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VOLKSWAGEN SHAPING THE FUTURE OF MOBILITY

Electrifying

The e-Golf

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The Golf Family Grows

Dr. Heinz-Jakob Neußer on the new e-Golf

Following the e-up!, Volkswagen now launches the e-Golf, its second e-car, onto the market. For whom is this car best suited?

The e-Golf is the perfect car for people who mainly travel in urban areas or within short and medium distances of them. As a member of the Golf family, it naturally meets all safety requirements familiar from the high-volume series. Furthermore, as a 5 door car with an extensive standard, and freely selectable optional equipment, it meets all the comfort requirements expected by our customers in this car class. Thanks to its practical range of 130 to 190 kilometres, this car is not only ideally suited for family use and for commuters but is also very practical for companies operating mainly in urban areas. Here is one fact probably very few people initially expect: the e-Golf is also well suited for mountainous and hilly areas. Hill starts and climbs can be overcome almost without effort, as well as comfortably, thanks to the high torque of the e-engine, even when accelerating from a full stop. Electric energy is regained via recuperation during braking, hill descents or in coasting mode, and can then be stored once again in the high-voltage battery. This further improves energy consumption and increases the available range. The e-Golf can be driven comfortably and very dynamically with its energy efficient and powerful drive, combined with its low centre of gravity, due to the installation position of the high-voltage battery between the axles.

A heat pump was installed for the first time in the e-Golf. How does this affect consumption?

When considering that all electric and electronic loads on an electric car are fed by the vehicle battery, one can imagine the importance of reducing onboard power consumption as much as possible by any means. Vehicle heating and air conditioning have a substantial impact on the available range, in relation to the energy stored in the high-voltage battery, due to their high energy consumption. The innovative heat pump installed in the e-Golf utilises the thermal energy in the coolant of the e-machine engine and power electronics, to heat the car in winter or cool it in summer. The energy saved increases the available range for the high-voltage battery.

What sense does it make for Volkswagen to launch a further electric vehicle onto the market?

Last year, with the e-up!, we launched a very good and fully usable electric car onto the market. With the e-Golf, we now extend our portfolio of alternative drive vehicles by adding an electric car in the compact segment, and for the first time offer a fully-fledged e-vehicle in mass production. Electromobility in the Volkswagen Group has reached the centre of our Modular Transverse Matrix. By taking this step, we will be able to satisfy different customer demands and requirements in our primary markets – and across all regions.

How do you imagine charging infrastructure will develop?

Unfortunately, current developments show that the charging infrastructure is only developing very slowly. This is very regrettable because we have reached the point at which the range of electric cars with alternative drives is continuously growing. It is counterproductive if

Dr. Heinz-Jakob Neußer, Board Member of Management for the Volkswagen Brand and Head of Powertrain Development

the infrastructure does not keep up with the growing range of vehicles with alternative drives, and therefore detrimental to the economic development of the automotive industry that has made very expensive preparatory efforts. An important signal, from our point of view, is that the Transport Committee of the EU Parliament in November came out in favour of constructing 450,000 charging stations in Europe by 2020 – 86,000 of which will be in Germany alone. Currently there are about 2,200 public charging stations in Germany. Now, concepts for their implementation have to be developed as fast as possible on both an EU and a national level, and the necessary prerequisites for a successful and quick implementation have to be created.

How will battery capacity develop? Can we expect electric vehicles to have the same range as conventional vehicles soon?

Firstly, I would like to point out that even today the daily driving ranges of the majority of our customers can be covered using the electric cars currently offered. Surveys have shown that our customers travel no more than 40 to 50 kilometres per day on average. Even today, ranges of 120 to 160 kilometres with the e-up! and 130 to 190 kilometres with the e-Golf are possible. With that, individual mobility is ensured. Work on the optimisation of storage capacity is ongoing globally, in order to further increase customer utility. A noteworthy technological leap in battery development, however, cannot be expected until 2020, according to our estimates. Until then there will of course repeatedly be smaller advances with the currently known battery cells. Beyond that, there are other parameters, such as lightweight construction, aerodynamics, drive technology, and onboard consumption that can positively affect the range. We attach great importance to the optimisation of these parameters during the development of our e-vehicles. As mentioned before, we will utilise an optional heat pump to improve the e-Golf's heating efficiency.

The charging process currently takes quite some time. Will one be able to charge the car more quickly in the future?

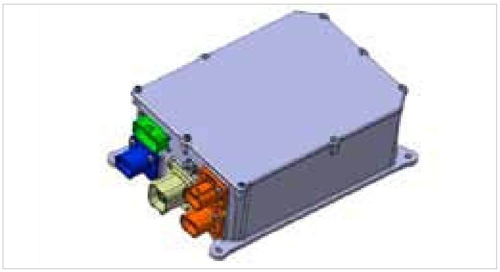
Today it is already possible to charge the battery at a quick charging station using direct current from 0 to 80 percent of its capacity in half an hour, when using the Combined Charging Systems. With that, we are on the right path. Previously, the charging process took considerably longer. Unfortunately, the quick charging infrastructure in Germany is still completely underdeveloped. The time has come now to faster develop the charging infrastructure in public parking spaces, if needs be by means of legal regulations – if Germany is to be the leading market for e-mobility. We offer our customers an optional Wallbox, when buying an e-car, with which the e-up! can comfortably be completely charged in six hours and the e-Golf in eight hours, in front of your own doorstep or while at work.

Centrepiece

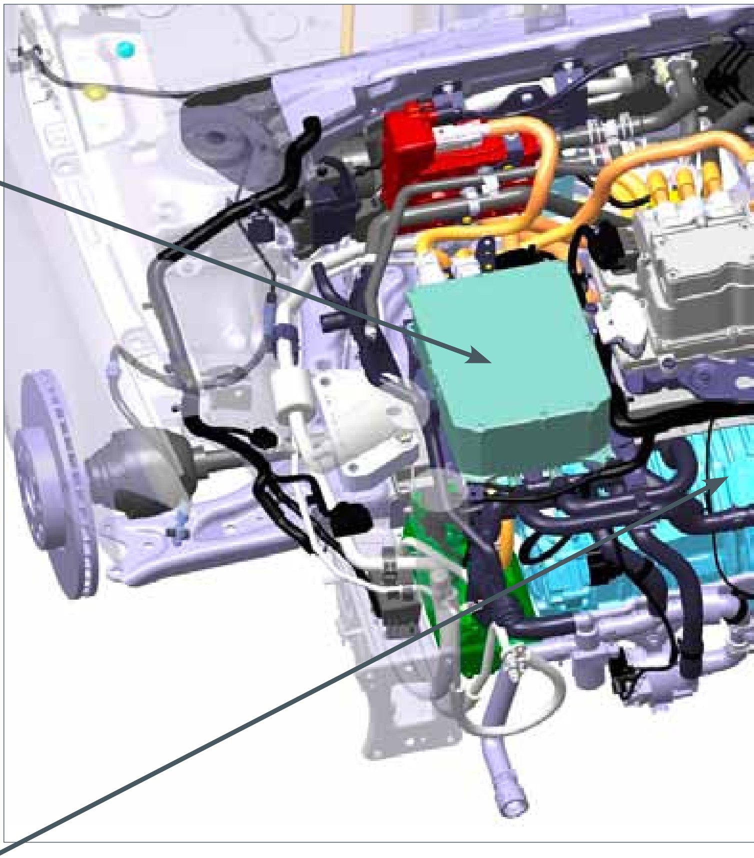
The drive accelerates the e-Golf

The main distinction between a car with a conventional combustion engine and the e-Golf is located beneath the bonnet: the electric motor, power electronics, gearbox, and engine control unit, in combination, ensure that the e-Golf drives almost noiselessly and without emissions. In the process, the motor spins at up to 12,000 revolutions and delivers up to 85kW/115hp. The electric drive developed by Volkswagen is part of the Modular Transverse Matrix (MQB), and is used in other models, for example in the e-up! mini car.

The Charging Unit



The charging unit, integrated in the engine compartment, transforms the available alternating current into high-voltage direct current, when charging the car. The charging unit can be connected to an ordinary 230 volt socket in a domestic garage or at a public charging station. A completely discharged high-voltage battery is charged within 13 hours, and in significantly less time with a CCS charging station using DC fast charging. Furthermore, a distribution point for the high-voltage onboard power supply is integrated into the charging unit.

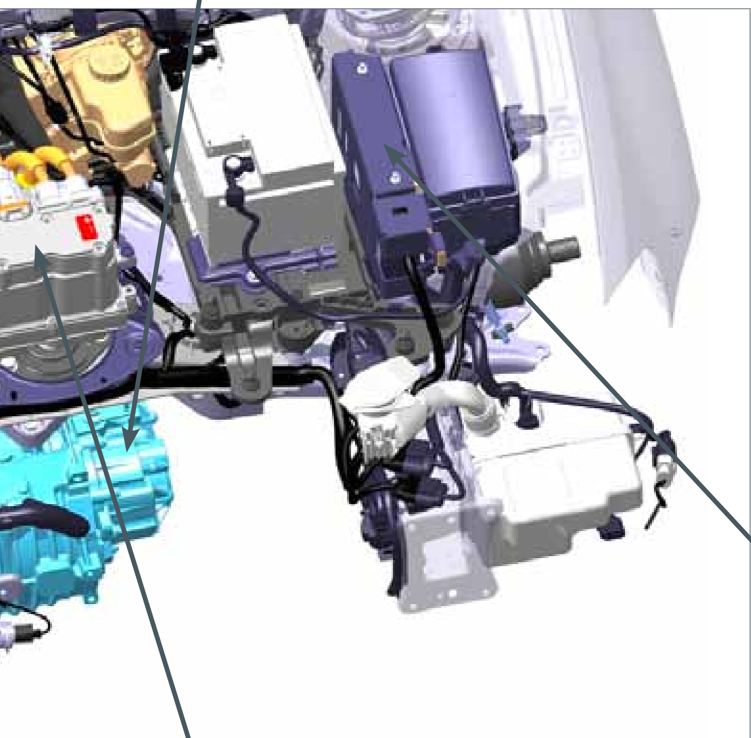


The Electric Motor

Motion in the electric motor is caused by the alternating attraction and repulsion of opposing and same polarity magnets. The e-golf is equipped with a permanently excited synchronous machine with a maximum output of 85 kilowatts. The permanent magnets in the rotor, the movable part of the motor, are alternating south and north poled magnets. The stator, the fixed part of the motor, generates a rotating magnetic field, created by applying current to the coils. As a result of the interaction with the permanent magnets, the rotor turns at a speed synchronous to the rotating magnetic field of the stator. The electric engine, called a synchronous machine for this reason, also runs particularly smoothly at low speeds.

The Gearbox

The e-Golf features a friction optimised one-speed gearbox, which is set up for a maximum speed of 12,000 revolutions per minute. The gearbox's task is to provide the speed and torque of the electric motor in relation to the transmission needed to power the wheels. The mashing gear teeth and the casing are optimised with regard to acoustics. The electric motor and the gearbox share a shaft bearing (see glossary), which further reduces friction in the drive. The gearbox and electric engine are integrated into one engine case. The mechanical parking lock is fitted on the engine shaft of the e-Golf.



The drive of the e-Golf is compact and light: the motor, gearbox and power electronics combined weigh only 110 kilograms.

Technical data

Engine and gearbox weight:	99.5 kilograms
e-Motor	
Power:	maximum 85 kilowatts
Torque:	maximum 270 newton metres
Gearbox	
Number of gears:	1
Oil volume:	0.75 litres
Revolutions:	maximum 12,000 revolutions per minute
Power electronics	
Electric current:	maximum 450 amperes
Voltage range:	250 to 430 volts
Weight:	10.5 kilograms

The Power Electronics

The power electronics are responsible for the transformation of the electric current. To do this, it is connected to the electric motor and the battery. When the engine is operating, the power electronics transform the direct current of the high-voltage battery into a three-phase alternating current (see glossary) that powers the electric motor. An integrated direct current transformer, in addition to the 12 volt battery, ensures the onboard electrical system is supplied. Additionally, the power electronics contains a controller for the control software.

The Engine Control Unit

The electronic engine control management controls all processes concerning the engine. The engine control unit ensures the gathering of all data that allows for a conclusion about the driving situation, such as the angle of the accelerator pedal. It processes all data and sends signals to the power electronics. In addition, the engine control unit coordinates the assistance systems and controls the climate control. It also monitors recuperation and registers how fast the driver wants to go. Unwanted deceleration or acceleration is prevented thanks to the engine control unit.

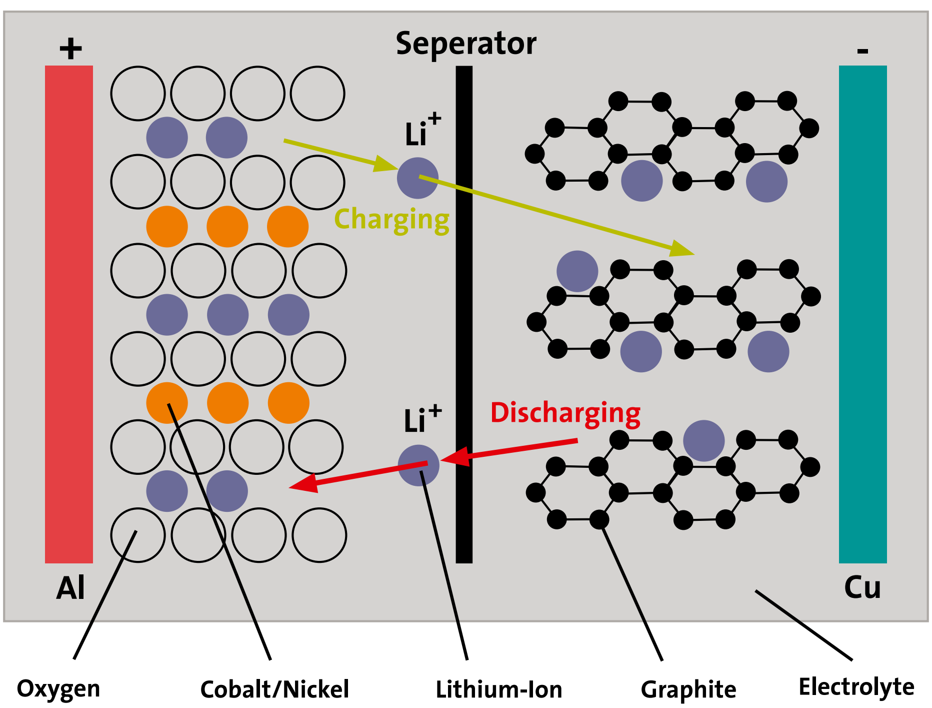
Energy Storage

Electricity instead of petrol

Developing an optimal battery is one of the biggest challenges concerning electromobility. Batteries that can provide sufficient energy are too big and heavy for use in cars. Next to the amount of storable energy, durability places high demands on the high-voltage battery.

A lithium-ion high-voltage battery is used in the e-Golf. This technology is currently considered the safest, with the widest driving range for use in electric cars. A negative pole, called an anode, and a positive pole, called a cathode, are in the individual cells of a lithium-ion battery. In between, there is an electrolyte and a separator. The anode consists of a graphite structure, the cathode of layered metal oxide. Freely moveable lithium-ions are deposited between these layers. When the battery is charged, the lithium-ions move from the anode to the cathode and accept electrons there. The more lithium-ions can fit into one cell, the more energy can be stored and supplied later. The number of ions essentially determines the energy density and has a direct impact on the range of the electric car. Not only is energy density important, but power density also impacts the operation of the car. When the driver accelerates, the lithium-ions release the accepted electrons to the anode again, and move back to the cathode. The electrons reach the electric motor via the outer electrical circuit and supply it with electricity. For high acceleration, it is important to be able to accept and release many electrons in a short space of time.

Research on improving batteries is continuously ongoing. The reason for a decrease in the capacity of the high-voltage battery at temperatures of -20 degree centigrade, for example, has been identified. The lithium-ions are slowed down by the cold during the charging process, which leads to them reaching the electrons of the anode on its surface rather than inside it. Using too high electric charging currents creates elemental lithium, which deposits on top of the anode covering the surface, and permanently seals the passage – so-called lithium plating. A possible solution could be to warm up the battery before charging. Discoveries such as these are taken into account during development, before series production, in order to ensure easy and unproblematic charging for the customer.



This simple representation of a setup of a lithium-ion high-voltage battery illustrates the running processes: The lithium-ions (purple) move from the cathode (red) to the anode (blue) and accept electrons there. At the discharge process they donate electrons while moving back.

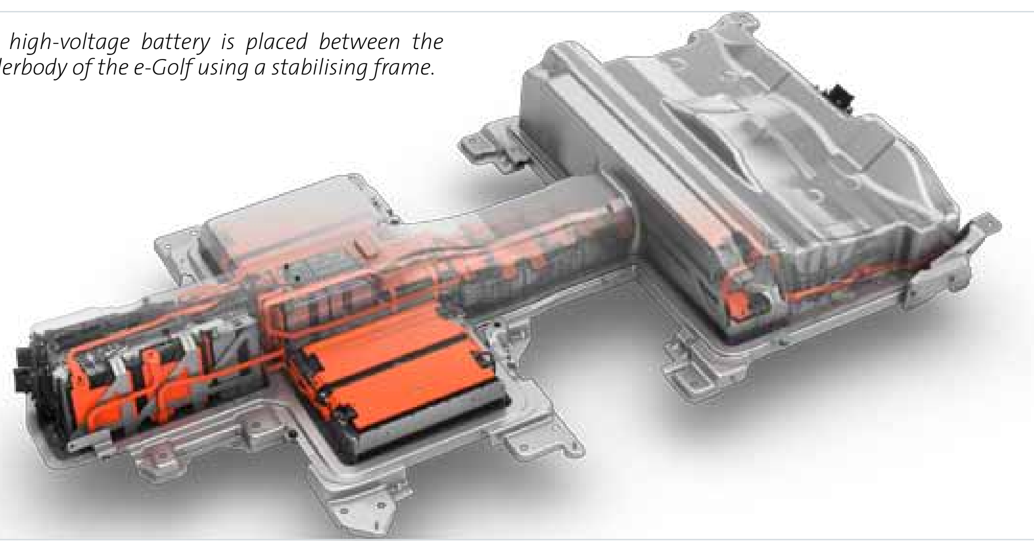
Lithium-ion high-voltage battery in the e-Golf

A battery management controller (BMC) monitors and controls the battery operation of the lithium-ion high-voltage battery in the e-Golf. This electronic control unit determines, among other things, the charging state of the individual cells, regulates temperature management, and protects the cells from overcharging or deep discharge. Electronically activated switches are integrated into the system which disconnect the batterysystem when idle, or in critical situations such as an accident.

Data sheet

Size:	length 2132 millimetres, width 1128 millimetres, height 273 millimetres
Weight:	318 kilograms
Cells:	264 cells
Cell modules:	17 modules of 12 cells, 10 modules of 6 cells
Capacity:	24.2 kilowatt hours
Voltage:	323 volts

The lithium-ion high-voltage battery is placed between the axles on the underbody of the e-Golf using a stabilising frame.



Plug technology and infrastructure

The International Electrotechnical Commission has standardised plug technology across all manufacturers, in order to facilitate the charging of all electric cars at public charging stations. The Combo Type 2 Connector and the corresponding socket on the vehicle allow for the charging of the battery using either alternating or direct current. Charging with direct current has a decisive advantage: the charging process is significantly faster. The battery can be recharged to 80 percent in less than 30 minutes, at a charging rate of 40 kilowatts. Alternating current only charges at a rate of 2.3 or 3.6 kilowatts, and correspondingly the charging process takes more time, but can be done with a standard wall socket or the optionally available Wallbox. For this reason, the charging infrastructure must be developed further, to enable the extensive dissemination of electric cars: in mid-2013 there were 14,000 petrol and diesel stations, compared to only about 2,200 publicly available AC charging stations as well as seven DC charging stations for electric cars in Germany.

Economic Driving

How the e-Golf drives further

In general, electric cars have less range than vehicles with a combustion engine. However, not only the performance of the battery impacts the range that can be covered. Energy consumption while driving, too, as well as the possibilities of energy recuperation, affect range. Even small improvements in the available technology and additionally developed parts help to save or regain energy more efficiently. The driver, not least, can affect the car's energy consumption according to their style of driving and use of different driving programs, and thus gain additional kilometres.

Heating efficiently

The heat pump, that customers can optionally have fitted in their e-Golf, saves energy when heating. For this purpose, the air conditioning is extended by additional coolant lines, valves, sensors, and a heat condenser. The heat pump utilises the heat from the surrounding air, as well as the waste heat from the drive, to heat the interior. For this reason, the high-voltage heater uses less electrical power. This way, the range of the e-Golf can be increased by up to 36 percent, during winter. The heat pump also functions as an air conditioner in the summer.

Braking for more range

During generator operation, an electric motor has a braking effect similar to the engine brake of a combustion engine. The inner resistance of the driving motor is responsible for this effect. When a gear is engaged, the car slowly decelerates, even without mechanical brakes. Many factors influence the force of this braking effect of the electric motor: engine speed, battery temperature, state of charge of the battery. This causes the deceleration to vary. The e-Golf is equipped with an electromechanical brake booster – in short e-BKV – to compensate for this variation. It balances the braking effect of the motor and the braking effect of the normal wheel brakes. The higher the braking force of the motor, the less braking pressure is conducted from the brake pedal to the wheel brakes. If this were not the case, the results when braking would be different every time. The deceleration potential of the electric motor can be fully used to charge the battery – this increases the e-Golf's range.

Varying range at the switch of a button

Three driving profiles give the driver the possibility of adjusting energy consumption and, consequently, range. Top speed and acceleration can be limited as can the performance of the climate control which can be reduced or even switched off, in order to save energy.

	normal	eco	eco+
Air conditioning	reduced, compared to combustion engines*	significantly reduced*	ventilation only
Acceleration (0 to 100 kilometres per hour)	10.4 seconds	13.4 seconds	20.9 seconds**
Mechanical performance	85 kilowatt	70 kilowatt (overrideable)	55 kilowatt (overrideable)
Top speed	140 kilometres per hour	115 kilometres per hour (overrideable)	90 kilometres per hour (overrideable)

* Measures for reducing air conditioning consumption in normal/eco:
- Adjustment of the desired temperature value to ambient temperature
- Reduction of the high-voltage heater activation and of the air conditioning's electric compressor

** Acceleration to 90 kilometres per hour in eco+

In eco mode, the top speed is reduced to 115 kilometres per hour and the performance of the air conditioning is limited. The eco+ mode switches off the air conditioning entirely and additionally further reduces top speed. Both settings can be overridden by the driver fully depressing the accelerator pedal.

Recuperation

Recuperation in a car means the regaining of motion energy, also called kinetic energy. Electric energy is generated in propulsion and braking phases, therefore when the car decelerates, the car's high-voltage battery is charged. The 12 volts battery is constantly charged using an alternator in conventional vehicles. In contrast, the drive motor in electric cars functions as an electricity generator in propulsion and braking phases, thus charging the battery. This way a considerable share of the energy invested into driving can be regained using recuperation.

Electrified Duo

e-up! versus e-Golf

An addition to the Volkswagen e-fleet: following the e-up!, in 2014 the electric version of the Golf also goes into production. The big brother positions itself relative to its smaller counterpart in several aspects. The motors, for example, are identically constructed, even if the e-Golf has more power. It accelerates faster and reaches a higher top speed than its little brother. Consumption, however, is only a little higher, not least because of its very good cd value.

Both Volkswagen e-models drive emission-free with the same e-engine but with different performance. The smaller, and consequently lighter, e-up! has a driving power of 60 kW, and is an efficiency world champion with a consumption of 11.7 kW/h/100 kilometres. The e-Golf has 85 kW driving power – and shines with better acceleration, a higher top speed of 140 kilometres per hour, and a greater range.

e-up! versus e-Golf

e-up!		
Motor:		Permanently excited synchronous machine
Maximum Power:		60kW/82hp
0 to 100 kilometres per hour:		12.1 seconds
Top speed:		130 kilometres per hour
Consumption:		11.7 kilowatt hours per 100 kilometres
cd value:		0.308
Energy content of the battery:		18.7 kilowatt hours
Charging time:	AC 2.3 kW	about 9 hours (100 percent)
	AC 3.6 kW	about 6 hours (100 percent)
	AC/DC 40 kW	about 30 minutes (80 percent)

e-Golf		
Motor:		Permanently excited synchronous machine
Maximum Power:		85kW/115hp
0 to 100 kilometres per hour:		10.4 seconds
Top speed:		140 kilometres per hour
Consumption:		12.7 kilowatt hours per 100 kilometres
cd value:		0.281
Energy content of the battery:		24.2 kilowatt hours
Charging time:	AC 2.3 kW	about 13 hours (100 percent)
	AC 3.6 kW	about 8 hours (100 percent)
	AC/DC 50 kW	about 30 minutes (80 percent)

Glossary

Combined Charging System (CCS):
The Combined Charging System is a new charging system for electric cars. It only requires one charging socket on the car, which can be used for all available charging options (direct and alternating current charging).

Deceleration potential:
A car's deceleration potential is caused by the inner resistance of the motor. Without fuel supply, the motor can only reach a certain speed when a gear is engaged. If the vehicle is faster than the current engine speed allows for, the car decelerates.

Control signal:
A control signal is the representation of a message by physical values such as electric current or voltage. The state of the signal, say for example its frequency, tells the receiving device which command to execute.

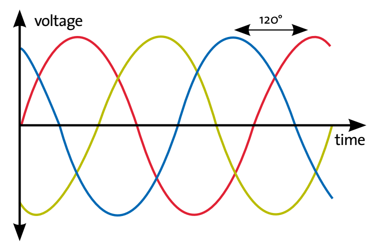
Overlithiated metal oxides:
A metal oxide is a compound of metal and oxygen, with an open structure, in which lithium-ions can be deposited. A metal oxide which can accept a larger amount of lithium-ions is called overlithiated metal oxide. This can be achieved by creating additional storage areas in the metal oxide's individual layers (see page 6).

Overcharging:
One speaks of battery overcharging when the amount of electrons deposited exceeds the battery cell's storage capacity.

Deep discharge :
Deep discharge means that the battery is completely empty and therefore no energy remains in the cells. This state can be critical for the cells.

Heat condenser:
The heat condenser is a heat exchanger within the air conditioning unit which conducts the heat from the refrigerant to the circulating air and into the car's interior, via the ventilation.

Three-phase alternating current:
Three-phase alternating current consists of three alternating currents or alternating voltages of the same frequency, with a phase angle offset by 120 degrees. It is also called rotary current, high-voltage current, site power supply, or heavy current.



Kinetic energy:
Kinetic energy is the motion energy of an object. Energy is needed in order to accelerate an object from rest, for example when starting a car. This energy input is maintained in the form of kinetic energy, which is only released slowly because of friction and air resistance, for instance when the car rolls to a standstill. Kinetic energy depends on the mass and speed of the object. The unit of measurement of kinetic energy is the joule.

Shaft bearing:
Shaft bearings facilitate rotation around the shaft's own longitudinal axis at an at the same time defined position in space.

Electric Drives

Micro hybrid:
Micro hybrids are start-stop systems which are operated in the range of 12 to a maximum of 48 volts and have a recuperation function. The recuperated braking energy is used to charge the conventional 12 volt battery. Due to the low voltage level and the generator technology used, the performance of the system is limited.

Full hybrid:
A full hybrid combines a combustion engine with a small electric motor. Full hybrids have a system voltage greater than 100 volts. Electric driving is possible over a limited range and with limited speed. In order to reduce consumption, and to avoid drag losses, the combustion engine is disconnected by a decoupler when driving electrically and during recuperation.

Plug-in-hybrid:
A plug-in-hybrid has a combustion engine, an electric motor, as well as a rechargeable high-voltage battery. The plug-in hybrid electric drive has an even higher performance during pure electric driving than a full hybrid. A special feature of these systems is the ability to recharge the battery via the power grid. Their electric range depends on the energy content of the battery systems used.

Electric car:
A purely electric car features a high-voltage battery with a large capacity and a charging socket. Additionally, energy is recuperated while braking and fed back to the battery.

March 2014

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VOLKSWAGEN SHAPING THE FUTURE OF MOBILITY

Electrifying

The e-Golf accelerates from 0 to 100 kilometres per hour in 10.4 seconds

The e-Golf has a maximum range of 190 kilometres with a fully charged battery