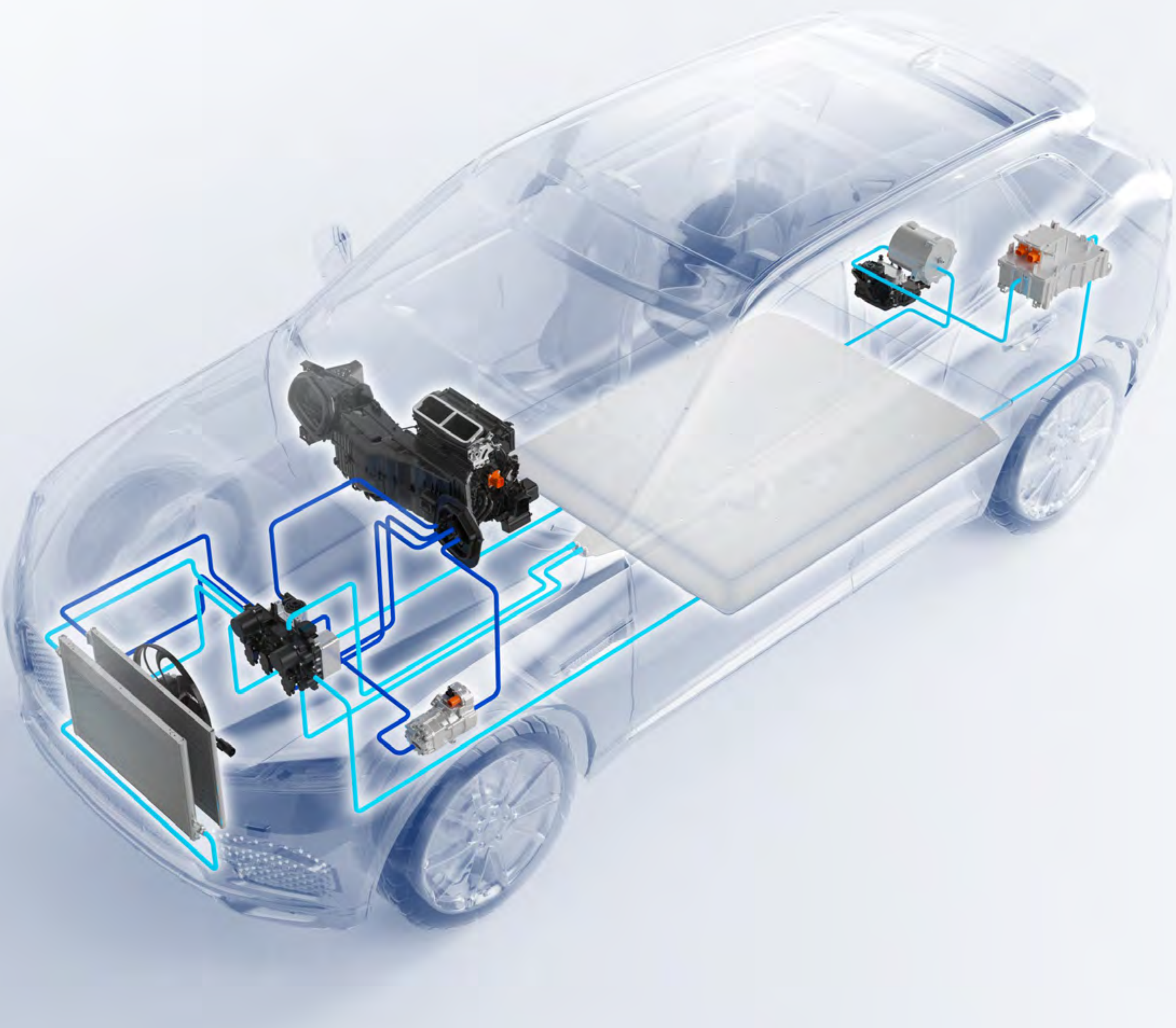
Thermal management

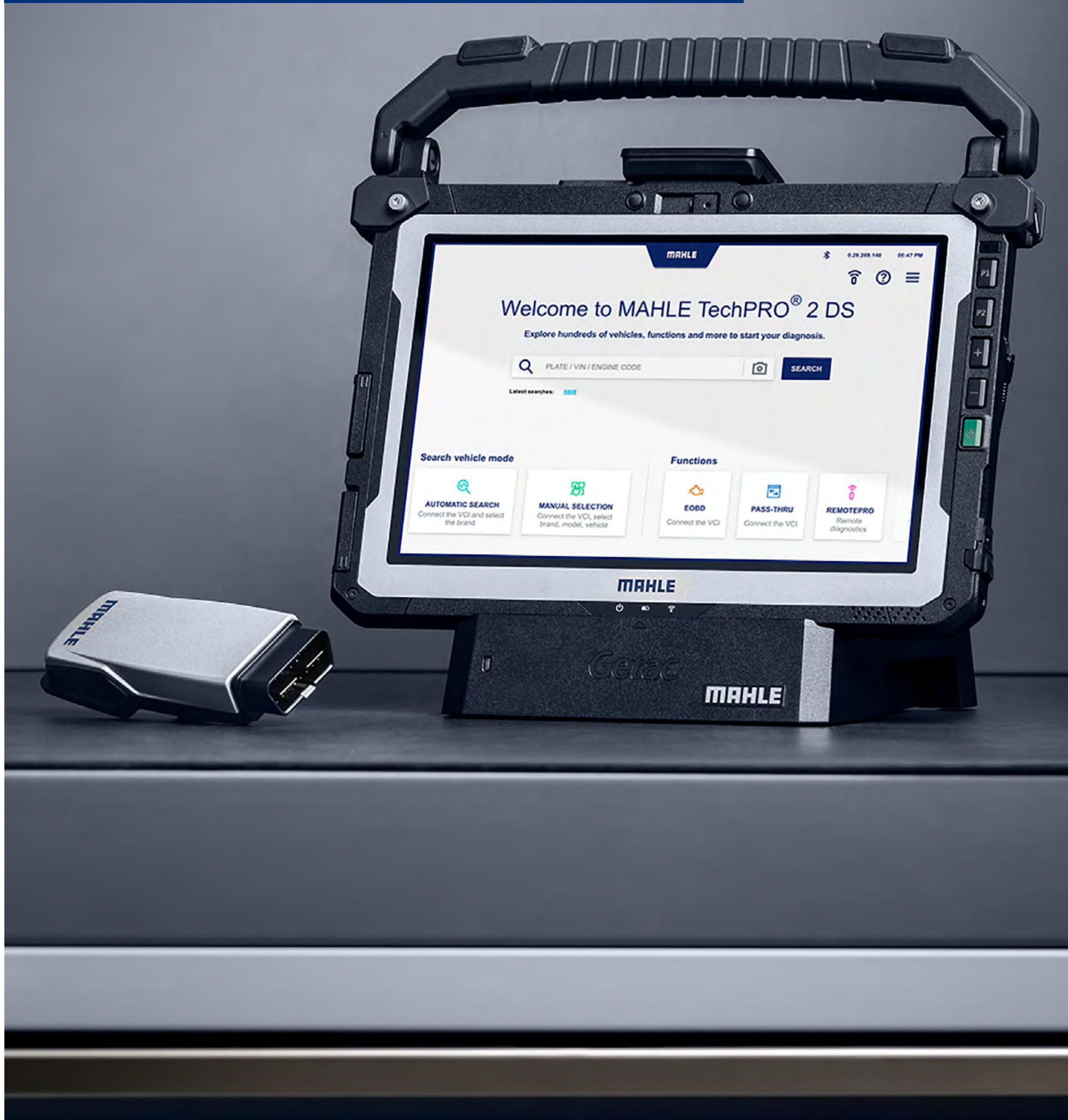
in electric and hybrid vehicles



Contents

Important safety information

The following technical information and practical tips have been compiled in order to provide professional support to vehicle workshops in their day-to-day work. The information provided here is intended for use by suitably qualified personnel only.



Introduction

New challenges mean new opportunities—including opportunities for more sales!

The triumphant advance of electric cars continues unabated. There continues to be a noticeable increase in the number of registered electric cars. And that's not even counting plug-in hybrids! So, one of these cars or its owner is bound to turn up at your workshop sooner or later!

Therefore, workshop operators: don't bury your head in the sand, but gear yourselves up for the new challenges. Because even if classic service work, such as changing the engine oil or replacing the muffler is on the decline, new opportunities are opening up in other areas!

For example, regular air conditioning maintenance is becoming even more important, since the air conditioning system is virtually drive-relevant in electric and hybrid vehicles. The air conditioning system helps to keep the traction battery within the optimal temperature range, which has a positive effect on the cruising range and the longevity of the traction battery. If the air conditioning system fails or if it doesn't function optimally, the results are no longer limited to uncomfortable and unsafe driving—as was previously the case with combustion engines.

Diagnostics relating to the traction battery is also becoming increasingly important—especially in the case of used cars or lease returns. That's why we've expanded our portfolio in this field too. Not to be forgotten are the components at the front of the vehicle, such as low-temperature radiators and air conditioning condensers, which must continue to be replaced in the event of accidents.

So, in the future, simply trust in MAHLE! Our comprehensive OE expertise as one of the world's leading suppliers, our broad and innovative product range, and our extensive services and additional workshop equipment solutions make us a reliable partner for all your thermal management needs, ensuring a smooth and successful workday—today and tomorrow.

Independent workshops are experiencing a growing influx of electric vehicles. Offering our customers the ability to perform battery diagnostics is an important first step in their transition toward e-mobility. We are working every day to open up new areas of business for workshops in the fields of diagnostics, calibration, thermal management, and fluid management.

Overview of hybrid technologies

Comparison

The term "hybrid" essentially means a mix or a combination. With respect to automotive engineering, this term indicates that an internal combustion engine with standard drive technology has been combined in one vehicle with the elements of an electric vehicle.

Hybrid technology has three stages of complexity: from micro hybrid to mild hybrid up to full hybrid technology. Despite technical differences, one thing all the technologies have in common is that the battery used is charged by recovering braking energy.

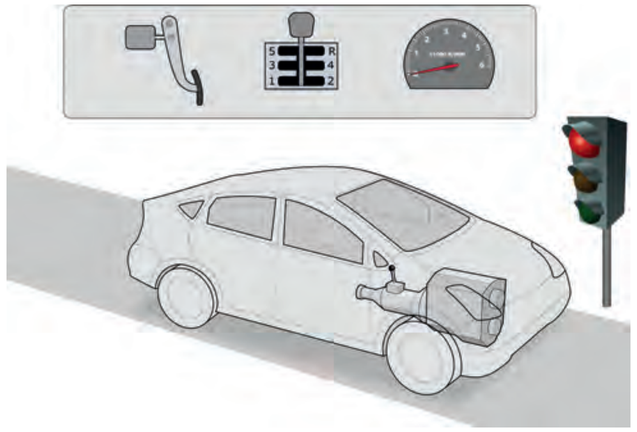
- **Micro hybrids** are usually equipped with a standard internal combustion engine, a stop-start system, and a brake energy recuperation system.
- **Mild hybrids** in contrast also have an additional small electric motor and a more powerful battery. The electrical auxiliary drive is only used as assistance when starting and for greater power delivery when overtaking, a concept known as "boosting."
- **Full hybrids** can not only "boost," but also run solely on electricity. To this end, they are equipped with a full electric powertrain. However, this requires a much more powerful battery than a mild hybrid.
- **Plug-in hybrids** allow the batteries to be charged overnight, for example. The positive side effect of this vehicle type is that, at the same time, the cabin can be brought to the desired temperature before the journey starts. This means that the vehicle is immediately ready for use the following morning. The plug-in hybrid is a type of full hybrid.

Function	Micro hybrid	Mild hybrid	Full hybrid
Output of the electric motor/alternator	2–3 kW (Regenerative braking via alternator)	10–15 kW	>15 kW
Voltage range	12 V	42–150 V	>100 V
Achievable fuel savings compared with a vehicle with conventional drive	<10%	<20%	>20%
Functions that help reduce fuel consumption	▪ Stop-start function ▪ Recuperation	▪ Stop-start function ▪ Boost function ▪ Recuperation	▪ Stop-start function ▪ Boost function ▪ Recuperation ▪ Electric driving

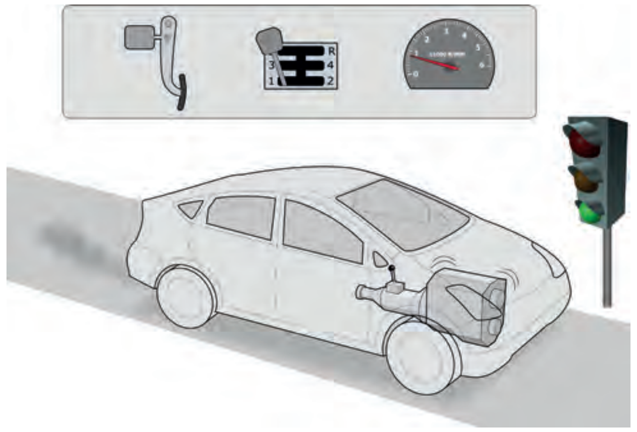
As the above overview shows, each of the technologies has various functions that contribute to reducing fuel consumption. These four functions are briefly described below.

Stop-start function

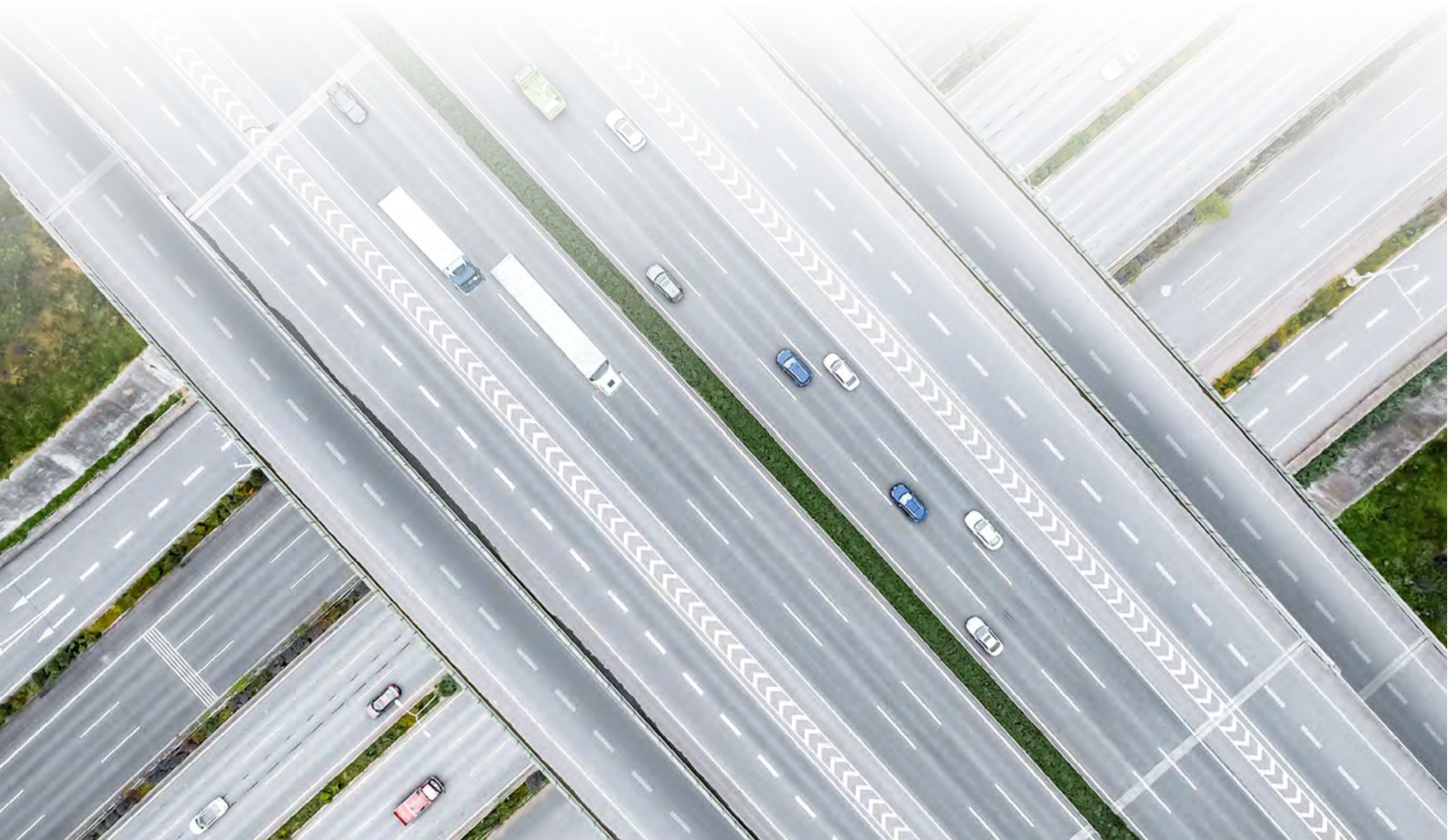
If the vehicle comes to a stop, e.g., at traffic lights or in a traffic jam, the internal combustion engine switches off. The combustion engine starts automatically if the clutch is pressed and first gear is engaged to drive off. This means it is ready to start driving again immediately.



The vehicle comes to a stop—the engine switches off automatically

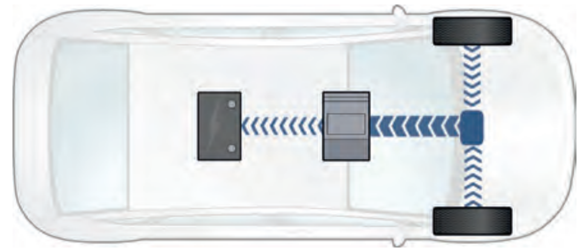


Press the clutch, engage the gear—the engine starts automatically



Recuperation

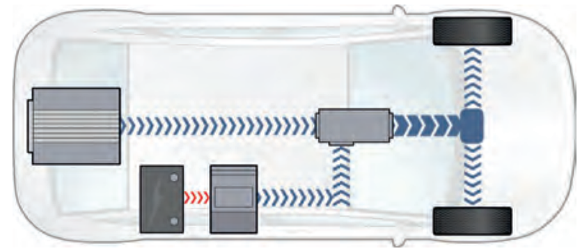
Recuperation is a technology that recovers a portion of the braking energy. Normally, this energy would be lost as thermal energy when braking. During recuperation, on the other hand, the vehicle's alternator is used as an engine brake in addition to the normal wheel brakes. The energy created by the alternator as the vehicle slows is fed into the accumulator (battery). This process specifically increases the drag torque of the engine, thus slowing the vehicle.



Braking vehicle—the battery is charged with more power

Boost function

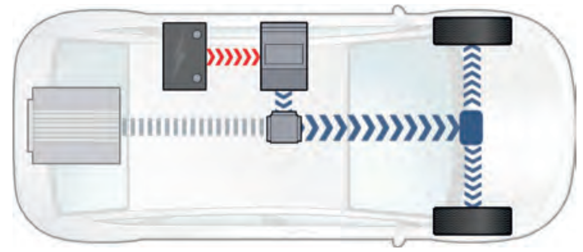
As the vehicle accelerates, the available torque of the internal combustion engine and electric motor are combined. This means that a hybrid vehicle can accelerate more quickly than a similar vehicle with a conventional drive system. The boost function provides assistance when starting and greater power delivery when overtaking. This power is generated by an electrical auxiliary drive that only serves these two purposes.



Boost function—the internal combustion engine and electric motor drive the vehicle

Electric driving

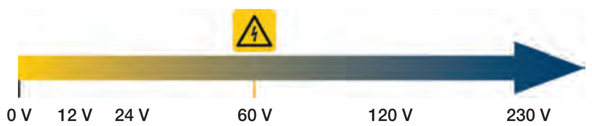
If less drive power is required, e.g., when driving in the city, only the electric motor is used as a power unit. The internal combustion engine is switched off. The advantages of this type of drive are no fuel consumption and no emissions. With these technologies in the vehicle, the conditions that you need to take into account in your daily work have also changed.



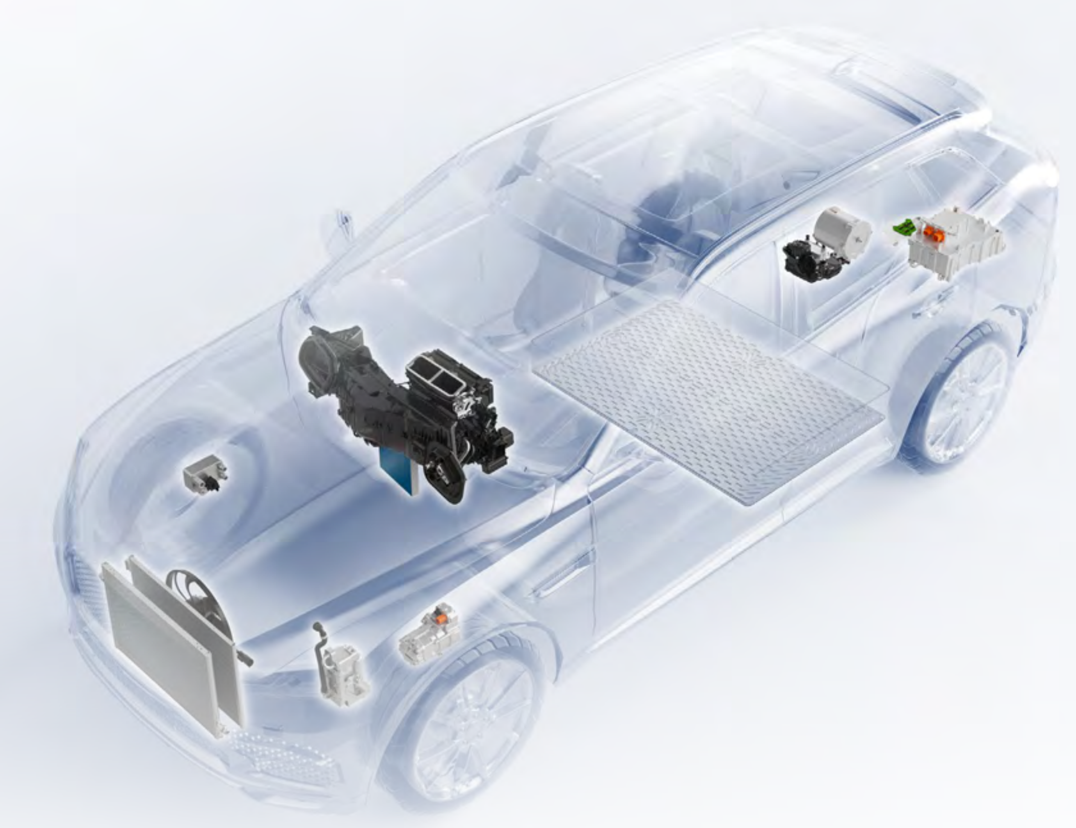
Electric driving—driven solely by the electric motor

Voltage in the vehicle electrical system

The requirements and performance levels that the electric drive of an electric/hybrid vehicle needs to satisfy cannot be achieved with voltage ranges of 12 or 24 volts. Much higher voltage ranges are required here. In vehicles with high-voltage systems, the drive and auxiliary components are operated with voltages from 30 to 1,000 VAC or 60 to 1,500 VDC. This applies to most electric and hybrid vehicles.



Voltage range Full hybrid



High-voltage systems in electric vehicles

Function

By definition, an electric vehicle is a motor vehicle driven by an electric motor. The electrical energy required for its movements is obtained from a powertrain battery (accumulator)—i.e., not from a fuel cell or a range extender. Since the electric car itself does not emit any relevant pollutants during operation, it is classified as a zero-emissions vehicle.

In electric vehicles, the wheels are driven by electric motors. Electrical energy is stored in accumulators, in the form of one or more powertrain or supply batteries. The electronically controlled electric motors can deliver their maximum torque even at standstill. Unlike internal combustion engines, they usually do not require a manual transmission and accelerate strongly even at low speeds. Electric motors are quieter than gasoline or diesel engines, almost vibration-free, and do not emit any harmful exhaust gases. Their efficiency of more than 90 percent is very high.

The relatively large weight of the accumulators is partly offset by the weight saving due to the elimination of the various components (engine, transmission, tank) of the combustion engine. Electric vehicles are therefore usually heavier than corresponding vehicles with combustion engines. The capacity of the battery(ies) has a great influence on the vehicle weight and price.

Air conditioning and cooling in electric vehicles

To enable an electric vehicle to operate at a particularly high level of efficiency, it is necessary to maintain an optimal temperature range for the electric motor, the power electronics, and the battery. This requires a sophisticated thermal management system.

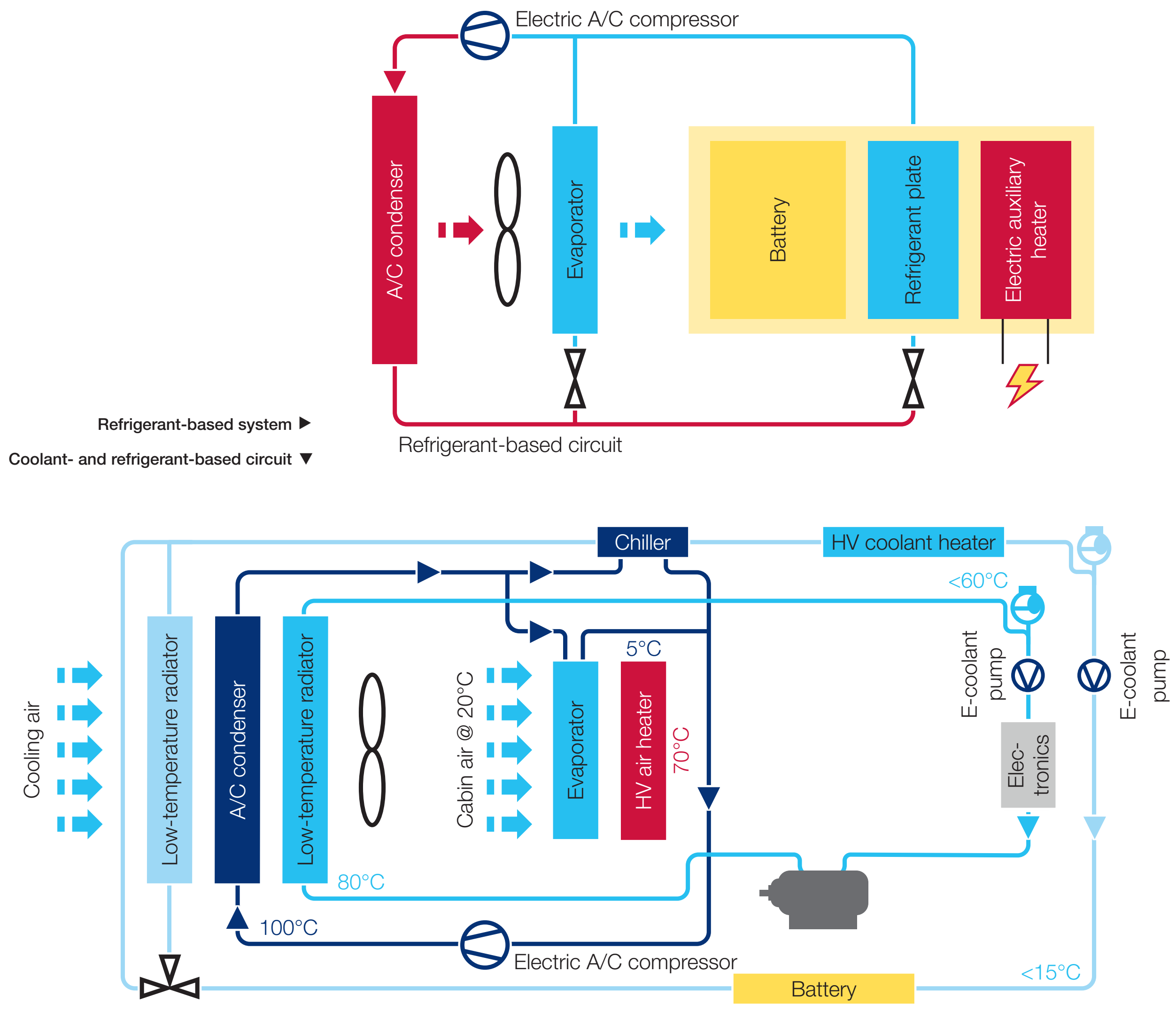
Refrigerant-based system (or direct battery cooling)

The circuit of the refrigerant-based system consists of the following main components: condenser, evaporator, and battery unit (battery cells, cooling plate, and electric auxiliary heater). It is supplied by the refrigerant circuit of the air conditioning system and controlled separately via valves and temperature sensors. The functions of the individual components are described in the explanation for the illustration of the coolant- and refrigerant-based system.

Coolant- and refrigerant-based circuit (or indirect battery cooling)

The more powerful the batteries are, the more sense it makes to use the comparatively complex coolant- and refrigerant-based circuit. The entire cooling system is subdivided into several circuits, each comprising a separate radiator (low-temperature radiator), a coolant pump, thermostat, and coolant shut-off valve. The refrigerant circuit of the air conditioning system is also integrated via a special heat exchanger (chiller). A high-voltage coolant heater provides sufficient battery temperature control at low outside temperatures.

The coolant temperature for the electric motor and the power electronics is maintained at below 60°C inside a separate circuit (inner circuit on the figure below) using a low-temperature radiator. To achieve maximum performance and ensure the longest possible service life, the battery's coolant temperature must be kept between approximately 15°C and 30°C at all times. When temperatures become too low, the coolant is heated via an auxiliary high-voltage heater. When the temperature gets too high, it is cooled via a low-temperature radiator. Should this not suffice, a chiller integrated into both the coolant circuit and the refrigerant circuit will further reduce the coolant temperature. Here, the refrigerant of the air conditioning system flows through the chiller and further cools down the coolant, which also flows through the chiller. The entire control is carried out via individual thermostats, sensors, pumps, and valves.



Component description

Chiller

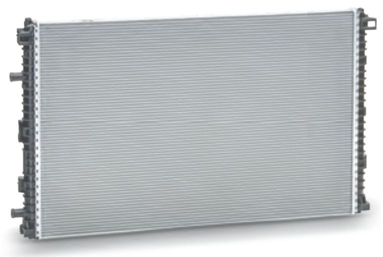
Chiller

The chiller is a special heat exchanger connected to both the coolant circuit and the refrigerant circuit, which allows the temperature of the coolant to be further reduced by the refrigerant in the air conditioning system. This permits additional indirect cooling of the battery by the air conditioning system if required. For this purpose, the coolant of a secondary circuit flows through the cooling plates of the battery. After the heat has been absorbed, the cooling medium is cooled to the initial temperature in a chiller. The temperature reduction in the chiller is caused by the evaporation of another refrigerant circulating in a primary circuit.

Electric air conditioning compressor

Electric air conditioning compressor

The compressor is electrically driven with high voltage. This enables vehicle air conditioning even when the engine is switched off. In addition, the air conditioning system can also be used to cool down the coolant.



Low-temperature radiator

Low-temperature radiator

The coolant temperature for the electric motor and the power electronics is maintained at below 60°C inside a separate cooling circuit using a low-temperature radiator.

Thermostat

Thermostats, whether electric or mechanical, maintain the coolant temperature at a constant level.

Coolant/refrigerant shut-off valve

Coolant/refrigerant shut-off valves are electrically controlled and open/close parts of the coolant/refrigerant circuit as required or connect several circuits with one another.

Power electronics

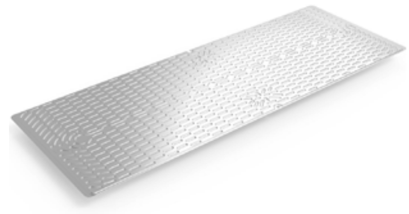
Power electronics

Their task in the vehicle is to control the electric motors, communicate with the vehicle control system, and perform diagnostics on the drive. As a rule, the power electronics consist of an electronic control unit, an inverter, and a DC/DC converter. In order to maintain the power electronics within a certain temperature range, they are connected to the vehicle's cooling/heating system.

High-voltage coolant auxiliary heater

High-voltage coolant auxiliary heater

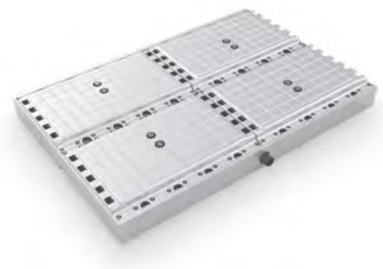
When temperatures become too low, the coolant is heated via an electric auxiliary high-voltage heater. This is integrated in the cooling circuit.



Battery cooling plate

Battery cooling plate

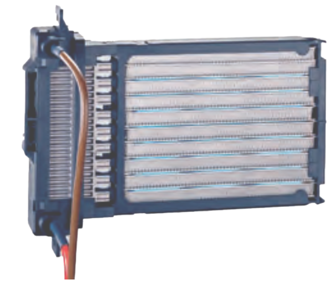
A battery segment is located on each side of the cooling plates. Battery segments and cooling plates form a permanently fixed battery module. In direct battery cooling, the refrigerant of the air conditioning system flows through the cooling plates. With indirect battery cooling, coolant flows through the cooling plates. If the cooling capacity is not sufficient for the indirect cooling of the battery, the coolant can be additionally cooled down via a chiller. The chiller is a special heat exchanger that is used for indirect battery cooling and is integrated in both the refrigerant circuit and the coolant circuit.



High-voltage battery

High-voltage battery module

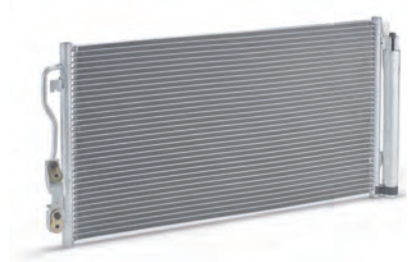
Along with the electric motor, the high-voltage battery (HV battery) is one of the key components of the electric vehicle. It consists of interconnected battery modules, which in turn are made up of cells. Batteries are usually based on lithium-ion technology. They have a high energy density. Due to a decreasing chemical reaction, the performance at temperatures below 0°C drops significantly. At temperatures above 30°C, the aging process increases sharply and at temperatures above 40°C, the battery can be damaged. In order to achieve the longest possible service life and effectiveness, the battery must be operated within a specific temperature spectrum.



Electric/high-voltage auxiliary heater

Electric/high-voltage auxiliary heater

Electric vehicles lack the dissipated heat from the engine, which is transferred to the coolant. It is therefore necessary to warm up the interior with the help of an electric auxiliary heater located in the ventilation system.



Air conditioning condenser

Air conditioning condenser

The condenser is needed to cool down the refrigerant that has become heated during compression in the compressor. The hot refrigerant gas flows into the condenser, discharging heat to the surroundings via the pipe and fins. Cooling reduces the refrigerant state of aggregation from gaseous to liquid.

E-coolant pump

E-coolant pump

Electric water and coolant pumps with integrated electronic control are variably activated according to the required cooling performance. They can be used as main, minor, or circulation pumps. They operate independently of the engine and as required.

Air conditioning

Due to their high efficiency, electric drives emit little heat to the environment during operation and no heat at all when stationary. In order to heat the car in the event of low outside temperatures or to defrost the windows, auxiliary heaters are necessary. These heaters are big energy consumers. They consume some of the energy stored in the battery, which has a considerable effect on the cruising range, especially in winter. Electric auxiliary heaters integrated in the ventilation system are a simple, effective, but also very energy-intensive form of heating.

Energy-efficient heat pumps are therefore now also being used. In summer, they can also be employed as an air conditioning system for cooling. Seat heaters and heated windows bring the heat directly to the areas to be heated and thus also reduce the heating requirement for the interior. Electric cars often spend their downtimes at charging stations. There, the desired vehicle temperature can be achieved before the start of the journey without loading the accumulator battery. On the go, considerably less energy is then required for heating or cooling. Smartphone apps are now also available for controlling the heating remotely.

Charging and discharging management

Different management systems are used for the accumulators, which take over the charge and discharge control, temperature monitoring, cruising range estimation, and diagnostics. The durability depends essentially on the operating conditions and compliance with the operating limits. Battery management systems including temperature management prevent harmful and possibly safety-critical overcharging or exhaustive discharge of the accumulators and critical temperature conditions. The monitoring of each individual battery cell allows it to react before a failure or damage to other cells occurs. Status information can also be stored for maintenance purposes and, in the event of an error, be issued as messages to the driver.

Basically, the battery capacity of most electric cars today is enough for the majority of all short and medium-length journeys. A study published in 2016 by the Massachusetts Institute of Technology concluded that the cruising range of current standard electric cars is sufficient for 87 percent of all trips. However, cruising ranges fluctuate significantly. The speed of the electric vehicle, the outside temperature, and especially the use of heating and air conditioning lead to a significant reduction in the radius of action. However, the ever-shorter charging times and the constant expansion of the charging infrastructure are making it possible to further increase the action radius of electric cars.

Practical tips

Basic rules for working on electric and hybrid vehicles

Electric and hybrid vehicles necessitate the installation of high-voltage components. These are clearly identified by standard warning signs. Additionally, all high-voltage lines are bright orange. ***Please observe the vehicle manufacturer's specifications and our workshop tips.***

The following procedure applies when working on vehicles with high-voltage systems:

1. Completely switch off the electrical system.
2. Secure against current being switched on again.
3. Check there is no voltage present.

What do workshops and employees have to pay attention to?

Starting and moving the vehicle:
In order to drive a vehicle with a high-voltage system—even if only from or to the workshop—the respective person must receive instruction.

Service and maintenance:
Service and maintenance work (changing wheels, inspection work) on high-voltage vehicles may only be carried out by persons who have previously been informed of the dangers of these high-voltage systems and instructed accordingly by an expert for work on high-voltage intrinsically safe vehicles.

Replacement of high-voltage components:
Persons replacing high-voltage components such as an air conditioning compressor must have the appropriate qualifications (expert for work on high-voltage intrinsically safe vehicles).

Replacing the battery:
The repair or replacement of live high-voltage components (batteries) requires special qualification.

Breakdown assistance/towing/recovery:
Anyone providing breakdown assistance on a vehicle with high-voltage systems or towing or recovering it must have received instruction in the structure and functioning of the vehicle and its high-voltage system. Furthermore, the respective instructions of the vehicle manufacturer must be taken into account in advance. If high-voltage components (battery) are damaged, the fire department should be consulted.

Interior air conditioning

Basics

In conventional drive concepts with combustion engines, the interior air conditioning is directly dependent on the engine operation due to the mechanically driven compressor. Compressors with belt drives are also used in vehicles that are referred to by specialists as micro hybrids and only have a stop-start function. The problem is that when the vehicle is at a standstill and the engine is switched off, the temperature at the evaporator outlet of the air conditioning system starts to increase after just two seconds. The associated slow rise in the discharge temperature of the ventilation and the increase in humidity can be annoying for passengers.

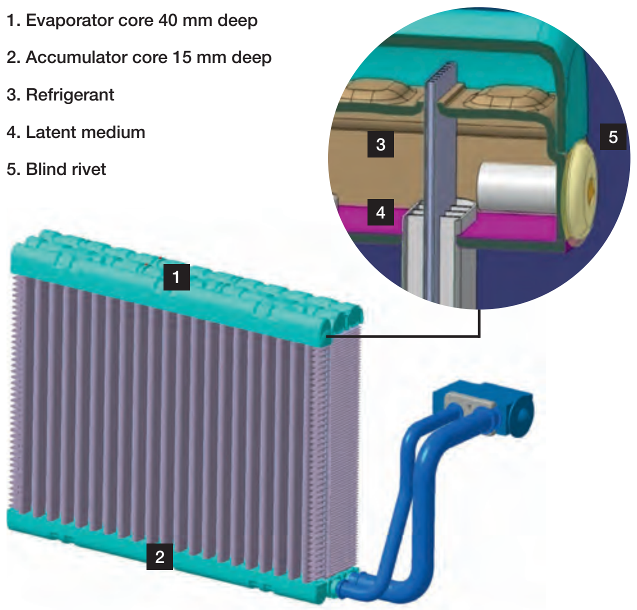
In order to counter this problem, newly developed cooling batteries, so-called storage evaporators, can be used. The storage evaporator comprises two cores: an evaporator core and an accumulator core. Refrigerant flows through both cores in the start-up phase or when the engine is running. In the meantime, a latent medium in the evaporator is cooled to the extent that it freezes, which makes it a cooling battery.

In the stop phase, the engine is switched off and the air conditioning compressor is not driven as a result. The warm air flowing past the evaporator cools down and a heat exchange takes place. This exchange continues until the latent medium has completely melted. Once the journey is resumed, the process restarts. After just one minute, the storage evaporator starts cooling the air again.

On vehicles that do not have a storage evaporator, the engine has to be restarted after a short standstill period in very warm weather. This is the only way to maintain interior cooling. Interior air conditioning also includes heating the passenger compartment, if required.

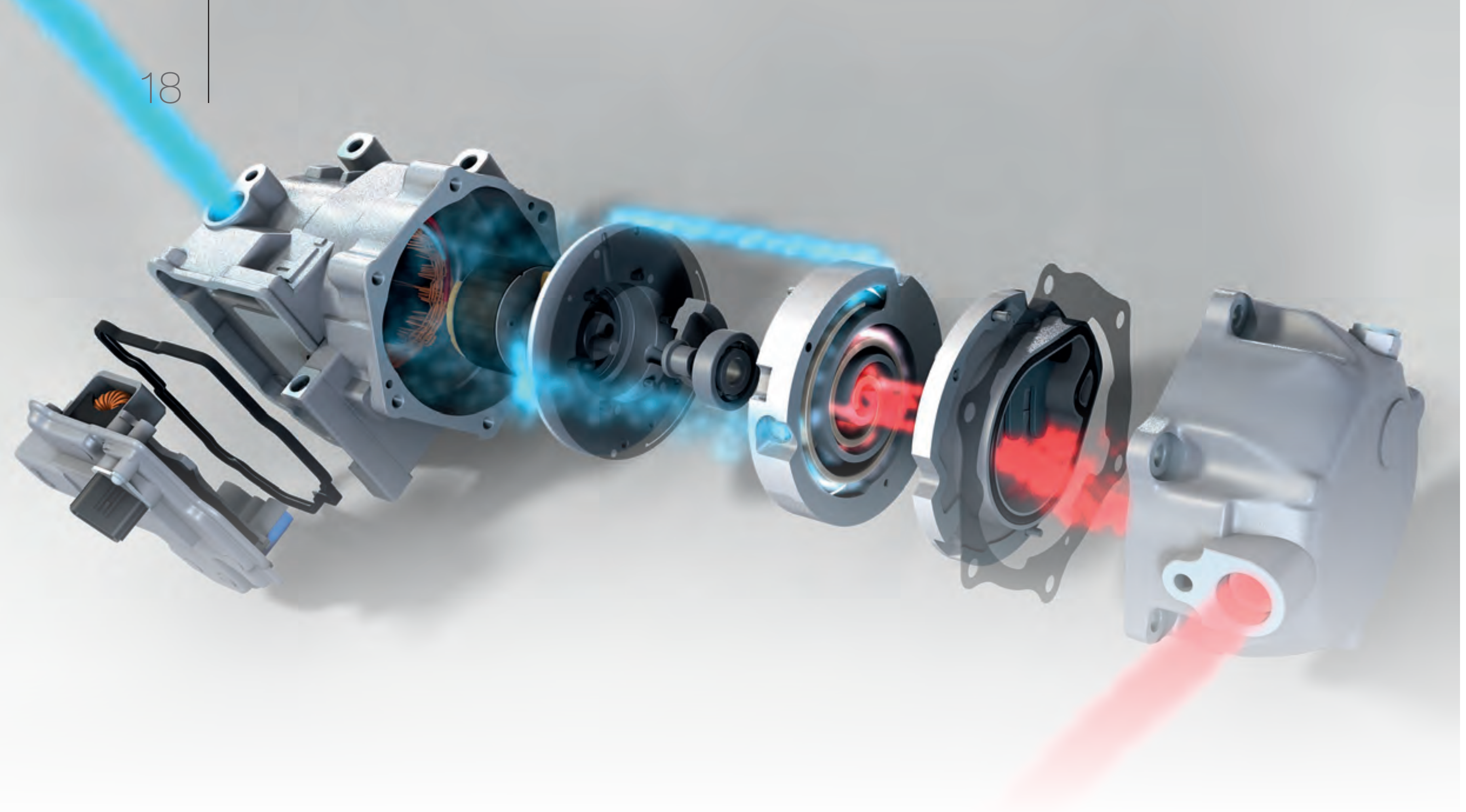
In full hybrid vehicles, the combustion engine is switched off in electric driving mode. The prevailing residual heat in the water circuit is sufficient to heat the interior for a short period of time only. As support, high-voltage air auxiliary heaters are then switched on to take over the heating function. The operation is similar to that of a hair dryer: the air that is drawn in by the interior blower is heated up as it flows past the heating elements and then passes into the cabin.

1. Evaporator core 40 mm deep
2. Accumulator core 15 mm deep
3. Refrigerant
4. Latent medium
5. Blind rivet



Schematic diagram—storage evaporator

Storage evaporator



High-voltage air conditioning compressor

Function

Electric vehicles and vehicles with full hybrid technology use high-voltage electric compressors that do not depend on the internal combustion engine running. This innovative drive concept allows functions to be carried out that lead to a further increase in comfort with regard to the air conditioning in the vehicle.

It is possible to precool the heated interior to the desired temperature before starting the journey. This can be activated via remote control.

Cooling while stationary is only possible if there is enough charge in the battery. The air conditioning compressor is turned down to the lowest power output possible while still providing the required level of air conditioning.

In the high-voltage compressors used today, the power is regulated by adjusting the speed in steps of 50 rpm. It is therefore not necessary to have an internal power control.

In contrast to the swash plate principle, which is used mainly in belt-driven compressors, high-voltage air conditioning compressors use the scroll principle to compress the refrigerant. The benefits are that the weight is reduced by around 20 percent and there is a decrease in the displacement of the same amount while the output remains identical.

A DC voltage of over 200 volts is used to generate the right amount of torque to drive the electric compressor—a very high voltage in this vehicle sector. The inverter fitted into the electric motor unit converts this DC voltage into the three-phase AC voltage required by the brushless electric motor. The return flow of refrigerant to the suction side facilitates the necessary heat transfer from the inverter and the motor windings.

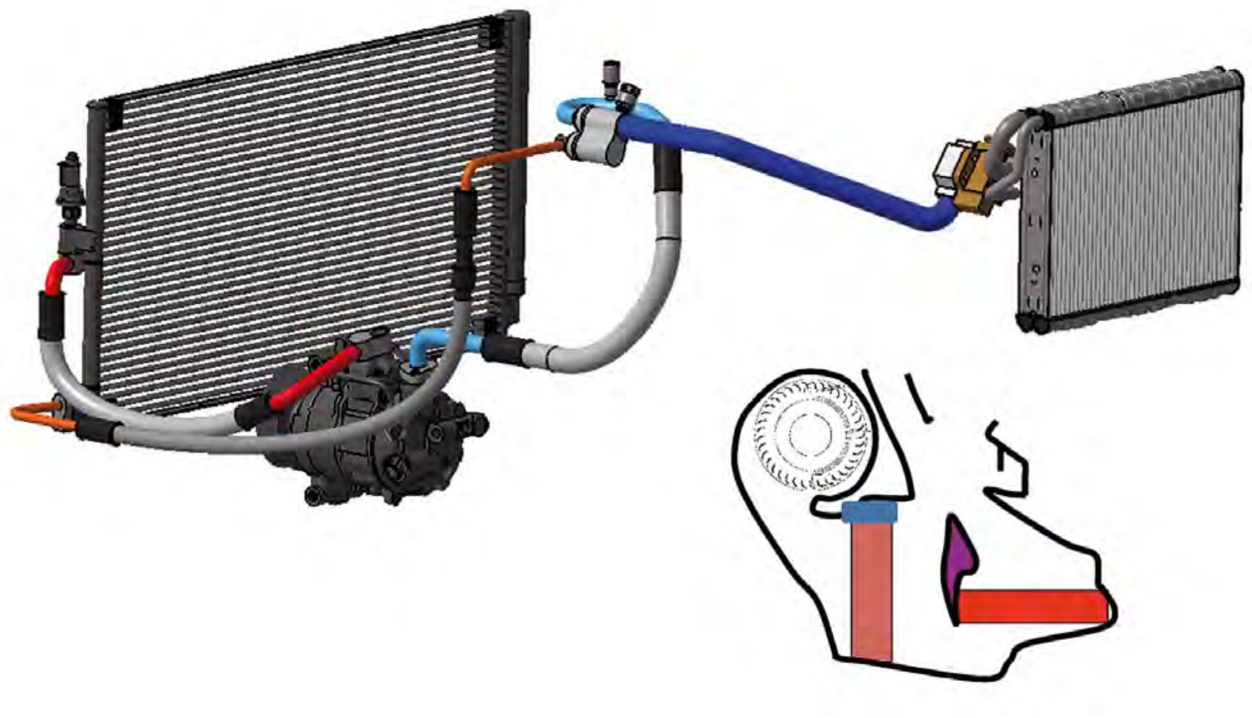
Battery temperature management

Comparison

The battery is essential for the operation of an electric or hybrid vehicle. It has to provide the large amount of energy required for the drive both quickly and reliably. Lithium-ion and nickel-metal hybrid high-voltage batteries are the most common types. This further reduces the size and weight of hybrid vehicle batteries.

It is essential that the batteries used are operated within a defined temperature window. Service life decreases at operating temperatures of 40°C or above, while efficiency drops and output is lower at temperatures below 0°C. Furthermore, the temperature difference between the individual cells must not exceed a particular value.

Brief peak loads in connection with high current flows, such as from recuperation and boosting, lead to a significant increase in the temperature of the cells. High outside temperatures in the summer months can also contribute to the temperature quickly reaching the critical 40°C level. The consequences of exceeding this temperature level are faster aging and the associated premature failure of the battery. Vehicle manufacturers strive to ensure that the calculated battery service life is one car life (around 8–10 years). Therefore, the aging process can only be countered with an appropriate temperature management system. So far, three different temperature management options have been used.

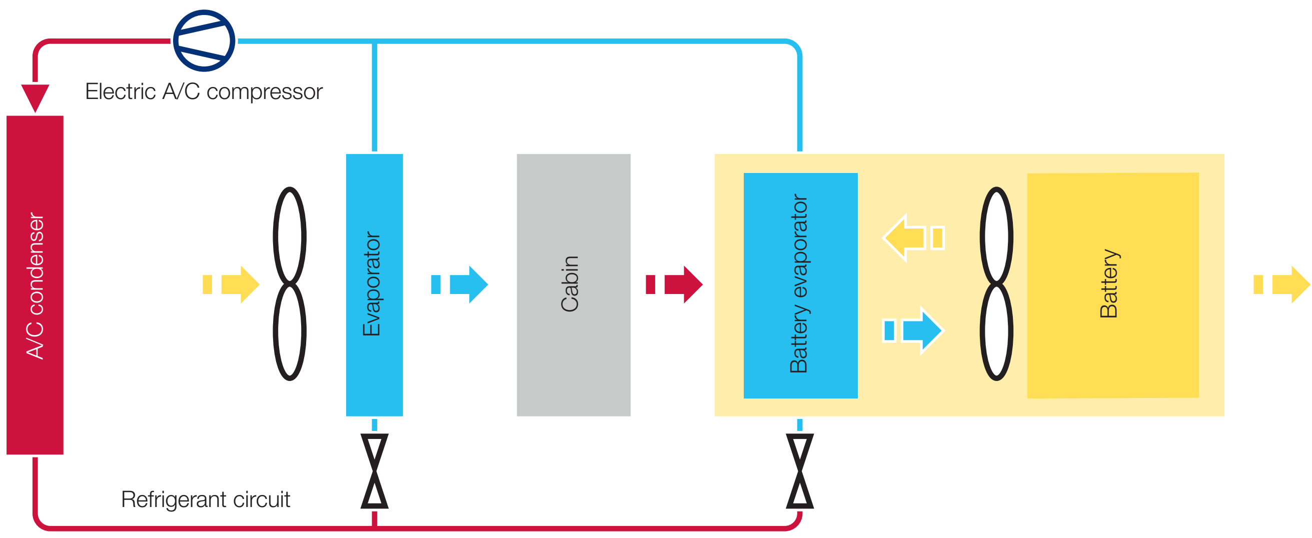


Option 1

Air is drawn in from the air-conditioned vehicle cabin and used to cool the battery. The temperature of the cool air drawn in from the cabin is below 40°C. This air is circulated around the accessible surfaces of the battery pack.

This has the following disadvantages:

- Low cooling effectiveness.
- Air drawn in from the cabin cannot be used to reduce the temperature evenly.
- Considerable effort required to guide the air.
- Possible annoying noises in the cabin due to the blower.
- There is a direct connection between the passenger cabin and the battery via the air ducts. This is problematic for safety reasons (e.g., outgassing of the battery).
- Another factor that should not be underestimated is the risk of dirt entering the battery pack, because the air from the vehicle cabin also contains dust. The dust is deposited between the cells, where it combines with condensed humidity to form a conductive layer. This layer allows leakage currents to arise within the battery. To avoid this risk, the intake air is filtered. Alternatively, air cooling can also be provided by a separate small air conditioning unit similar to the separate rear air conditioning systems in premium-class vehicles.



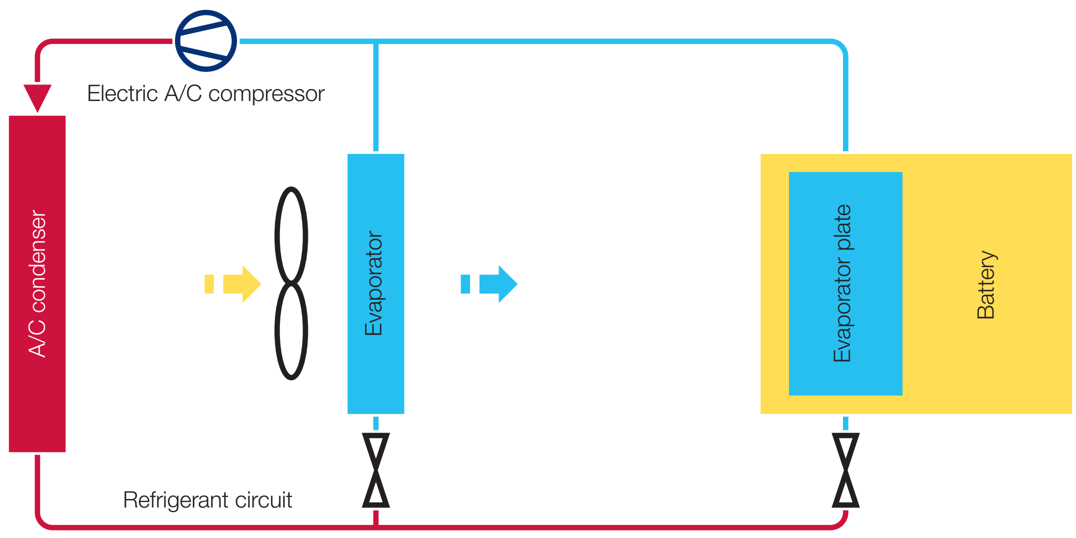
Option 2

A special evaporator plate inside the battery cell is connected to the air conditioning system in the vehicle. This is achieved with the so-called splitting process on the high-pressure and low-pressure side via pipelines and an expansion valve. The interior evaporator and the evaporator plate of the battery, which works like a conventional evaporator, are thus connected to the same circuit.

The different tasks for the two evaporators result in correspondingly different requirements for refrigerant flow. While the interior cooling system aims to satisfy the comfort demand of the passengers, the high-voltage battery must be cooled to varying degrees of intensity depending on the driving situation and the ambient temperature.

These requirements are the defining factors for the complex control of the quantity of evaporated refrigerant. The special design of the evaporator plate and its resulting integration into the battery offer a large contact surface for the heat transfer. This means it is possible to guarantee that the critical maximum temperature of 40°C is not exceeded.

When outside temperatures are very low, an increase in the temperature of the battery to bring it to its ideal temperature of least 15°C may be required. However, the evaporator plate cannot help in this situation. A cold battery is less powerful than one at the right temperature. It is also difficult to charge the battery when temperatures are significantly below freezing. In a mild hybrid, this can be tolerated: in extreme cases, the hybrid function is only available in a limited capacity. It is, however, still possible to drive with the internal combustion engine. In a battery electric vehicle, on the other hand, a battery heater needs to be fitted so that the vehicle can be started and driven in any situation in winter.



Note

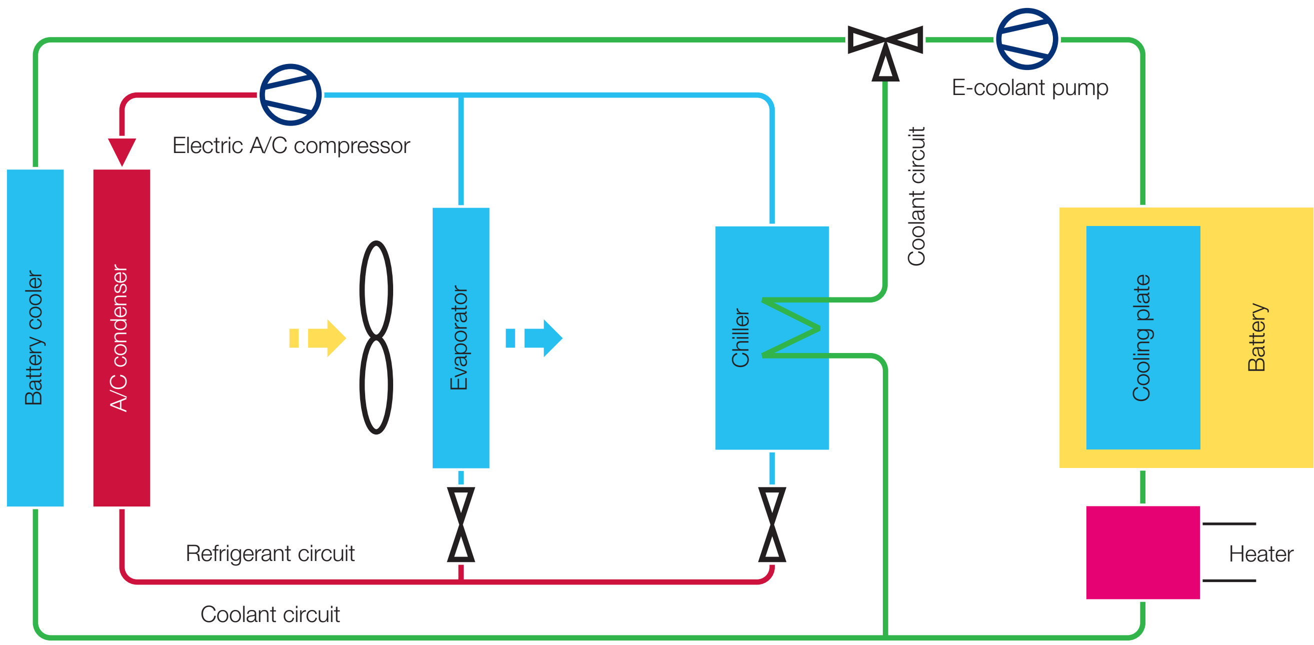
Evaporator plates integrated directly into the battery cannot be individually replaced. Therefore, the whole battery needs to be replaced in the event of damage.

Option 3

The correct temperature plays a key role for batteries with higher capacities. Therefore, at very low temperatures, additional heating of the battery is required to bring it within the ideal temperature range. This is the only way to achieve a satisfactory cruising range when in electric driving mode.

To enable this additional heating, the battery is integrated into a secondary circuit. This circuit ensures that the ideal operating temperature of 15°C–30°C is maintained at all times. Coolant made of water and glycol (green circuit) flows through a cooling plate integrated into the battery core. At lower temperatures, the coolant can be quickly heated by a heater to reach the ideal temperature. The heater is switched off if the temperature in the battery rises when the hybrid functions are being used. Benefiting from the airstream, the coolant can then be cooled via a battery cooler or a low-temperature radiator located in the front of the vehicle.

If the cooling provided by the battery cooler is not sufficient at high outside temperatures, the coolant flows through a chiller. This is where the refrigerant from the vehicle air conditioning system is evaporated. Moreover, heat can be transferred from the secondary circuit to the evaporating refrigerant in a very compact space and with a high power density. An additional recooling of the coolant takes place. Thanks to the use of the special heat exchanger, the battery can be operated within the most efficient temperature window.

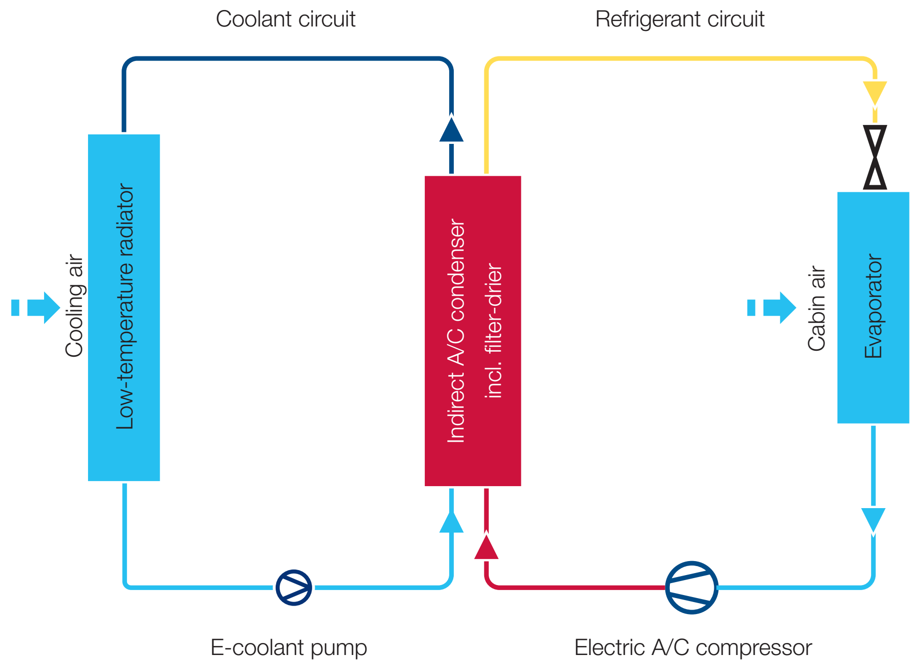


Indirect A/C condenser

Indirect air conditioning condensers, which cool down and thereby liquify the heated refrigerant after compression in the air conditioning compressor, are already used in many modern vehicles with combustion engines and also represent the best technical option for hybrid and electric vehicles. They are more compact, efficient, and powerful than directly cooled air conditioning condensers, because there is significantly better heat transfer to the coolant than to the ambient air. With the indirect design and the resulting flexibility over where it can be positioned in the vehicle, the conventional air conditioning condenser at the vehicle front is no longer needed. After all, an indirect air conditioning condenser doesn't make use of the ambient air. Instead, the refrigerant and additionally the coolant from the low-temperature radiator flow through it. The lower coolant temperature is used to cool down the hot, gaseous refrigerant coming from the air conditioning compressor, thus enabling the refrigerant to liquify. As the indirect air conditioning condenser doesn't have to be installed in the vehicle front, it is better protected against mechanical damage (stone chip, accident). The main radiator and low-temperature radiator get more air, which in turn boosts the efficiency of the entire system.

Depending on the vehicle architecture and where the indirect air conditioning condenser is installed, not only is less space needed, but shorter pipes and lines can also be used to and from the indirect air conditioning condenser. This means that less refrigerant is needed in the circuit compared with a direct air conditioning condenser.

The indirect air conditioning condenser has two inlets and two outlets for refrigerant and coolant as well as an integrated filter-drier in expansion stages. This makes it very compact and also reduces the number of lines. In the different versions (without/with dryer), the air conditioning condenser can be used in vehicles with air conditioning or with heat pump and air conditioning.



Thermal management module

The thermal management module shown below takes the components that were previously installed individually and combines them in a single unit. The module contains the electric air conditioning compressor, the chiller, the indirect air conditioning condenser, the filter-drier, refrigerant valves, e-water pumps, and other components.

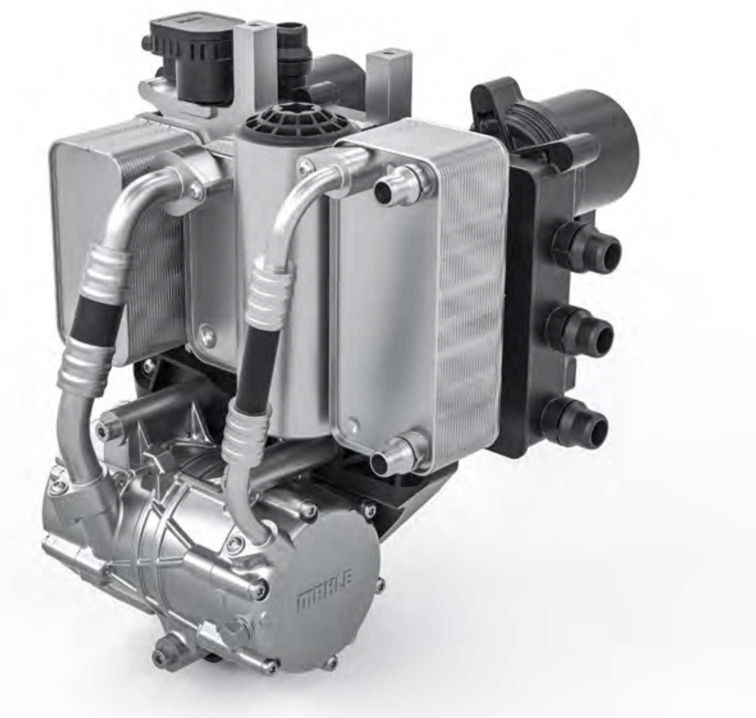
Through the interaction of its components, the thermal management module is able to perform important tasks in electric and hybrid vehicles, such as maintaining optimal battery temperature, ensuring efficient operation of the powertrain, and regulating the temperature in the vehicle cabin under various environmental conditions.

The module also connects the refrigerant circuits with the coolant circuits. As a result, the battery, powertrain, and vehicle cabin can be supplied with sufficient heat in winter and optimally cooled in summer with greater efficiency.

Advantages of the modular solution

The modular approach requires less installation space and significantly reduces assembly effort, ultimately simplifying installation and saving costs. In addition to reduced system complexity, temperature control and system reliability are also improved. Furthermore, the modules work much more efficiently than their individual components and can extend the cruising range of an electric car by up to 20 percent and boost charging speed appreciably. As result, the concept helps to make electric and hybrid vehicles more cost-effective.

Video: MAHLE thermal management module ▼



Bionic cooling plate

The bionic cooling plate from MAHLE is a technological advancement in the field of battery cooling. Inspired by nature, MAHLE engineers have developed an innovative cooling channel structure that imitates the shape of coral. This bionic innovation significantly improves the thermodynamic performance and structural characteristics of the cooling plate.

The bionic cooling plate's novel structure increases cooling performance by 10 percent and reduces pressure loss by 20 percent, resulting in even temperature distribution within the battery. Another advantage of this technology is that the material thickness is reduced, further increasing the efficiency of the cooling plate while also cutting material consumption by up to 15 percent. In turn, this lowers CO_2 emissions by 15 percent. Optimized cooling performance means accelerated battery charging, extended battery life, and improved performance even under extreme conditions such as fast charging.

Intelligent control of the coolant flow rate makes heat transfer more efficient, especially when temperature differences are minimal. This helps to significantly lower the battery's peak temperatures and maintain its performance.

Heat pump

Even in an electric car, the interior must be heated in winter. However, if the required heat amounting to several kilowatts is generated via electric heaters, the range of the traction battery is noticeably reduced. A heat pump is an efficient, low-consumption solution.

A heat pump extracts heat from the outside air and conveys it into the cabin. Depending on the outside temperature, the heat pump needs only about a third of the electrical power from the traction battery to heat the interior equally.

How does a heat pump work?

Every air conditioning system is actually a heat pump. To cool the vehicle cabin, heat is conveyed outside to the air conditioning condenser. The same happens in battery cooling, where heat is conveyed from the battery to the air conditioning condenser at the front of the vehicle (outside).

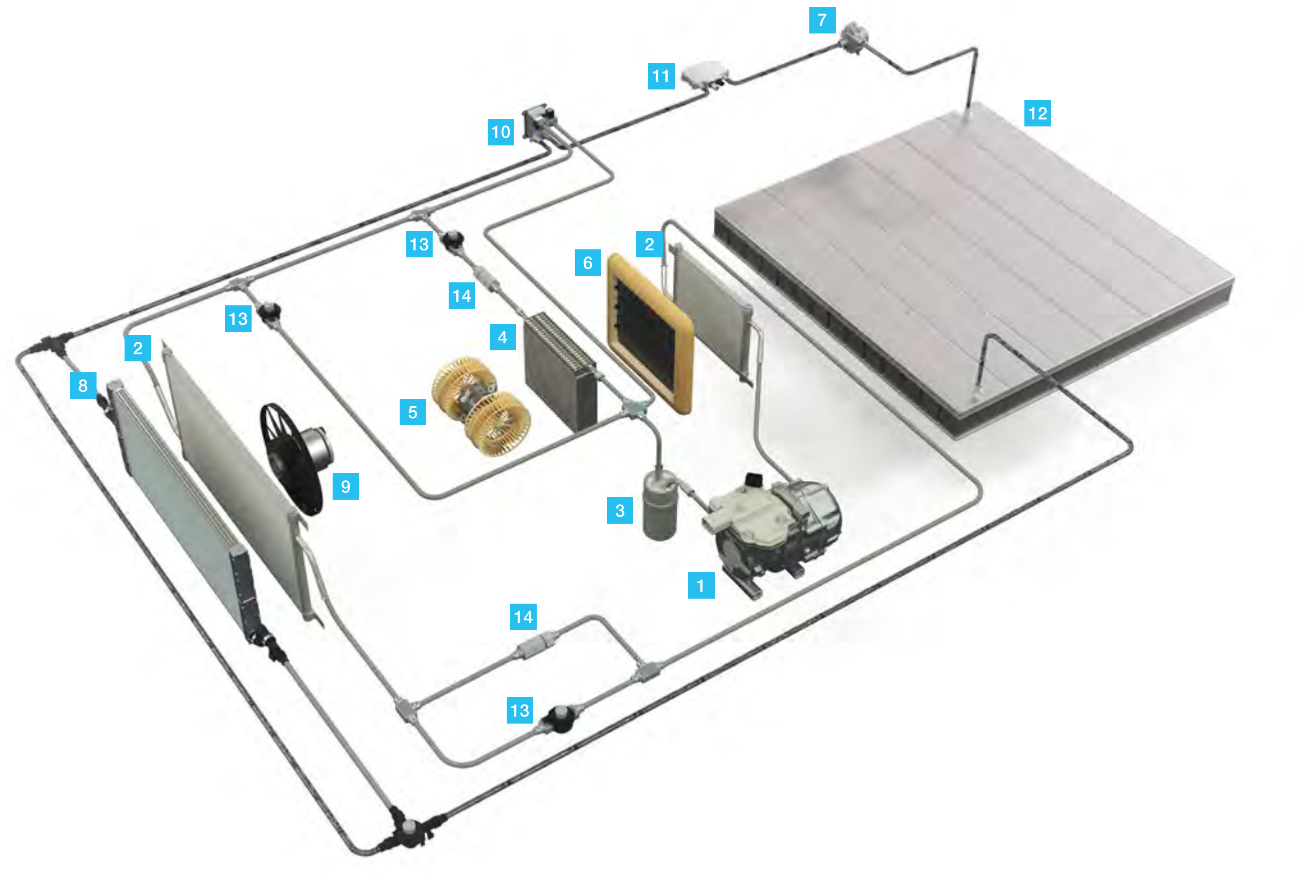
The same air conditioning compressor belonging to the air conditioning system is used for the heat pump. An additional air conditioning condenser in the vehicle cabin supplies the cabin with heat via an air flap. Meanwhile, a solenoid valve controls the coolant circuit so that the air conditioning condenser at the front of the vehicle now serves as an evaporator.

The heat pump in operation

In an electric car, the heat pump combines interior air conditioning with battery temperature management. At the heart of this system is the chiller, which acts as a heat exchanger and is connected to both the battery's coolant circuit and the air conditioning system's refrigerant circuit.

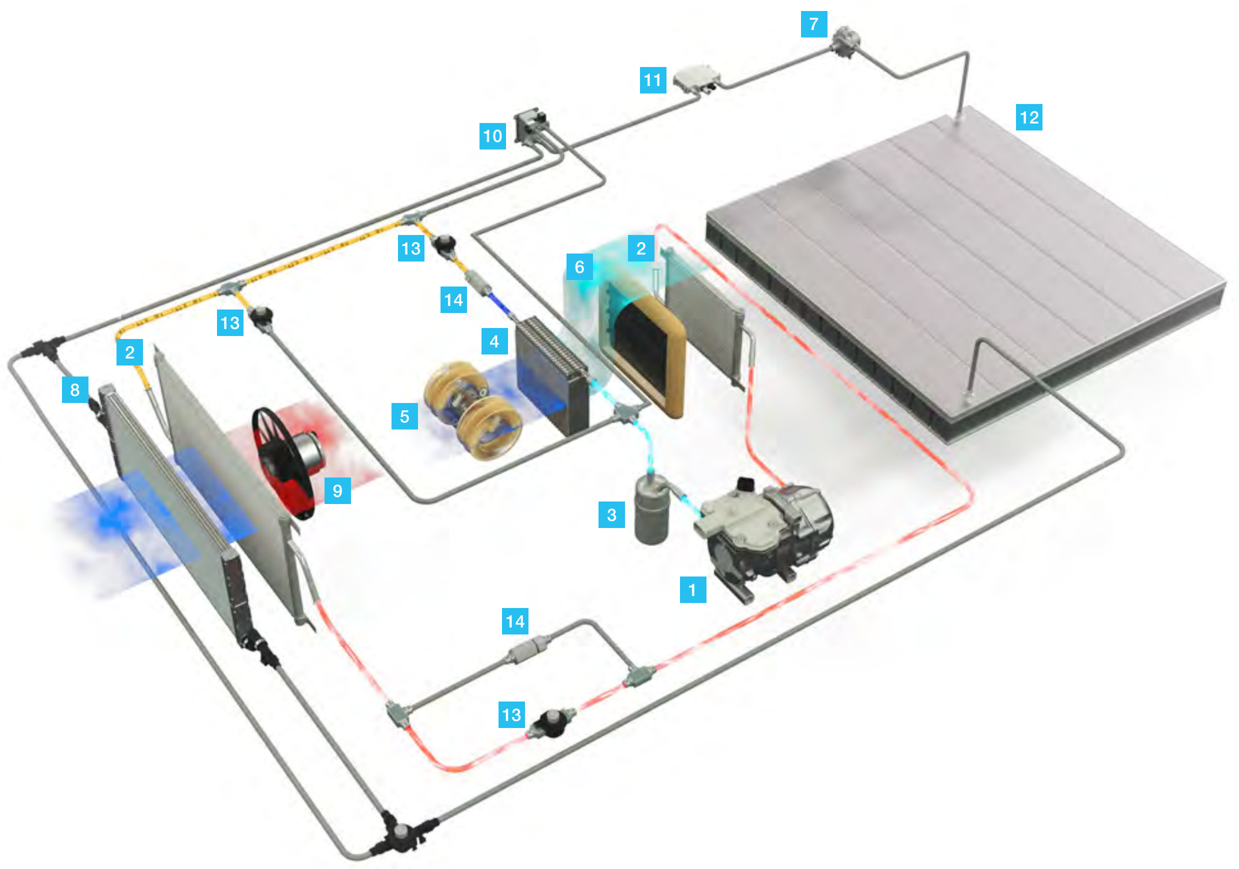
The use of solenoid valves means that there are three main circuits: air conditioning, battery cooling, and heating. As a result, the system can be operated in different modes, which can be combined depending on the situation.

For an animated version of this diagram, visit our **TechTool**.



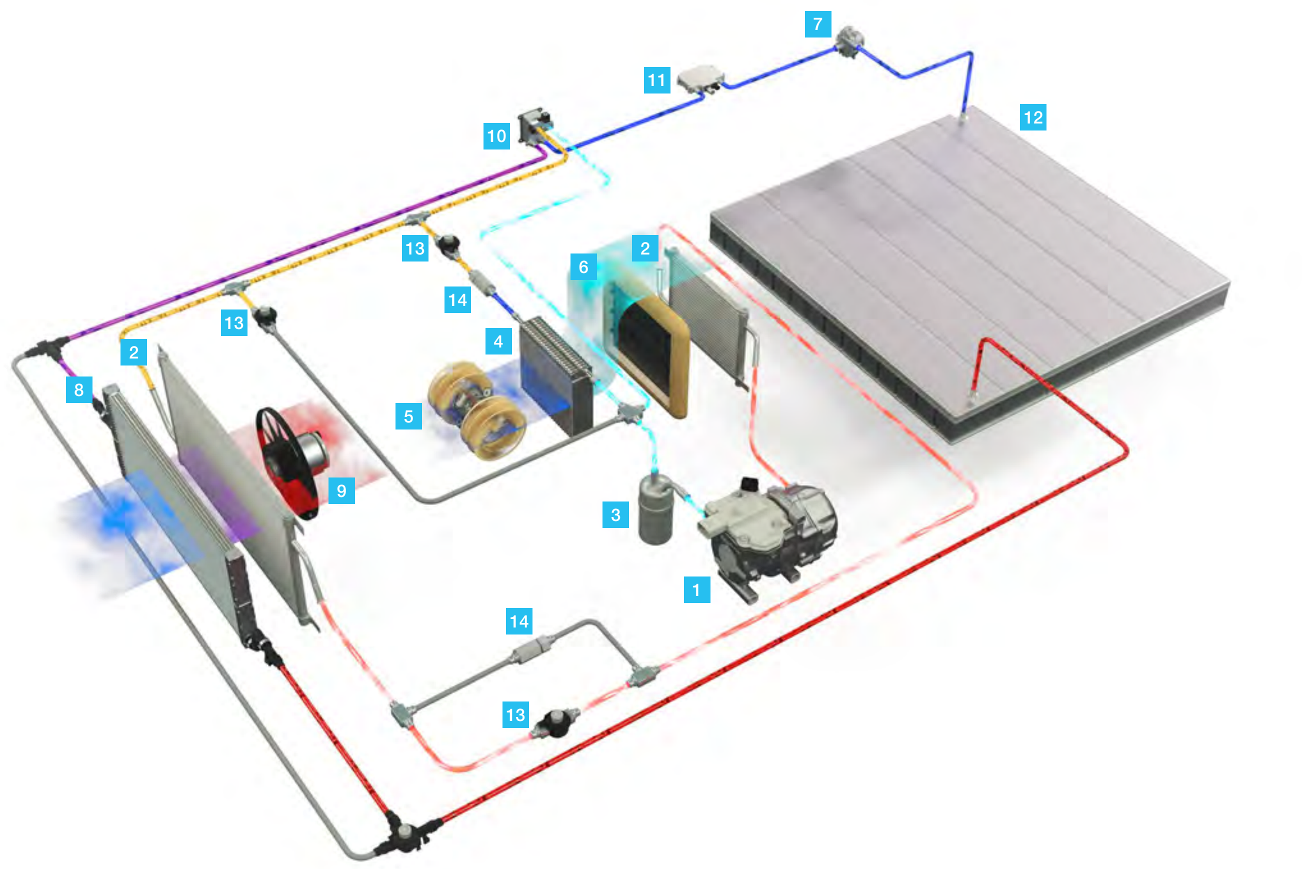
1 High-voltage compressor
2 A/C condenser
3 Accumulator
4 Evaporator
5 Interior blower
6 Air flap (fins)
7 Coolant pump
8 Low-temperature radiator
9 Electric radiator fan
10 Chiller
11 High-voltage coolant auxiliary heater
12 Battery
13 Refrigerant shut-off valve
14 Throttle valve

Mode: cooling the interior



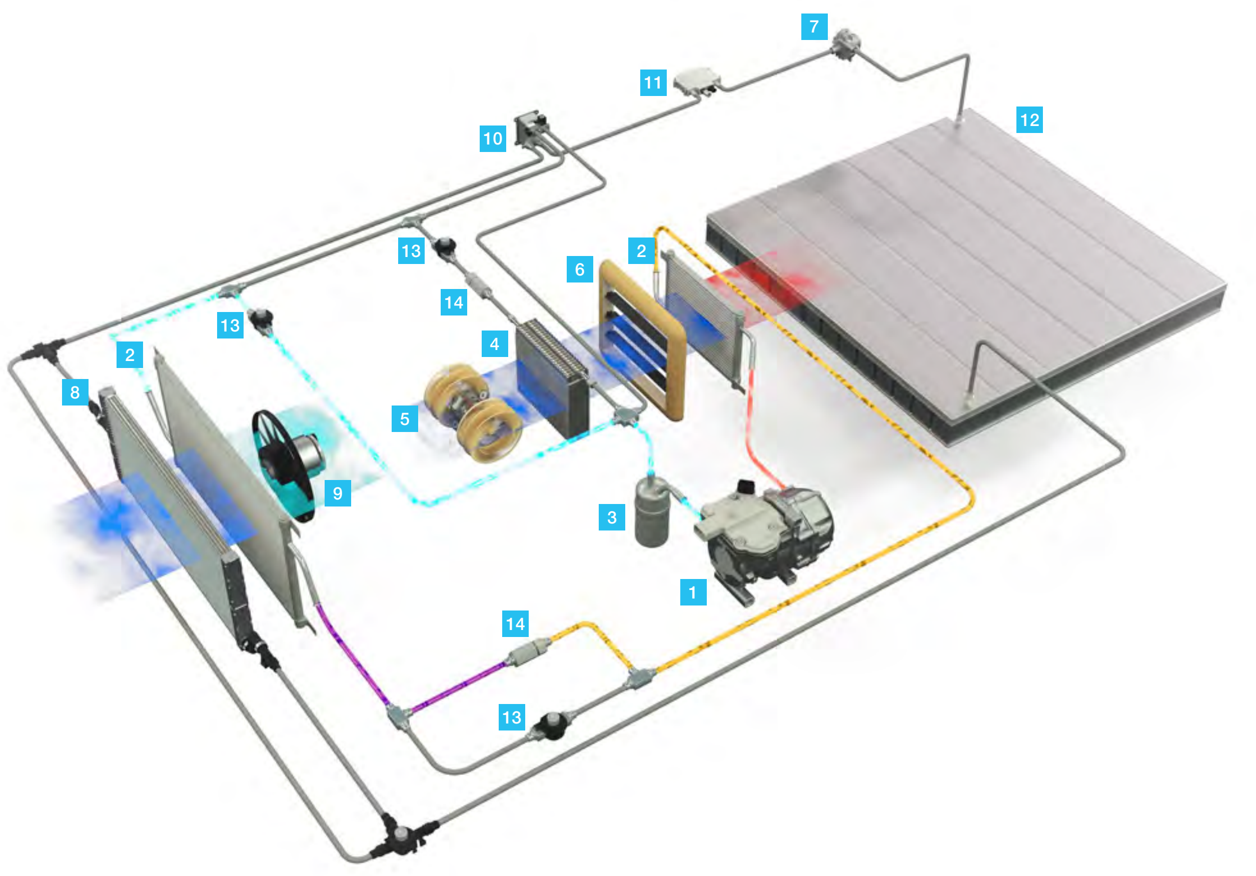
To cool the cabin, the "air conditioning" circuit is activated. The hot, compressed, gaseous refrigerant is first fed from the air conditioning compressor into the condenser in the vehicle's interior. However, no condensation takes place here because the flap to the interior remains closed. This means that the refrigerant remains gaseous and its temperature does not change. It is only in the condenser at the front of the vehicle that it is cooled by the ambient air. Now liquid but still at high pressure, the refrigerant then reaches the evaporator in the cabin. A constant throttle valve (orifice tube) is installed upstream of the evaporator. By reducing the cross section of the line, this valve causes rapid pressure loss, thereby cooling the refrigerant. The interior blower ensures that the evaporation cooling generated by the evaporator is circulated around the vehicle interior. The refrigerant, which is discharged from the evaporator in a gaseous state at low pressure, is returned to the compressor via a filter-drier (accumulator).

Mode: cooling the interior and battery



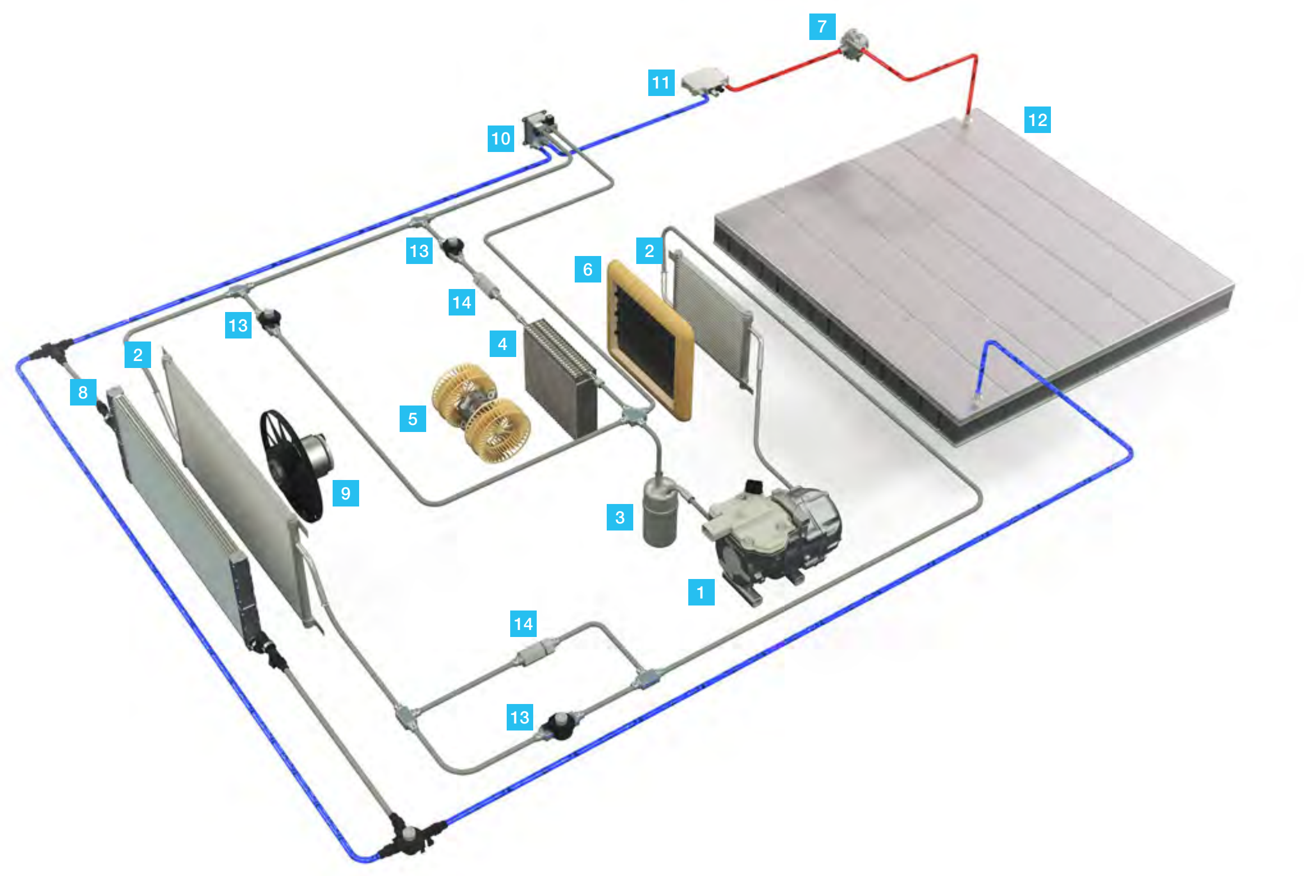
In "battery cooling" mode, the refrigerant circuit is expanded so that it can be used to cool the battery. This is primarily accomplished via the low-temperature radiator at the front of the vehicle, but rather than conducting the coolant back to the battery directly, it is pumped on to the chiller. By opening a solenoid valve, the chiller is simultaneously supplied with liquid refrigerant from the condenser at the front. As result, some of the refrigerant flows to the chiller, while the rest flows via the orifice tube to the interior evaporator (as described above). The chiller acts as a special kind of heat exchanger, using the refrigerant to further reduce the temperature of the battery coolant. A coolant pump then directs the coolant through the (inactive) high-voltage coolant auxiliary heater and back to the battery. At the same time, the now gaseous refrigerant is routed past the interior evaporator, directly into the accumulator, and thus back to the compressor.

Mode: heating the interior



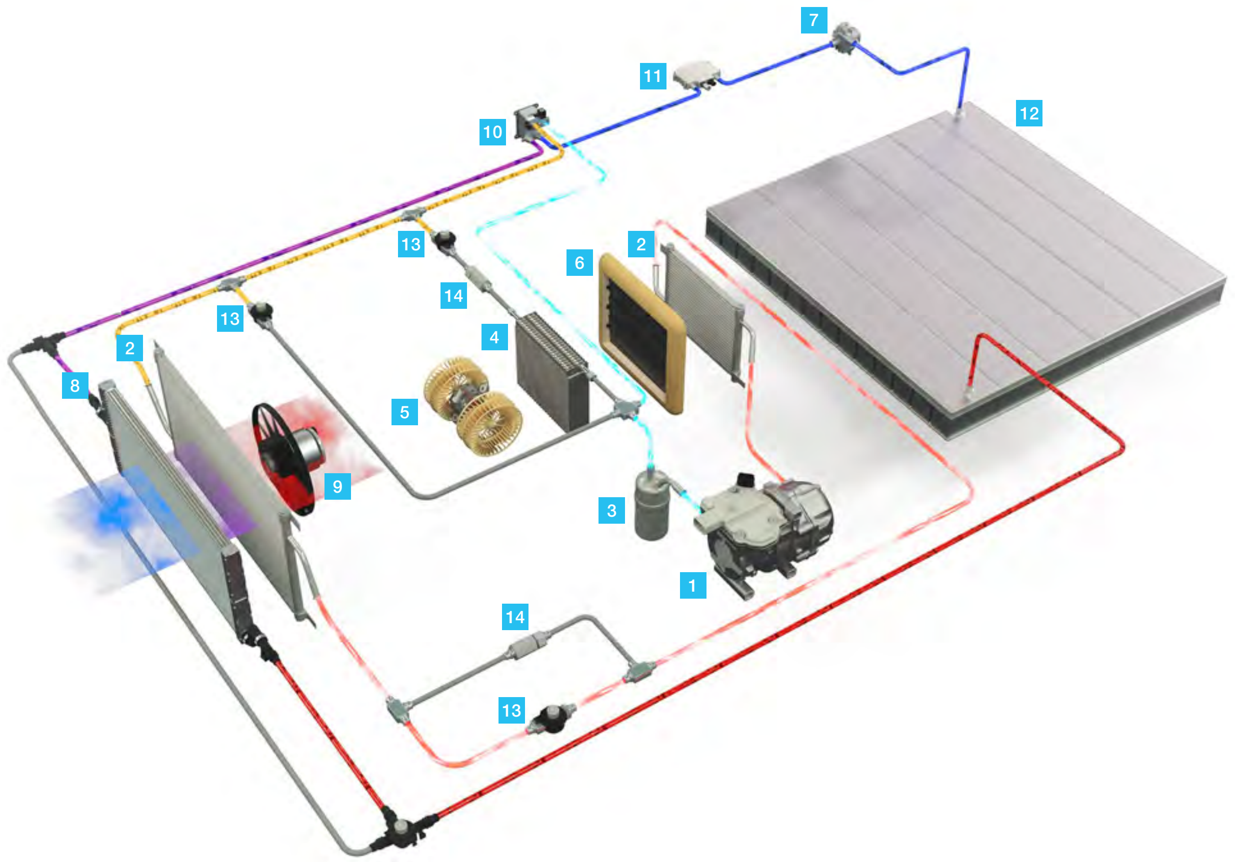
The high-voltage air conditioning compressor also plays the leading role in heating the interior. In this case, however, compressing the gaseous refrigerant is not simply a means to an end. Rather, the system makes use of the resulting temperature rise in the refrigerant by conducting the refrigerant directly to the condenser in the vehicle's interior. The air flap's fins are open, allowing the air flow generated by the blower to reach the condenser and transport the heat released there into the cabin. At the same time, the refrigerant cools and leaves the condenser in a liquid state. It is further cooled by a throttle valve (orifice tube) and conducted into the condenser at the front of the vehicle, which serves as an evaporator in this mode: the ambient air and the electric radiator fan cool the refrigerant considerably, and it turns back into a gas. The refrigerant is then sucked in again by the compressor via the filter-drier, and the process begins again.

Mode: preheating the battery



In winter, the battery must be brought to its operating temperature of around 15°C–30°C before it is charged or the vehicle is driven in order to maintain the battery's service life and performance. This is achieved by means of an electric high-voltage auxiliary heater integrated into the coolant circuit. When the heater is activated, the coolant is conducted past the radiator. The corresponding solenoid valves shut down the circuit so that no refrigerant flows through the chiller.

Mode: cooling the battery



High charging power causes the individual cells of the battery to heat up significantly. The battery needs to be cooled. However, the same is not necessarily the case for the vehicle's interior. The heat pump system is therefore designed so that the battery can also be cooled even without air conditioning the cabin. The electric radiator fan at the front of the vehicle acts in place of the airstream by forcing air to flow through the low-temperature radiator and the air conditioning condenser. While this already lowers the temperature of the battery coolant a little, the air conditioning compressor pumps the gaseous, compressed refrigerant through the condenser in the vehicle's interior. However, the interior blower remains inactive, and the air flap is closed. Liquefied in the condenser at the front of the vehicle, the refrigerant in the chiller lowers the temperature of the battery coolant even further. Now in a gaseous state again, the refrigerant is returned from the chiller to the compressor at low pressure via the filter-drier.

The fuel cell and hydrogen

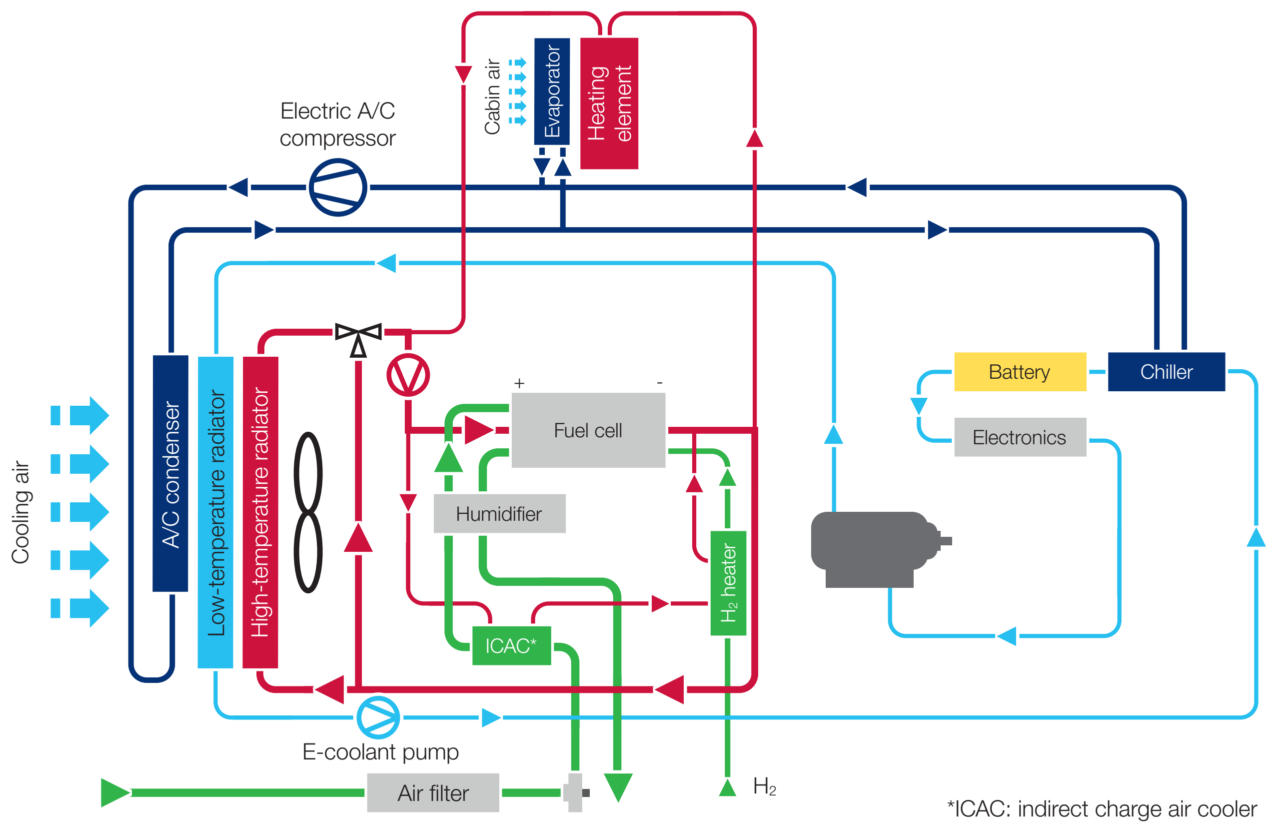
Electric vehicles with fuel cells use hydrogen as an energy source. When refueling, the vehicle's pressure vessels are filled with compressed hydrogen. The hydrogen is fed into the fuel cell together with compressed intake air. The fuel cell generates electrical current for the traction motor and the auxiliary components.

Because the fuel cell operates rather slowly, a smaller battery is also installed in the vehicle. The battery serves as a buffer for acceleration and also for recuperation.

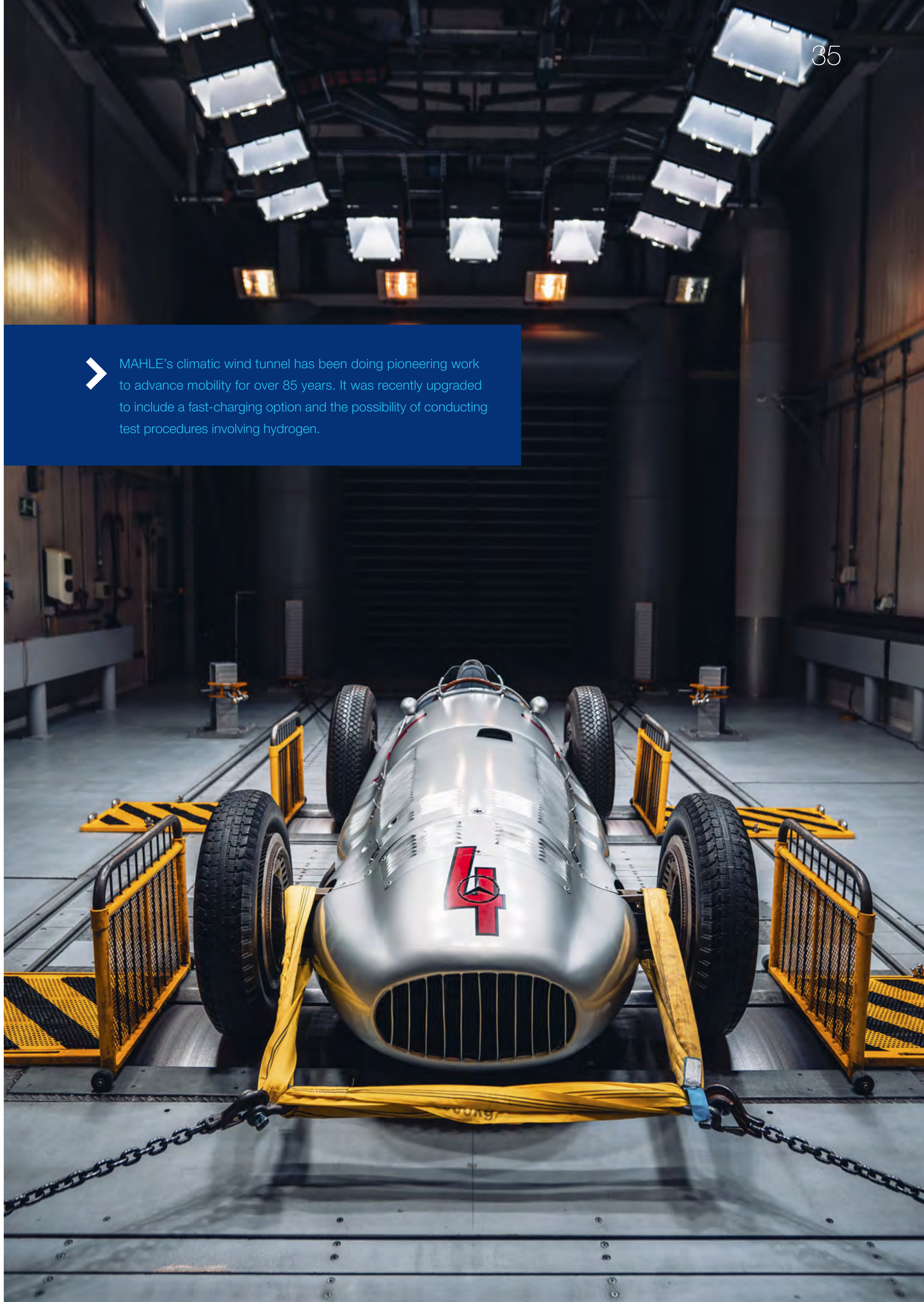
The demands are high when it comes to optimum temperature control for power electronics, the engine, and the fuel cell. In addition, the fuel cell requires exceptionally clean air that is free of harmful gases such as ammonia. The membranes of the fuel cell must also be kept moist so that they can operate reliably for a long time.

Some advantages of an electric vehicle with a fuel cell are a long cruising range and quick refueling.

Components and assemblies in electric vehicles with fuel cells



*ICAC: indirect charge air cooler



MAHLE's climatic wind tunnel has been doing pioneering work to advance mobility for over 85 years. It was recently upgraded to include a fast-charging option and the possibility of conducting test procedures involving hydrogen.

A/C compressor oils for electric A/C compressors

A defective electric air conditioning compressor could lead to major expenses. Air conditioning compressor oil plays a crucial role in compressor durability. Just like in an engine, the use of low-grade or incorrect oils results in increased wear, premature failure of the air conditioning compressor, and loss of the warranty or guarantee.

That is why we recommended PAO 68 oil from MAHLE. This nonhygroscopic, multigrade oil reliably lubricates the air conditioning compressor and is an economical solution for workshops. The clear version (without leak detecting agent) is suitable for R134a and R1234yf refrigerants as well as for mechanically and electrically driven air conditioning compressors. Alternatively, PAO 68 oil is also available with UV leak detecting agent.

PAO 68 oil

- Nonhygroscopic: in contrast to other oils, PAO 68 oil does not absorb any moisture from the ambient air
- Can be used as an alternative to a range of PAG and POE oils (see application overview)—so you don't need to keep so many different oils in stock
- Successfully used in practice for more than 20 years
- Helps to increase the air conditioning system's performance
- No adverse effects on components in the air conditioning circuit (also applies to use in air conditioning service units/ confirmed by manufacturers on the basis of sealed tube tests in accordance with the ASHRAE 97 standard)
- Our PAO 68 AA1 Clear Version oil (without leak detecting agent) can be used not only with R134a refrigerant but also with R1234yf refrigerant and in electrically driven air conditioning compressors in hybrid and electric vehicles

Advantages and effect

- Being nonhygroscopic, PAO oil is easy to use in workshops; the required amount of oil can also be taken from large containers (e.g., 5 liters)
- A low degree of refrigerant solubility in the oil means that the PAO oil is not diluted and retains its full viscosity in the air conditioning compressor
- Oil film inside the components creates a better seal and decreases friction between the air conditioning compressor's moving parts
- Reduced operating temperature and wear
- These factors increase operational safety, reduce noise, and reduce the running times and energy consumption of the air conditioning compressor

MAHLE ref. no./ MAHLE Service Solutions ref. no.	Product	Viscosity class	Contents	Can be used for refrigerant	Can be used for	Can be used for A/C compressor types
PAO 68 AA1—Clear Version (without leak detecting agent)						
ACPL 10 000P 1010350483XX	PAO AA1 Clear Version	ISO 68	1.0 L	R1234yf R134a R413a R22 R12 R507a R500 R502 R513a	A/C systems in vehicles with conventional gasoline or diesel engines (passenger cars, commercial vehicles, agricultural and construction machinery); A/C systems in hybrid and electric vehicles; A/C systems in refrigerated trucks	All compressor types (including electrically driven compressors) except for vane compressors
ACPL 11 000P 1010350484XX	PAO AA1 Clear Version	ISO 68	500 ml			
ACPL 14 000P 1010350486XX	PAO AA1 Clear Version	ISO 68	5.0 L			
PAO 68 AA3—Clear Version (without leak detecting agent)						
ACPL 13 000P 1010350485XX	PAO AA3 Clear Version	ISO 100	1.0 L	R1234yf R134a R413a	A/C systems in vehicles with conventional gasoline or diesel engines as well as hybrid and electric drives (passenger cars, commercial vehicles, agricultural and construction machinery)	Especially for vane compressors

Find additional information about our PAO 68 oil and other A/C compressor oils **here**.

Tips for workshops

Maintenance of electric and hybrid vehicles

A special situation arises when performing routine inspections and repair work (e.g., on exhaust systems, tires, shock absorbers, oil change, or tire change) on electric and hybrid vehicles. This work may only be performed by employees who have been trained on the dangers of these high-voltage systems and instructed accordingly by an expert for work on high-voltage intrinsically safe vehicles.

Workshops are required to provide appropriate training to all employees involved in the operation, maintenance, and repair of electric and hybrid vehicles. It is also essential to use tools that comply with the specifications of the vehicle manufacturer. Please take into account the respective country-specific requirements.

Tools for working on high-voltage systems

Breakdown assistance, towing, and recovery of electric and hybrid vehicles

Drivers of vehicles with high-voltage (HV) systems are not exposed to any direct electrical hazards—not even in the event of a breakdown. A large number of measures taken by vehicle manufacturers secure the HV system. Breakdown assistance for vehicles with HV systems is also harmless as long as no intervention in the HV system is necessary to eliminate faults.

However, there are dangers in the event of a breakdown or towing of vehicles damaged in an accident or that have to be recovered from snow or water. Although the intrinsic safety of the vehicles in terms of protection against hazards from electric shock or arcing is very high, safety cannot be 100-percent guaranteed in every damage scenario. In case of doubt, the respective information from the vehicle manufacturer must be taken into account or requested.

Who is allowed to provide breakdown assistance?

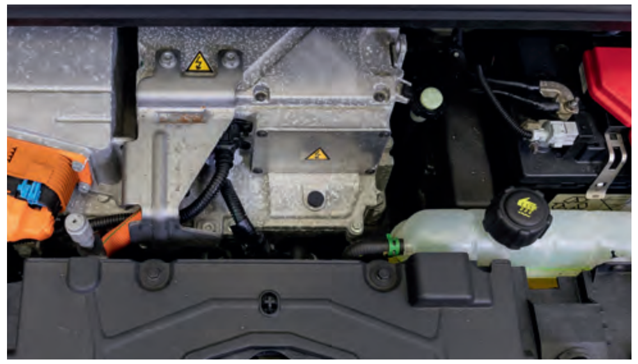
Breakdown assistance for electric and hybrid vehicles may be provided by anyone who has been specially qualified for this purpose. Anyone providing breakdown assistance therefore receives instruction in the design and operation of vehicles with high-voltage systems. The respective country-specific requirements and conditions for “nonelectrical work” apply. (For Germany, the German Social Accident Insurance (DGUV) publication 200-005 *Qualifizierung für Arbeiten an Fahrzeugen mit Hochvoltsystemen* (Qualification for work on vehicles with high-voltage systems) (previously BGI 8686) applies. Please take into account the respective country-specific circumstances.)

How do I tell if a vehicle has a high-voltage system?

- By the lettering on the dashboard or on the vehicle
- By orange high-voltage cables (see illustration); if you see orange cables, do not touch them or any high-voltage components
- By the marking on the HV components (see illustration)

What are the first steps in roadside assistance?

- Remove the ignition key (caution: transponder systems switch on automatically when approaching) and then pull the disconnector of the high-voltage battery.
- Visually check whether HV components are damaged.
- Do not carry out any work on the HV components. This may only be carried out by persons who are qualified to work on vehicles with high-voltage systems. This also applies if HV components are damaged or found to be damaged during the breakdown service.
- A residual voltage can still be present after the HV system has been switched off—this may last for several minutes depending on the manufacturer.



High-voltage components in the engine compartment

Disconnector

Jump starting—what needs to be considered?

It is essential to observe the manufacturer's instructions. Only a few vehicles can be jump started via the 12/24 VDC vehicle electrical system. After switching off, dangerous residual voltages may be present, which are not discharged via continuous discharge resistors. Before opening, observe the instructions in the operating manual and/or technical information from the vehicle manufacturer.

Towing and recovery—what needs to be considered?

- Undamaged vehicles can generally be loaded onto a recovery vehicle (platform vehicle).
- When towing with a rod or cable, the manufacturer's specifications must be observed.
- To recover vehicles safely, all measures from the chapter "**Basic rules for working on electric and hybrid vehicles**" must be taken into account.
- If the vehicle is towed/recovered with a winch, no HV components may be located in the area of the attachment points or be damaged. The same applies when lifting with a jack or loading crane.

What should I do in the event of an accident?

- In the event of an accident, in most cases the HV system is switched off when the airbag is deployed. This applies to almost all passenger cars, but not necessarily to commercial vehicles.
- To be able to work without danger, all measures from the chapter "**Basic rules for working on electric and hybrid vehicles**" must be taken into account.
- Some manufacturers recommend or prescribe that the negative terminal of the 12/24 VDC vehicle electrical system battery be disconnected (further information can also be found in the respective rescue guidelines).
- If HV batteries or HV capacitors (energy storage devices in commercial vehicles) have been damaged or torn out by an accident, this poses a particular hazard. The fire department should be called in to help in this case. When handling damaged HV batteries, appropriate personal protective equipment (face protection, protective gloves for working with voltage) is required.
- Spilled battery fluids may be corrosive or irritant, depending on battery type. Contact should be avoided at all costs. After an accident, HV batteries may still catch fire later as a result of internal reactions. Damaged vehicles should therefore not be parked in enclosed spaces.

Further training for the repair of electric and hybrid vehicles

Useful information

Ongoing training is required to maintain and repair the complex systems, especially those for thermal management in electric and hybrid vehicles. In Germany, for example, employees working on such high-voltage systems require an additional two-day training course to become "experts for work on high-voltage (HV) intrinsically safe vehicles."

This course teaches the participants to recognize the risks when working on systems of this kind as well as how to switch off all the current to the system for the duration of the work. People who have not received appropriate training are prohibited from working on high-voltage systems and their components. The repair or replacement of live high-voltage components (batteries) requires a special qualification.

Training courses

No matter if you are currently in training, already have professional experience in the workshop, or are working in engineering: MAHLE Lifecycle and Mobility has the right training course for you.

In addition to covering theory, MAHLE Lifecycle and Mobility offers special practical training on damage prevention for passenger cars and trucks as well as for agricultural and construction machinery.

At MAHLE Lifecycle and Mobility, we are flexible: you select the topic, tell us when and where the training should take place—and we take care of the rest. Simply speak to your trading partner from MAHLE Lifecycle and Mobility or contact us directly at **ma.training@mahle.com**.

Our technical experts look forward to organizing interesting and exciting events for you.

Visit our **website** for more information and the latest training dates.

Workshop equipment from MAHLE Service Solutions

MAHLE Service Solutions is the perfect partner when it comes to the increasingly important professional servicing of air conditioning systems. After all, in electric and hybrid vehicles, the air conditioning system also regulates the temperature of the traction battery! Equally good for the battery are our diagnostic tools TechPRO® with E-SCAN function and the new BatteryPRO E-HEALTH, which performs quick traction battery diagnostics. And once you're kitted with such tools, as well as with our new E-CARE service unit for the maintenance of vehicle battery cooling circuits, you're fully equipped for the future!

ArcticPRO® A/C service units

Reference no. 1010350383XX

ArcticPRO® ACX 380 is the top A/C service unit in the equipment series for R134a. You can't get better than that! It offers all the distinguishing features of this series, in addition to the extreme convenience of the integrated POE oil circuit, which is a must for anyone who frequently services hybrid or electric cars in addition to vehicles with traditional engines. ACX 380 for R134a systems can be easily converted to R1234yf or, if required, R513a refrigerant. Thanks to the optional integration of our diagnostic tool for air conditioning systems, an expert diagnosis of the air conditioning components can be carried out directly on the air conditioning service unit.

Reference no. 1010350384XX

ArcticPRO® ACX 480 is the flagship model in the equipment series for R1234yf. With the ACX 480, the complete A/C service can be entrusted fully to the unit's automated processes, ensuring an accurate result and freeing you to take care of other tasks in the meantime. This guarantees a reliable, effective, and economical A/C service! The ACX 480 also offers integration with highly innovative and practical management apps, as well as with the TechPRO® diagnostic tool, which expands the unit's capabilities even further.

As standard, all MAHLE ArcticPRO® air conditioning service units have an integrated flushing function that allows fast, low-cost flushing of the air conditioning system with R134a or R1234yf refrigerants. An external flushing unit and parts from a flushing kit are required—these are available separately. After starting the function on the unit, the vehicle air conditioning system is flushed with liquid refrigerant under high pressure and then evacuated. This cycle should be completed three times in order to achieve an optimal cleaning result.

Accessories for flushing with ArcticPRO® A/C service units

With the A/C service units, MAHLE is expanding its range for workshop connectivity. Using a smartphone app, workshop technicians can view the workflows and unit status or automatically order a service. The ASA interface on the unit and the integration of the unit in the workshop network enable fast data exchange. The large touch screen, which is standard on all units, provides a display of all information and programmed procedures, as well as the current status. A quick-start can be initiated at any time. While automatic software updates are performed in the background via Wi-Fi, work can continue on the vehicle. Possible leaks in the air conditioning system are quickly detected with nitrogen or forming gas via a direct connection to the air conditioner. For a time-saving service, the devices can be maintained remotely: workshops can obtain fast support and diagnostics directly on the unit via Wi-Fi.

ACX universal flushing unit for R134a and R1234yf refrigerants

- Flushing tank with support for flexible usage—entirely independent of the A/C service unit location and model
- Ergonomically positioned: control sight glass to check flushing process and refrigerant purity
- Flexible application: HP hose connector and adapter set for various A/C service units
- Flushing adapter set (⅜" and ¼") allows connection to all standard flushing adapters for air conditioning systems or to a system's individual components
- Coupling adapter set for R134a and R1234yf refrigerants to connect the LP coupling to the flushing unit
- Optional: protective storage cover

Reference no. 1010350276XX

An even more extensive range of A/C service units and accessories can be found **here**.

ArcticPRO® ROU—recovery only unit

- Removes unknown and contaminated refrigerants from vehicle air conditioning systems simply and safely
- Environmentally friendly: professional and safe disposal protects people and the environment
- Economical: the ROU is immediately ready to use together with an A/C service unit; no other materials and supplies are required
- Efficient: our patented internal cycle guarantees a fast service with a 95% recovery rate within 30 minutes

Reference no. 1010350326XX

IDX 500 refrigerant analysis unit

Internal analysis unit for MAHLE ACX A/C service units for R134a and R1234yf refrigerants.

- Faster than the predecessor model
- Clearly indicates whether R134a or R1234yf is detected in the system
- Gives the A/C service unit maximum protection
- Safe analysis via LP coupling
- Plug-and-play function allows immediate integration with the unit
- Simple, automatic operation and instant measurement result
- Fully automated control via integrated software process

Reference no. 1010350393XX

Flushing kit for R134a and R1234yf refrigerants

The flushing kit contains special filters and accessories required for flushing processes. The kit can be used with all our service units.

Reference no. 1010350053XX

Diagnostics and servicing of the traction battery

As the number of electric and hybrid vehicles has increased, battery diagnostics, maintenance, and charging have become essential everyday tasks for workshops. With its BatteryPRO diagnostics and service solutions, MAHLE Lifecycle and Mobility is one of the first providers worldwide to enable independent workshops to perform battery diagnostics on electric vehicles—completely independently of the manufacturer. This means that workshops can offer extra services and tap into additional business volume.

More information
is available **here**.

E-SCAN

Software for high-voltage battery diagnostics

E-SCAN is a powerful software feature on TechPRO®/CONNEX diagnostic tools that can perform an initial analysis of the high-voltage battery in electric and hybrid vehicles. With just one click, the software provides all the information about the status of the battery management system in a standardized report. Among other details, the report also includes crucial data for determining the residual value of lease returns and used cars.

E-CHARGE 20

Flexible solution for fast charging

E-CHARGE 20 is a portable stand-alone DC charging solution designed to charge electric vehicles quickly and easily. Fitted with casters, it can be used flexibly in the workshop. To use the device, simply plug it into a three-phase 32 A outlet, move it near the vehicle's electrical charging socket, and it's ready to go!

E-HEALTH Charge

Battery diagnostics via the charging plug

In combination with TechPRO® and an intelligent algorithm, the E-CHARGE 20 charging station becomes a valuable diagnostic tool: E-HEALTH Charge. While the battery is charging, the tool quickly generates a detailed, manufacturer-independent report on the high-voltage battery's state of health, based on its available residual capacity. The measurement process is vehicle- and manufacturer-independent and supplemented with data obtained via the OBD port. The results are then evaluated in relation to existing data on batteries of the same type and compared with the vehicle model's original capacity. And it's all done without you having to move the vehicle.

E-CARE Fluid

Maintenance of vehicle battery cooling circuits

High-voltage batteries in electric and hybrid vehicles must deliver maximum performance. To reduce their sensitivity to temperature fluctuations, they are fitted with a cooling circuit that requires appropriate maintenance. As a specialist in fluid management and maintenance, MAHLE Lifecycle and Mobility has developed a dedicated product for the e-mobility market: E-CARE Fluid. The device makes it easy for workshops to drain, flush, and refill coolant, as well as search for leaks. It can also be used to maintain the cooling circuit in any vehicle—regardless of the drive type.

MAHLE Insider

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