



Self-study programme 499

**Basics of Electric Drives
in Automobiles**

Design and function

part or in whole, is not permitted unless authorised by Volkswagen AG. Volkswagen AG does not guarantee or accept any liability with respect to the c



According to current estimates, 2050 will be the last year of oil extraction as we know it. The technology required for oil extraction will then become extremely complex. For this reason, we need to use resources cautiously and efficiently. The task of "Think Blue." is to educate people and create an awareness of resource conservation. The use of energy and raw materials requires constant optimisation. The burden on the environment needs to be continually reduced at a steady rate. The aim is to prevent the global temperature rising more than 2°C by the year 2050. In order to reach this goal, the output of greenhouse gases like, for example, carbon dioxide (CO₂), must be curbed.

Unlike vehicles with combustion engines, vehicles with electric drives do not produce exhaust gases during operation. This property alone makes electric vehicles more environmentally friendly than vehicles with conventional technology. However, the electrical energy for charging the vehicle does have to be produced from renewable sources, e.g. from wind, solar, hydroelectric or biogas power plants. One further aspect is the low energy costs for a journey of 100km with an electric drive compared with a conventional vehicle.

By the year 2020, at least one million electric vehicles will be driving on Germany's roads. The German government underlined the importance of this issue in Germany by introducing a national electromobility development plan (Nationalen Entwicklungsplan Elektromobilität, NEPE) in August 2009. The electrification of vehicles will therefore rise steadily. An initial step will see hybrid vehicles that combine the advantages of both the electric motor and combustion engine systems.

By combining the drives, the overall efficiency of the vehicle is improved and fuel consumption is reduced.

The Touareg 2011 sees Volkswagen supply a production vehicle with an electric hybrid drive. The new technology requires special training for handling and working on high-voltage vehicles. This self-study programme describes the realistic hybrid and electromobility concepts and the basics of high-voltage qualification for service staff.

The self-study programme shows the design and function of new developments.
The contents will not be updated.

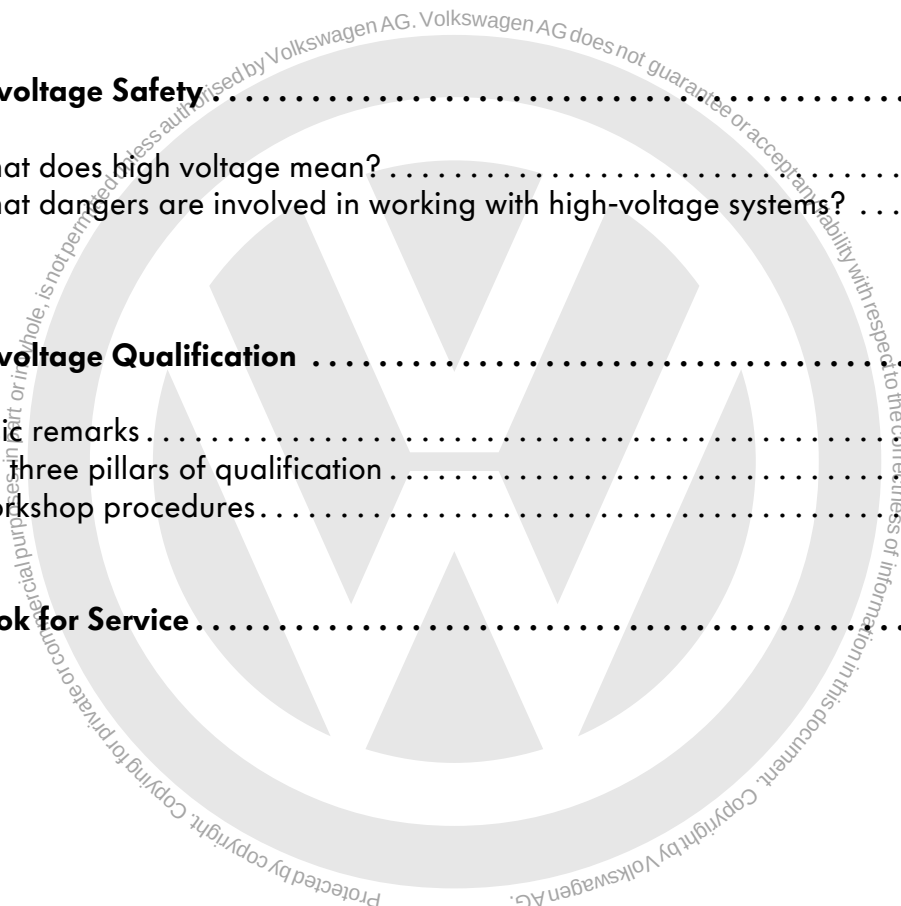
Current testing, setting and repair instructions can be found in the provided service literature.



**Important
Note**



Introduction	4	
The history of electromobility	4	
Why is electromobility interesting?	8	
Basics of Electromobility	14	
Classification of electric vehicles	14	
The main components of an electric vehicle	16	
Drive train configurations	28	
Vehicle Concepts	30	
Overview of the different drive combinations	30	
The Touareg with full hybrid drive (HEV)	31	
The Golf 6 TwinDrive (PHEV)	33	
The Golf blue-e-motion (BEV)	36	
The Audi A1 e-tron (RXBEV)	38	
The Tiguan HyMotion (FCBEV)	40	
High-voltage Safety	42	
What does high voltage mean?	42	
What dangers are involved in working with high-voltage systems?	42	
High-voltage Qualification	50	
Basic remarks	50	
The three pillars of qualification	51	
Workshop procedures	56	
Outlook for Service	60	





The history of electromobility

Electromobility has always been an issue that has helped drive the development of vehicles. It did become less important for a while because the oil fields did not appear to be drying up, but now electromobility is becoming increasingly significant as people become aware of the depletion of oil reserves and the requirements of global environmental and climate protection.

1821

Thomas Davenport builds the first electric car with a non-rechargeable battery and a range of 15 to 30 kilometres.

1881

The first officially recognised electric vehicle is a tricycle made by Gustave Trouvé in Paris. Using a rechargeable lead-acid battery, the vehicle can reach speeds up to 12km/h.

1898

A company belonging to Charles Jeantaud from Paris is the leader in the field of electromobility at the turn of the century (1893 to 1906).

One of these vehicles sets a speed record by reaching 37.7km/h.

1902

A. Tribelhorn, a pioneering Swiss electromobility company, builds its first vehicles with an electric motor. Over a period of almost 20 years, the company produces mainly electrically powered commercial vehicles. They only manufacture passenger vehicles in small numbers and mainly as prototypes.

1860

The rechargeable lead-acid battery is invented.

1882

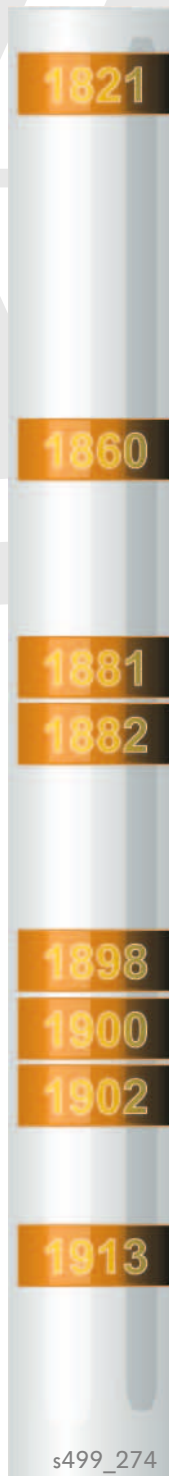
In this year, Ernst Werner Siemens builds an electrically driven carriage. This vehicle, which was also known as the "Elektro-Motte" or "Elektromote", is considered to be the world's first trolleybus.

1900

Ferdinand Porsche presents a vehicle with in-wheel motors on both wheels of the front axle at the world exhibition in Paris.

1913

The first petrol station starts business in Pittsburgh (USA). Soon afterwards petrol stations open in every town. A better infrastructure, cheap petrol and the development of internal-combustion engines with greater ranges are the reasons for the triumph of vehicles with internal-combustion engines.





1960

Dr Charles Alexander Escoffery presents probably the world's first solar car. It is a Baker Electric from 1912 registered in California with a photovoltaic panel made up of 10,640 single cells.

1973

The first oil crisis shows the industrial nations how dependent they are on oil-exporting countries. Fuel prices rise drastically.

1987

The "World Solar Challenge", a competition for solar vehicles, is staged.

1992

German car manufacturer Volkswagen develops the VW Golf Citystrome, a converted Golf that is equipped with an electric motor.

1996

General Motors offers the two seater electric coupé "EV 1" (Electric Vehicle 1) with 500kg lead-acid batteries. Later nickel-metal hydride batteries improved the performance of the vehicle.

2009

The German government introduces the national electromobility development plan (Nationalen Entwicklungsplan Elektromobilität, NEPE).

The aim is to promote the research and development, the market preparation and the launch of battery-powered vehicles in Germany. It is hoped there will be one million electric cars on German roads by 2020 and Germany will develop into the lead market for electromobility.



1969

The "Lunar Rover" is developed in the USA for the moon landings. It has an electric motor at each wheel. Two silver-zinc batteries are used as the power source giving the "Lunar Rover" a range of approximately 92km.

1985

The world's first race for solar-powered cars, the "Tour de Sol", is staged in Switzerland.

1991

The THINK is one of the first cars to be conceived as a purely electric vehicle and not a conversion into an electric vehicle.

1995

PSA Peugeot Citroën builds 10,000 electric vehicles from 1995 to 2005.

2008

The exclusively electric-powered "Tesla Roadster" built by Tesla Motors is launched on the US market with 6,187 laptop batteries connected in series. It accelerates from 0 to 100km/h in 3.8 seconds.

Introduction



History of electromobility at Volkswagen

VW can look back on over 40 years of experience in electromobility.

Back in 1970, the "T2 Electric" was the first generation of a purely electric vehicle.

T2 Electric



Golf 1 Electric



T3 Electric



Golf 3 CitySTROMer



Jetta CitySTROMer

Electric vehicles

1970

1975

1980

1985

1990

T2 City Taxi



Golf 1 Hybrid



Golf 2 Hybrid



Chico Hybrid

Hybrid vehicles

Vehicles with fuel cells



Volkswagen AG. Volkswagen AG does not

Golf TwinDrive



Electro Van



Electro UP



Golf blue-e-motion



1995

2000

2010

2015

Golf ECO Power



Touareg Hybrid

Bora HyMotion



Tiguan HyMotion



Bora HyPower



Touran HyMotion

accept any liability with respect to the correctness of information in this document



Why is electromobility interesting?



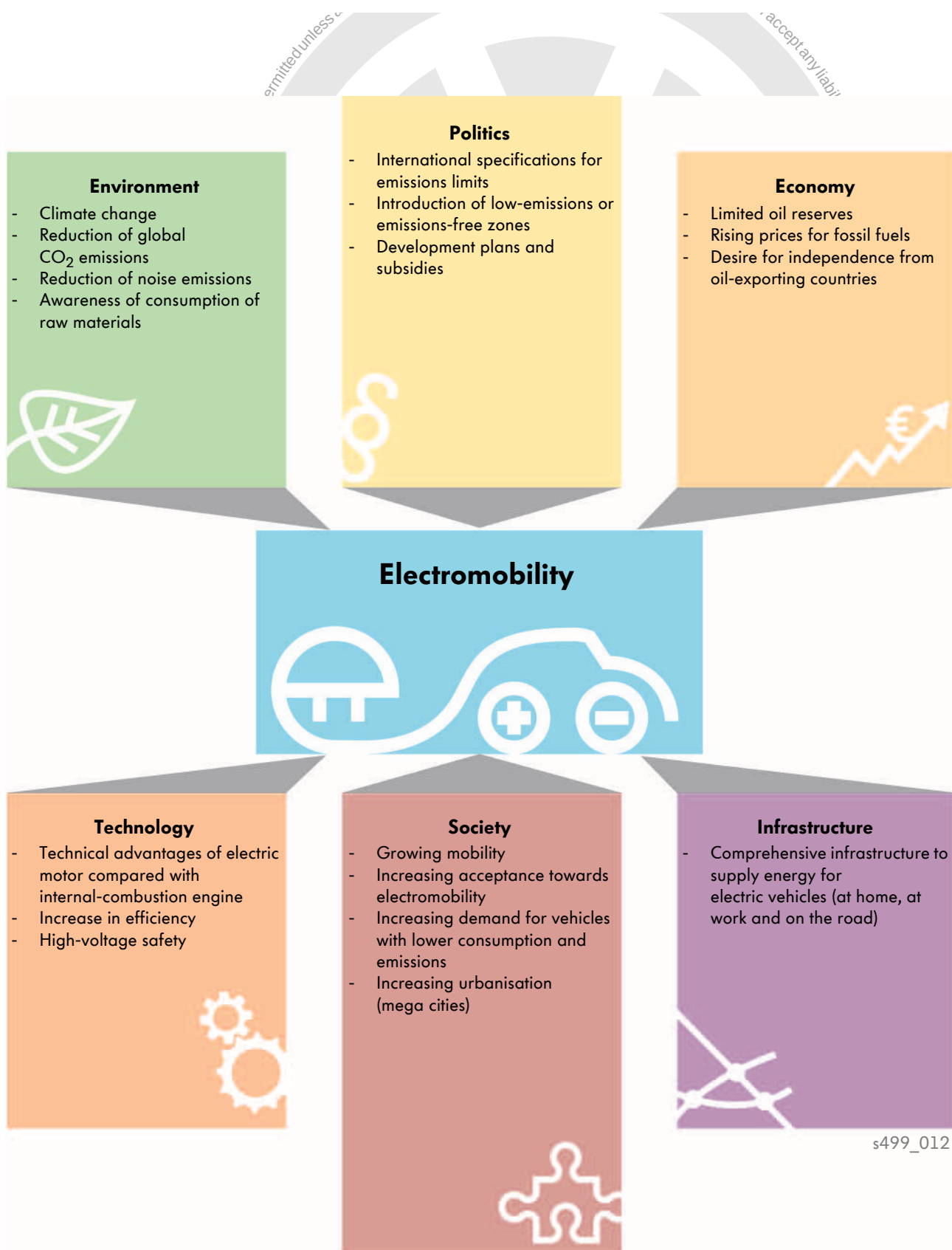
For our study of the core aspects of electromobility, we have chosen the areas of environment, politics, economy, society, infrastructure and technology. It is not possible to completely separate the content of these areas because there are complex relationships between them.

Climate change and the conditions for the use of fossil resources (limited availability, price) are causing countries to change their climate and energy policies and are causing changes to their national societies.

Politicians are responding to these changes with national emissions limits that unfortunately vary at international level. As a rule, these limits cover direct emissions of CO_2 or other environmentally harmful gases.

Electric vehicles do not produce direct emissions in the form of CO_2 .

The introduction of low emissions or emissions-free zones in towns and a changed political framework will speed up the expansion of electromobility. State or municipal funding will stimulate the economy and support advances in science and research. An increasing number of companies are investing in electromobility and are thus improving existing concepts, technological innovations and their future applications in collaboration with researchers.



s499_012

Introduction



Advantages of electromobility

- Electric drive motors run considerably more quietly than internal-combustion engines. The noise emissions from electric vehicles are therefore very low. At high speeds, the rolling noise from the tyres is the loudest sound.
- Electric vehicles produce no harmful emissions or greenhouse gases while driving. If the high-voltage battery is charged from renewable energy sources, an electric vehicle can be run CO₂-free.
- In the near future, if particularly badly congested town centres are turned into zero-emissions zones, we will only be able to drive through them with high-voltage vehicles.
- The electric drive motor is very robust and requires little maintenance. It is only subject to minor mechanical wear.
- Electric drive motors have a high degree of efficiency of up to 96% compared with internal-combustion engines that have an efficiency of 35–40%.
- Electric drive motors have advantageous torque and output characteristics. They develop maximum torque from standstill. This allows an electric vehicle to accelerate considerably faster than a vehicle with an internal-combustion engine producing the same output.
- The drive train design is simpler because vehicle components like the gearbox, clutch, silencers, particulate filters, fuel tank, starter, alternator and spark plugs are not required.
- When the vehicle is braked, the motor can also be used as an alternator that produces electricity and charges the battery (regenerative braking).
- The high-voltage battery can be charged at home, in a car park and by using any accessible mains sockets. The blue charging connector on the vehicle and on public charging stations has been standardised across Germany and is used by all manufacturers.
- The energy is only supplied when the user needs it. Compared with conventional vehicles, the electric drive motor never runs when the vehicle stops at a red light. The electric drive motor is highly efficient particularly in queues and bumper-to-bumper traffic.
- Apart from the reduction gearbox on the electric drive motor, the electric vehicle does not require any lubricating oil.

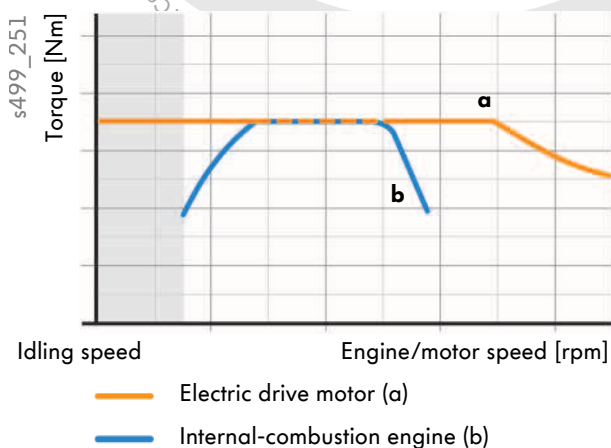
Disadvantages of electric vehicles

- Electric vehicles have a limited range. The electrical energy needs to be stored in sufficient quantities in a modern high-voltage vehicle battery. This quantity of energy is decisive for the range of an electric vehicle.
- If a high-voltage battery needs to be charged from fully flat to fully charged and only a basic charging possibility is available, the charging procedure will take up to 7.5 hours.
- The possibilities for charging the electric vehicle at public facilities are still being established. The network of electric charging stations is sparse.

If the destination is beyond the range of the electric vehicle, the driver will need to plan the journey.

“Where can I charge my electric vehicle on the road?”

Comparison of torque development



Electric drive motor

The electric drive motor (a) reaches its maximum torque as early as the first revolution. It does not require a start-up phase to reach idling speed. Once a specific rpm figure has been reached, the available torque falls as the revs increase.

This motor speed is approx. 14,000rpm.

In addition, these characteristics of an electric drive motor mean that a complex vehicle gearbox is not required.

Internal-combustion engine

The internal-combustion engine (b) requires an idling speed to produce a torque. The available torque increases when the engine speed is raised. In addition, this characteristic of the internal-combustion engine requires a gearbox with several gear ratios. The torque is transferred to the gear wheels via a clutch or a torque converter.



Introduction



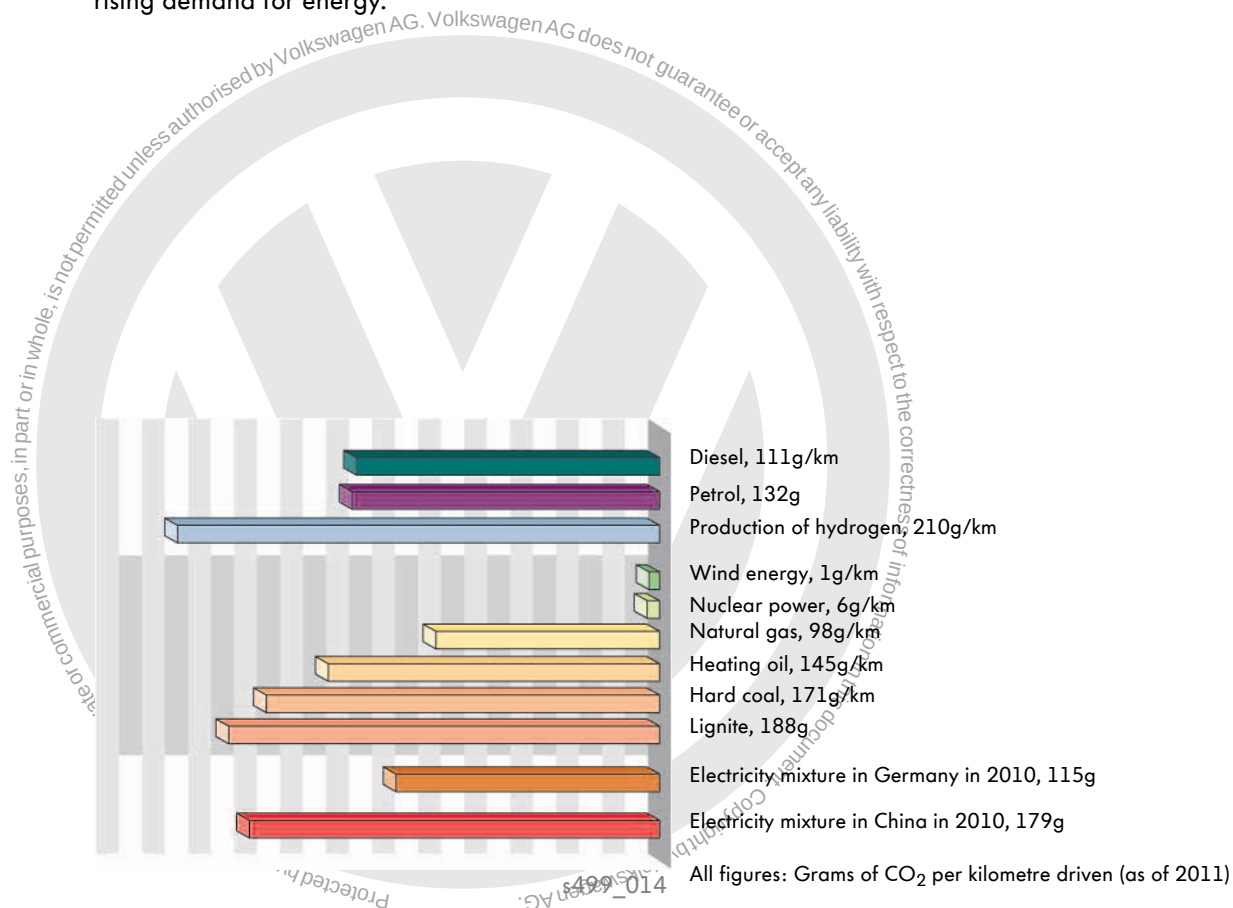
Environmental aspects

CO₂ emissions

Before 2050, global warming should not exceed the value of 2°C related to the earth's temperature from pre-industrial times. This goal can only be achieved by reducing CO₂ emissions. The plan is to reduce the CO₂ emissions per capita from the current 45 tonnes per year to 0.7 tonnes per year by 2050.

Electric vehicles do not directly produce CO₂ emissions. However, the analysis of CO₂ producers does not just evaluate the vehicle, but also the emissions that occur during the production of the electrical energy (e.g. in coal power stations).

In Germany in particular, electromobility is closely linked to the use of “clean electricity” (i.e. from renewable energy). Therefore it can be presumed that today's electricity mixture causes lower CO₂ emissions per vehicle compared with vehicles with internal-combustion engines. Analysing the electricity mixture at international level is less favourable. The environmental balance of the electricity generation in threshold countries like China and India is not so good since they mainly rely on electricity generated from coal due to the rapidly rising demand for energy.



Did you know?

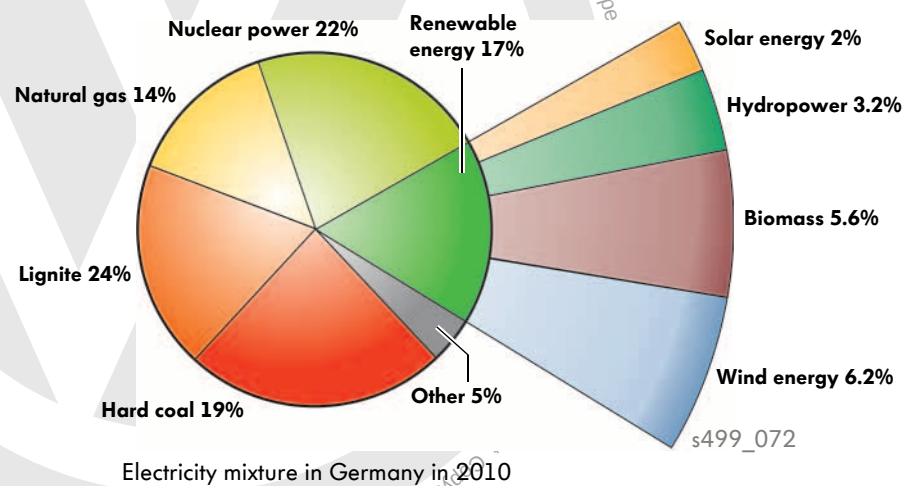
Since the pure hydrogen required for a fuel cell does not exist in nature, it must be produced using a complex process. This process requires a large amount of electrical energy.



Renewable energy

Renewable energy sources are energy sources that will be available in inexhaustible supply in the short run by human standards. Renewable energy sources include wind power, solar power, geothermics (terrestrial heat), hydropower and biomass.

A further reduction of CO₂ emissions in the electromobility field will be possible when the share of renewable energy sources is expanded in the electricity mixture. This share of European electricity production should rise to 48% by 2030 compared with the 17% in 2010.



Potential of solar energy

The solar energy shining onto the earth corresponds to about ten thousand times today's total global energy requirement. Therefore sunlight can provide more energy than we will need in the future.

However, the costs and efficiency of solar cells stand in the way of the development of this potential. While the efficiency of the photovoltaic modules was around eight percent at the start of the eighties, the average modules currently on the market reach 17% and the leading-edge products almost 20%. In order for solar energy to be able to compete with other energy sources, solar power plants need to be made more efficient.



Did you know?

Within 24 hours, the amount of energy that reaches the earth around the world in the form of sunlight is enough to supply the world's population with electrical energy for a year.

The share of geothermics (the use of heat in the earth's crust) in the generation of electricity is still smaller than 1% in Germany in 2011.

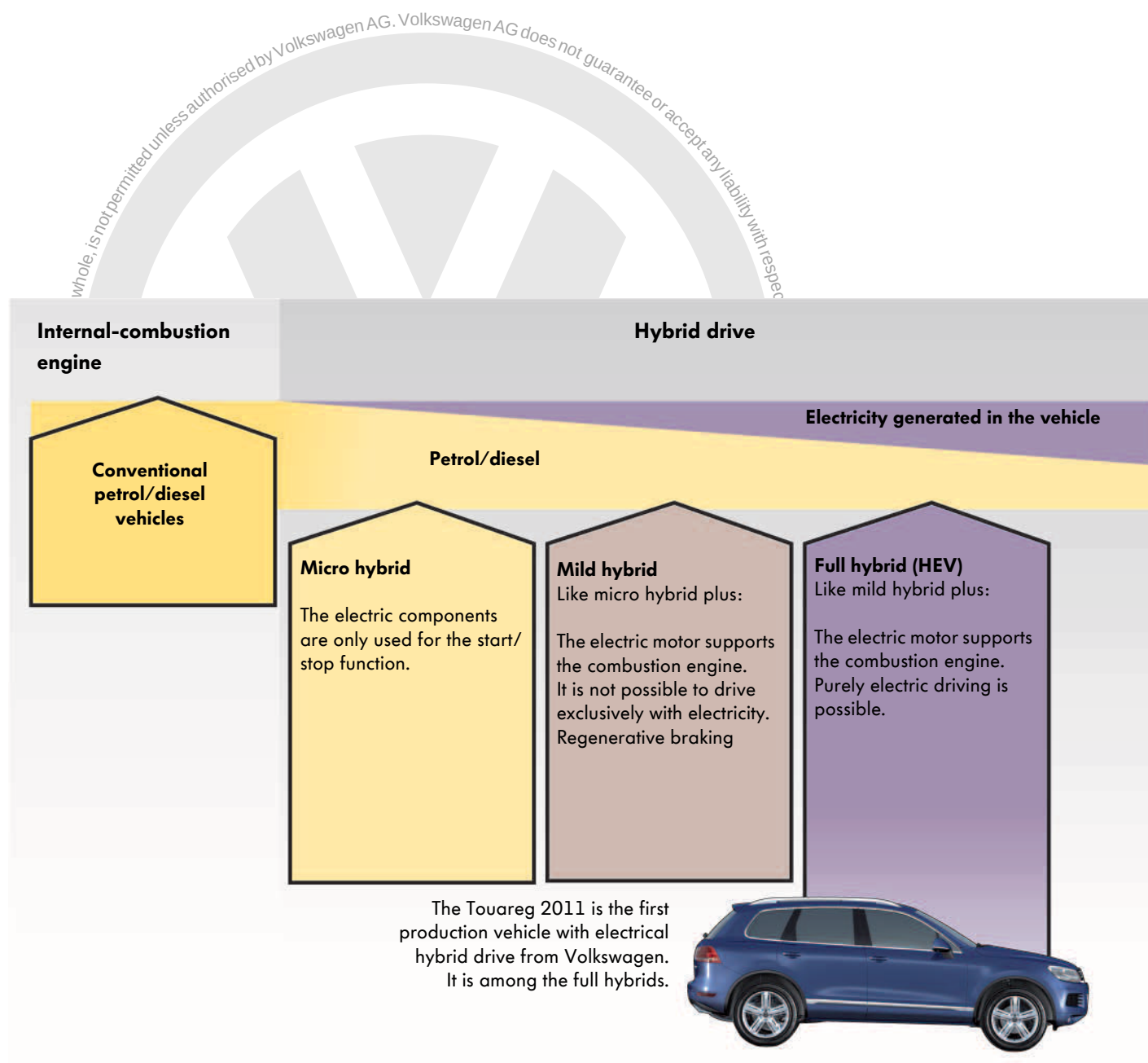
Basics of Electromobility

The topic of “electromobility” basically refers to all vehicles that are driven by means of electrical energy. This includes both battery-powered vehicles and hybrid vehicles (full hybrid vehicles) or vehicles with a fuel cell.



Classification of electric vehicles

Electric vehicles are categorised primarily according to concept and their names indicate how the electrical energy is supplied:

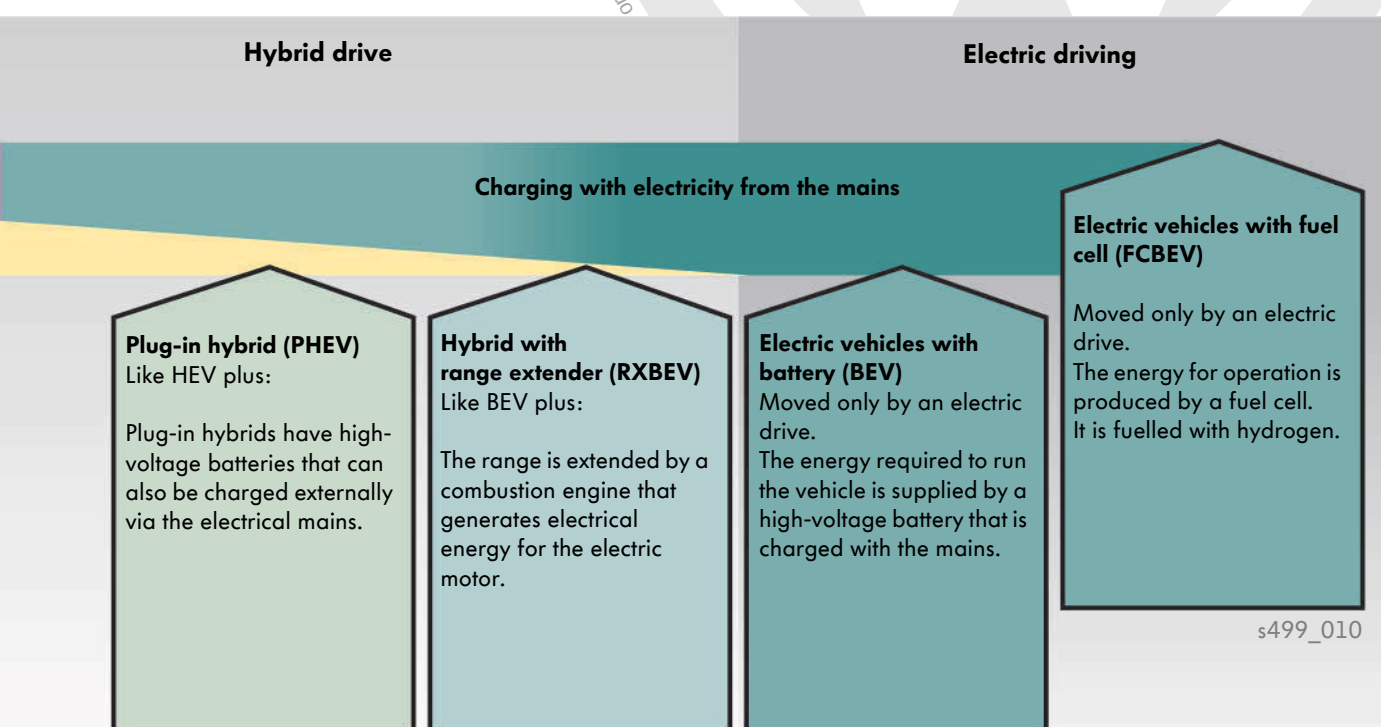


Terminology

Emission-free vehicles that do not release exhaust gases into the environment during operation are also called “zero-emission vehicles” (ZEV).

Battery-powered vehicles that are moved exclusively by an electric drive are also called “battery electric vehicles” (BEV). The energy required to run the vehicle is supplied by a high-voltage battery that is charged with the mains.

The “Electric Vehicle Index” (EVI) measures the development of electromobility. It uses nine different criteria to evaluate both the market for electric cars and the production in different industrial nations. The current order of investigated countries is: USA, France, Germany, Italy, Japan, China, Korea, Spain, United Kingdom, Denmark, Portugal and Ireland.



Overview of the abbreviations used:

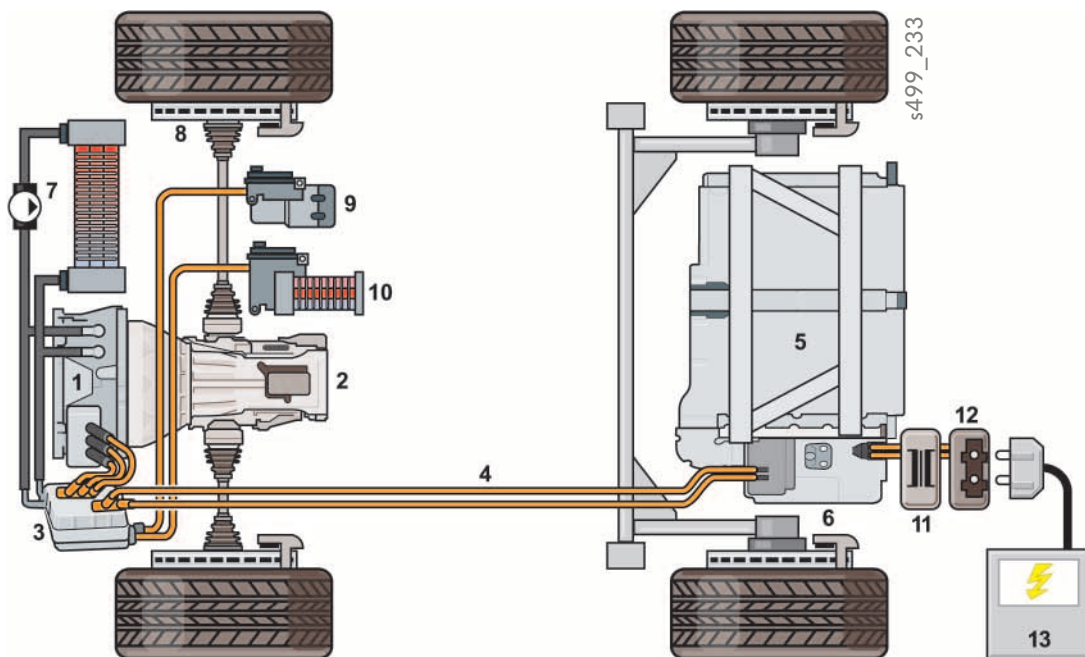
- BEV - Battery Electric Vehicle
- HEV - Hybrid Electric Vehicle; full hybrid vehicle
- FCBEV - Fuel Cell Battery Electric Vehicle; battery-powered vehicle with fuel cell
- PHEV - Plug-in Hybrid Electric Vehicle; vehicle with full hybrid drive and external charging facility
- RXBEV - Range Extender Battery Electric Vehicle; battery-powered vehicle with additional generator drive to increase range (range extender)

Basics of Electromobility

The main components of an electric vehicle

The whole drive system in electric vehicles includes:

- High-voltage battery with control unit for battery regulation and necessary charger
- Electric motor/generator with electronic control (power electronics) and cooling system
- Gearbox incl. differential
- Brake system
- High-voltage air conditioning for vehicle interior

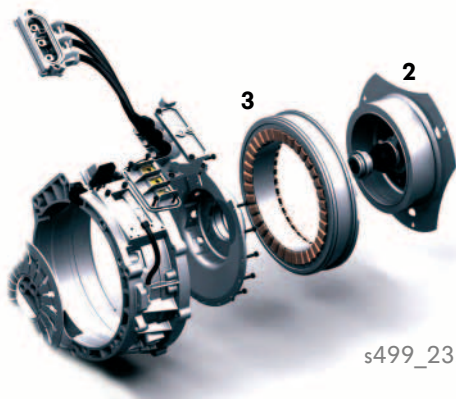


- 1 Electric motor/generator
- 2 Gearbox with differential
- 3 Power electronics
- 4 High-voltage lines
- 5 High-voltage battery
- 6 Electronics box with control unit for battery regulation
- 7 Cooling system
- 8 Brake system
- 9 High-voltage air conditioner compressor
- 10 High-voltage heating
- 11 Battery charger
- 12 Charging contact for external charging
- 13 External charging source

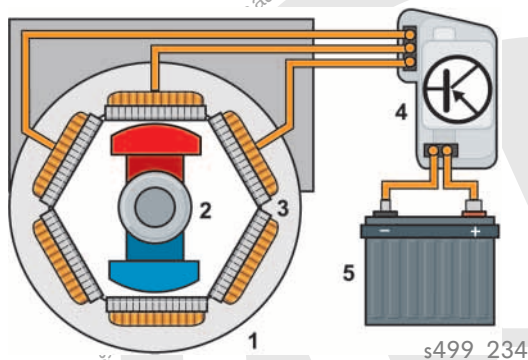
The electric motor/generator

The term electric motor/generator is used instead of alternator, electric motor and starter. In principle, any electric motor can also be used as an alternator. When the electric motor/generator is driven mechanically, it supplies electrical energy as an alternator. When the electric motor/generator is supplied with an electrical current, it works as a drive. Electric motors/generators used for propulsion are water-cooled. Air cooling would also be possible, however.

In full hybrid vehicles (HEV), the electric motor/generator also functions as the starter for the combustion engine.



Three-phase motors are often used as the electric motor/generator. A three-phase motor is powered by a three-phase alternating current. It works with three coils that are arranged in a circle around the rotor to form the stator and are each electrically connected to one of the three phases. Several pairs of permanent magnets are located on the rotor in this synchronous motor. Since the three coils are supplied sequentially with a current, together they generate a rotating electrical field that causes the rotor to rotate when the electric motor/generator is used to drive the vehicle.



Electric motor/generator (1), rotor (2), stator (3), power electronics (4) and high-voltage battery (5)

When used as an alternator, the movement of the rotor induces a three-phase alternating voltage in the coils that is transformed into a direct voltage for the high-voltage battery in the power electronics.

Normally so-called "synchronous motors" are used in vehicles. In this context, the term "synchronous" means "running in synchronism" and refers to the ratio of the rotation speed of the energised field in the stator coils to the rotation speed of the rotor with its permanent magnets.

The advantage of synchronous motors compared with asynchronous motors is the more precise control of the motor in automobile applications.

Basics of Electromobility

Strengths of the electric motor/generator

The electric motor/generator is very environmentally compatible thanks to the lack of noise and harmful emissions. The electric motor/generator responds quickly, has good acceleration figures and a high level of efficiency. In contrast to combustion engines, electric motors supply their nominal power steplessly over a broad rev range. The maximum torque is available even at low revs (i.e. when pulling away) and only falls away once the motor reaches very high speeds. As a result, neither a manually operated gearbox, an automatic gearbox nor a clutch are required in principle.

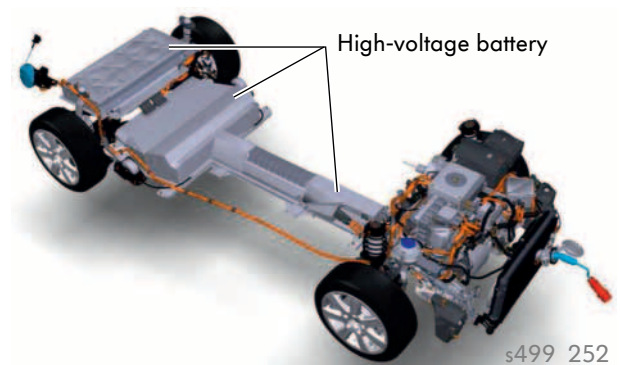
The direction of rotation of an electric drive motor is freely selectable. It can therefore turn clockwise to move the vehicle forwards and anti-clockwise to reverse it.

Electric motors start automatically. A separate starter motor is not required. Electric motors have a simpler design and have considerably fewer moving parts than internal-combustion engines. Only the rotor with its permanent magnets rotates inside the electric motor/generator. There are no vibrating masses as in internal-combustion engines. Oil changes are not necessary as lubricating oil is not required. Consequently electrically powered vehicles are low-maintenance in terms of their drive unit.

The high-voltage battery

The battery is the heart of electric vehicles. The high-voltage battery is charged, for example, externally via a mains socket. It supplies its direct voltage to the power electronics.

The power electronics convert the direct voltage into an alternating voltage and supply the electric motor/generator with three electrical phases via the three wires (U, V and W). The electric vehicle starts moving.



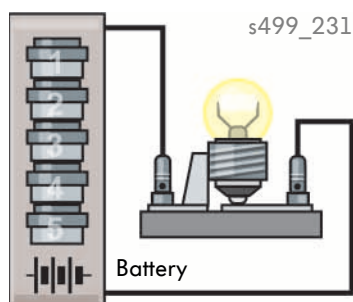
The high-voltage battery at the rear of a high-voltage vehicle

Explanation of terms

The term accumulator is sometimes used for rechargeable batteries. Originally batteries and accumulators were two different types of storage media for electrical energy. Today, the term rechargeable battery is generally used.



Battery



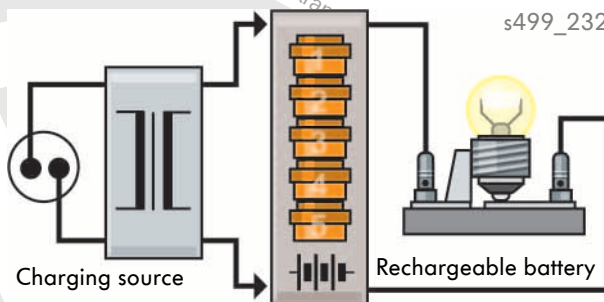
In its original meaning a battery refers to a storage medium for electrical energy that cannot be recharged. The battery is made up of so-called primary cells.

The total voltage depends on the number of and voltage of the individual cells.

A primary cell releases the chemical energy it has stored as electrical energy in a chemical reaction.

The original charge state cannot be restored by means of electrical recharging.

Rechargeable battery/accumulator



A rechargeable battery is made up of secondary cells. The most familiar rechargeable battery is the lead-acid battery that is commonly used as a car battery.

Electrical energy is also stored in a secondary cell. As with non-rechargeable batteries, the available quantity of energy is determined by the number of secondary cells that are connected to each other. The chemical reaction that occurs here is easy to reverse, however, in contrast to the primary cell. This means you can recharge the discharged battery with energy again with the aid of a charger.



Did you know?

The cycle stability of laptop batteries and mobile telephone batteries is around 500 cycles. This means that these batteries can be charged from flat to full up to 500 times due to their technical configuration. After that, these batteries only have approximately 50% of their original capacity. The capacity is given as the "State of Capacity" (SOC). The SOH (State of health) indicates the "health" of the battery.

Basics of Electromobility

In the following section, the term high-voltage battery (HV battery) is used for the rechargeable battery that supplies electricity to the electric motor/generator.

The typical electrical data for a high-voltage battery, like the nominal voltage, the efficiency and the energy density, depend on the type of chemical substances that are used for the internal configuration of the energy storage medium.



Energy density

This figure indicates the performance of a battery related to its weight. The higher the energy density, the more energy can be stored and then released again to perform a task. The unit of energy density is watt hours per kilogram [Wh/kg] and is calculated from the electrical work [Wh] and the weight [kg] of the battery. The range of an electric vehicle can be determined from the energy density.

Example of high-voltage battery weighing 85kg and supplying 288volts and a current of 6.5amperes:

The electrical power (P) is equal to the electrical voltage (U) times the electrical current (I); $P = U \times I$.

$U = 288\text{ volt}$ and $I = 6.5\text{ amperes}$

$P = 288\text{ V} \times 6.5\text{ A} = 1872\text{ VA}$; 1 VA corresponds with approx. 1 W (unit watt)

$P = 1872\text{ W}$ or 1.872 kW (unit kilowatt)

The electrical work is equal to the electrical power multiplied by the time.

This high-voltage battery can therefore perform electrical work of 1872 Wh (watt hours) over an hour (1h).

Calculation of energy density: $1872\text{ W} \times 1\text{ h} : 85\text{ kg} = 22.02\text{ Wh/kg}$

Life

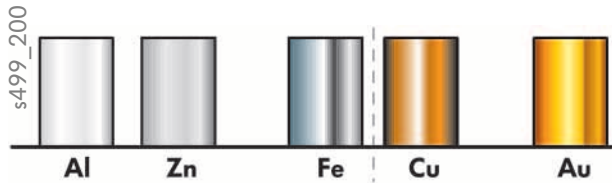
The life of a battery is described by the cycle stability. The cycle stability of a high-voltage battery is set at a total of 3,000 cycles over a period of 10 years, i.e. 300 cycles/year. On the basis of this property, so-called “automotive batteries”, i.e. batteries for use in a high-voltage vehicle, cannot be compared with the “consumer batteries” used in laptops or mobile telephones.

Efficiency

The efficiency of a rechargeable battery is given as a percentage. In simple terms, the efficiency indicates how much of the energy that is invested into charging can be made useful again when the battery is discharged.

A battery can never have 100% efficiency since a small part of the charging energy is released in the form of heat (charge loss).

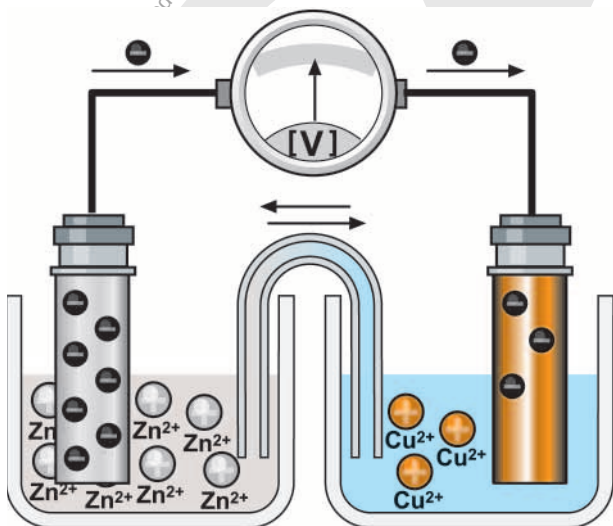
Functional principle



Excerpt from electro-chemical series of metals:

Al - Aluminium
Zn - Zinc
Fe - Iron
Cu - Copper
Au - Gold

The function of a battery is based on the fact that metals have different levels of electrode potential. In this context, precious means that two metals like zinc and copper differ in their chemical ability to release electrons. The elements can be arranged in a so-called electro-chemical series on the basis of this chemical property. Zinc releases electrons easily. This means it is easy to oxidise. Copper does not give up electrons for a chemical reaction so easily. This means it is more difficult to oxidise.



Schematic diagram of a battery

If you hang a zinc rod and a copper rod in a suitable electrolytic solution in separate containers, both metals will release ions into the electrolytes at different rates and will leave electrons in the metal rod. In one container there are many positive zinc ions in the solution and many electrons in the zinc rod. In the other container, there are only a few positive copper ions in the solution and a few electrons in the copper rod. If both containers are now connected to each other by an ion bridge, a charge exchange will occur due to the different ion concentrations. Due to the high excess of electrons in the zinc rod, it will act

as an anode while the copper rod forms the cathode. A voltage can be measured between the two due to the different electron concentrations. If you connect both electrodes with a conductor, the electrons will flow from the anode to the cathode. This set-up is generally called a galvanic cell and is the simplest form of a battery. If energy is released from the battery, the anode is the minus pole. In rechargeable batteries, the same electrode can alternately work as the anode or cathode depending on whether the battery is being charged or discharged.



Basics of Electromobility

Types of rechargeable battery

The different types of rechargeable batteries are distinguished by the materials used for the electrodes and electrolytes. The most common rechargeable batteries are lead-acid, nickel-cadmium, nickel-metal hydride and lithium-ion batteries. They will be described briefly in the following section and their main features will be presented.



Lead-acid battery

The traditional 12V vehicle electrical system battery. Plates made from lead and lead/lead oxide are used as electrodes. Sulphuric acid is the electrolyte.

Lead-acid batteries require maintenance. This means that distilled water needs to be topped up to ensure the required electrolyte liquid level. Lead-acid batteries are not very suited to powering purely electrically driven vehicles because they are very heavy in relation to their volume and would thus take up a large space in the vehicle. This would reduce the load capacity of such a vehicle.

A lead-acid battery can in some cases lose a large part of its capacity after just six years.

If damaged, electrolyte (acid) can leak.

Nickel-cadmium battery

Cadmium (Cd) and a nickel compound are used for the electrodes in these batteries. Potassium hydroxide is used as the electrolyte. Therefore this type is also called an alkaline battery. They have a higher energy density than lead-acid batteries and are less prone to damage and electrolyte leaks. Nickel-cadmium batteries are subject to a memory effect. This type of battery can cope with deep-discharging or overcharging only to a certain extent. It becomes less efficient as a result. Cadmium and cadmium compounds are poisonous.

Nickel-metal hydride battery

These batteries use a nickel compound and a compound of another metal for the electrodes. Potassium hydroxide is also used as the electrolyte. They have a higher energy density than Ni-Cd batteries and are relatively resistant to damage.

Even if a memory effect does not occur to the extent of the Ni-Cd batteries, these batteries do also lose efficiency over the course of their life. This loss in efficiency is reversible to a certain extent. One advantage of the nickel-metal hydride batteries: they do not contain any poisonous heavy metals like lead or cadmium. The electrolyte is stored in the battery in solid form. Only a few droplets will escape even if the housing is broken.



Lithium-ion battery

This is one of the newer battery generations that uses lithium compounds for its internal set-up. Various lithium-metal oxides and graphite are used as electrodes. Different solvents for lithium salts form the electrolyte. Lithium-ion batteries contain only a small amount of water and do not have a memory effect. Compared with the nickel-cadmium batteries, they have more than twice as much energy density. This means that this battery type requires less space in an electric vehicle leaving more room for the occupants and the luggage compartment.

Lithium (Li) is a chemical element. The word lithium originates from the Greek word "lithos" meaning stone because it was discovered in stone in 1817. Like sodium, lithium belongs to the alkali metals due to its chemical behaviour and is considered to be a light metal due to its low density. After hydrogen and helium, it is the third lightest chemical element.

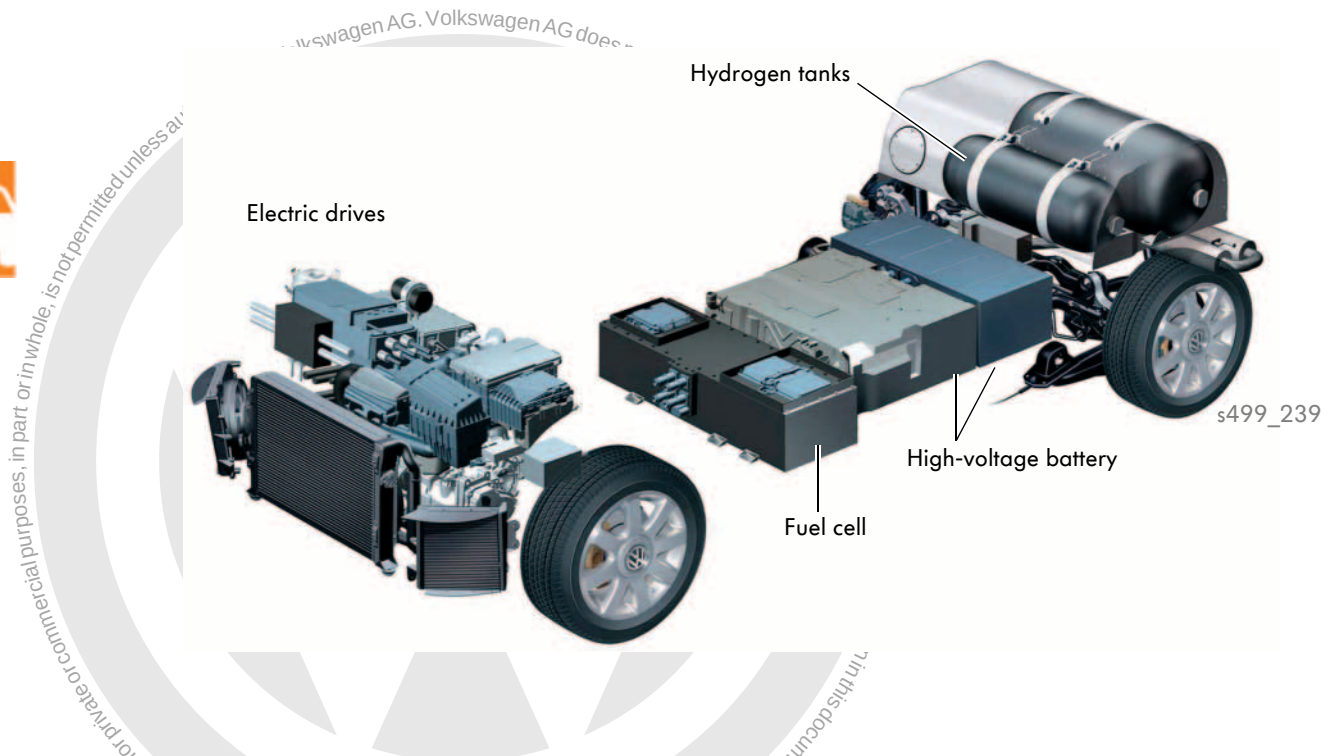
Density	0.534g/cm ³ (in comparison: H ₂ O = 1g/cm ³)
Usage in batteries	In form of lithium-carbonate (Li ₂ CO ₃), approx. 3 kg of pure lithium are required to build a battery delivering 20kWh.
Advantages	Quick charging due to low ion radius. No memory effect



If lithium-ion batteries are exposed to high temperatures, decomposition processes can result in the battery. This can lead to fire or the emission of dangerous gases. Therefore you should always observe the manufacturer's warning information when working with these batteries.

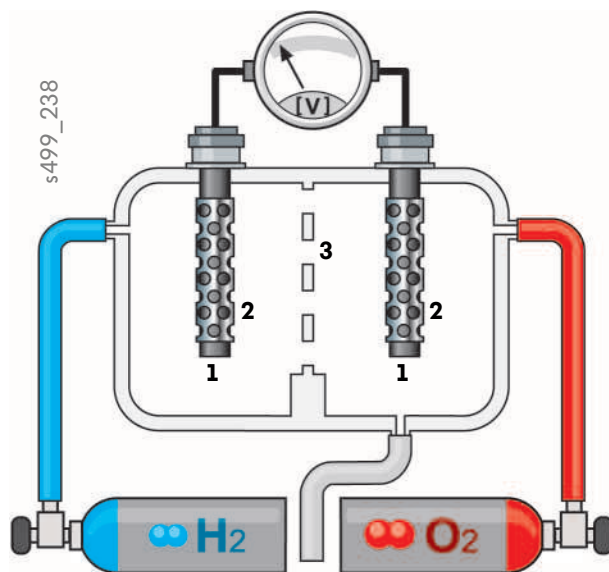
Basics of Electromobility

Fuel cell



The fuel cell is a development for alternative drives. Using the principle of energy conversion, the process that takes place in the fuel cell to produce electrical energy from chemical energy is similar to a combustion engine. The energy conversion from “fuel” to output is much more direct with the fuel cell. For this reason, the efficiency of a fuel cell is greater than a combustion engine. You can thus look at a fuel cell as a motor.

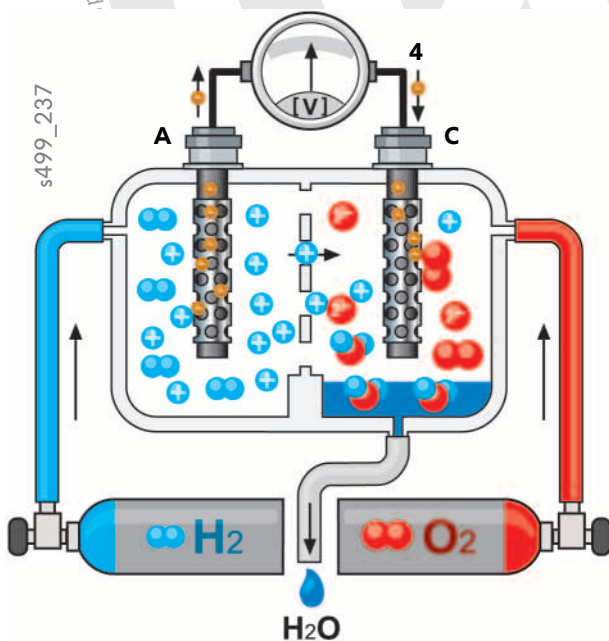
In a combustion engine, the chemical energy that is contained in the fuel molecules is converted into kinetic energy by combustion. This can then be used to drive a gearbox or supply an alternator. In a combustion engine, a large amount of energy is converted into heat due to friction. In the fuel cell, chemical energy is converted into electrical energy. In contrast to a combustion engine, no additional alternator is required to generate electrical energy. The fuel used is industrially manufactured hydrogen that is converted into water in the fuel cell with the oxygen from the air. Hydrogen does have less energy than the hydrocarbons contained in fuel, but it is easier to combust and there are only small losses in the energy conversion. Furthermore there is no combustion residue or harmful exhaust gases as with combustion engines.



Schematic diagram of a fuel cell

Structure of a fuel cell

A hydrogen/oxygen fuel cell is a special form of galvanic cell. The main components are two electrodes (1) e.g. nano tubes made from carbon with a platinum coating that serves as a catalyst (2) and a special membrane (3). Various compounds can be used as the electrolyte. The special membrane is gas tight, non-conductive for electrons and permeable for protons (hydrogen nuclei without electrons). The oxygen (O_2) comes from the ambient air and does not need to be filled specially.



Electricity is generated by burning hydrogen.

How it works

Hydrogen (H_2) and oxygen (O_2) are sent separately to the two electrodes: the hydrogen to the anode (A) and the oxygen to the cathode (C). The hydrogen releases two electrons with the help of the catalyst and splits into two positively charged hydrogen nuclei (protons). These can penetrate the membrane and pass through it because there are fewer protons in the electrolyte on the other side of the membrane (cathode side) than on the anode side (diffusion). The oxygen absorbs electrons catalytically at its electrode and then immediately reacts with the free hydrogen protons to form water (H_2O).

If you connect the anode and cathode to each other electrically, a current will flow due to this reaction (4). Electrical energy is produced directly in the fuel cell from the conversion of hydrogen into water.



Further high-voltage components

Inverter



The inverter is also known as a transducer or DC/AC converter. It has the job of converting the 3-phase alternating voltage of the alternator into a direct voltage for charging the battery. The three phases of the alternating voltage are first commutated and then smoothed in order to obtain an almost constant direct voltage. In the reverse case, the direct voltage from the battery is converted into a 3-phase alternating voltage when the electric motor is driven.

DC/DC converter

A DC/DC converter is basically a transformer. It is used to transform the high direct voltage from the high-voltage battery into a corresponding low charge voltage for charging the 12V onboard supply battery. DC/AC converters and DC/DC converters are often combined with other electronic components of the high-voltage system in a power electronics module.

Charging source/charging contact

A charger that is incorporated in the high-voltage system in the vehicle is also called an AC/DC converter. It converts the alternating current supplied from the mains via the charging contact into a direct current since only direct currents can be stored in batteries.

Charging with direct voltage (DC charging) is also possible. The supply of a direct voltage via a public electricity system is complex, however.

High-voltage system

The high-voltage system is separate from the 12V vehicle electrical system with one exception. The DC/DC converter is the only component that is connected to both electrical systems. All high-voltage lines are coloured orange and are highly resistant to damage. They are further reinforced by an additional woven sleeve that is also orange in colour. Electrical connectors for the high-voltage system are reverse polarity protected and colour coded. The electrical consumers outside the high-voltage system (e.g. lights, steering, vacuum pump for brake servo and cigarette lighter) are powered by the conventional 12V vehicle electrical system.

Other high-voltage units

In addition to the pure drive components, further units and components can be supplied with high voltage in high-voltage vehicles. Examples are the air conditioning system and/or the heating and ventilation system.

In high-voltage vehicles that are run without combustion engine, all units that are driven mechanically by the combustion engine, for example, with a belt drive, need to be operated electrically. This does not necessarily have to be done with the high voltage. Instead, the units can also be configured as 12V components that are supplied via the 12V onboard supply (e.g. power steering pump, brake servo, ...). Units will be configured as high-voltage components only if a high output is required, like with the air conditioner compressor. All high-voltage units are marked with a warning sticker.



Gearbox

Pure electric vehicles (BEV) do not require the traditional gearbox with several speeds. The polarity of the electric motor is simply reversed when you want to reverse the vehicle. This means that the direction of rotation of the electric motor changes. This is done with a gear selector lever, which simply has the positions “Neutral”, “Forwards” and “Reverse”. The speed can be regulated steplessly with the accelerator pedal. Full hybrid vehicles (HEV) and plug-in hybrid vehicles (PHEV) still have a conventional gearbox. As a rule, these are not manual gearboxes, but automatic or dual clutch gearboxes.

Brake system

In simple terms, an electric vehicle has two independent brake systems. One system is the traditional mechanical/hydraulic brake system. The second brake system is formed by the electric drive motor as a “motor brake”. The advantage of this “motor brake” compared with the combustion engine is that the energy released by the electric motor/generator during braking and deceleration is recovered and fed into the high-voltage battery. This so-called regenerative braking contributes to the high efficiency of the electric vehicles in particular in city traffic. At the same time, the wear of the vehicle brakes is reduced by the regenerative braking system.

Drive train configurations

An electric vehicle is driven by at least one electric drive motor. It can be configured as a four-wheel drive vehicle or with one drive axle. Further hybrid variants are also possible. These are described in SSP450 “The Touareg Hybrid”.

- The two main concepts are presented in the following section.
- drive with in-wheel motors
 - drive with just one electric drive motor in the central drive train

Drive with in-wheel motors

The following table provides an overview of the different drive train configurations with in-wheel motors.

Front-axle drive	Rear-axle drive	Four-wheel drive
		
2 in-wheel motors	2 in-wheel motors	4 in-wheel motors

Design

The wheels are connected directly to the in-wheel motors. Today, the in-wheel concept is used for electric scooters, electric bicycles and electrical driven wheel chairs.

Features

- No drive shafts are required
- No differential gearbox required

Advantages

- Four-wheel drive technically possible.
- The output axes of the in-wheel motors are directly on the wheel.
- High efficiency of drive because there are hardly any mechanical losses.
- Possibility of regenerative braking.

Disadvantages

- The unsprung masses in the wheel are greater compared with the wheels on a conventional vehicle.
- High mass of driven components (inertia and torque of whole vehicle affected)
- Independent vehicle concept required
- Control is complex. Both electric motors need to run synchronously.
- The combination with a hydraulic friction brake is still necessary at present.
- There is limited space on the wheel.

Drive with electric motor in central drive train

The following table provides an overview of the different drive train configurations for vehicles with one central electric motor.

Front-axle drive	Rear-axle drive	Four-wheel drive	Four-wheel drive
			
1x central electric motor and two drive shafts	1x central electric motor and two drive shafts	1x central electric motor and five drive shafts plus transfer box	2 x central electric motors and four drive shafts

Design

The electric motor/generator drives a gearbox, the drive shafts and thus the wheels. In a pure electrically powered vehicle, a reduction gearbox is sufficient. Four-wheel drive can be achieved with a propshaft from the front axle drive. Another possibility is to use a second electric motor.

Features

- Two drive shafts on each driven axle
- A differential on each driven axle
- Propshaft required

Advantages

- Single-axle drive simple to design
- Four-wheel drive technically possible
- Combination as hybrid drive (HEV / PHEV / RXHEV) very much possible
- Integration in existing vehicle concept is possible

Disadvantages

- Output shaft of central electric motor/generator is not on the drive axes.
- Differential required
- Reduction gear required

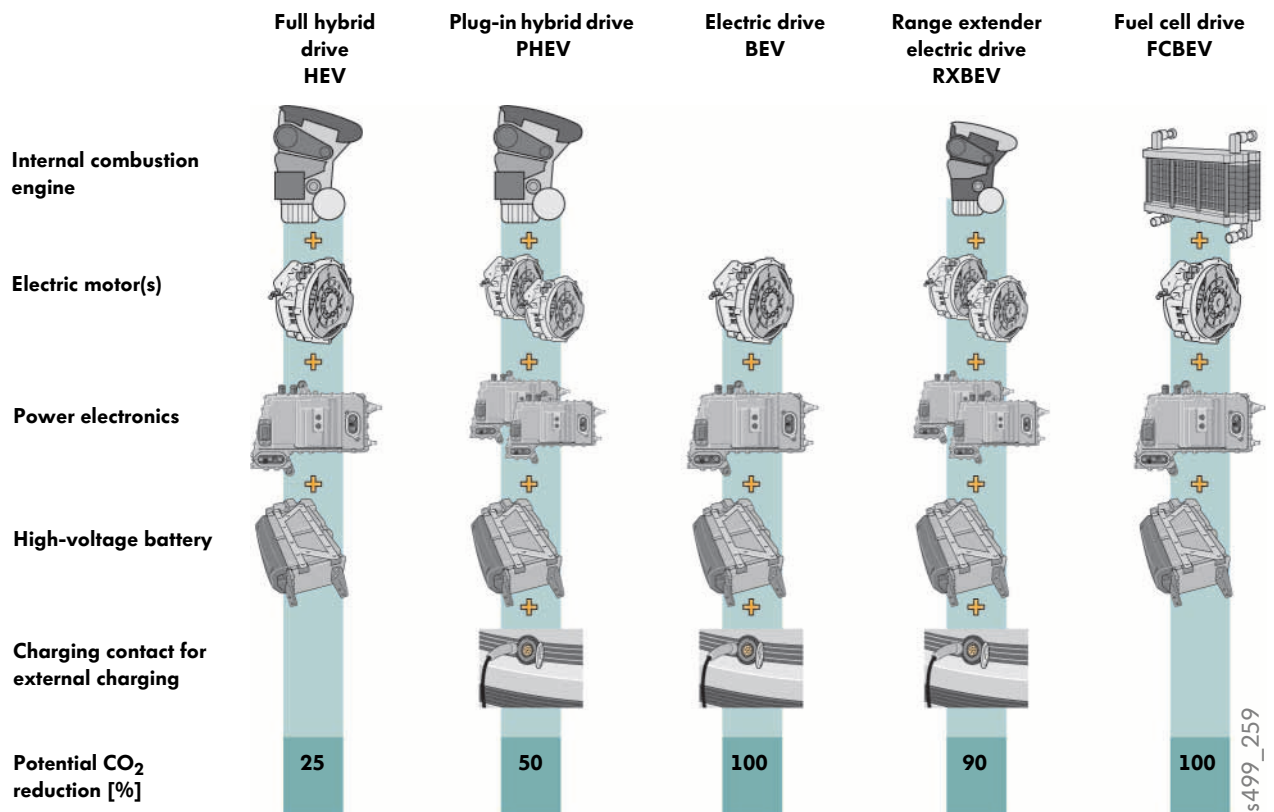


Volkswagen is currently only using drives with a central electric motor/generator as the only drive or in combination with combustion engines as hybrid drives. In-wheel motors are currently not used. Future use in vehicles is conceivable, however.



Vehicle Concepts

Overview of the different drive combinations



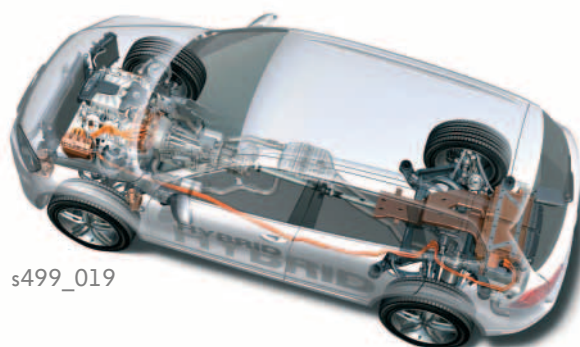
Essentially there are different hybrid and electric vehicle concepts. Some are currently on the market. Others exist as prototypes for now.

All concepts have a certain number of common high-voltage components. The components are found in all high-voltage vehicles in adapted form.

The fuels are not indicated in the diagram. The internal-combustion engine uses fuel.

The fuel cell is fuelled with hydrogen.

The Touareg with full hybrid drive (HEV)



In full hybrids, the vehicle has a conventional internal-combustion engine and an electric motor/generator that functions as an alternator, drive unit and starter motor. The individual operating modes depend on factors like the charge state of the high-voltage battery, the accelerator pedal position and the brake pedal value. Both the internal-combustion engine and also the electric motor/generator transfer their power via a clutch and a common gearbox to the drive axles.

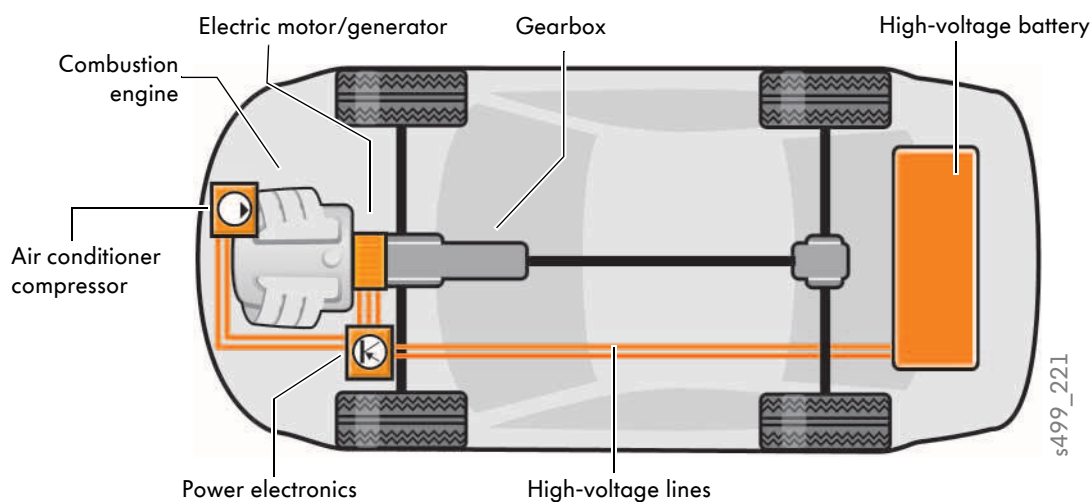
In addition to the high-voltage system, the vehicle also has a 12V onboard supply with its own 12V onboard supply battery.

In this concept, the interior is heated with the heated coolant from the combustion engine.



Design

Power units and high-voltage components

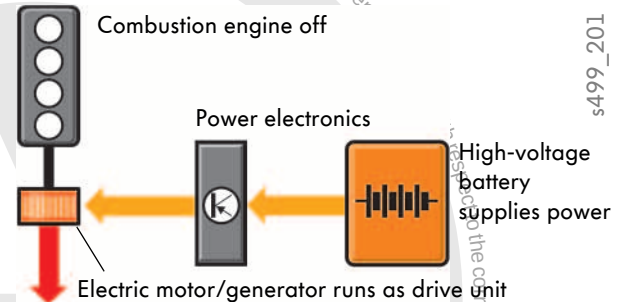


Vehicle Concepts

HEV operating modes

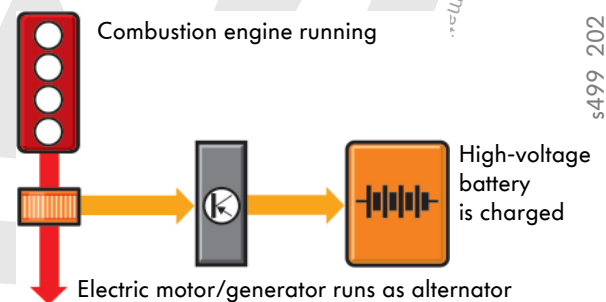
Electric driving

The combustion engine is deactivated. The electric motor/generator drives the vehicle. In a hybrid, all functions that are normally driven by the running combustion engine are performed by different high-voltage and 12V units.



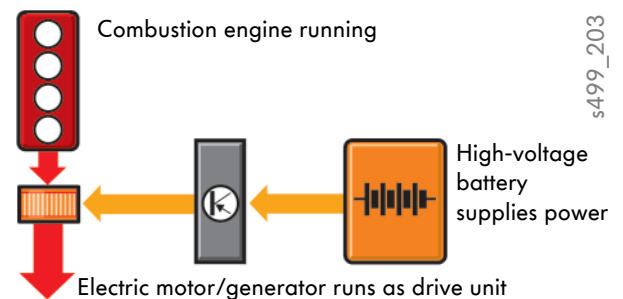
Combustion engine operation

Combustion engine drives the vehicle. The high-voltage battery is charged (depending on the charge status). The operating point of the engine is shifted to an efficient range.



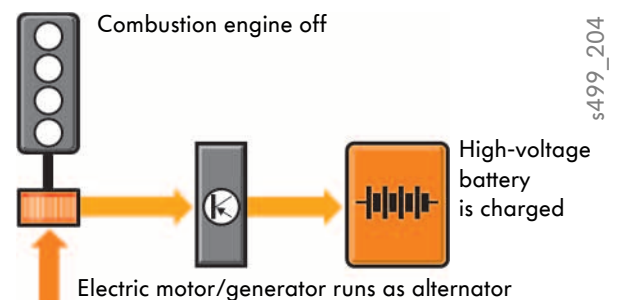
E-boost

The electric drive motor supports the combustion engine when there is a high load requirement. The outputs of the combustion engine and electric motor/generator are combined briefly.



Regenerative braking

The combustion engine is normally switched off. The braking energy is converted into electrical energy by the electric motor/generator (which is functioning as an alternator) and stored in the high-voltage battery.



The Golf 6 TwinDrive (PHEV)



In contrast to the full hybrid drive, the TwinDrive has two electric motors. One of the electric motors is used exclusively as an alternator or starter while the other electric motor is used as an electric motor and alternator. The two electric motors and the combustion engine are connected to each other via clutches.

Here too, the operating mode determines the interaction of the two electric motors and the combustion engine. The high-voltage battery in the TwinDrive can also be charged via an external 230V mains connection. It can even feed electricity into the

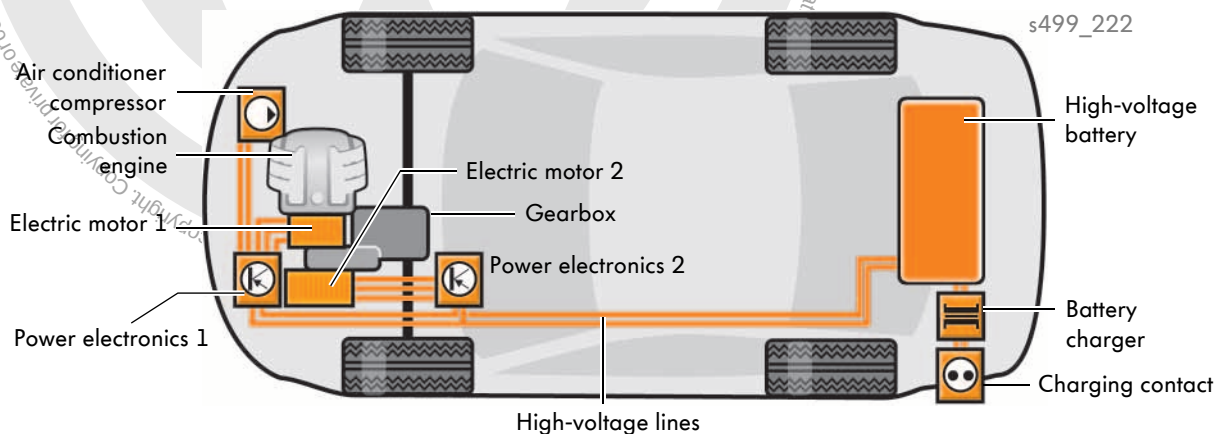
230V mains via the charging cable if the house connection to the 230V mains is suitably configured.

In addition to the high-voltage system, the vehicle also has a 12V onboard supply with its own 12V onboard supply battery. In a hybrid, all functions that are normally driven by the combustion engine (e.g. air conditioner compressor) are performed by different high-voltage and 12V units.



Design

Power units and high-voltage components

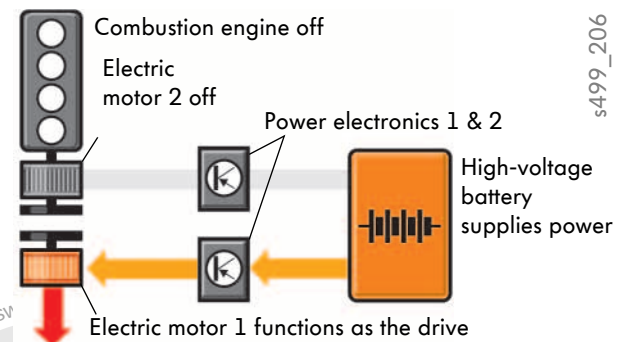


Vehicle Concepts

PHEV operating modes

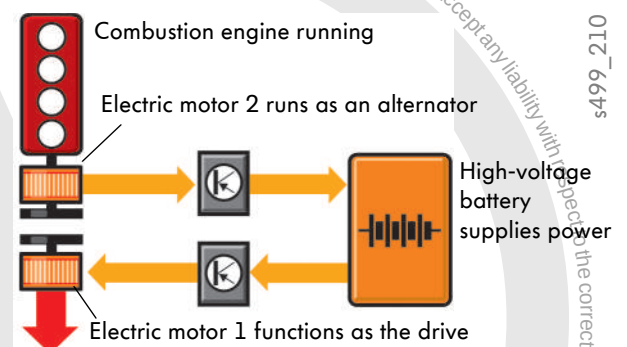
Electric driving

The combustion engine is deactivated. The vehicle is driven by electric motor 1. The high-voltage battery supplies the energy via power electronics 1.



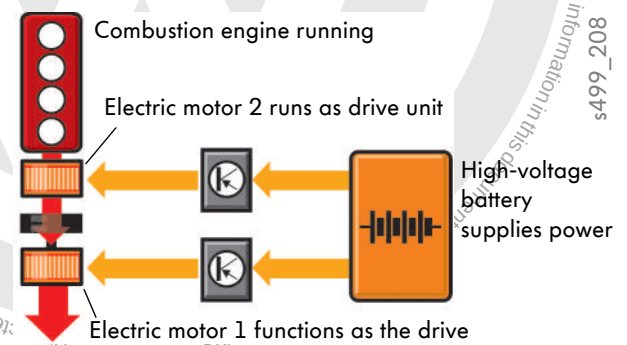
Series driving

Electric motor 2 starts the combustion engine. Then electric motor 2 runs as an alternator and feeds the high-voltage battery. This motor supplies energy so electric motor 1 can drive the vehicle electrically. This operating mode is an exception.



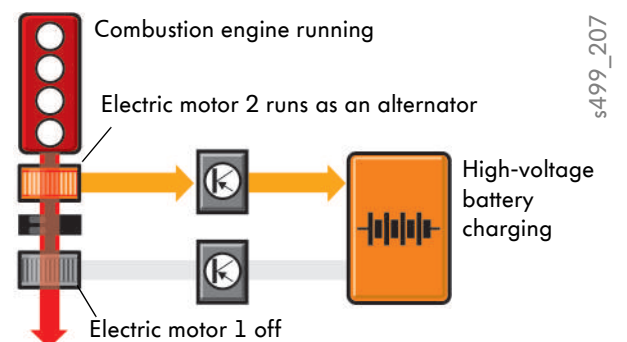
Boost

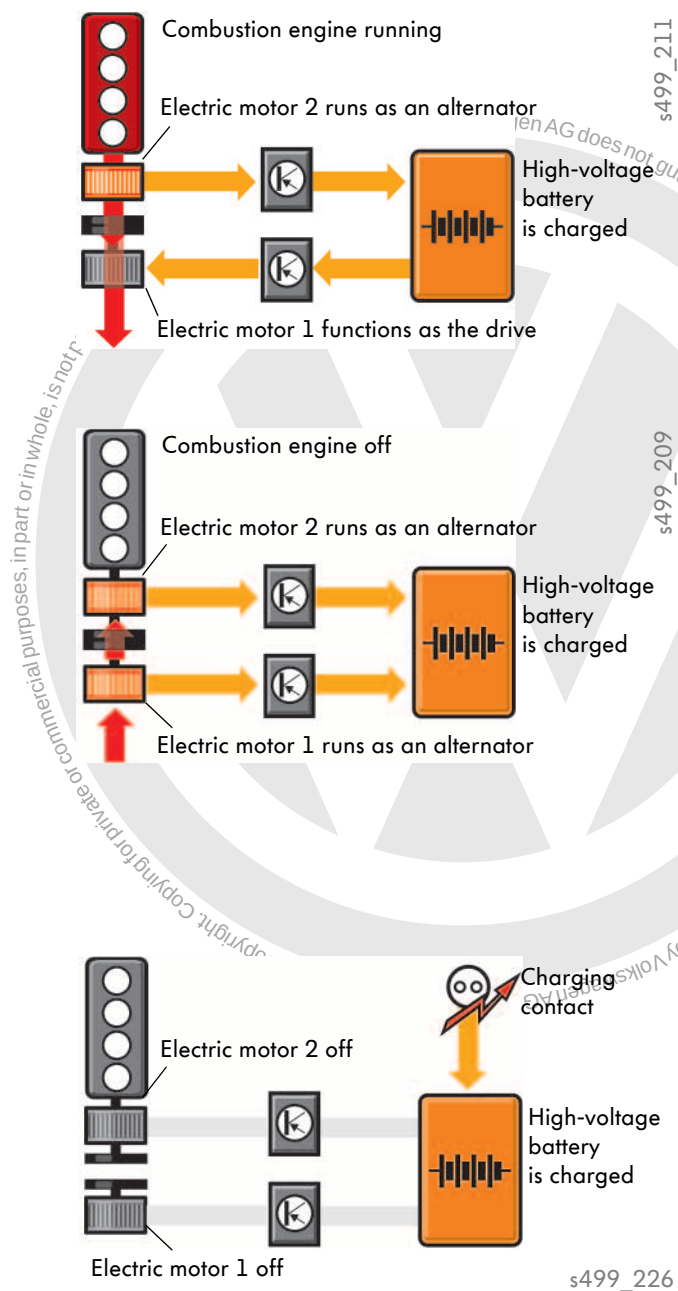
The combustion engine and electric motors accelerate the vehicle. This function depends on the charge state of the high-voltage battery.



Driving with combustion engine

If the high-voltage battery is completely discharged, electric driving is no longer permitted. In this case, the vehicle drives with the combustion engine and simultaneously charges the high-voltage battery with the surplus power using electric motor 2.





Coupled driving and charging

The route planned by the driver may require that the combustion engine drives the vehicle and, at the same time, the surplus power is used to charge the high-voltage battery.

Regenerative braking

Both electric motors can be used for regenerative braking when the clutch is engaged. The energy from the deceleration of the vehicle can be converted into a direct voltage by the two power electronics units and immediately stored in the high-voltage battery.



External charging

The high-voltage system is in stand-by mode during the charging process from an external source. The electric motors and power electronics are deactivated. The charging cable is connected to the vehicle via the charging contact. When a source of electricity for charging the high-voltage battery is recognised by the control unit, two charge protection relays are closed.

The charging process is started. The charging process is stopped once the required capacity has been reached. Electrical consumers that are activated during the charging process are powered by the external charging source.

Vehicle Concepts

The Golf blue-e-motion (BEV)

Example of 2011 test fleet

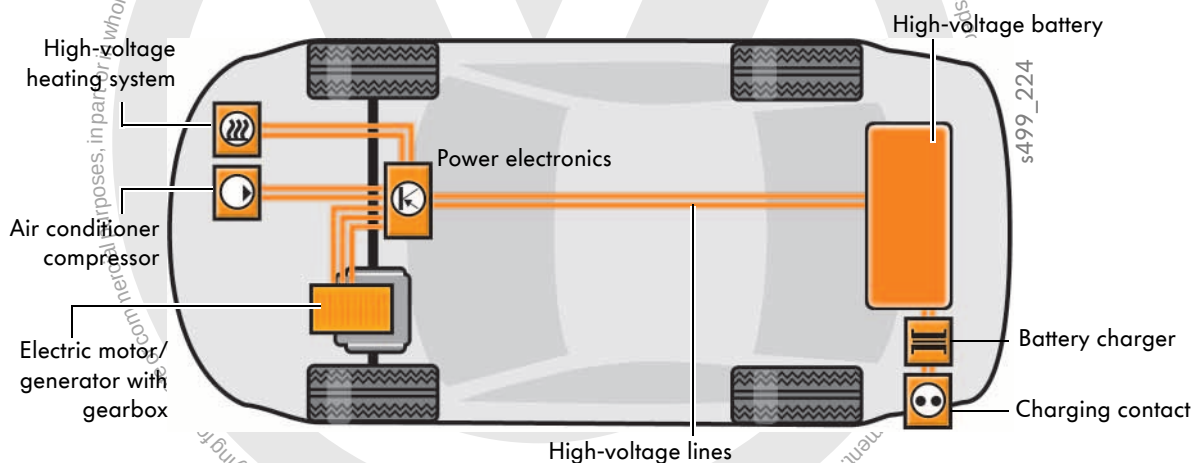
The blue-e-motion is a purely electric vehicle without combustion engine. Except for battery charging by means of regenerative braking, the high-voltage battery can only be charged externally via a charging station, a 230V mains socket or a charging cable connected to a public charging station. In addition to the high-voltage system, the vehicle also has a 12V onboard supply with its own 12V onboard supply battery. The electric motor/generator delivering 85kW transfers the output to the drive wheels via a reduction gearbox and differential.



The driver operates the vehicle in exactly the same way as a vehicle with an automatic or dual clutch gearbox. The reduction gearbox has a mechanical parking lock. In addition, the gearshift gate has the position "B" (regenerative braking). In this position, the system supplies the maximum possible regenerative braking when you take your foot off the accelerator. The vehicle can be brought to a standstill in this way without the brakes. The heat from the electric drive motor is not sufficient to heat the interior. Therefore the blue-e-motion has a high-voltage heating system.

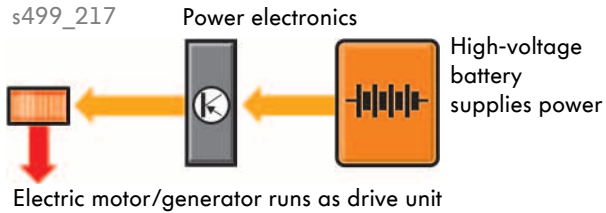
Design

Drive units and high-voltage components



BEV operating modes

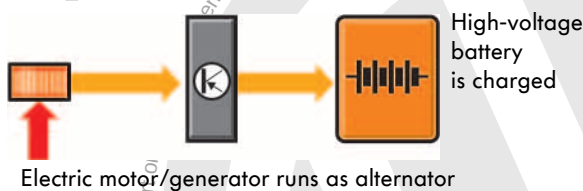
s499_217



Electric driving

Electrical driving with a purely electrical automobile is configured in exactly the same way as a full hybrid vehicle: the high-voltage battery supplies energy to the power electronics. The power electronics convert the direct voltage into an alternating voltage to drive the electric motor.

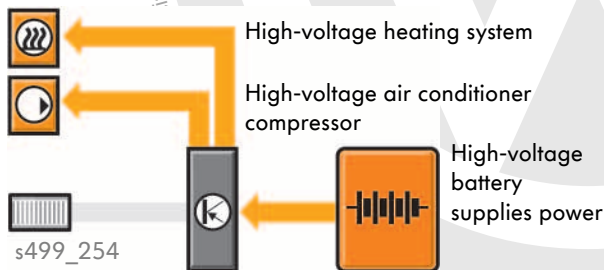
s499_228



Regenerative braking

If the electric vehicle “coasts” (the vehicle moves without drive torque from the electric motor), part of the kinetic energy is fed into the high-voltage battery by the electric motor that functions as an alternator.

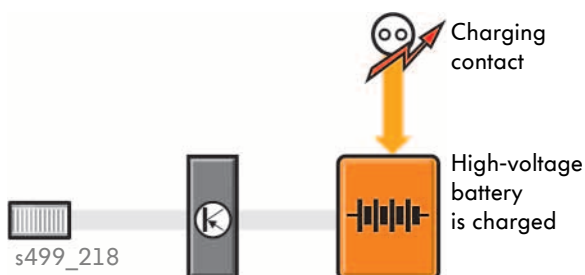
s499_254



Climate control while vehicle is stationary

If, for example, the electric vehicle is standing in a traffic jam, no output is required from the electric motor/generator. The comfort requirements of the occupants are met with a high-voltage heating system and a high-voltage air conditioner compressor.

s499_218



External charging

The high-voltage battery is charged via the charging contact on the vehicle. When the external charging source is connected, the vehicle is charged automatically up to the previously set value. The process is ended automatically. If electrical consumers are used during the charging process, they will be supported by the charging voltage.



Vehicle Concepts

The Audi A1 e-tron (RXBEV)

(concept vehicle)

This is an example of a range extender (RXBEV).

It is driven by a combustion engine and two electric motors. Unlike the previously described systems, the combustion engine does not have a mechanical connection to the drive axles, however. The vehicle has an electric-only drive.

The combustion engine only drives electric motor 1, which functions as a generator and charges the high-voltage battery while the vehicle is driven. In this function, the combustion engine runs in its optimum map with high output and low consumption. This set-up allows the vehicle range to be extended. The high-voltage battery is mainly charged externally.

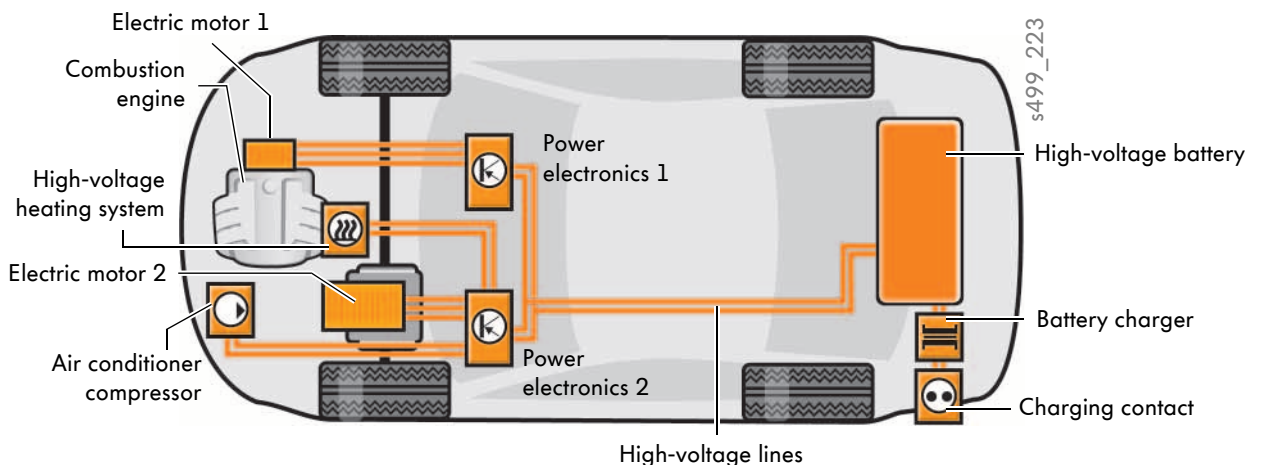
The mobile recharging possibility with the combustion engine and electric motor 1 working as an alternator can be seen as a back-up generator. In addition to the high-voltage system, the vehicle also has a 12V onboard supply with its own 12V onboard supply battery.



s499_256

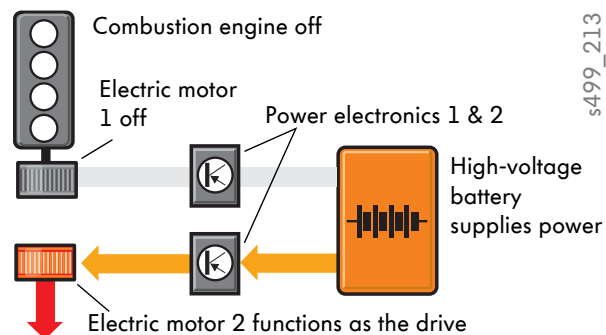
Design

Drive units and high-voltage components



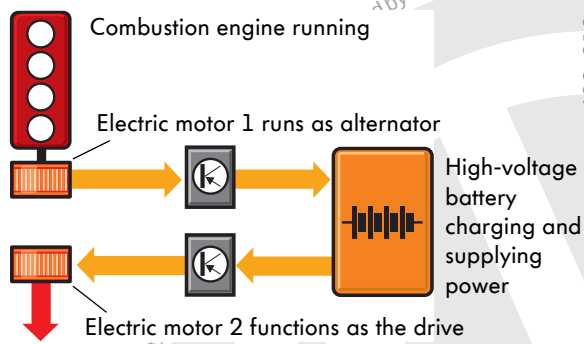
s499_223

RXBEV operating modes



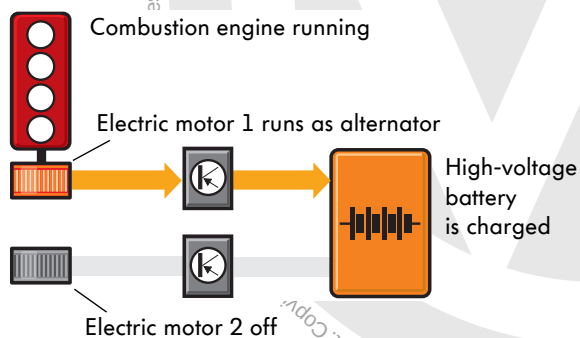
Electric driving

If the high-voltage battery is charged, the vehicle is driven electrically with electric motor 2. Convenience consumers (high-voltage heating system and high-voltage air conditioner compressor) and the 12-volt onboard supply battery are powered via power electronics 2.



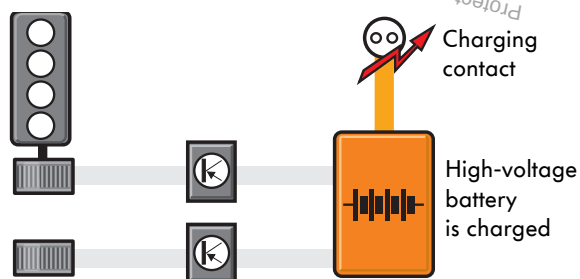
Electric driving and charging

The high-voltage battery is discharged. The combustion engine starts in order to continue the journey. It drives electric motor 1 and thus charges the high-voltage battery. Electric motor 2 is the sole source of propulsion and the sole means of regenerative braking.



Charging battery when vehicle is stationary

An external voltage source is not available to charge the high-voltage battery. In this case, the combustion engine can charge the high-voltage battery via electric motor 1 while the vehicle is stationary.



External charging

The high-voltage system and the complete drive are deactivated. The high-voltage battery is charged via the charging connection on the vehicle, the high-voltage charger and the two charge protection relays. The charging process is automatically monitored and ended by the system.



Vehicle Concepts

The Tiguan HyMotion (FCBEV)

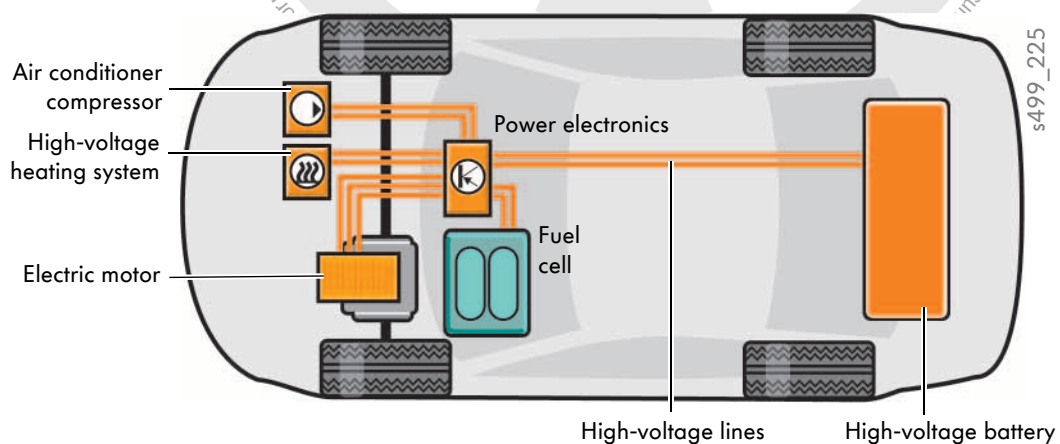
The HyMotion features a fuel cell drive. The vehicle is fuelled with hydrogen and obtains the electrical energy for the electric motor from a fuel cell module. In this module, the hydrogen is turned into water to produce electrical energy. Depending on the operating mode, the charging voltage for the high-voltage battery is used for the drive.

An additional combustion engine is not installed. The high-voltage battery can only be charged externally by workshops with a special battery charger. In addition to the high-voltage system, the vehicle also has a 12V onboard supply with its own 12V onboard supply battery.

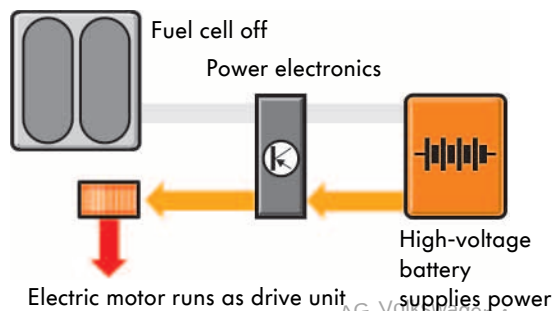


Design

Drive units and high-voltage components

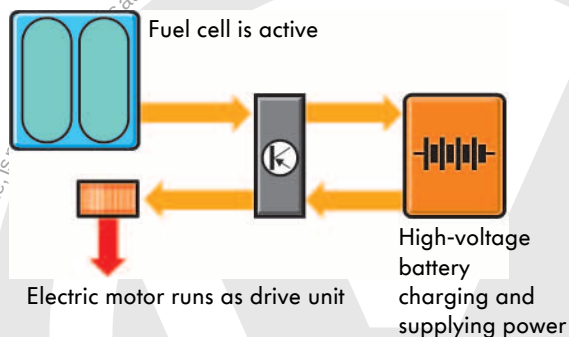


FCBEV operating modes



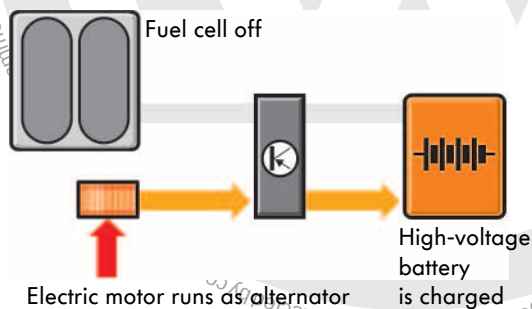
Electric driving

If the high-voltage battery has been charged, the vehicle can be driven electrically. In this case, the fuel cell does not supply any energy and does not consume any hydrogen.



Electric driving and charging

The fuel cell is activated when the charging state of the high-voltage battery requires its power. The electrical energy for driving and for charging the high-voltage battery is produced from the fuelled hydrogen with the aid of oxygen from the air.



Regenerative braking

The electric motor exclusively takes care of regenerative braking. During over-run, the electric motor functions as an alternator. It charges the high-voltage battery via the power electronics.

Hydrogen for the fuel cell

The hydrogen is topped up at special filling pumps. The fuelling procedure is identical to that for natural gas. The hydrogen is pumped into pressurised tanks under the vehicle at pressures up to 700 bar. Due to the physical properties of hydrogen, 80 litres weigh about 6.44kg. The hydrogen reaches the fuel cell via pressure reducers. At an operating pressure of 3 bar, it supplies a direct voltage of 250V to 450V.



High-voltage Safety

The increasing electrification and hybridisation of drive concepts is leading to greater use of high-voltage systems in vehicles.

What does high voltage mean?

Vehicles with high-voltage systems (HV) are fitted with components that work with voltages above 60V direct voltage or 25V alternating voltage. Some of the components in these vehicles require a high level of electrical power. The high-voltage systems in vehicles work with direct voltages of up to 650V and very high peak currents.

What dangers are involved in working with high-voltage systems?

All movements in the human body are initiated by electrical control mechanisms. All muscle reactions, like your heart beat or eyes winking, are controlled by electrical stimulation. These electrical stimulations are conducted inside the body via nerve pathways in a similar way to currents in electrical circuits.

If you touch live high-voltage components, the current can flow through your body. Even with direct currents above approximately 30mA, temporary heart pulse disturbance can occur depending on how long the current flows through the body. At even higher currents in the body, serious internal burns occur and in some cases ventricular fibrillation can result.

If the two poles of an electrical system are short-circuited, there is a risk of arcing. This can cause serious external burns on the human body and electro-ophthalmia of the eyes.



Safety precautions

The risk of contact with live high-voltage components must be ruled out.

Only specially qualified personnel may perform work on the high-voltage system. In addition to the colour coding and warnings given on labels on the components, there are technical safety measures.

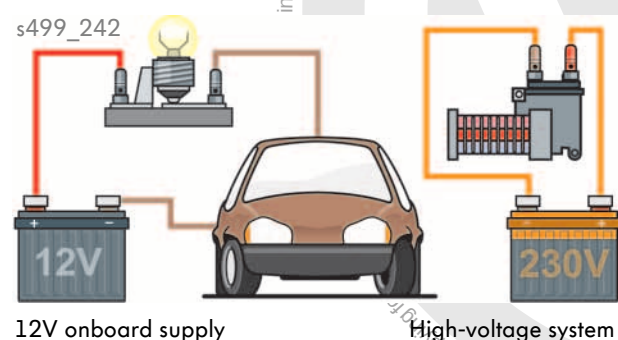
The exact safety equipment used depends on the vehicle. In the following section, basic safety aspects are explained without looking at the special installation situation in a vehicle.

Please refer to the workshop literature for which safety equipment is fitted in a specific vehicle.

The electrical isolation of the high-voltage system and 12V onboard supply

Purpose

The strict isolation of the high-voltage system and 12V onboard supply should prevent unintentional short-circuits with the vehicle earth. This isolation of the high-voltage system from the body earth is also called electrical isolation.



How it works

To achieve this isolation, the high-voltage system has its own equipotential bonding. The high-voltage system and the 12V onboard supply are electrically isolated from each other so that there can be no accidental short-circuit and thus a flow of current to the body earth.

While the circuit in the 12V onboard supply normally runs via the vehicle earth, all high-voltage components have two wires with which their electrical circuit is formed. There is no connection to the body earth.

High-voltage isolation with ignition “off”



Task

The simplest way to deactivate the high-voltage system and disconnect the high-voltage system from the high-voltage battery is to turn the ignition key to the “Drive Off” position.

Depending on the vehicle equipment, this can also be done with an “Engine Off” button (e.g. with Keyless Entry).

How it works

The ignition lock or the “Engine Off” button is used as switches with which the electric circuit to the protective relay of the high-voltage system is interrupted (see next page). This opens the protective relays and the high-voltage battery is disconnected from the high-voltage system. The high-voltage system is de-energised after a short time. The high-voltage battery itself and the high-voltage lines up to the protective relay are still energised, however.



High-voltage Safety

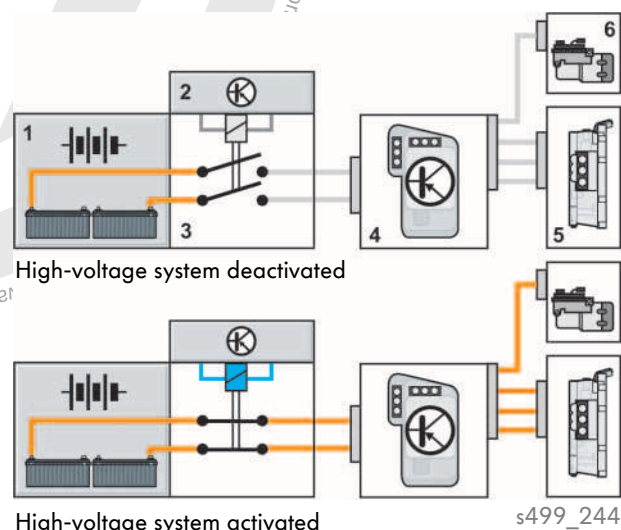
The protective relays in the high-voltage system (high-voltage contactor)

Purpose

The high-voltage battery is connected to the high-voltage system. Each of the high-voltage connections has its own protective relay that can interrupt the circuit. The protective relays therefore have the task of connecting the high-voltage system in the vehicle (contactor closed) or disconnecting it (contactor open).

How it works

The protective relays are switched only together by the high-voltage system. If the contactors are de-energised, they open and the high-voltage battery is disconnected from the high-voltage system in the rest of the vehicle. The command to open can be triggered by different situations. If you switch off the vehicle and remove the ignition key, this will also open the contactors and activate the other safety systems.



- 1 High-voltage battery
- 2 Battery management
- 3 Protective relay (contactor)
- 4 Power electronics
- 5 Electric motor/generator
- 6 Air conditioner compressor

Safety information



Work on the high-voltage system may only be performed by qualified Volkswagen high-voltage technicians. The instructions in the service literature must be followed strictly for the proper and safe use of the special high-voltage tools.

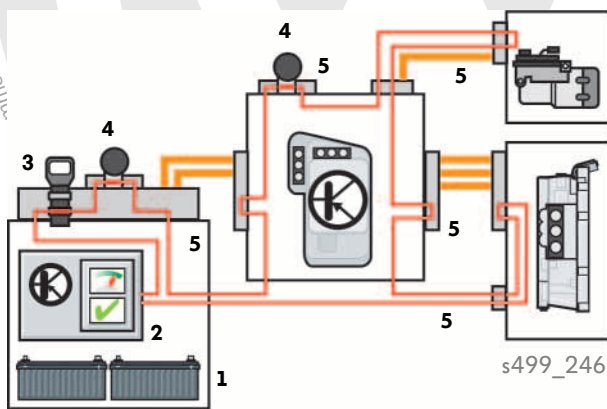
The pilot line

Purpose

The pilot line is a completely independent safety system. It determines whether all high-voltage components are correctly connected to the high-voltage system. The pilot line is a low-voltage system.

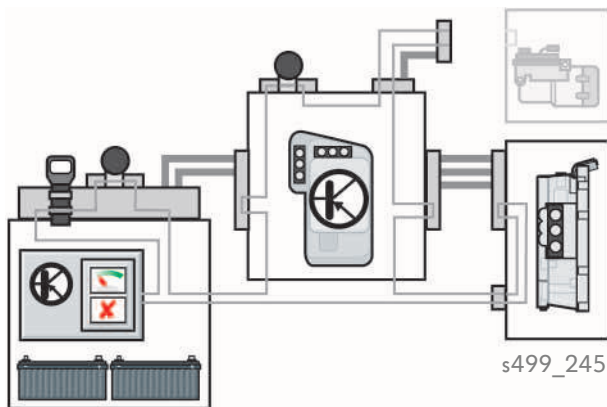
Design

The pilot line connects all high-voltage components. The system checks whether the high-voltage connections of the components incorporated in the pilot line are correctly connected. Depending on the vehicle, various connector types are integrated into the pilot line.



Pilot line continuous

- 1 High-voltage battery
- 2 Battery management
- 3 Maintenance connector
- 4 Pilot line connectors
- 5 Connections for high-voltage components



Pilot line interrupted

How it works

The pilot line circuit is interrupted as soon as a high-voltage contact on a high-voltage component is disconnected, e.g. when a high-voltage component is replaced. The same happens when one of the pilot line connectors is disconnected. As soon as the high-voltage system detects that the pilot line is interrupted at just one point, the protective relays are opened and the high-voltage battery is isolated from the high-voltage system.



High-voltage Safety

Maintenance safety

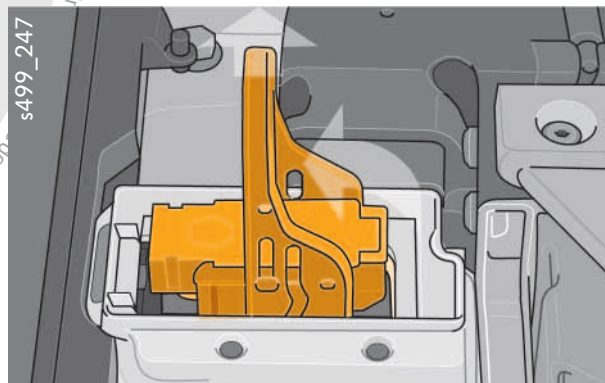
Purpose

The high-voltage system normally has a maintenance connector near to the high-voltage battery as an additional safety feature for de-energising the high-voltage system when work is carried out in the workshop. If you unlock the maintenance connector and pull it out of its fitting, the contactors and the high-voltage battery will be disconnected from the high-voltage system. In addition, the maintenance connector may also contain the main fuse for the high-voltage battery (e.g. Touareg Hybrid 2011).

Set-up using Touareg Hybrid 2011 as example

The maintenance connector is under an orange-coloured cover near to the high-voltage battery in the electronics box. It is an electrical bridge between the battery modules of the high-voltage battery and, at the same time, part of the pilot line. The maintenance connector needs to be unlocked before it can be pulled out of its fitting.

The appearance of the connector may vary and depends on the vehicle type.



How it works

Unlocking the maintenance connector interrupts the pilot line and thus deactivates the high-voltage system. The protective relays (contactors) open and disconnect the high-voltage system from the high-voltage battery. Disconnecting the maintenance connector will electrically isolate the battery modules of the high-voltage battery from each other. Only the actual battery modules are now still live with a reduced voltage.

Safety information



Make sure you follow the three basic rules of high-voltage safety:

1. De-energise the high-voltage system.
2. Secure the vehicle against reactivation.
3. Check that/determine whether the high-voltage system is de-energised.

This procedure is known as certified de-energisation and may only be performed by a high-voltage technician.

Crash safety

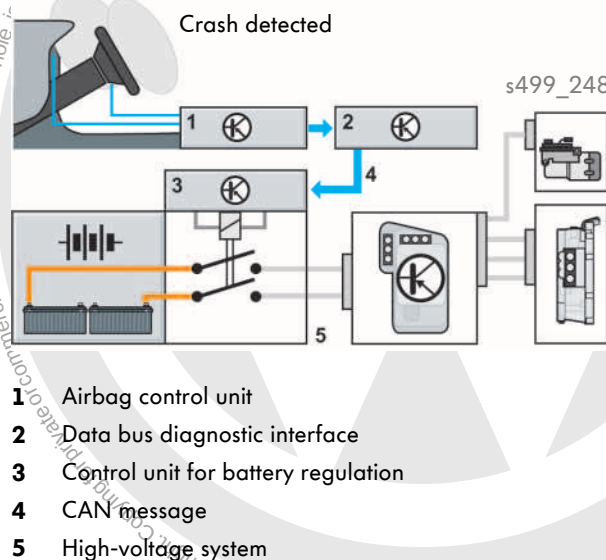
Purpose

Deactivation of the high-voltage system and thus the de-energisation of the high-voltage system is very important for occupant protection in accidents, the safety of rescue personnel and safety in accident vehicles that have been brought in for repair. For this reason, the high-voltage safety is linked to the crash detection system via the airbag control unit.

How it works

As soon as the airbag control unit detects an accident and deploys the belt tensioner or airbags, the battery regulation control unit is instructed via the CAN data bus to open the protective relays.

If just the belt tensioners are deployed (single-stage crash deployment), it will be possible to close the contactor again by switching the ignition on and off again. The belt tensioners and airbags are deployed in the second crash stage. The contactors can then be closed again only with the VAS tester.



Safety information



Always refer to the respective guidelines for rescue services for information on the different ways to deactivate the high-voltage systems in crashed vehicles.



High-voltage Safety

Safety during external charging

If the vehicle has a charging contact for external charging, protective relays are also fitted in the charging circuit of the high-voltage system. They only connect the high-voltage battery to the charging contacts if the system detects that the charging contact has been connected and a voltage is present. The charging procedure can also be performed safely in rain or if the contacts have been exposed to moisture.

Monitoring the insulation resistance

The battery regulation control unit transmits a test voltage while the high-voltage vehicle is in use. The test voltage is 500V and has a very low current. It is therefore not dangerous for humans.

If all high-voltage components and wires are correctly insulated and shielded, the control unit calculates and compares the previously set total resistance of the high-voltage system. If the insulation of a wire is damaged externally, for example, by a vermin bite, the insulation resistance will change.

The control unit detects an insulation fault due to this change in resistance. Depending on the severity of the fault, various messages can appear in the vehicle instrument cluster.



Damaged high-voltage lines are always replaced. The insulation cannot be repaired due to the insulation resistance monitoring system. Slight deviations in the resistance, for example, due to damp weather with salt ingress, can cause an insulation fault again.

Warning stickers

During work with high-voltage vehicles, different warnings draw attention to the special characteristics of the high-voltage technology.

Warning notices related to high voltages

s499_273



Do not switch on.
Work on high-voltage system in progress

s499_269



Caution, hazardous voltage!



s499_271

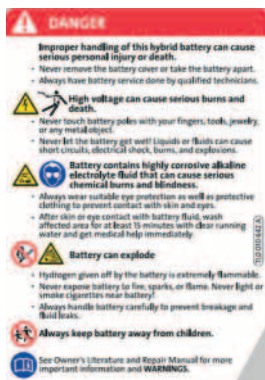
Caution!
Parts carrying high voltages.
Before starting work, perform certified de-energisation of the high-voltage system.



s499_270

Hazardous voltage!
Electric shock if touched!
De-activate high-voltage system.

s499_272



Caution! High-voltage battery
Incorrect handling can cause injuries.

- High voltage
- Risk of explosion
- Chemical burns and eye injuries



High-voltage Qualification

Basic remarks

- Nobody may perform any work on a high-voltage vehicle without the right high-voltage-specific qualifications and tools.
- All Volkswagen workshops worldwide must train their staff to electrically instructed person (EIP) level as a minimum.
- The latest service literature provides a list of which operations require deactivation of the high-voltage system in specific high-voltage vehicles.
- There are numerous repair operations that can be carried out on a high-voltage vehicle that do not require certified de-energisation of the high-voltage system. These repairs can generally be carried out by an EIP.



All employees at the service partner who come into or could come into contact with high-voltage vehicles need to be qualified at least as an “electrically instructed person” (EIP).

Only high-voltage technicians (HVT) are allowed to work on the deactivated high-voltage system.

Requirements for personnel

All prospective high-voltage technicians need to have basic electrotechnical knowledge.

In Germany (requirements in other countries depend on national legislation), persons with the following professions have the corresponding training, for example:

- Motor vehicle mechanics, electricians and mechatronics technicians who began and completed their apprenticeship after 1973.
- Motor vehicle body and vehicle construction mechanics or mechanics for body maintenance who began and completed their apprenticeship after 2002.
- Individuals who can prove that they have completed the appropriate additional training to become a motor vehicle service technician, master technician or engineer.



The aforementioned requirements may vary from country to country.

The three pillars of qualification

Among the persons authorised to work on high-voltage vehicles, distinctions are made according to their particular high-voltage qualifications.

- Electrically instructed person (EIP)
- High-voltage technician (HVT) and
- High-voltage expert (HVE).

Electrically instructed person (EIP) - retail	High-voltage technician (HVT) - retail	High-voltage expert (HVE) - importer
Qualification: - No prior training; - Making employee aware of the issues involved; - 90 minutes on vehicle - EIP instruction from Volkswagen Training Online (VTO)	Qualification: - Basic principles of electrical engineering required - 2 days of high-voltage technology - 1 day of high-voltage product technology	Qualification: - HVT required - 3 days of face-to-face training
Authorisation: - The EIP is permitted to carry out general repairs on vehicles and mechanical operations on the disconnected high-voltage system that have been ordered by the high-voltage technician (HVT).	Authorisation: - Like EIP In addition the HVT may: - Deactivate the high-voltage system. - Secure against reactivation. - Determine system de-energisation. - Instruct EIPs on repair operations on the deactivated high-voltage system. - Put the vehicle back into operation.	Authorisation: - Like HVT In addition the HVE may: - Deactivate and secure high-voltage systems using all available means.

The individual qualification routes are explained over the following pages.

99.9% of all operations on a high-voltage vehicle can be carried out by the EIP and HVT.

These two groups of persons must be qualified at the retailers.

In the special case that the high-voltage technician cannot perform certified de-energisation or cannot verify it with the measuring methods and measuring tools available to him, the importer will dispatch a high-voltage expert (HVE).



High-voltage Qualification

Electrically instructed person (EIP)

Prior training

Prior training is not required for qualification as EIP.

Qualification

An EIP is made aware of the issues and thus qualified in the EIP safety course by a high-voltage technician for about 90 minutes on the specific high-voltage vehicle.

The EIP safety course is produced for each individual high-voltage vehicle and published via Volkswagen Training Online (VTO) in different languages.

The course is given by the high-voltage technicians for the specific high-voltage vehicles.

Authorisation

The course serves to make the employee aware of the issues involved with the high-voltage system.

The EIP is permitted to carry out general repairs on vehicles and mechanical operations on the disconnected high-voltage system that have been ordered by the high-voltage technician (HVT).



High-voltage technician (HVT)

International qualification

- Successful completion of training module "Diagnosis VAS 505X" or comparable knowledge
- Successful completion of training module "Fundamentals of electrics" or comparable knowledge
- Successful completion of training module "Systematic fault finding – Electrical system" or comparable knowledge
- Successful completion of training module "Power supply and starting systems" or comparable knowledge
- Self-study programme 450 "The Touareg Hybrid"
- Self-study programme 499 "Basics of Electric Drives in Automobiles"
- Multimedia Training "Electrics 1", "Electrics 2" and "Electrics 3"
- Establishing initial requirements by the importer.
- Entry test for electrotechnical basics [multiple choice] (80% correct answers).
- Participation in two-day face-to-face training.
- Final test with 60 questions (50% correct answers)
- After passing test: certificate for Volkswagen high-voltage technician.
- Training for the specific product technology of a new high-voltage vehicle: 1 day.

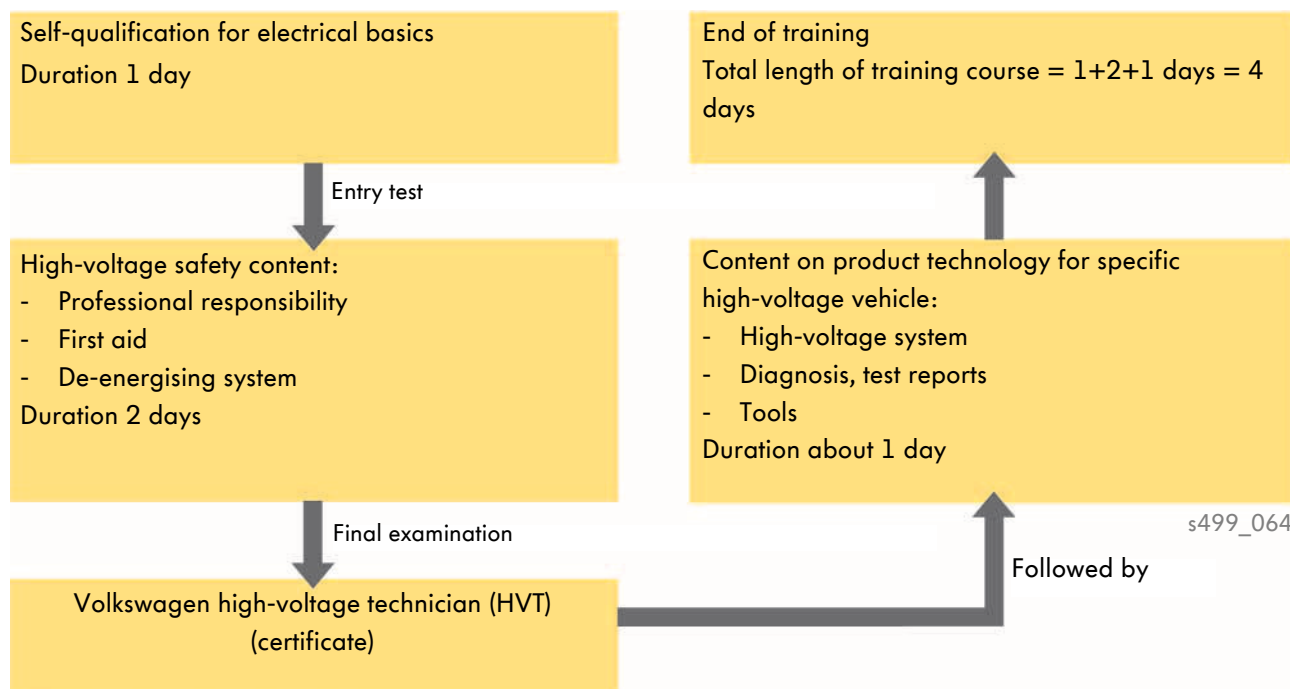


In future, a separate "Product technology" qualification course lasting approx. one day will be offered for each new high-voltage vehicle.

The high-voltage technician is responsible for always keeping himself up to date on the latest technology. Participation in the high-voltage vehicle-specific training courses is required.

High-voltage Qualification

Obtaining the qualification



Technical responsibility of high-voltage technician

The HVT is responsible for ensuring that all employees at the dealership or at the importer who come into contact or could come into contact with the high-voltage vehicle are qualified at least as an electrically instructed person (EIP). This qualification is specific to the high-voltage vehicle and needs to be taken again for each new high-voltage vehicle. The current documents are available from Volkswagen Training Online (VTO).



The EIP and HVT qualifications cover 99.9% of all realistic cases in work on high-voltage vehicles.

High-voltage experts (HVE)

If the high-voltage system of a vehicle cannot be certified de-energised by the high-voltage technician (HVT) using the measuring methods and measuring tools prescribed by the manufacturer, the authorisation of the high-voltage technician to work on this high-voltage vehicle will be rescinded.

The high-voltage technician must notify the importer. The importer must then send a high-voltage expert (HVE) or recover the vehicle.

Prior training

The prerequisite for the qualification as high-voltage expert (HVE) is high-voltage technician (HVT).

Qualification

3-day technical training

The training course is held exclusively at the manufacturer.

Content:

- Professional responsibility of HVE
- Knowledge and practical exercises for determining/assessing the high-voltage potential
- Protective measures against electrical currents.
- Practical exercise for securing a faulty high-voltage system
- Removal of high-voltage batteries from selected high-voltage vehicles
- Storage of the damaged high-voltage battery
- Use of 1000-volt safe tools during training course and practical exercises

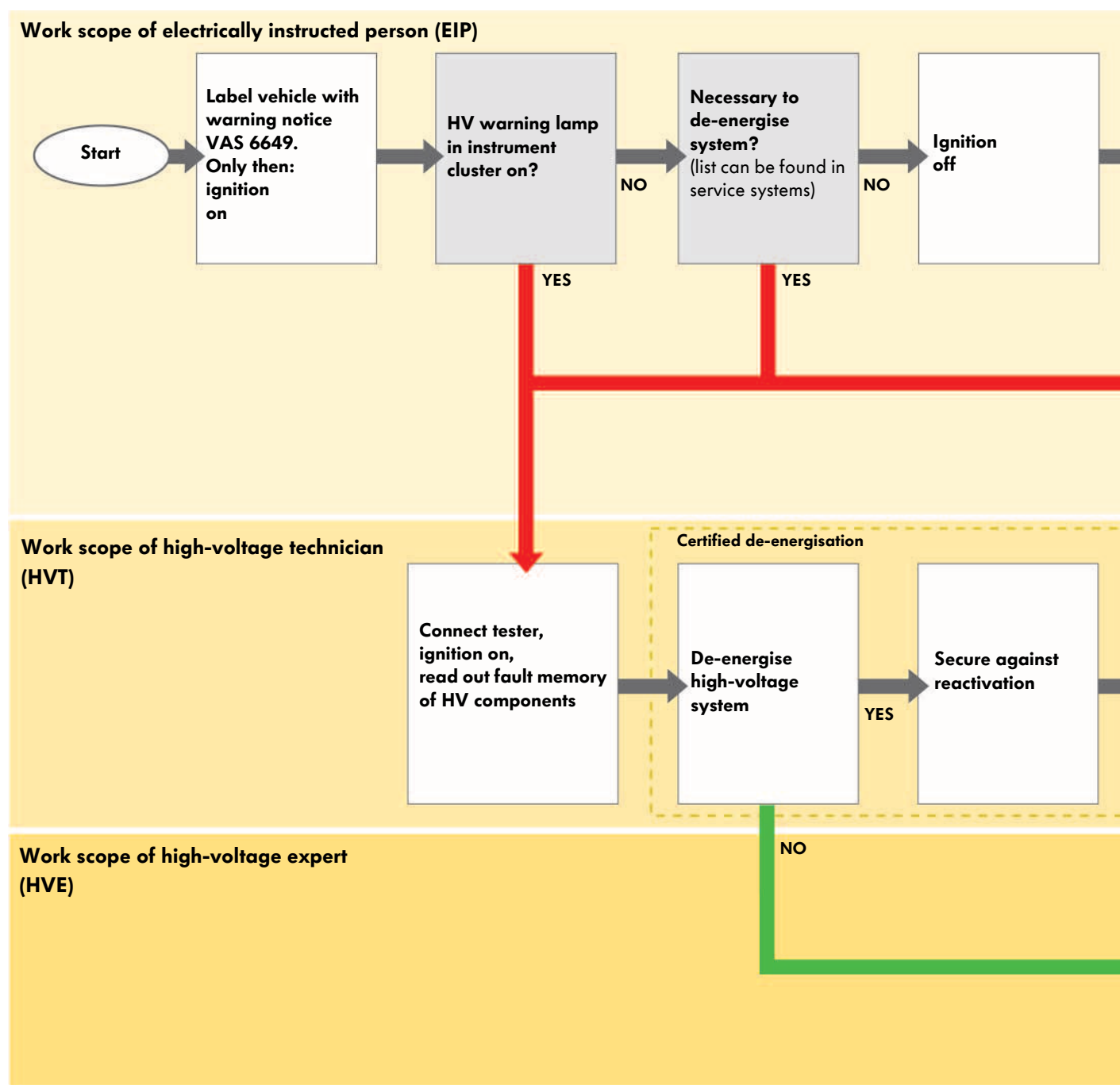


High-voltage Qualification

Workshop procedures

Overview

The following chart shows the workshop process for high-voltage vehicles covering maintenance, complaints regarding the high-voltage system, work near or on the high-voltage system and damaged vehicles after a minor or major accident.



Key



Assign electrically instructed person (EIP)

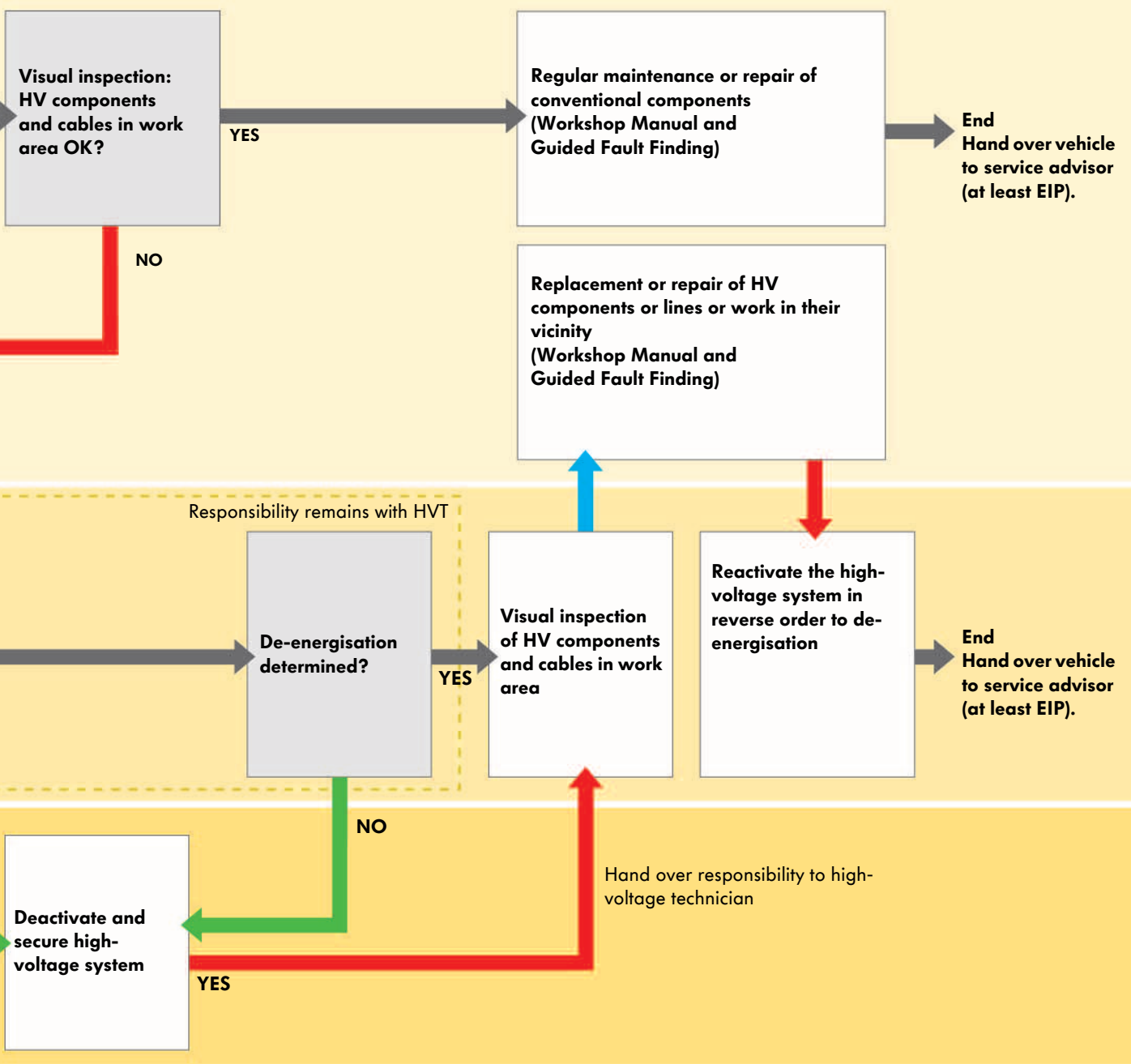


Assign high-voltage technician (HVT)



Assign high-voltage expert (HVE)

s499_066



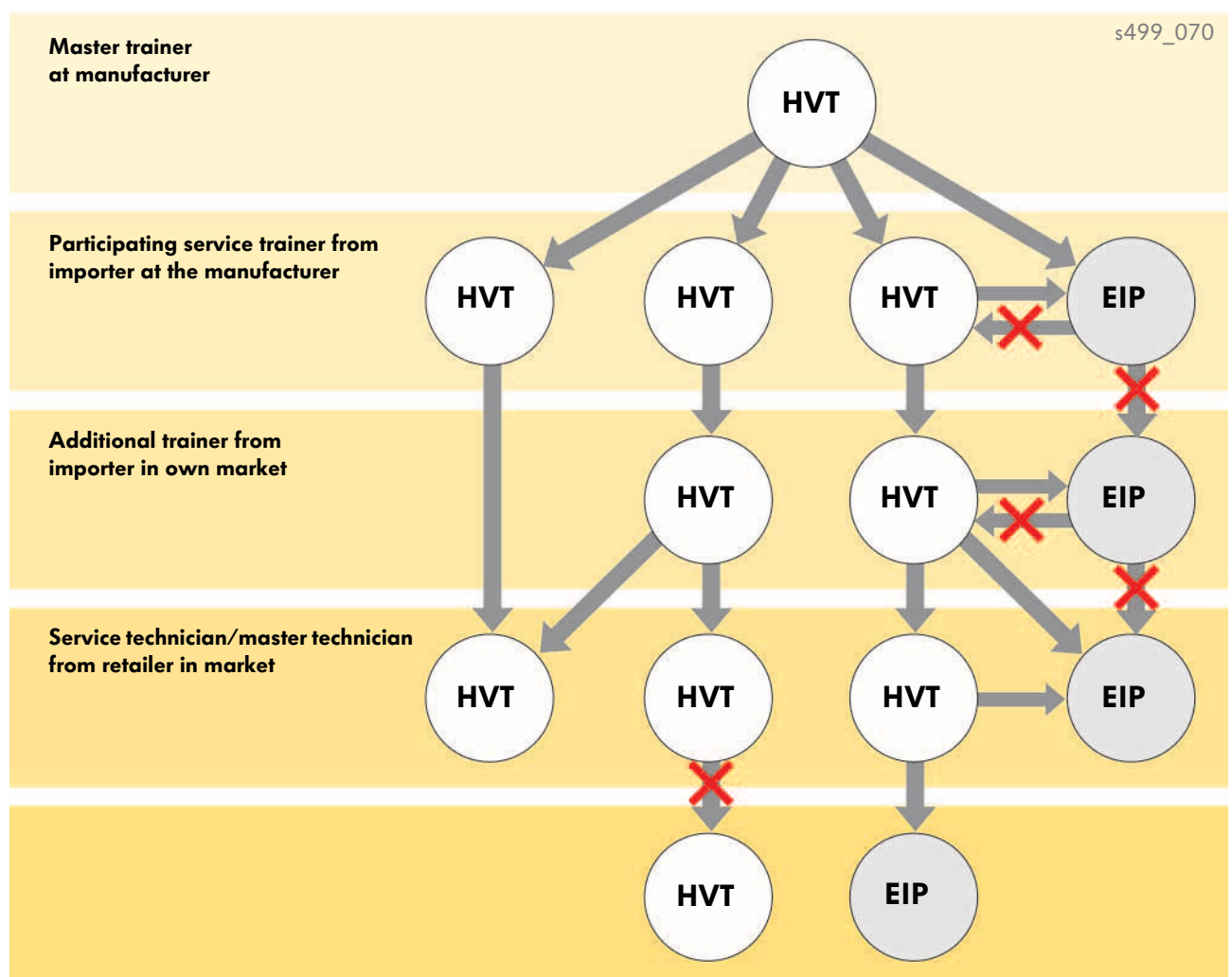
High-voltage Qualification

Principle of maximum distribution

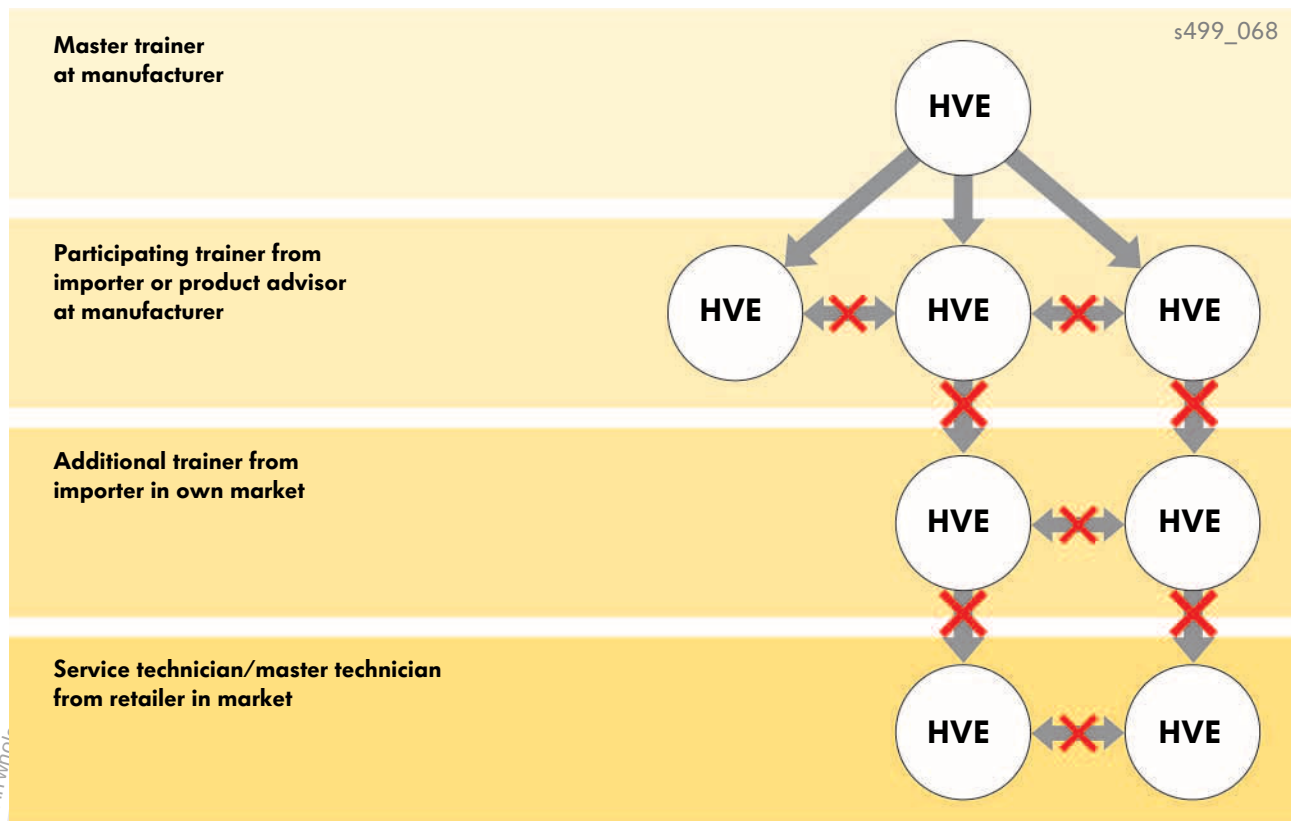
The prospective high-voltage technicians at the importer take part in qualification courses at the manufacturer. After passing the final examination, the HVTs can train their colleagues at importer level to become HVTs. Then all HVTs at the importer may train the service technicians in retail in their market to become HVTs. Each HVT from importer to retailer is responsible for training the staff in their department to be EIPs.

The HVT at retailer level does not have authorisation to train any other person to become an HVT. This task is fulfilled exclusively by the importer and the manufacturer.

Qualification as high-voltage technician (HVT)



Qualification as high-voltage expert (HVE)



Due to the extensive qualification course with different vehicles and faulty high-voltage components, this measure takes place only at the manufacturer. Due to the authorisation, this training course is not to be used exclusively for the trainers from the importers.

The main focus is on the target group of product advisors from the importers.

The only prerequisite for this training course is being qualified as a high-voltage technician.



Outlook for Service

Charging infrastructure for high-voltage vehicles

A high-voltage vehicle can consume between 3.3kW and almost 10kW of electrical power while the high-voltage battery is being charged.

Example: In Germany using household mains socket (230V alternating current)

Normal household sockets have one phase and supply a maximum current of 16A at 230V.

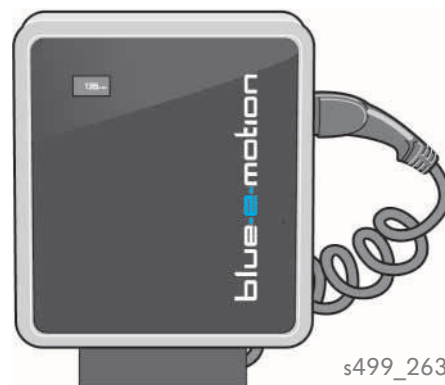
$$\begin{aligned} P_{(\text{single-phase})} &= U \times I \\ &= 230\text{V} \times 16\text{A} [1\text{VA} \sim 1\text{W}] \\ &= 3680\text{W} = 3.68\text{kW} (\text{absolute}) \end{aligned}$$

Due to electrical losses during charging (power dissipation), the value must be corrected to 3.3kW of the absolute value.

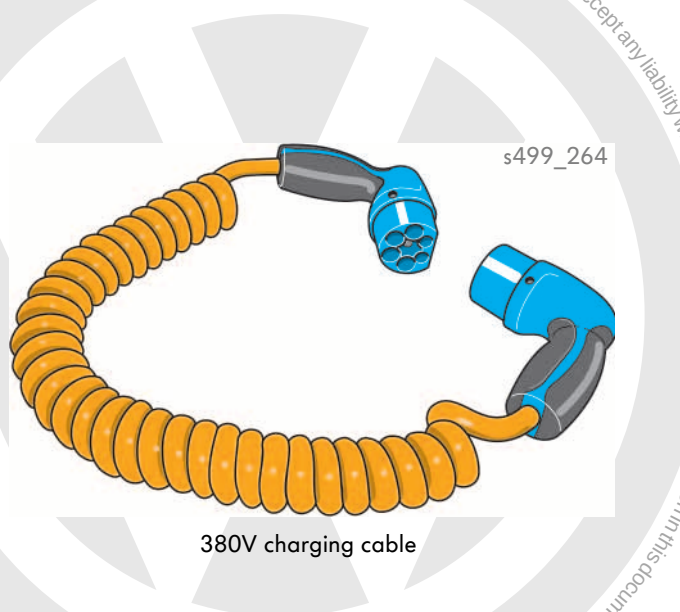
If the high-voltage vehicle can be charged via a socket with three phases, the electrical power that is fed to the high-voltage battery is tripled. As a result, the charging process is shorter compared with single-phase charging.

$$\begin{aligned} P_{(\text{three-phase})} &= 3.3\text{kW} \times 3 \\ &= 9.9\text{kW} \end{aligned}$$

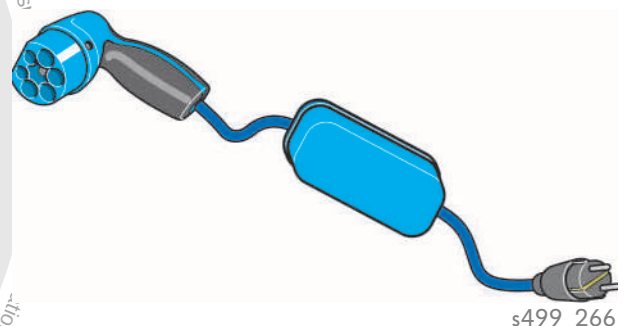
In future, customers will be able to choose from three charging possibilities for their high-voltage vehicle.



Charging unit for private households



380V charging cable



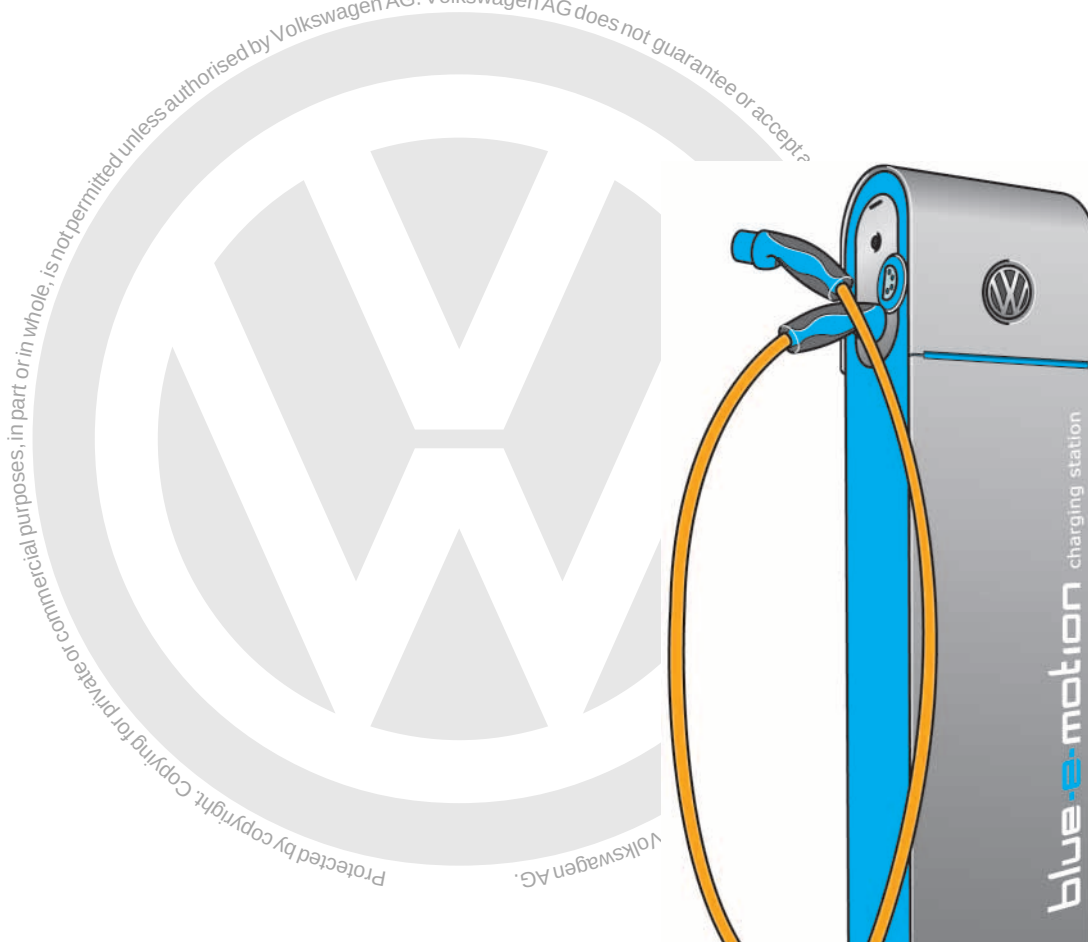
230V charging cable

A connection check should be performed on site before a customer purchases a high-voltage vehicle with external charging facility. It should be ensured that the household electrical mains can supply a constant high current for charging the high-voltage battery. This stress test is currently performed by an electrician. In future, this could become a task for the dealership.

The charging unit is fully set up at the customer's house and connected to the household mains. Ideally the unit should be installed as a three-phase charging facility. However, this option depends on the electrical infrastructure that is available at the customer's house or flat.

In many cities, electricity suppliers offer high-voltage vehicle users the possibility to charge the high-voltage batteries at public charging stations. This charging option is three-phase in most cases.

When the high-voltage vehicle user is travelling, he can charge the high-voltage battery via a conventional electrical socket. The current rating can be changed with the selector housing in the centre of the cable. This serves as protection so that the electrical mains are not overloaded. In addition, the housing contains a residual-current-operated circuit-breaker. This charging method takes longest to charge the high-voltage battery.



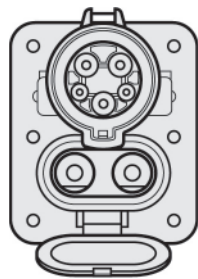
Public charging station

s499_268

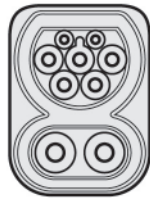


Outlook for Service

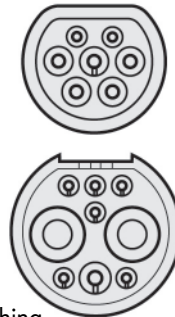
Connector types



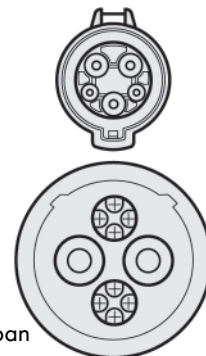
USA



Europe



China



Japan

s499_265

Across the world a large number of different connector types are used for a wide range of electromobiles like bicycles, light vehicles, scooters and wheelchairs.

During the talks between German car manufacturers, a standard connector type was agreed on.

The standard VDE connector for charging high-voltage batteries in vehicles (VDE = Association for Electrical, Electronic & Information Technologies)

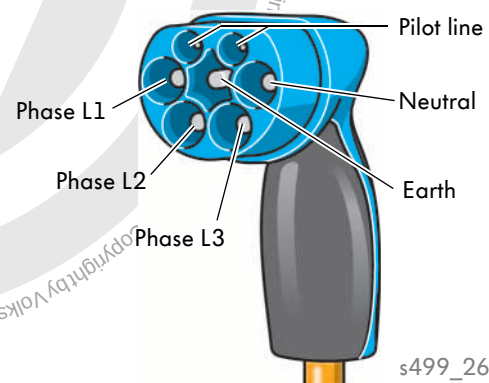
The blue connector is used in conjunction with the specially installed charging unit at the customer's home, the charging cable for public networks and the household cable for charging with any conventional socket.

Charging can be 3-phase using 380 volts or with just one phase using 230 volts.

The connections L1, L2 and L3 are the phases with 230 volts each. The phase shift of 120° results in an effective voltage of 400V.

During the charging process, the vehicle body is earthed via the mains connection (protective conductor) for electrical safety.

The safety contact of the charging connector activates the charger in the vehicle. The vehicle cannot be driven when the cable is connected.



s499_267

Standard VDE connector for charging high-voltage batteries



The connector contacts are scoop-proof (IPXXB protection class). In addition a leading pilot line is fitted.

This connector and the charging socket on the vehicle allow a charging process to be performed safely without further measures in any weather.

Remote services

Using a mobile telephone as a remote control for the electric vehicle

A mobile telephone that has Internet functions similar to a miniature computer is called a smart phone. Thanks to its Internet capability and thus the networking connection, the phone can be used to operate certain electric vehicle components. An additional application (app) allows the smart phone to be linked to the vehicle.



s499_262

Example: German-language remote control display on a mobile telephone

The user can use the following features of the app:

- Display charge state of high-voltage battery
- Expected range of electric vehicle
- If the high-voltage battery is being charged, you can monitor the charging duration
- Status of vehicle: locked, windows closed, charging connector connected
- Set climate control requirement for interior
- Delayed charging to use cheaper night-time electricity
- Vehicle information like average consumption in kWh/100km
- Display of convenience consumers in kWh/100km
- Current vehicle position
- Nearest public charging possibility
- Plan the remaining electrical range of a hybrid vehicle

This function will become useful in the future when city centres, like London, may only be driven through with zero-emissions vehicles (ZEV), i.e. vehicles without direct exhaust gas emissions.

For certain hybrid vehicles with an electrical range of about 50km, route planning is possible via the telephone.



Outlook for Service

Think Blue.

“Think Blue.” sees Volkswagen dedicate itself to the question of how individual mobility and sustainable behaviour can be reconciled.

An electric vehicle does not produce any direct emissions when driven. The high-voltage battery needs to be charged to move the vehicle. The electrical energy from the external charging source needs to be produced with renewable technology in order to rigorously implement CO₂ reduction measures. The generated energy is used highly efficiently by an electric vehicle.

The aim is the conscious use of resources by humans.

“Think Blue.” goes one step further.

This scheme invites us to think further and shows that ecologically sustained behaviour is possible without sacrifices and can also be fun.

“Think Blue.” lives through dialogue with customers. The slogan refers to the “Think small” campaign for the Beetle in the sixties. Back then mobility for everyone was addressed with the Volkswagen Beetle. At the web page **www.volkswagen.com/thinkblue**, anyone interested will find information on fuel-saving driving styles, ecological sustainability and conscious use of resources.

The creation of awareness starts with small things.

Does the television standby function always have to be active?

Maybe it is enough to open a window instead of switching on the air conditioning system?

Can I save more energy by opening the blinds during the day and switching off the artificial lighting?

Are driving pools more efficient in terms of CO₂ savings?

How can I save water at home?

Recognising savings potential is not the source of sacrifice.

The aim is fun while saving: the “fun theory”.



The technical scope from the following concepts is combined under the umbrella term “Think Blue.”:

- “BlueMotion”
- “BlueMotion Technologies”
- “EcoFuel”
- “Blue TDI”
- “BiFuel”
- “Hybrid”
- “blue-e-motion”
- “Think Blue. Factory.” Low-emissions automobile production

The “blue-e-motion” brand stands for electromobility within the framework of the “Think Blue.” idea.

The cornerstones of “Think Blue.” are:

1. Environmentally compatible products and solutions
2. Environmental behaviour
3. Environmental commitment

Towing an electric vehicle

The drive wheels of an electric vehicle are coupled to the electric motor via the differential and the reduction gear. This connection cannot simply be separated. If the drive wheels are rotated, the electric motor will also rotate. If the high-voltage system is activated and ready to drive, the system will recognise the towing procedure as regenerative braking.

The high-voltage battery will therefore be charged by the towing procedure.

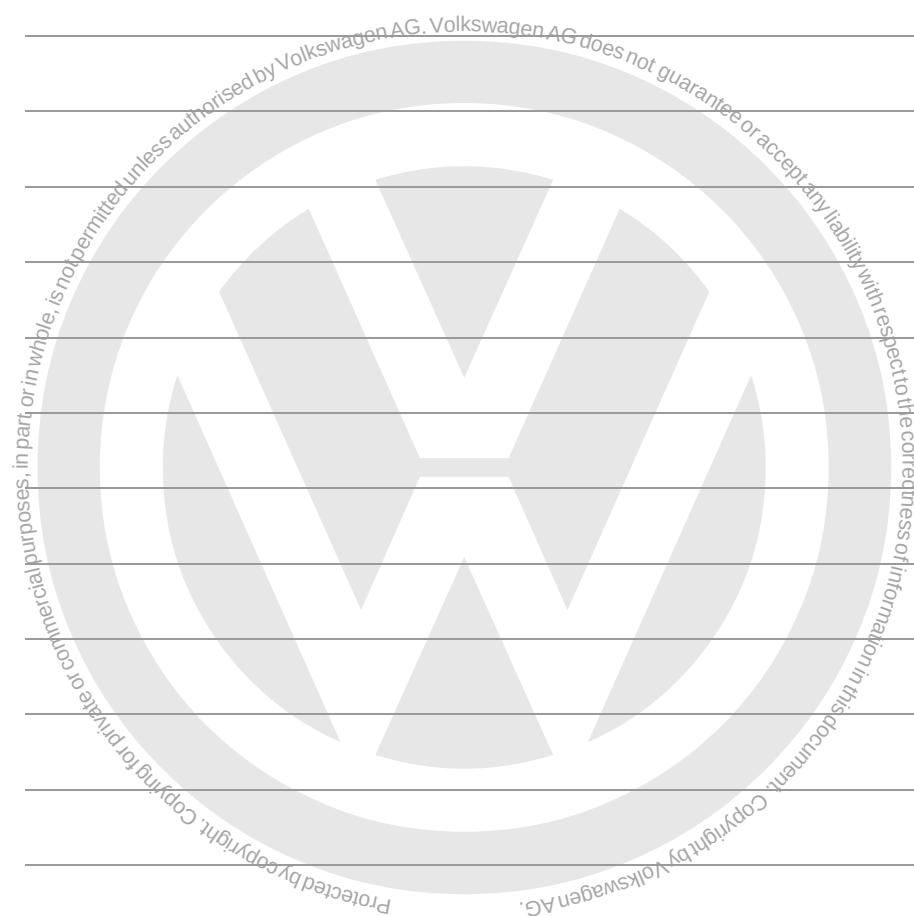
For this reason, towing electric vehicles on their own wheels is not permitted.

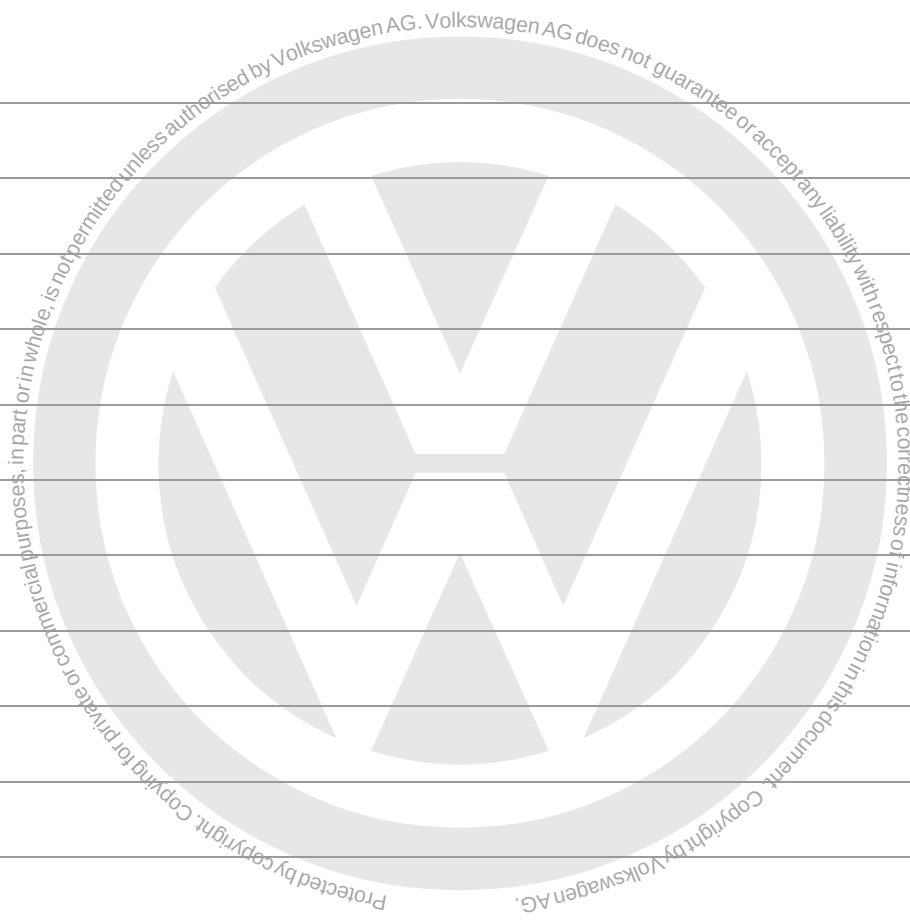
The towing procedure should only be started once the electric vehicle is no longer in running condition.

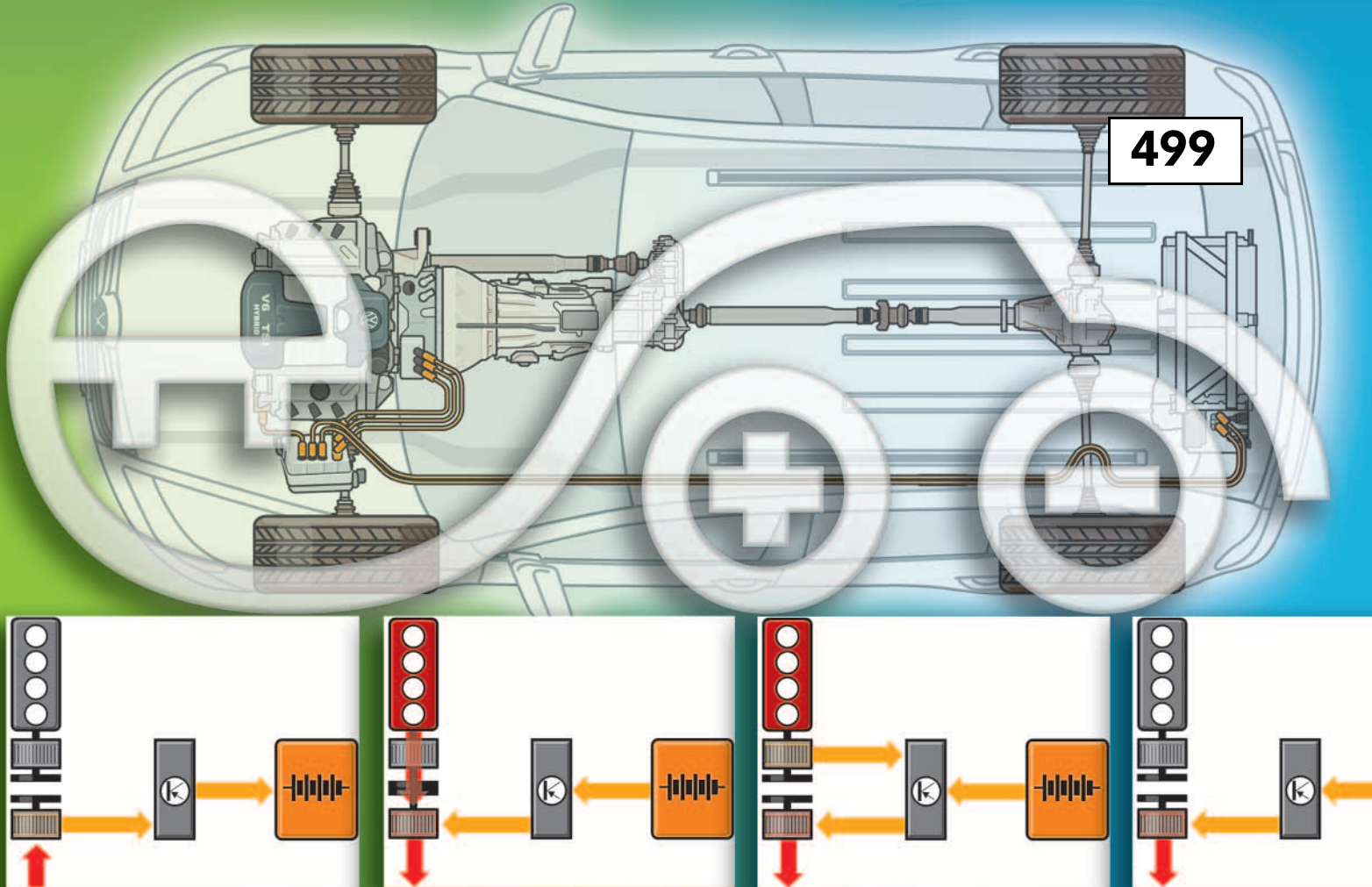
If the high-voltage system is deactivated, the rotation of the electric motor can cause temperatures that damage or destroy components. Furthermore the rotary movement in the electric motor produces an inductivity that acts as a resistance to movement of the vehicle (like a bicycle dynamo).

You are allowed to slowly push the electric vehicle out of a dangerous area, however.









© VOLKSWAGEN AG, Wolfsburg

All rights reserved including the right to make technical alterations.

000.2812.56.20 Technical status 10/2011

Volkswagen AG

After Sales Qualification

Service Training VSQ-1

Brieffach 1995

D-38436 Wolfsburg

♻️ This paper has been manufactured from pulp bleached without the use of chlorine.