September 2013

VIAVISION

VOLKSWAGEN SHAPING THE FUTURE OF MOBILITY

Electromobility

The e-up! Made by Volkswagen

Index

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2013: Volkswagen's Emergence in Electromobility

Why is 2013 a special year for Volkswagen?

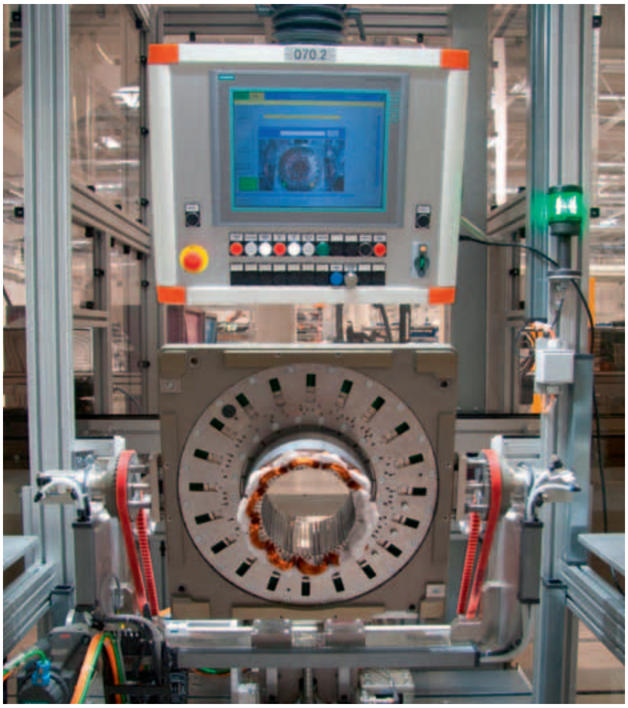
For Volkswagen, 2013 is a pivotal year for electromobility. For us, the year began with the presentation of the XL1, Volkswagen's technological beacon. The XL1 is a two-cylinder plug-in diesel hybrid and at a standard consumption of 0.9 litres per 100 kilometres and a CO_2 emission of only 21 grams per kilometre, it is the most economical production car in the world. The year's second highlight will be the presentation of the new e-up! at this year's IAA, prior to its launch into the market in autumn as the first completely electric high-volume production car. The e-Golf will follow shortly after and in 2014, the Golf will also be available with plug-in hybrid technology. With these two drive technologies, electrification has definitively arrived in the Modular Transverse Matrix and can be applied to different vehicle series.

Dr. Heinz-Jakob Neußer is the new Board Member for Development of the Volkswagen brand.

> "The drive is the heart of the car."
> **Dr. Heinz-Jakob Neußer**

Why is Volkswagen starting high-volume production with the e-up!?

Pure electromobility will initially establish itself in cities and built-up areas and the electrified up! is the best vehicle for these environments. Volkswagen is launching the ideal urban vehicle into the market – not only is the e-up! a four-seater suitable for everyday use for private owners, but is also ideal for corporate customers for daily commutes. Electric cars have to store the energy needed to drive in a high-voltage battery and any additional weight decreases range, so we have minimised the e-up!'s weight – it is only 1139 kilograms, including the battery. We have also optimised the e-up! in terms of efficiency, with a power consumption of only 11.7 kilowatt hours per 100 kilometres as well as giving it superior aerodynamics and manoeuvrability. This is why the e-up!, our new, small city speedster from the New Small Family, is the ideal vehicle for pure electromobility.



The electric drives for the e-up! are produced in the Kassel Baunatal plant. A new electric motor and transmission assembly has been specially created in the transmission plant.

Is Volkswagen well positioned in terms of electromobility?

Yes, we are very well positioned. We have developed a great core competence over the past few years, not only in our development departments but also in our Kassel and Brunswick component plants – thanks to the on-site development and production of efficient powertrains. As a result, our workers have developed a deep fundamental understanding of the complex interactions between these innovative technologies.

Why does it make sense, from your point of view, to develop and produce an e-drive autonomously, since all components could be purchased from external suppliers?

Next to the design, the drive is the main component that determines the customer's relationship with his car. One could say the drive is like the heart of a car. Many customers buy a Volkswagen, among other reasons, because over many decades we have proven our compentence in drives. From the start it was important to us that we rely on autonomous development and production of alternative drives so that we could ensure all future Volkswagens with alternative drives are exemplary in every aspect. This is why we have worked intensively on the development of e-motors and battery systems, and developed the necessary production competence in our Kassel and Brunswick plants.

Will the cars be charged with green electricity?

Electric vehicles are only carbon neutral if their high-voltage batteries are charged with electricity from renewable energy sources. For this reason Volkswagen has created a partnership with Lichtblick, offering private customers 100 percent CO_2-free, TÜV-certified energy from hydro power plants in Germany, Austria and Switzerland. This offer will be available for all our customers at the market launch of the e-up!. Green electricity is closely tied to the holistic electromobility strategy of the company.

What else needs to be done to ensure that we reach a fully carbon neutral mobility system?

There is sufficient green energy for electric vehicles available through the grid already. However, it is important that this clean energy is provided at the charging stations, and that an infrastructure in many different areas of public life is established. The set-up of a comprehensive charging infrastructure is vital for a smooth market introduction. In particular, the innovative Combined Charging System should be taken into account here in order to allow cars to be recharged via quick-charging in barely an hour.

The battery systems for the e-up! are produced in-house in series in Brunswick. Forty employees produce 11,000 units per year.

The Electric Motor

Pocket Power Pack

The entire construction and technical requirements of an e-car's drive unit differ significantly from the structure of conventional combustion engines. Volkswagen has developed an electric motor for the e-up! that is also part of the Modular Transverse Matrix – which means that it can be installed in other models.

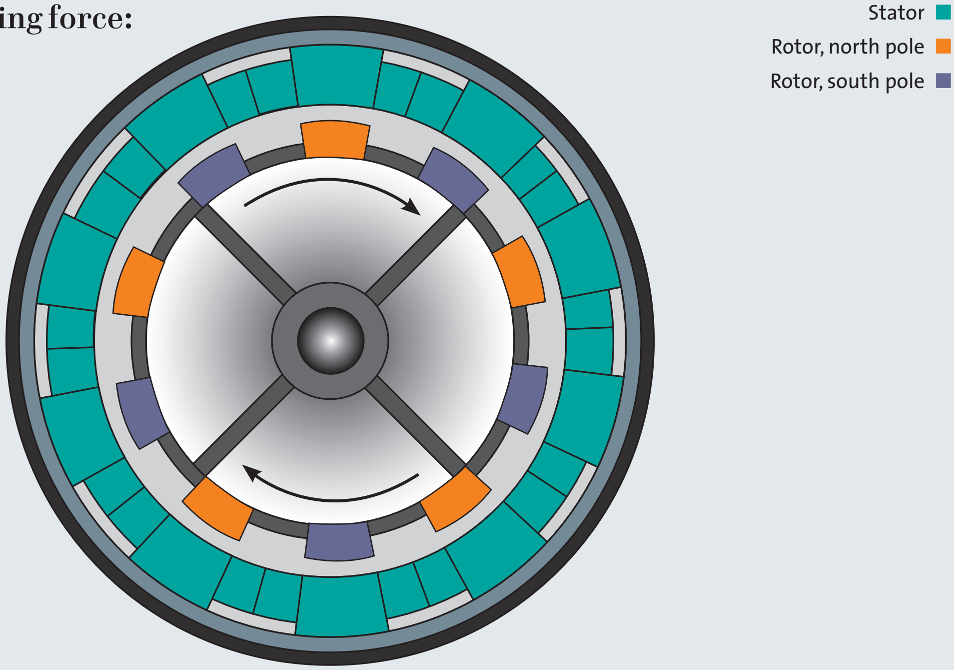
In principle four components have to interact to drive an electric vehicle: the power electronics, the electric motor, the transmission, and the engine control unit.

In drive mode the power electronics transform the battery's direct current to three-phase alternating current (see glossary, page 11) – the state it is required to be in by the electric motor. The power electronics transform the electricity. To do this it is connected to both the electric motor and the battery. This system transforms alternating current into direct current when the vehicle is braking which, in turn, charges the battery (also called recuperation, see page 8).

The motor's mechanics are based on magnetism: similar poles repulse and opposing ones attract each other. The fixed part of the electric machine, the stator, consists of coils which are offset to each other, and become magnetic when in an electrified state activated by a current flow. When the voltage is applied consecutively, these electromagnets interact with the permanent pole magnets in the rotor, causing it to spin. The rotor is fitted with alternating south and north pole magnets, which are attracted or repulsed by the magnetic forces created by the current applied to the stator coils. This force emanating from the engine is subsequently directed to the wheels via the transmission and prop shafts. The electronic engine management ensures that all the engine processes are perfectly synchronised and maintained. Its job is to enable a smooth and efficiently operating engine, ensure good driving performance and maximising its range.

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. The engine control unit processes this data and sends signals to the power electronics for the optimal operation of the electric motor.

Magnetism is the driving force:

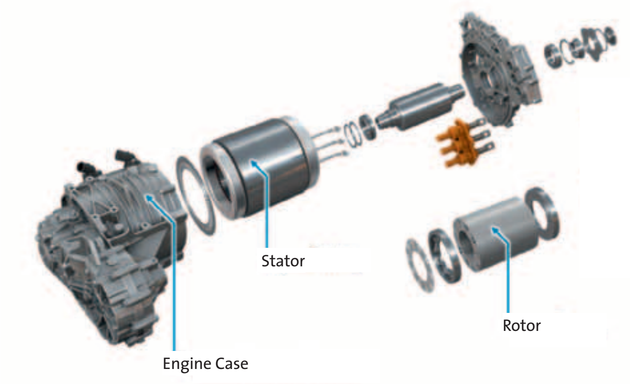


Motion in the electric motor is caused by the alternating attraction and repulsion of opposing and similar polarity magnets. While the permanent magnets in the rotor are permanently of northern or southern polarity, the magnetic poles in the stator alternate because of the electric current applied to the coils.

Electric Motor and Co. in the e-up!

The Electric Motor

In technical terms, a permanently excited, three-phase synchronous machine is fitted in the Volkswagen e-up!. Behind this complicated name is, simply, an electric motor, which is defined as synchronous because its rotor rotates with a speed synchronous to the circular moving magnetic field of the stator and as a result runs smooth even at low speeds. This is partly due to the special type of current, consisting of three single alternating currents which flow through the coils of the stator. The magnets installed in the rotor of the e-up! are permanently of northern or southern polarity.



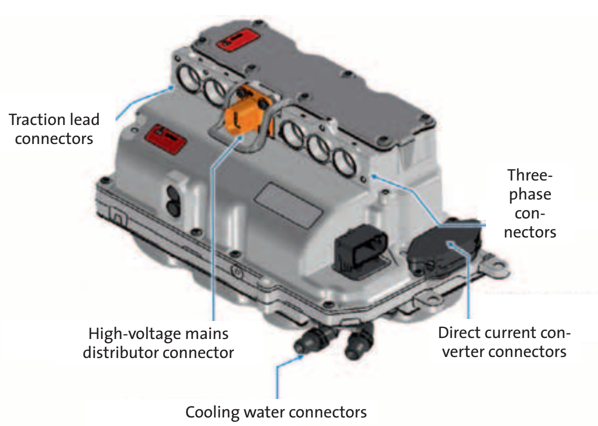
The Transmission

The e-up! features a friction-optimised 1-speed transmission which spins at 10,000 revolutions per minute. The e-motor is connected to the front wheels, powering them via the transmission and prop shafts.

The Engine Control Unit

The central engine control unit takes over drive management with newly developed functionality, such as the optimisation of engine response for more comfortable and harmonic load changes, and the dynamic driveability that comes with it. The customer can choose between three distinct driving programs with different driving characteristics and driving power (see page 8). The engine control unit takes over the control of the thermal and energy management of the drive and secondary units, with regard to maximum electric range as well as comfortable climate control and component protection. Requirements for assistance systems such as cruise control or Automatic Distance Control (ADC) are also coordinated here.

The Power Electronics



The power electronics of the e-up!, as the conduit between the battery and the electric motor, ensures that the correct current is always available. It is connected to the electric motor by a three-phase line and by a traction lead to the battery. A range of 296 to 418 volts are used in the e-up!, depending on the battery potential. When the engine is running, the power electronics transform the alternating current into three-phase alternating current. In generator mode the alternating current is transformed into direct current, in order to charge the battery. Additionally, an integrated direct current converter in the power electronics feeds the 12-volt electrical system of the vehicle.

The Battery in the e-up!

The Energy Centre

The battery is a crucial component of the electric drive. For a long time it was a technological challenge to overcome, before the full-scale implementation of e-mobility became possible. Important questions included: where should it be installed? Which materials have to be used to ensure short charging times, high energy density and safe handling? How does it stay sufficiently cool? How should the battery system be constructed? The engineers have found answers to all these problems.

The electrically driven e-up! is the first high-volume series production electric car by Volkswagen, and solves a whole series of challenges that have been associated with the use of batteries. A high-voltage lithium-ion battery is installed in the e-up! which has a high energy and power density as well as high levels of efficiency. Thanks to its compact construction it fits under the seats and transmission hump, in place where the fuel tank and exhaust system would be fitted in conventional cars.

Cooling is not necessary: in driving mode the battery does not heat up beyond the permitted temperature range, even when temperatures are high outside the car. The battery is controlled by the Battery Management System (BMS) which exchanges information such as the state of charge, output limits and error conditions with the engine control unit and power electronics – this ensures efficient and safe operation while driving.

The BMS controls the battery's different operating modes while driving or parking, and provides the electric energy for the vehicle via so-called protective relays. If a significant error occurs, these relays are switched off by the BMS software, isolating the battery. The BMS also determines the state of charge of the whole battery as well as for individual cells. This eliminates overcharging and deep discharge of the individual cells during regular driving. This is important because the output limits – the maximum charge and discharge performance as well as the maximum charge and discharge duration – depend strongly on the current charge state and the temperature. As in all batteries, the cells used in the high-voltage battery will self-discharge slightly. This leads to differing states of charge in the cells which can impact the car's range as well as the reliability of the range calculation. The Battery Management System compensates for this problem by continuously comparing the state of charge of all cells and restoring the balance of charge for the whole system by treating the cells individually.

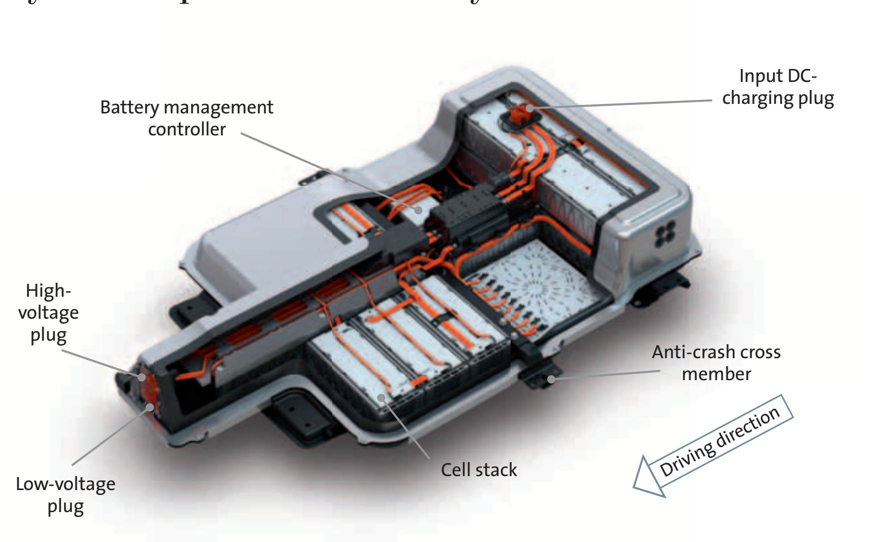
In addition, the high-voltage system of the e-up! is monitored by a main line called the pilot line. This main line acts as a current hoop through all the important high-voltage components. An interruption of this current hoop indicates a fault and results in a red warning light lighting up in the car's interior, and a preventive shut-off of the battery by the protective relays. The interaction between bodywork and high-voltage battery also increases safety: it is set up in such an ideal way that the bodywork protects the battery in many accident scenarios. In addition the protective relays, integrated in the high-voltage battery, switch off the current in an accident and deploy airbags or seat belt pre-tensioners.

Profile

Lithium-ion battery:

Weight:	230 kilograms
Capacity:	18.7 kilowatt hours
Cells:	204 (102 cell-pairs)
Potential:	374 volts
Output:	75 kilowatts

System components of the battery:



The high-voltage battery of the e-up! is installed in the underbody of the vehicle.

One for All

It is the goal of the German Government to get one million electric vehicles on German roads by 2020. Presently there are slightly more than 52,000 – including hybrids. There are four main reasons for their current lack of prevalence: high cost, the limited range of battery powered vehicles, the lack of standardisation of the charging interface and the lack of charging infrastructure. The range of the batteries is being intensively researched. In the field of standardisation, progress is also being made. For example, the European Commission has agreed on uniform connector technology for AC and DC charging (see glossary, page 11) and put a legislative process in motion at the beginning of 2013. This uniform plug has up to seven electrical contacts depending on the power level, two of which function as data lines via which the electric vehicle and the charging point can exchange information. This enables future integration of electric vehicles into a smart grid (an intelligent electricity grid) or to charge the battery in a public space, for example in car parks. At home the charging is simple thanks to retrofittable, special loading outlets – called 'Wallboxes'. These can be fitted by professionals after a review of any house's electric infrastructure.

The charging infrastructure has a lot of catching up to do though: Germany's 14,000 petrol and diesel stations compare to only about 3,000 AC charging stations.

The Combo Type 2 connector, shown here, is installed in the e-up!. It enables alternating current charging (AC) as well as direct current charging (DC) . This combo-charge connector is part of the Combined Charging System (CCS). This system encorporates the technical standardisation within its plug and charging-communication system, independent of the manufacturer. The Type 2 plugs and charging connectors are planned to become standard by no later than 2017 for all e-cars sold in Europe.

It's All in the Plugs

The e-up!, as Volkswagen's first high-volume production electric car, doesn't require conventional fuel any more. Instead, it needs electricity to charge its battery with energy. The energy stored by the high-voltage or traction battery, can be charged with either alternating current (AC) or direct

The Combo Type 2 Connector makes it possible to charge with alternating or direct current.

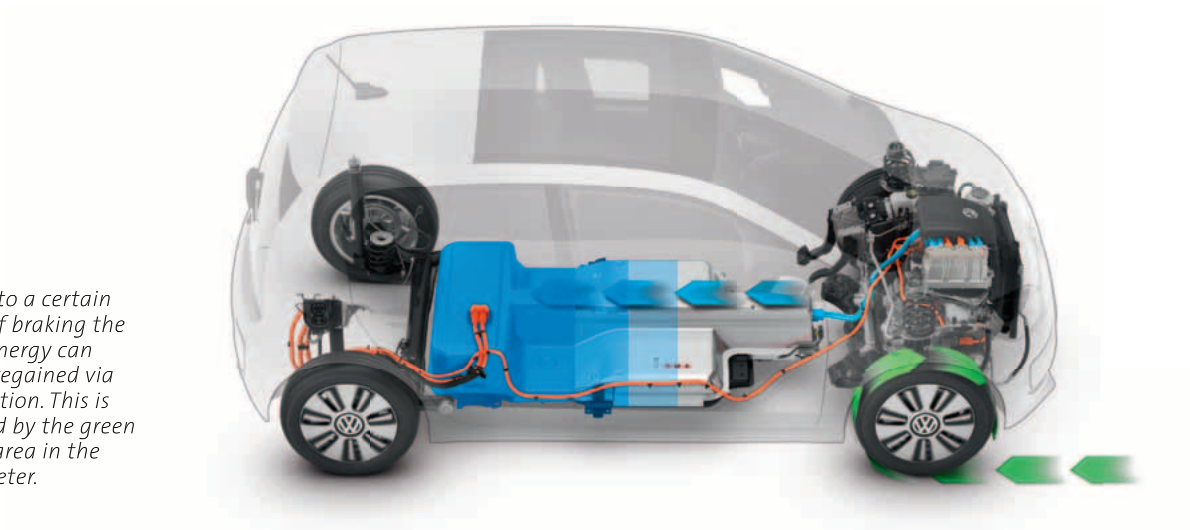
current (DC). The greatest advantage of DC charging (at 40 kilowatts) is that 80 percent of the charging capacity can be restored in 30 minutes, significantly faster than AC-charging (at 3.6 kilowatts). The e-up! can optionally be charged with either direct or alternating current through the same plug with the Combo Type 2 connector – although only AC charging is equipped as standard. The e-up! offers a matching AC charging cable as standard for charging at home or during the night. This can be connected to a conventional, technically faultless electrical outlet in a normal domestic electrical infrastructure, at a charging rate of up to 2.3 kilowatts. This means that the vehicle can be charged almost anywhere. Anyone charging the car regularly at the same spot, for example in a residential garage, can make use of a comfortable AC-Wallbox with a charging rate of 3.6 kilowatts. This shortens the charging time to under seven hours and is ideal for overnight charging. DC charging is ideal for topping up some energy while out shopping or when returning from work.

The Wallbox can increase the charging rate in the residential garage to 3.6 kilowatts.

Recuperation

Regaining the Energy

Recuperation is derived from the Latin *recuperare* and means regaining. This is also the objective of recuperation in the electric car. The kinetic energy (see glossary, 'kinetic energy' page 11) of the car is regained as electric energy during the coasting or braking phases, which is whenever the car is slowing down, and this charges the electric car's battery. This increases the car's electric range. It requires special software for the energy management and modified software for the engine control unit in order to make use of recuperation and optimise energy consumption.



Only up to a certain degree of braking the kinetic energy can be fully regained via recuperation. This is displayed by the green Charge-area in the powermeter.

How does energy recuperation work when braking?

The drive motor of the e-up! selectively operates as a generator for producing electricity during coasting and braking phases, instead of charging the battery permanently using an alternator as in conventional vehicles. The recuperated energy is used for supplying comfort and secondary consumption systems with any excess energy stored in the high-voltage battery. At the same time, the resistance caused by the electricity generation is utilised as an electromagnetic brake for slowing the vehicle down. Thanks to recuperation the energy already invested into driving can be used as economically as possible. The wear on the brakes is significantly reduced, resulting in lower maintenance costs, and there is less fine dust pollution, a positive side effect. At lower speeds, the electromagnet braking torque caused by the generator is reduced. Recuperation is not possible if the vehicle is fully charged and thus the car cannot be slowed down in this fashion: so in this situation to slow the car the driver just applies the brake as in a conventional car.

What possibilities does the e-up! offer to drivers?

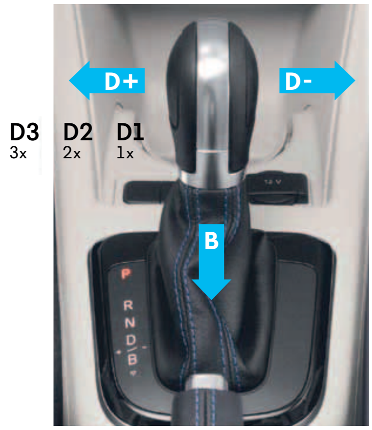
As shown in the diagram (see page 9), the driver can individually preselect the desired braking effect of the generator with the recuperation settings D1 to D3 and the setting B. The setting D1 only causes slight deceleration. The braking effect of the generator is progressively increased in the settings D2 to D3. The setting B offers the greatest coasting deceleration.

The recuperation potential is determined by the car's kinetic energy and therefore stays the same in all recuperation settings. The level of deceleration can be flexibly adjusted to handle any given traffic situation and partialy recuperate energy. Another alternative is offered by the setting D, which allows the driver to utilise the kinetic energy of the car and stay in the coasting phase for as long as possible: in this way the car runs without active braking torque and is comparable to a declutched combustion engine.

In this setting it is also possible for energy recuperation to be activated when the driver applies the brake. In this case, the electronic brake booster automatically controls the balance of the ratio of braking caused by the generator and the wheel brakes. The brake function necessary for doing so is called brake blending.

The recuperation settings in the e-up!:

Recuperation settings	Properties
D	minimum deceleration, no braking energy recuperation
D1	increasing deceleration and braking energy recuperation
D2	
D3	
B (Level of recuperation deceleration)	maximum deceleration (40 kilowatts at 100 kilometres per hour) and braking energy recuperation



The e-up! offers four settings to manually select the level of recuperation (left). The level of recuperation is set with the shift lever shown on the right. The driver can freely adjust the respective level of electronic braking effect with the lever's position.

The Origins of E-cars

First Steps Towards E-mobility

As early as 1976, an electrically powered research vehicle based on the first Golf was created. In 1991 Volkswagen upped the ante with the CityStromer – an e-car based on the second Golf. *VIAVISION* shows the first steps by Volkswagen towards electromobility.

Jetta CityStromer (1988)

Motor:	26 kilowatts
Battery:	Sodium-sulphur
Range:	up to 120 kilometres
Top speed:	105 kilometres per hour

Unlike its colleagues from the Golf series, the Jetta CityStromer was equipped with an innovative sodium-sulphur battery, which increased the car's range to up to 120 kilometres.

Only 120 Golf Mk2 CityStromer were produced for employees of large energy providers. They were only sold to private customers after their official use.

Golf Mk2 CityStromer (1992)

Motor:	23 kilowatts
Battery:	Lead-gel
Range:	about 70 kilometres
Top speed:	100 kilometres per hour

Golf Mk3 CityStromer (1994)

Motor:	20 kilowatts
Battery:	Lead-gel
Range:	about 70 kilometres
Top speed:	100 kilometres per hour

The next e-car from the Golf series was also produced in low volume and was initially used as an official car for public administration and energy providers.

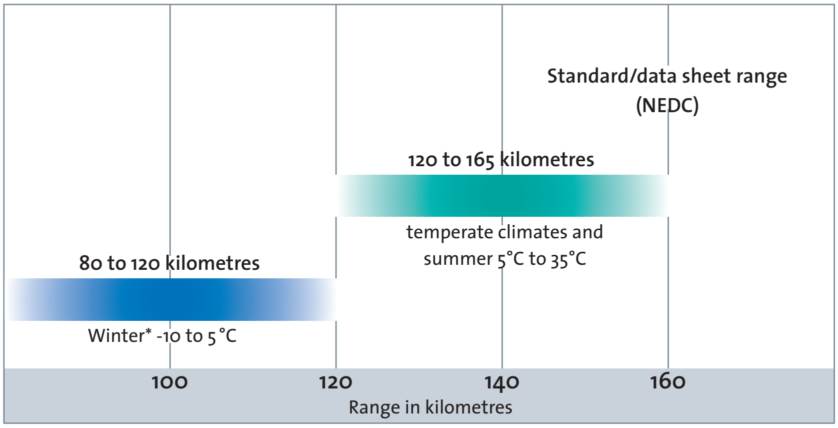
The e-up! as an Everyday Car

Stay Flexible

The numbers speak for themselves: the e-up! will take you an impressive 165 kilometres on a single battery charge. Of course external conditions and your own personal style of driving is crucial in achieving this range. The high level of efficiency in driving and charging mode leads to low daily energy costs.

The range of the e-up!:

(In different conditions, in kilometres)



Factors that impact range:

- Driving style
- Speed
- Use of comfort and secondary systems
- Outside temperature
- Number of passengers and load weight
- Selected driving profile
- Topology

The e-up! has a range of up to 165 kilometres, depending on factors such as weight, topology and driving profile setting. Even at cold temperatures, distances of 100 kilometres are possible.

*with winter tyres, interior temperature 22°C

Training

On top of the energy efficient profiles, the e-up! offers a very special training program for drivers: the Think Blue.Trainer. This trainer continuously monitors the driving behaviour in terms of acceleration, braking and speed, visually displaying the results in the shape of an iris (see picture). This direct feedback helps the driver to drive economically and optimise range.

The Think Blue.Trainer

The Think Blue.Trainer continuously displays tips concerning the current driving profile, the speed selection or how well anticipated the driving behaviour is, in the central element of the visualisation, the so-called iris. The maximum number of points that can be scored for each drive is 100. The higher the score, the more energy efficient and consequently economical the driving behaviour.

Three types of energy efficient driving

In the e-up! the driver can select from three different driving profiles. This way you can not only control the car's driving performance but strongly influence energy consumption and the corresponding recuperation.

Driving profiles in the e-up!:

	normal	eco	eco+
Air conditioning	normal	reduced	deactivated
Acceleration (in seconds) to 100 kilometres per hour to 60 kilometres per hour	less than 12.4 7	less than 15 –	– –
Peak performance (in kilowatts)	60	50	40
Top speed (in kilometres per hour)	130	120	95
Maximum starting torque (in newton metres)	210	167	133

The top speed is 130 kilometres per hour in normal driving mode. The e-up! accelerates from 0 to 100 kilometres per hour in seven seconds. The standard eco-mode is the ideal setup for drivers who value range but also appreciate agility. The top speed in this mode is 120 kilometres per hour. The air conditioning is significantly reduced which saves energy. Maximum range can be reached with eco+, through slower acceleration and a reduced top speed. In addition, the heating and cooling function of the Climatronic is deactivated in this mode.

Glossary

Electric potential: The electric potential is a physical value which specifies how much work, in other words energy, is needed to move a particle with a certain electrical charge within an electrical field. It is the source of electricity. Its symbol is [U].

Volt: The unit corresponding to the electric potential. It is calculated by the division of work input and transported charge. Its symbol is [U] too, its unit of measurement, however, is a capital V.

Electric current: Electric current denominates the amount of electric charge moving in the same or regularly alternating directions and its symbol is [I]. The term **current strength** is the corresponding physical value; it states exactly how much charge has travelled through the cross section of a conductive material in a set amount of time.

Ampere: An ampere is the physical unit to define current strength. It consists of the division of charge and time. Its symbol is a capitol [I] and its unit of measurement is A.

Alternating current (AC): Alternating current is an electric current that changes polarity, and therefore flow direction, at regular intervals from positive to negative, so that a neutral polarity is created over the entire period.

Direct current (DC): Unlike the alternating current, the direct current does not change its polarity over a certain period.

The **three-phase alternating current** flows through three live wires with current supplied alternately. It is also called rotary current. It is generated by a rotary current generator, which shifts the amplitudes of the alternating currents it creates, meaning the charge peaks at 120 degrees for each channel.

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. The kinetic energy depends on the mass and speed of the object. The unit of measurement of kinetic energy is Joule.

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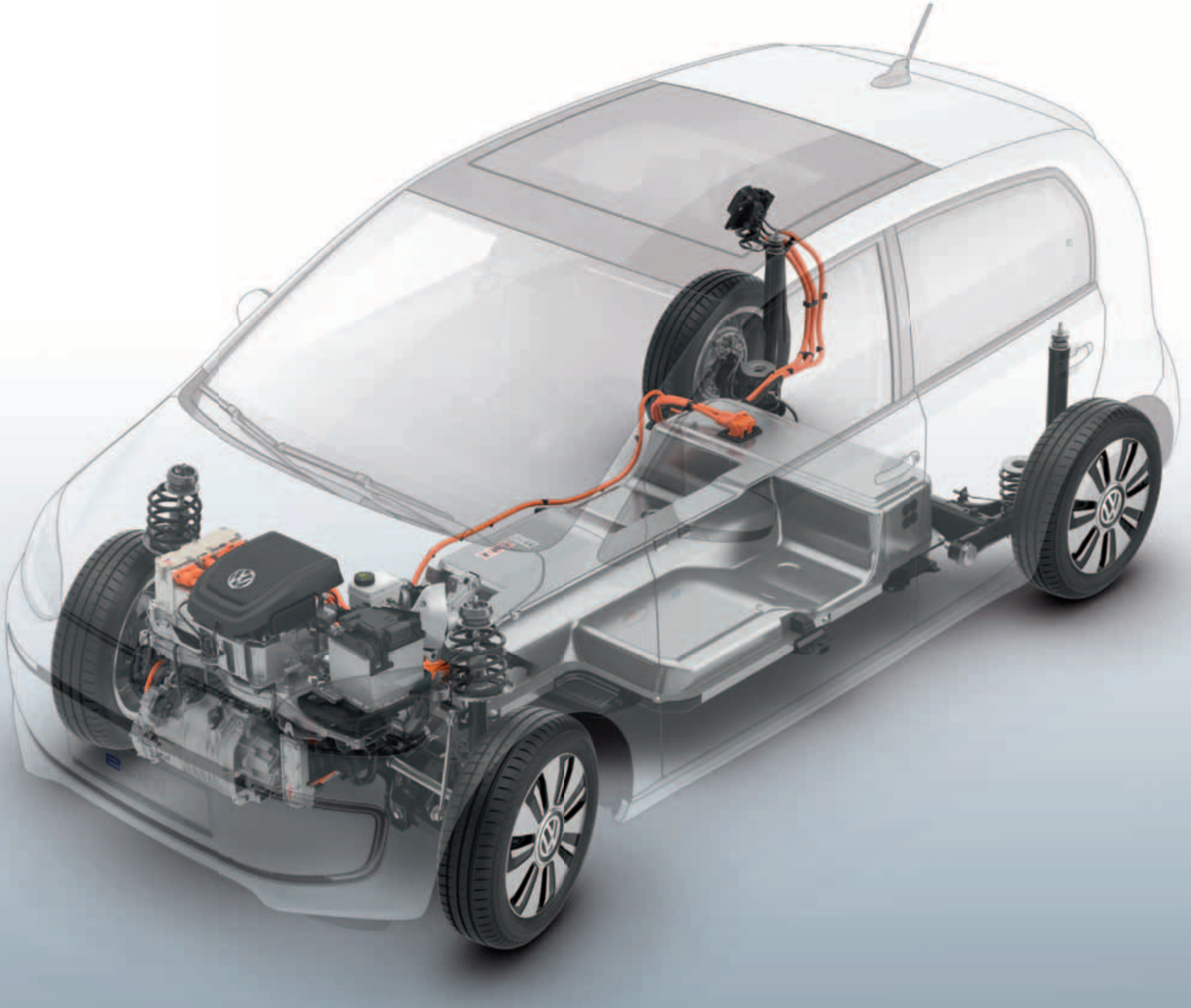

In the e-up! the driver can choose between three driving profiles with a shift lever.

In the standard driving profile the top speed is 130 kilometres per hour.