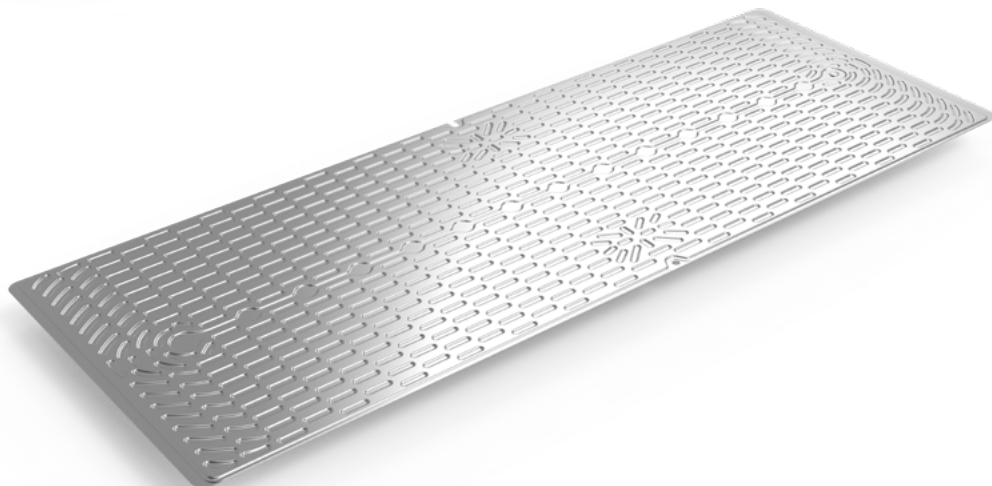


< 40°C

is the optimum operating temperature for lithium-ion batteries in hybrid and electric vehicles.

Battery cooling plate

Vehicle electrification poses new challenges for thermal management. A temperature below 40 degrees Celsius is needed in order to cool the lithium-ion batteries in hybrid and electric vehicles. The battery packs heat up considerably during charging and under extreme load when the vehicle is driven. MAHLE's battery cooling plate keeps the temperature of the cells within a defined range and thus also increases the service life of the battery.



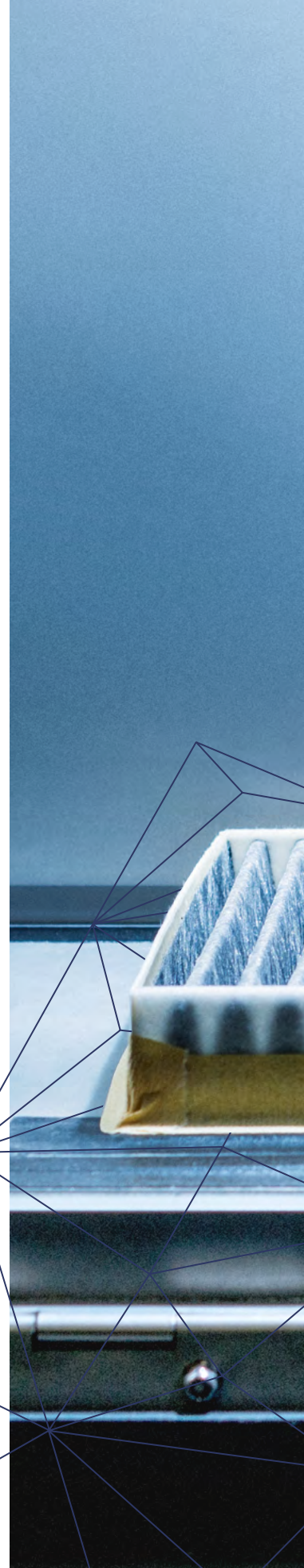
FILTRATION

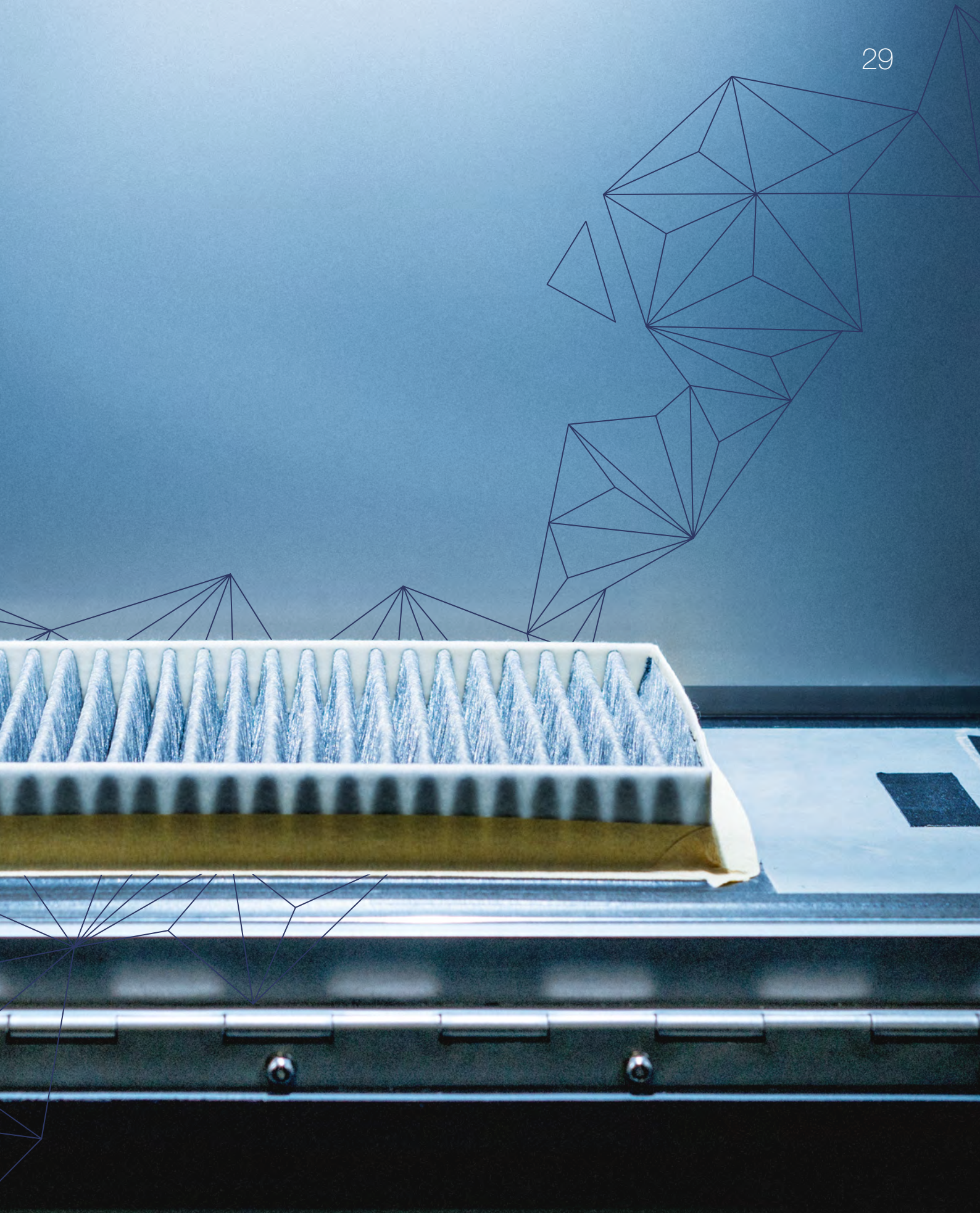
A breath of fresh air

Clean air—invisible yet indispensable. Within a fuel cell, it protects the sensitive stacks; inside the vehicle cabin, it allows people to breathe easily. Air management and filtration expertise will continue to be in demand in the future. More than ever. For every drive type.

When a vehicle is on the road, more than 100,000 liters of air are swept from the outside into the cabin every hour. Fine particles, dust, viruses, and allergenic pollen can all be suspended in it. The only barrier: the cabin filter in the ventilation system. MAHLE ventilation systems reliably supply vehicle occupants with clean air. They also reduce the amount of dust in the cabin.

Just as it does in people, clean, filtered air also increases the well-being of the components in a combustion engine. For example, good engine performance, high torque, low fuel consumption, and minimal emissions can only be guaranteed if the supply air is clean. Especially in modern units for passenger cars and commercial vehicles, ever smaller installation spaces require ever higher filtration capabilities. The solution: high-performance filter media, optimized flow guidance design, and new filter elements from MAHLE. Thanks to plasticized filter systems, MAHLE engineers can meet any requirement with a wide variety of designs.





One topic that will be important in the future, especially for commercial vehicles, is air management for fuel cells. To prevent damage to the fuel cell, gases such as sulfur dioxide, ozone, nitrogen oxides, and ammonia, as well as particles, need to be reliably eliminated. To this end, MAHLE is developing a highly effective, multilayer filter medium. The passivated surfaces pre-

vent ion discharge from the MAHLE cathode air cooler, which is then able to reduce the air temperature behind the compressor. In addition, humidifiers supply the fuel cell stack with optimally humidified air, preventing it from drying out. At the end of the fuel cell circuit, a special exhaust air pathway made of plastic weighs around 70 percent less than steel designs and also reduces noise.



Air filter system



Humidifier



Cathode air cooler



Exhaust system



Together for clean air

MAHLE is helping to improve air quality in an alliance with other leading companies from Baden-Württemberg/Germany. As an active member of the *Bündnis für Luftreinhaltung*, MAHLE is committed to reducing air pollution, especially in the Stuttgart region. MAHLE's primary contribution involves purchasing a fleet of electric cars for journeys between its locations in the greater Stuttgart area and installing 100 EV charging points in MAHLE's own parking garage in Bad Cannstatt. These charging points, designed by the chargeBIG start-up, have been operating since summer 2019. In addition, MAHLE is improving the infrastructure for employees who cycle to work in order to incentivize zero-emissions commuting.



Filters to stop the spread

Filter media from MAHLE can also directly protect human health, as proven by their use in face masks. Right at the start of the pandemic in 2020, MAHLE cooperated with underwear manufacturer Triumph to produce protective masks. In addition, the automotive supplier is making high-quality FFP2 versions on a repurposed production line at its location in St. Michael/Austria.

OzonePRO

Infection control from MAHLE. With its OzonePRO device, MAHLE provides a solution to car rental businesses, fleet operators, public authorities, and owners of private and commercial real estate that ensures effective protection against COVID-19 in vehicle cabins and building interiors. The portable unit, which is the size of a carry-on case, uses ozone to clean the air in indoor spaces. To this end, all doors into the vehicle or room must be closed. During the sanitizing process, the OzonePRO sensors continuously measure the concentration of ozone produced in the environment and adjust it until the ideal value is reached. The unit is fully automated and notifies the user once the air has been cleaned. The effectiveness of the method has been confirmed by the certified laboratory Eurofins Biolab Srl. According to the test results, OzonePRO reduces the number of active COVID-19 virus particles by approximately 99.7 percent. Interiors are thus cleaned effectively in around 30 minutes. The O3-Easy app is a handy support feature, allowing the user to control the air cleaning device remotely and monitor the entire process.

99.7%

of the active coronavirus particles in a room are neutralized with OzonePRO.



CONVENTIONAL DRIVES

E-fuel ready

In a world of purely battery-powered e-mobility, conventional engines and fuels would be rendered obsolete. But can the energy requirements of the entire transportation sector really be met by green electricity alone? The approach pursued by MAHLE is open to all technologies. On the one hand, the Group applies itself to the ongoing development of the combustion engine—also with the aim of running it on green hydrogen. On the other, it's focused on the phasing out of fossil fuels.

In the future, which powertrain technology will get people and goods to their destinations reliably, efficiently, and cleanly? It's not a trivial question. Answering it properly involves a great deal of technical complexity. According to forecasts, the proportion of electric vehicles is set to rise steadily in many regions of the world. At the same time, vehicles with combustion engines will continue to transport large numbers of people and products to their destinations reliably and efficiently. MAHLE is equally dedicated to conventional and alternative drives. After all, it's only by remaining open to all technologies in an approach based on scientific facts that we can exploit all possibilities for reducing the emissions from road transportation quickly and effectively.





New fuels

MAHLE remains convinced of the potential offered by the combustion engine and continues to exploit it. Key future technologies in this area include carbon-neutral e-fuels—i. e., gasoline and diesel fuels produced synthetically using eco-friendly electricity—and green hydrogen. MAHLE engine components and filters continue to function properly even when as much as 20 percent synthetic fuels are admixed with conventional fuels. This has been demonstrated in extensive trials on engine test benches and a joint field trial with a German premium manufacturer. This means that the technology is compatible with higher admixture rates than the fuel standards currently allow. MAHLE is e-fuel ready. With relatively minor adjustments, it's also possible to burn green hydrogen in engines equipped with MAHLE components. This is good news for the climate, for every motorist, and for the global automotive industry.



Modular hybrid drive

Hybrid cars combine the classic combustion engine with an electric motor in one vehicle and thereby help to reduce CO₂ emissions. MAHLE has developed its own innovative solution for this important future technology: the MAHLE Modular Hybrid Powertrain (MMHP). It combines the internal combustion engine, alternator, traction motor, transmission, and power electronics in a self-contained, compact, and lightweight assembly. At the same time, the MAHLE Jet Ignition prechamber ignition process ensures extremely lean operation. As a result, the system is more efficient, smaller, lighter, lower cost, and scalable for different vehicle sizes. With the MMHP, MAHLE is narrowing the gap between conventional and purely electric drives—and making a speedy and therefore very valuable contribution to more efficient mobility.

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E-fuels and green hydrogen are the most effective means of cutting CO₂ in the existing fleet too. They are important complements to e-mobility when it comes to meeting the CO₂ targets in the transportation sector.

Dr. Peter Wieske

MAHLE Advanced Engineering, Stuttgart/Germany

Lightweight and versatile

Camshaft module made from fiber-reinforced thermoset polymers

MAHLE has taken advantage of its expertise in plastics to produce an innovative camshaft module. The component, developed in collaboration with a German premium manufacturer and the Fraunhofer Institute for Chemical Technology, is made from high-strength, fiber-reinforced thermosets. This special plastic makes the module lighter, cheaper, and more durable than comparable aluminum components—while exhibiting the same load capacity.



Air conditioning module (HVAC)

A sought-after innovation for all drive types. The distribution of heating, ventilation, and air conditioning in MAHLE's latest solution takes place via two- and three-zone temperature regulation and air distribution with variably adjustable footwell temperature. The module's special design also gives it best-in-class acoustics.



On track for a sustainable future

Innovations for e-mobility, carbon-neutral locations, and an approach that's open to all technologies: Martin Wellhöffer (MW) and Rolf Berkemann (RB) discuss the opportunities for sustainable mobility at MAHLE.



Martin Wellhöffer, Corporate Executive Vice President OE Automotive Sales and Application Engineering



Rolf Berkemann, Vice President Sales and Application Engineering S1 / SE

The mobility of the future needs to be efficient, cost-effective, and socially and environmentally responsible. How is MAHLE helping to make this a reality?

RB: We're working with our customers to shape the transition as a systems provider for new mobility. Together, we want to meet the Paris climate targets. The fastest way to do this is to take an open approach to all technologies for the market in question. Globally, tried-and-tested concepts will still be with us for a long time to come. At the same time, mobility will continue to evolve.

Which technologies is MAHLE focusing on?

MW: Our components for electric vehicles help significantly to reduce carbon emissions. We're also making these vehicles more suitable for everyday use with our battery modules or charging solutions, for example. As for the fuel cell drive, we're optimizing the peripherals in order to get it established on an industrial scale. Today, we already generate more than 60 percent of our sales through activities in new fields of technology and unrelated to the passenger car combustion engine. And this figure is set to rise. We're also working on the further development of components for modern internal combustion engines with the aim of cutting CO₂.

What do you expect in terms of future mobility trends?

MW: The mobility landscape is changing as a result of societal trends and expectations. For us, this means becoming even more sustainable. We want to achieve climate neutrality by 2040. This will already be the case at our German locations in 2021. Coupled with our R&D investments in new technologies, we have the opportunity to work with our customers to develop new mobility on a sustainable basis.

What are your thoughts on the market situation with regard to rising raw material prices and supply bottlenecks?

RB: These are both exceptional difficulties—for the entire industry. Despite temporary delivery bottlenecks, we've successfully dealt with the situation. The current increase in raw material prices is a challenge we have to confront together with our customers.

Layer-by-layer 3D construction

For the first time, MAHLE has successfully produced a high-performance aluminum piston using 3D printing technology. Tests demonstrate that the special component increases engine performance and efficiency.

MAHLE has opened a new chapter in design and production. The novelty? Additive manufacturing of high-performance drive components. This approach offers the opportunity to implement functional integration and bionic design in a MAHLE component. When applied to the production of high-performance pistons, this means that more material is used only in areas subjected to load, which is exactly what happens in nature. As a result, the structure of the piston is adapted to the load. This saves material; as a result, 3D printed pistons are up to 20 percent lighter than their conventional counterparts—while increasing their rigidity. In addition, the developers at MAHLE have introduced an optimally positioned and specially shaped cooling gallery near the piston rings. This helps to reduce the temperature in the areas under the most stress.

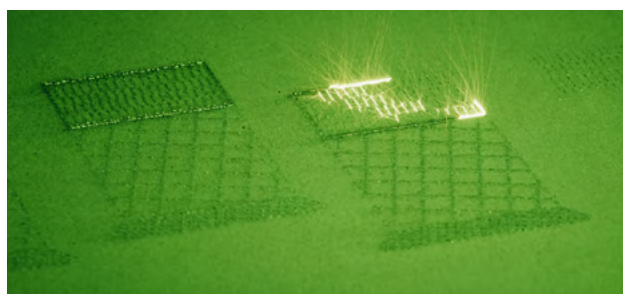
The new production process is based on a special aluminum alloy developed by MAHLE. A laser beam melted the aluminum powder to a specific layer thickness, thereby building the piston up one layer at a time. Using this method, it took around 12 hours and approximately 1,200 layers to produce the piston blanks.

High quality confirmed in rigorous testing

The piston blank was then finished, measured, and tested at MAHLE and had to meet the same strict standards as a conventionally manufactured part. When it came to practical testing, six pistons were fitted in the engine of a Porsche 911 GT2 RS, and the drive unit successfully completed 200 hours of endurance testing under the toughest conditions on the test bench. The results of the extensive tests show that the printed piston achieves the same high quality standard as a conventional production piston.

New 3D printing center

MAHLE believes additive manufacturing is the future—particularly for accelerated development and even the series production of components for electric vehicles and alternative drives. That's why it has opened a new 3D printing center in Stuttgart/Germany.



22 kW

of extra power is produced by the Porsche 911 GT2 RS engine thanks to the special piston.

HYDROGEN AND FUEL CELL TECHNOLOGIES

One element, many possibilities

Green hydrogen is seen by many as the future of energy storage. It can store eco-friendly electricity and even deliver sustainable energy to heavy industry and the heating supply. As an energy carrier, it has the potential to be a key building block for the mobility of the future when used in fuel cells.

The process is already over 200 years old: Electricity is used to split water into its components, oxygen and hydrogen. This is how hydrogen is produced—an energy carrier whose only “exhaust gas” when combusted is water vapor. If the electricity used for the splitting process comes from renewable sources, such as wind turbines or solar plants, then the hydrogen is considered green and is completely climate-neutral.

More and more countries are turning to green hydrogen in the fight against climate change. Gigantic investment programs are expected to create a global hydrogen economy in the next few decades. In terms of possible applications, the element has the potential to serve multiple functions. Hydrogen can store surplus energy from wind or solar and thus compensate for the volatile availability of such power sources, replace coal in steel furnaces, and even power rocket engines. It's also expected to play a critical role in the shift to a sustainable transportation system, because green hydrogen in fuel cells and combustion engines can be used as a zero-emissions source of power for the kinds of commercial vehicles for which batteries would not be an ideal solution.





Fuel cells for trucks

Commercial vehicles account for a considerable share of CO₂ emissions from transportation. However, as the journeys they make are often long and frequently also international, battery or hybrid solutions are less suitable. Fuel cell technology offers a long cruising range, rapid refueling, and route flexibility—while maintaining the same high payload capacity. These are all decisive criteria in transportation and logistics.

MAHLE has long been active in this promising technology segment. For more than a decade, the company has supplied components for series production applications relating

to fuel cells on behalf of many international manufacturers, and it is currently working on customer projects for the next generation of drives.

The new test bench at the Stuttgart plant will also be used for this purpose, and will mean that the overall system can be tested more effectively. “The design criteria for the components change as soon as the focus shifts from the individual parts to the system,” says Philipp Sommer, Head of the Fuel Cell Project House. His team is working to make the drive system significantly more robust and much cheaper.

“

We want to pursue ambitious targets, particularly in terms of the costs and performance of our components.

Philipp Sommer
Head of the Fuel Cell Project House



Endurance testing

At MAHLE, hydrogen is literally on the test bench. In the company's new test center in Stuttgart, components for fuel cells and hydrogen engines, whose operation is carbon-neutral, are intensively tested for their suitability for everyday use in heavy-duty commercial vehicles.

If you expect an engine test bench to be a noisy environment, you may be disappointed by a visit to MAHLE's new test center—at least when fuel cell drives are running. Amid cables, hoses, and chains, they get on with their work in near silence; even the air conditioning is louder than the quiet humming of the cells.

In its new test center in Stuttgart, MAHLE is testing fuel cells and conventional combustion engines, although these engines run on hydrogen instead of gasoline or diesel. The tests are all about the smooth interaction of all components—the so-called systems solution must work.

In the case of a fuel cell, this means, for example, that temperatures, pressures, or voltages must also be managed in the drive system. Only then can hydrogen and ambient air generate the electricity needed to drive a vehicle.

"We want to find systems solutions that are economical and robust," says Peter von Kietzell, who manages the test center. Kietzell and his 100-strong team test hydrogen drives in a facility covering 1,400 square meters. Until recently, test benches for conventional gasoline and diesel engines stood where hydrogen engines hum quietly today. "Our new hydrogen test center is an important step and another example of a successful transformation project by MAHLE," comments Dr. Martin Berger, the Group's Vice President Corporate Research and Advanced Engineering.



MAHLE has been a supplier for fuel cell vehicles for more than ten years. With this new test center, the automotive technology expert is continuing to expand its research and development in this field. The Stuttgart-based company has already invested EUR 2 million in the state-of-the-art facility at its headquarters. But it's not done yet: further expansion of the test benches is already planned.

The peripherals are key

How is hydrogen turned into electricity that then drives a truck? The degree of efficiency with which the stacks in a fuel cell generate energy for the electric motor depends to a large extent on the peripherals. In the drive system, filtered ambient air and hydrogen must first be directed into the fuel cell. In the stacks—which form the heart of the unit—oxygen and hydrogen react to produce an electric current, which must then be routed back out of the cell.

The entire process requires a sophisticated air and filter system. Temperatures and pressures must be regulated, and an intelligent control unit links everything together. MAHLE offers a complete portfolio of these components as a systems solution.

Thermal management



Fan

Electronically controlled fans detect all of the temperatures relevant to cooling and air conditioning and precisely regulate the required fan speed.



Coolant pump

Constructed in a modular design, it moves deionized coolant with minimal electrical conductivity around the fuel cell peripherals.

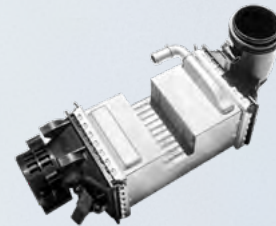


Air management



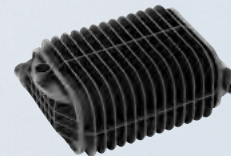
Air filtration system

Filters block harmful gases and particles, which could damage the cell or shorten its service life.



Cathode air cooler

Compression heats the air, which must then be cooled back down prior to cold combustion in the cells.



Membrane humidifier

Fuel cells must be kept reliably moist. Humidifiers from MAHLE transfer humidity from the exhaust air to the initially dry supply air.

Hydrogen preheater



Hydrogen preheater

Especially in winter, the hydrogen must be brought back up to the ideal temperature prior to the reaction process in the stacks.



URBAN MOBILITY

How smart is that?

Lightweight, sporty, and connected—these are the characteristics that set e-bike systems from MAHLE apart. More than 40 manufacturers fit technology supplied by the Group in their electric bikes. For urban, rural, and off-road cycling.

The number of e-bikes in the European market is growing rapidly. At the same time, customer requirements are increasingly high. They want an elegant design, a powerful motor with a long range, and smart technology—not forgetting a ride feel comparable with that of a conventional bike. MAHLE has managed to balance all these requirements.





MAHLE

SPEED

24,8 km/h

DISTANCE 46,92 km TIME 02:09:14

RANGE 74 km BATTERY 61%

Home, Stop, Settings, Profile icons

MAHLE

All in the frame

The lightest e-bikes featuring drives from MAHLE weigh barely 10 kilos—which is astonishingly little. Furthermore, cyclists who can manage without the motor's help don't feel resistance in the pedals, as used to be the case. The 250-watt drive can be switched on at the push of a button as required. Weighing in at just 2 kilos, the powerful wheel hub motor is barely noticeable. The mid-drive motor variant, which is mounted on the bottom bracket, is similarly compact.

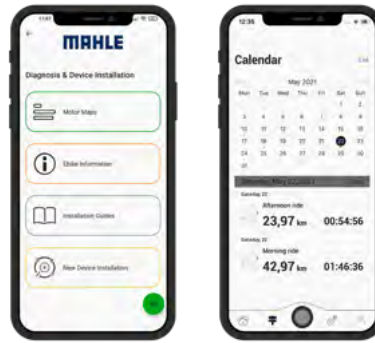
The battery is also lightweight and so slim that it disappears completely in the frame. No component detracts from the bike's sporty styling. The battery has a capacity of 245 watt-hours, which guarantees a decent range considering the light weight. For longer days in the saddle, a range extender with a capacity of 208 watt-hours can be connected.



10 kg

is how much the lightest e-bikes fitted with MAHLE drive systems weigh.

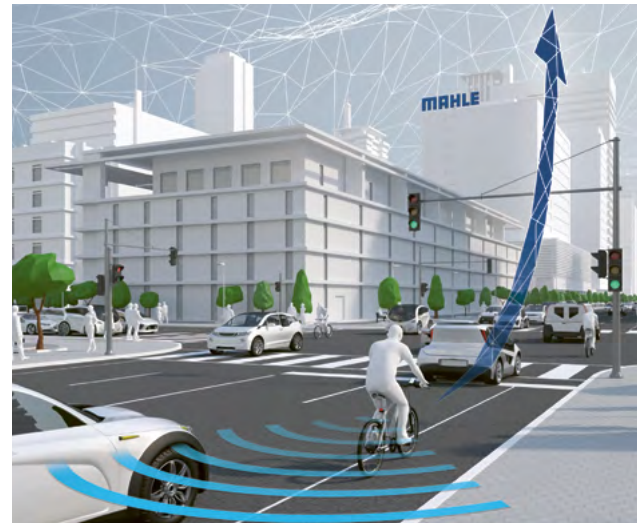




Fully connected

One of MAHLE's key focus areas is the complete connectivity of its drive systems. For example, two apps are already available that can connect the smart system to digital devices. An online dashboard also allows users to check key ride data or their bike's general status at any time. It's also a useful feature for brick-and-mortar specialist retailers, as they can offer servicing to meet the customer's particular requirements.

With this new form of connectivity, MAHLE is creating an unprecedented relationship between the product, customers, manufacturers, and specialist retailers. New safety features are among the future possibilities. For example, via intelligent sensors on the bike or with the help of artificial intelligence, MAHLE aims to raise the safety of cycling in urban traffic to a whole new standard.



MAHLE solutions for bikes with electric drives

2 Range extender

If the integrated battery is empty or a longer ride is planned, an additional power unit can be attached to the frame like a water bottle to add further capacity of 208 watt-hours. This flexible external battery only needs to be carried when required. At 1.45 kilograms, the range extender weighs no more than a large bottle of water. The unit charges in three hours.

1 X35+ motor

A drive that adapts to the user. The virtually silent MAHLE X35+ rear motor with a power output of 250 watts can be switched on at the touch of a button. If the bike is ridden with muscle power only, the X35+ offers no resistance. Weighing just 2.1 kilograms, the unit is extremely light and blends in with the sporty styling of a racing bike.





3 Streamlined battery

Chunky batteries that adversely affect an e-bike's design are a thing of the past—at least at MAHLE. This super slim power store completely disappears into the frame and weighs just 1 kilogram. With a capacity of 245 watt-hours, the battery ensures a long range. It takes just four hours connected to a power socket to reach full charge.

4 iWOC

At first glance, an elegant on/off switch. Installed on the top tube, the iWOC can be operated quickly and easily in any position. However, switching on the electric drive system isn't the unit's only use. It also helps the rider to select the type of support required. Depending on the level, a ring on the switch lights up in a certain color. Since all of the iWOC's cables are integrated within the frame, the e-bike's cockpit is remarkably uncluttered.

5 e-Shifter

At MAHLE, safety is a top priority. That's why we developed the e-Shifter. The electric control button can be flexibly mounted anywhere on the handlebars. This allows the rider to adjust the amount of support without taking the hands off the curved handlebar.

6 Wireless PulsarONE display

The 2.1-inch display gives a clear overview of all of the e-bike's key data. It's easy to operate and can also be used to change the level of assistance.

Conspicuously inconspicuous

An interview with MAHLE e-bike expert Jochen Sommer

Jochen, what's special about the e-bike drive from MAHLE?

Jochen Sommer: Our drive system allows bikes to retain their identity. You can barely detect any signs of electrification. Our “Light. Sport. Smart.” design concept begins with the drive, which is installed out of sight in the rear wheel, and continues with the ultra-compact battery, which is perfectly integrated into the frame. Even the control elements, such as our iWOC ONE, are inconspicuous yet highly functional. Manufacturers like Berlin-based Schindelhauer have praised this design, which has been conceived to allow maximum integration into existing parts of the bicycle. In other words, if you stand a conventional e-bike next to one with our drive, you won't realize that the one with the MAHLE drive is an e-bike—whereas the other will usually be instantly recognizable.

Where does the drive technology come from?

We use technologies from the automotive industry. More specifically, we're drawing on our Mechatronics business unit's expertise in power steering motors. Of course, we haven't started from scratch. It's well known that we've accumulated a great deal of knowledge at



MAHLE about these kinds of electronic and mechatronic components over a long period.

What's smart about MAHLE's e-bike components?

There was already some digitalization in the first generation of e-bikes, but they weren't smart. Today, the connectivity is much more advanced. We've connected the drive to an app. It tells me where I went and how fast I was going. I can see everything on a map or plan routes. And unlike on standard fitness apps, I can see what work I did myself and where the motor helped. This means that an e-bike can be used as an active training partner. Social media is not forgotten, of course, since I can share trips with friends or the wider public and arrange to go on rides with other people. Another thing that's smart is that I know when maintenance is next due thanks to the connection to the drive. This is also handy for workshops or manufacturers, who can

optimize their service by retrieving diagnostics data via the app and benefit from a direct relationship with the customer. Last but not least, connectivity also increases security by means of additional features, such as anti-theft protection via tracking and geofencing.

What else can we expect in the future?

The e-bike market is rightly booming, and we still have plenty of ideas. In addition to new safety features that are sensor-based, for example, and communicate with other vehicles in traffic, our focus will be on optimizing how the battery is charged and the suspension is controlled. This will particularly be the case for routes that the system itself identifies or the rider names. The ability of the systems to learn will increase and, for example, they'll be able to automatically identify the route to work, and adjust the drive control accordingly. There's great potential in sensors and machine learning.

Scooters and commercial vehicles



Two-wheel drive systems for scooters

E-scooters are agile, lightweight, and flexible. But there's also very limited space for the drive system. That's why MAHLE offers highly compact powertrain solutions for these motorized two-wheelers. Less powerful models generally use air-cooled IPM motors (interior permanent magnet synchronous motors) and extremely space-efficient electronics. Each scooter is also fitted with a hybrid controller. It combines rotational speed and torque control for a dynamic handling experience. Larger and more powerful drive systems are usually liquid-cooled.



Low-voltage drives from MAHLE for scooters and three-wheelers with outputs of 6–14 kW

Induction motors for commercial vehicles and golf carts

MAHLE induction motors with the corresponding drive controllers are the ideal solution for electric micro commercial vehicles and golf carts. An algorithm regulates traction and adapts the torque smoothly and precisely to all ground and load conditions.

If required, the controllers can also contain drivers for braking resistors, which are used to brake the vehicle when the battery is fully charged.



Low-voltage drives from MAHLE for commercial vehicles and golf carts with outputs of 10–18 kW



R&D experts — MAHLE Powertrain

The next generation of drive technology will be more varied than ever before. As an experienced specialist in powertrains of all kinds, MAHLE Powertrain supports automobile manufacturers as they take their next step forward. Engine, transmission, hybrid unit, software, and operating strategy—MAHLE Powertrain handles it all.

If you're looking for expert engineering and consultancy services, MAHLE Powertrain is the partner for you—whatever the drive system. Its broad range of services includes the design, testing, development, calibration, and integration of hybridized internal combustion engines and electrified powertrain systems. In all projects, the ultimate goal is to achieve real innovations or advance to the next level of technology for solutions suitable for series production. As they move into the future, the experts are always there to support vehicle manufacturers as partners for cutting-edge research, development, and application.

Advanced testing

To stay one step ahead of the latest technology trends, MAHLE Powertrain continuously invests in state-of-the-art development and test infrastructure. This is also the case at the e-drive test center in Fellbach near Stuttgart/Germany, where the team is developing and testing e-axes and e-drive units for a wide range of electric and hybrid vehicles. To ensure compatibility with all potential vehicle drive applications, systems are operated with high-voltage and low-voltage batteries. Highly specialized permanent-magnet synchro-

nous electric motors replicate the loads applied by the driven wheels, while a thermal soaking system makes it possible to test e-drives in a wide temperature range.

Battery engineering partner

State-of-the-art simulation and testing are just two of MAHLE Powertrain's strengths. Thanks to in-depth understanding of new technologies, our experts also support the international automotive industry as a development partner. With a view to the increasing electrification of mobility, the demand for engineering services for new batteries is increasing. The newly developed 48-volt battery pack from MAHLE is a successful example of this within the MAHLE Group. It was designed with the support of MAHLE Powertrain for repeated high-level





charging and discharging to maximize the potential for energy recovery during deceleration and braking. The basis was data from the analysis of the driving behavior of a typical mid-range vehicle.

International presence

As the MAHLE Group's Engineering Services subsidiary, MAHLE Powertrain supports customers independently of the parent company in the selection of the most appropriate technologies or components for specific requirements. MAHLE Powertrain is represented internationally with eight locations in the UK, Germany, the USA, China, and Brazil. This means that customers in the world's major automotive markets can work directly with our experts on site.



3

million euros were invested by MAHLE in the test bench for electric motors in Fellbach.

8

international centers offer customers on-site expertise in the UK, Germany, the USA, China, and Brazil.

MAHLE Motorsports

Innovations transferred straight from the track to the road. Together with its partners, MAHLE delivers not only adrenaline rushes for motorsports fans but also technological leaps forward, such as in the e-mobility segment.





For many decades, MAHLE has been committed to making motorsports technologies available to all drivers. Without the technology group's expertise, countless victories and championship titles in all motorsports disciplines and competitions would be unthinkable.

Numerous US racing teams have relied on high-performance pistons from MAHLE Motorsports for many years. At the same time, MAHLE is driving technological innovations in partnerships with the successful Formula E team DS TECHEETAH and with Scuderia Ferrari in Formula 1—for vehicles with either electric drives or combustion engines.

Since August 2020, MAHLE has been a technology partner to DS TECHEETAH, the current defending champion of the trailblazing ABB FIA Formula E racing series. The development partner is using its many years of expertise in e-mobility to support the racing team, gathering key insights with regard to sustainable mobility in the process. The best example of this is the 97 percent energy efficiency achieved on the track by its electric drives.

97%

of the input electrical energy can be converted into propulsion by Formula E cars.

Esports with Williams

Racing fever has long since spread to the digital world. That's why MAHLE is contributing its own know-how in simulation and testing to simulated racing in partnership with the Williams racing team, familiar from traditional motorsports. The technology group's expertise is also successfully put to use in race cars of almost all series, classes, and brands worldwide. And because this is the case, MAHLE components are not only found in the sportiest models of every kind of automobile manufacturer, but they also get all other motorists to their destinations efficiently, cleanly, and with minimal energy use.



Zero-carbon road map

Where will our energy come from in the future? What carbon footprint will it have? A look at tomorrow's energy landscape.



Legend:
— Electricity
— Hydrogen

1 Source:

Wind, solar, hydropower, biomass, natural gas with carbon capture, and nuclear energy—many low-carbon energy sources will play a key role in the energy mix of the future.

2 Conversion:

Many forms of energy or raw materials cannot be used directly but must first undergo conversion. Two examples: electrical energy that is not needed immediately can be converted into hydrogen via electrolysis, or biomass can be converted into biogas.

3 Grid and storage:

Energy is often produced centrally in large plants and transported from there to a wide range of users. In the case of chemical energy carriers, such as hydrogen or e-fuels, the grid/network can also act as storage. When it comes to electricity, the grid acts exclusively as a means of transmission.

4 Usage:

In the mobility sector, all forms of energy—electricity, hydrogen, e-fuels/biofuels, and biogas—will play an important role in the medium term. Each has its own advantages. Irrespective of the application and mobility concept concerned, MAHLE offers solutions for the mobility of the future.

5 Electricity:

Zero-carbon electricity is the key to achieving climate neutrality. It can be obtained from wind, hydropower, or solar power. However, to keep the grid stable, supply and demand must be balanced, or the electricity must be temporarily stored in hydrogen by means of electrolysis. In the mobility sector, the direct use of electricity in battery electric drives is especially suited to lighter vehicles and shorter distances.



6 Hydrogen:

Hydrogen will be a key component of the future energy mix. In the mobility sector, it can be used directly in fuel cells or internal combustion engines. Thanks to its high energy density, it is an excellent choice, especially for long-haul transportation. In industrial sectors, such as steel or chemicals, hydrogen has great potential to help reduce CO₂ emissions. It can also be used to store electricity from volatile renewable energies or as a key ingredient in synthetic fuels.

7 E-fuels/biofuels:

Biofuels and e-fuels produced using renewable energies offer a promising opportunity to use both the current infrastructure and the current vehicle fleet to reduce CO₂ emissions right away through their use as admixtures, for example.

8 Gas:

Gas produced from biomass can be fed into the existing gas and storage network and then used in a range of applications, for example, to operate buildings or large marine engines. In addition, its use in gas-fired power plants to generate electricity contributes to stabilizing the power grid.

Sustainability at MAHLE

MAHLE is firmly committed to sustainability. Every day, MAHLE works to steadily relieve the pressure on people and the environment through its resource-efficient technologies as well as its sustainable products and production processes. As an innovative partner for efficient, environmentally friendly mobility solutions, MAHLE supports its customers on their journey into a sustainable future.

Reducing emissions with MAHLE know-how

To achieve the targets set out in the Paris Agreement, greenhouse gas emissions from transportation must be dramatically reduced. MAHLE has considerable leverage when it comes to the transition to environmentally friendly mobility models, since its products are used in passenger cars, commercial vehicles, large engines, and two-wheeled vehicles all around the globe. Customers worldwide therefore benefit from the development and systems expertise accumulated over decades by a global market leader in engine systems and components. As a reliable partner to customers and society, MAHLE complies with current and future legislation and helps to reduce pollutants, greenhouse gases, and noise ever further.

Further development of established technologies

In some application scenarios and markets, the combustion engine is expected to play an important role for some time to come, in medium-sized and heavy-duty commercial vehicles as well as during the transition to e-mobility. That is why MAHLE works to further optimize established technologies with the goal of making the combustion engine even cleaner and more efficient, and of significantly reducing energy consumption as well as CO₂ and other emissions—to make a difference today.

20%

lighter than conventional aluminum modules
is MAHLE's new plastic camshaft module.

Major CO₂ savings potential lies, above all, in the use of synthetic fuels and green hydrogen. Aerodynamics, friction, and thermal management also come into play, with new components such as an innovative and lightweight camshaft module achieving an immediate impact. Made of special plastic, these components not only reduce the weight of the combustion engine, but production is also more climate-friendly than for conventional aluminum camshaft modules. MAHLE's innovative cooling systems can also help to reduce fuel consumption and therefore CO₂ emissions.

Innovative technology for alternative drive types

In urban transportation, particularly in the case of passenger cars and light commercial vehicles, alternative drive types are increasingly supplementing existing technologies. MAHLE is intensifying its efforts to drive forward the development of corresponding systems. These include hybrid and battery electric drives as well as fuel cell technology. As a fully integrated and modular plug-in hybrid drive, the MAHLE Modular Hybrid Powertrain uses a highly efficient two- or three-cylinder turbocharged gasoline engine, making it suitable for a wide range of vehicle types. Its space-efficient design also makes it cheaper, more compact, and lighter than other hybrid drives. The innovative MAHLE battery management system with integrated thermal management increases the fast charging capability of batteries in electric vehicles. The advantage of faster charging is that smaller and lighter batteries can be installed instead. This improves the carbon footprint of the electric vehicle while lowering the demand for raw materials needed for battery production, which are becoming increasingly scarce worldwide.

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Together with our suppliers,
we're setting out to advocate
climate protection and sustainable
business — worldwide.

Kathrin Apel

Head of Corporate Sustainability, Occupational
Health, Safety, and Environment Management



Sustainability in the supply chain

As an important link in the automotive industry's global value chain, MAHLE not only takes responsibility for its own activities, but it also factors in the entire upstream supply chain. The Group's Supplier Code of Conduct contains, among other things, strict requirements for upholding human rights and providing fair working conditions as well as measures to prevent corruption and protect the environment and climate. When selecting suppliers, MAHLE considers whether they work in accordance with certified quality and environmental standards.

Rigorous standards also apply to the materials MAHLE uses and their impact on people and nature. Minerals such as tin, tungsten, or gold, for example, often come from war-torn regions. To avoid indirectly supporting conflicts and related human rights abuses, suppliers of these so-called conflict minerals must closely monitor and document their origin.



83%

of MAHLE's approximately 160 locations were certified in accordance with the environmental management systems ISO 14001 and/or EMAS in 2019.

MAHLE's zero-carbon road map

Production in the automotive industry consumes a great deal of energy and releases emissions into the air and water—this is also the case at MAHLE. To minimize the impact on people and the environment, MAHLE's products, consumables, processes, and machines are subject to ongoing review and optimization above and beyond the legal requirements.

-11.7%

The MAHLE Group significantly reduced its absolute greenhouse gas emissions between 2018 and 2019.



Ever since it was founded, MAHLE's filter plant in St. Michael/Austria has obtained its electricity from hydropower and other renewable energy sources.

In terms of direct CO₂ emissions and those associated with purchased energy, the entire Group is on track to be carbon-neutral by 2040, with the German locations achieving this target as early as the end of 2021. MAHLE aims to achieve this ambitious goal through annual reductions in energy consumption and by means of carbon credits and guarantees of origin. MAHLE is also generating more and more of its own renewable electricity using photovoltaic systems, or increasingly purchasing green electricity. In the long term, MAHLE will use compensation measures to offset any CO₂ emissions that remain unavoidable in the future.

A holistic approach to sustainability

Sustainability is an important operational principle for a foundation-owned company like MAHLE. Its efforts to protect the environment range from research and development to production through to the recycling of MAHLE products. MAHLE is also broadly positioned with regard to social engagement and its responsibilities as an employer. Numerous measures have been introduced to promote the health and safety of MAHLE's workforce. Diversity and equal opportunity in the workplace are top priorities, and MAHLE strictly opposes discrimination of any kind. In addition, MAHLE has supported numerous projects and initiatives in the vicinity of its global locations for many years.

Early on, the company founders, Hermann and Dr. Ernst Mahle, associated MAHLE's success with social responsibility. They established the nonprofit MAHLE Foundation in 1964, which still holds 99.9 percent of the Group's shares. This arrangement guarantees MAHLE's entrepreneurial independence and ensures that the majority of the profit generated

can be reinvested in the company. The MAHLE Foundation uses its annual dividend from the Group's net income for the year to support social projects relating to health and nursing care, agriculture and food, education and upbringing, as well as art and culture.



>100

projects and initiatives supported by the MAHLE Foundation worldwide in 2020.

MAHLE International GmbH
Pragstraße 26-46
70376 Stuttgart/Germany
Phone: +49 711 501-0

www.mahle.com

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