VIAVISION

VOLKSWAGEN GROUP • SHAPING THE FUTURE OF MOBILITY

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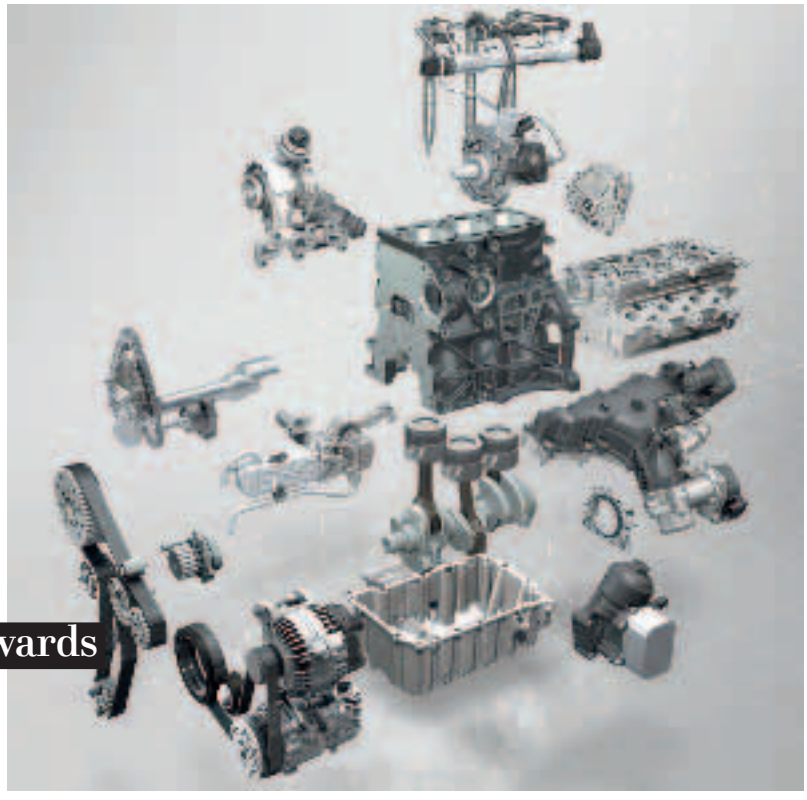
September 2011

Engines

How the Car Gets Going

98.7 percent
of cars in Germany have a combustion engine.

88 percent
of Germans have a positive attitude towards electric cars.



Editorial

Dr. Ulrich Hackenberg, Member of the Board of Management of Volkswagen Brand with responsibility for Research and Development.

Petrol or diesel, gas or electricity – today's engines work with different fuels in different ways. Yet they have one thing in common: They are becoming more and more efficient. In this edition of *VIAVISION*, you will find out how engines work and about what potential still exists for their optimization.

Happy reading.

The Right Stroke

Combustion Drives the Car

No matter whether small or big, black or white, young or old: No car drives without an engine. Not unlike the human heart, it is vital to the supply of energy. The engine generates propulsion from whichever energy source is employed and thus gets the car moving along the street. Alternative drive systems, such as electric engines, have been around for a long time but now they are ready to enter the mass production market. High purchase cost and supply concepts that are as yet not technically mature, make the combustion engine the principle drive system in the medium term.

85 percent of cars sold globally will be equipped with combustion engines in the year 2025. Source: Oliver Wyman consultancy

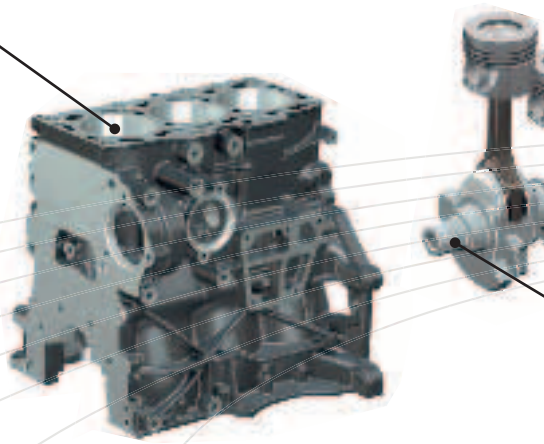
72.1 percent of the 42.3 million cars in Germany have petrol engines, about 26.6 percent have diesel engines, and the remaining 1.3 percent have either gas, electric or hybrid engines. Source: Federal Motor Transport Authority of Germany (as of 2010)

Electronic engine management

The purpose of electronic engine management is the coordination of all engine parameters to ensure they work as efficiently as possible. The control unit operates by taking into account revolutions per minute, engine temperature, the type of fuel and the position of the throttle. For example, depending on the engine model, ignition timing, the amount of fuel injected or exhaust gas recirculation are controlled. Engine management also includes the electronic throttle and the knock sensor.

The driving force – The engine:

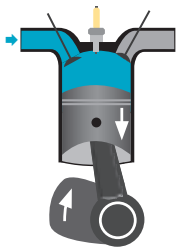
The actual work of the engine takes place in the **cylinders**. Two to eighteen cylinders work on a time-delay, this means that ignition takes place in each cylinder consecutively. Engine performance and consumption increase with the number of cylinders.



Engines have become technological masterpieces of performance and efficiency in order to meet today's requirements. Assisted by microprocessors, the engine management system controls and operates many of the roughly 1, 400 engine parts. The parts shown above are from the TDI engine of the Polo BlueMotion by Volkswagen.

Four strokes to action – How the pistons work:

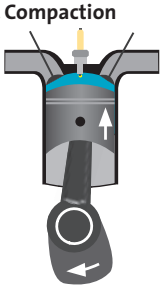
1. Intake



Petrol engine: The suction process conveys the fuel air mix into the cylinder.

Diesel engine: The suction process conveys air into the cylinder.

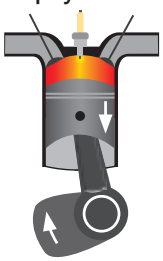
2. Compaction



Petrol engine: The fuel air mix is compressed by the upward stroke of the piston and is thus heated up to 400 to 500 degrees.

Diesel engine: The piston compresses the air even more than in a petrol engine, heating it up to 700 to 900 degrees.

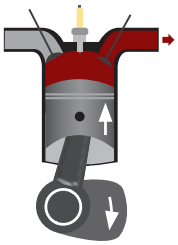
3. Employment



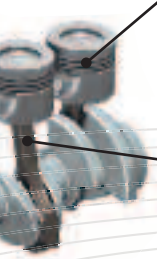
Petrol engine: The spark plug ignites the fuel air mix. It expands explosively and pushes the piston downwards.

Diesel engine: The fuel is injected into the cylinder and is ignited by the heated air. The fuel air mix expands and pushes the piston downwards.

4. Ejection



Petrol and diesel engines: Finally, the piston is pushed upwards again due to its connection to the crankshaft, releasing the resulting emissions.



The **pistons** are pushed downwards by the pressure that results from the expansion of the fuel air mix during combustion.

Each **piston rod** connects a piston to the crankshaft. Flexible anchoring transforms the combustion pressure into a rotation movement. This action powers the crankshaft.

The **crankshaft** powers the flywheel which, via the engine and drive train, conveys the movement to the wheels – driving the car.

The electronic throttle

is part of the engine management system. Like a sensor, it electronically conveys its position, as well as particularly quick upward or downward movements. Based on these signals, the engine electronics control the ignition, air and fuel feed; boosting pressure and thus enabling rapid response times.

The knock sensor

is installed on the outside of the engine. Another part of the electronic engine management system, it prevents self-ignition by registering the knocking of the engine, comparing it to reference values and adjusting the operation of engine, injection and ignition accordingly. The knock sensor also recognizes the quality of the fuel. The ignition time is adjusted, if the quality is low, preventing damage to the engine.

Every Drop Counts

How Engines Are Made More Efficient

Which car engine will win the race to be the drive technology of the near future? Although electric engines get by without any combustion, and thus have a relatively good CO_2 balance, their average range of 150 kilometers is rather limited. Classical combustion engines have much bigger ranges but are dependent on oil and emit more CO_2. Nonetheless, they hold numerous possibilities for optimization. *VIAVISION* gives an overview.

Downsizing

is a method by which the cubic displacement of engines, that is the cylinder capacity, is decreased. This is achieved by installing either fewer or smaller cylinders. In order to prevent loss of performance, better sealed cylinders provide for higher pressure. The decisive advantage of this method: Less energy is lost. Sources: Motorlexikon.de; ADAC

consumption can be achieved if capacity is reduced by 25 percent. Source: ADAC (as of 2011)

Direct injection

is a technology that conveys the fuel to the cylinder at the ideal time. Diesel engines generally work using direct injection but now it is also being employed in petrol engines. In the case of diesel engines, the fuel is only injected if the air in the cylinder is already under high pressure, and thereby hot. The fuel combusts instantly. In the case of petrol engines, the fuel is injected directly into the cylinder, rather than first via the antechamber, where it is immediately ignited by the spark plug. In both cases, the fuel atomizes into small droplets. It combusts faster, cleaner and more thoroughly and thus creates more energy.

Sources: Motorlexikon.de; Karlsruher Institut für Technologie

fuel consumption is possible as a result of direct injection. Source: ADAC (as of 2011)

Cylinder deactivation

is generally used in engines equipped with more than four cylinders. A lot of cylinders under the hood make for fast driving but result in unnecessary fuel consumption when driven at low speeds. In order not to waste fuel at low speeds, fuel injection is simply stopped in some cylinders.

Sources: Motorlexikon.de; *ATZ-Automobiltechnische Zeitschrift*

15 % less

fuel is used thanks to cylinder deactivation.

Source: ADAC (as of 2011)

Turbo chargers

are a combination of turbine and compressor. The energy generated using exhaust emissions is used to drive a turbine. The turbine then drives the compressor, which pushes more air into the cylinder; increasing not only the pressure but also the concentration of oxygen. This optimizes the fuel combustion process: Engine performance rises, without an increase in fuel consumption.

Sources: Motorlexikon.de; *ATZ-Automobiltechnische Zeitschrift*

60 %

better performance is possible in a mass production car due to the additional energy generated using a turbo charger.

Source: Motorlexikon.de (as of 2011)

Start-stop systems

switch off the engine as soon as the driver changes into neutral and releases the clutch, when stopping. Sensors in the vehicle recognize the vehicle has halted and stop the engine. The engine starts back up again as soon as the driver engages the clutch or releases the brake.

Sources: Motorlexikon.de; ADAC

15 % less

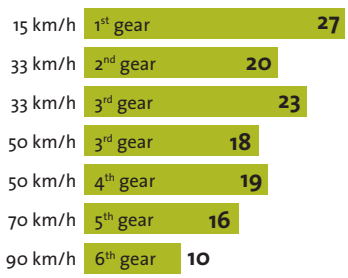
fuel consumption is possible by using the start-stop system in urban traffic.

Source: ADAC (as of 2011)

Cylinder deactivation at Volkswagen

Volkswagen will first employ cylinder deactivation in the 1.4 TSI four-cylinder engine. The electronic engine management system can switch off two cylinders in the low to medium engine speed range, according to the situation; this does not happen during uneven drive, such as on a roundabout. When the driver accelerates, for instance when moving onto the motorway, the inactive cylinders reactivate. This takes only 13 to 36 milliseconds and is barely noticeable. From 2012 onwards, cylinder deactivation will be used in TSI engines.

Less consumption through cylinder deactivation:
(in percent)



How much fuel is saved thanks to cylinder deactivation depends on both speed and the gear selected.

Source: Volkswagen (as of 2011)

Entirely Electric?

Alternative Engines Are on the Way

Automobile producers are increasingly focusing on electricity in their search for new drive technologies: Electric engines, hybrid engines and so-called plug-in hybrids are all on their way. Although the number of passenger cars in Germany that drive purely electrically is rather low, at a little over 2,000, the electric engine offers new perspectives. It is set to reduce the dependency on oil in the long run.

2,307 electric cars were driving on the streets of Germany in 2010, that is a 45.3 percent increase compared to the year before.

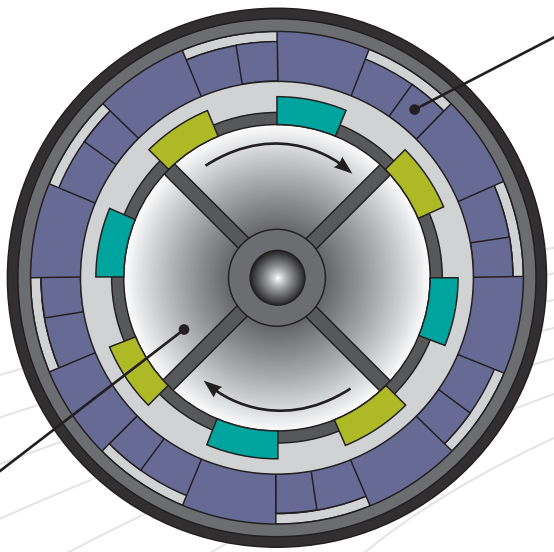
Source: Federal Motor Transport Authority of Germany

88 percent of Germans have a positive attitude towards electric cars. 74 percent can imagine purchasing one in theory.

Source: ADAC (as of 2010)

Magnetism as a driving force – The electric engine:

Movement in the electric engine is created alternately by the attraction of magnets of differing polarity and the repulsion of magnets of the same polarity. While the permanent magnets in the rotor are constantly poled to north or south, the electric magnets in the stator are switched on and off sequentially.



The **stator** consists of several areas which are equipped with offset coils. These magnetize only using electric voltage. By supplying electricity to the individual areas in succession, the magnets spin the rotor permanently. The rotor then works like the crankshaft in a combustion engine, driving the wheels using a rotating motion.

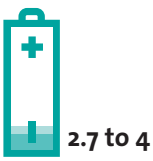
The **rotor** is a moving part which is covered all over with permanent magnets with alternating polarity.

Two Are Better Than One

Hybrids in Comparison

Hybrid cars have not just one but two engines: one – mostly small – combustion engine and one electric engine. Hybrid cars are distinguished by the performance and function of the electric engine installed as well as by the type of drive.

Performance of hybrid vehicles:
(in kilowatts per metric ton)



2.7 to 4
Micro hybrid

The electric engine is not used for propulsion but to charge the starter battery and supply the start-stop system. Applicable to any type.

6 to 14
Mild hybrid

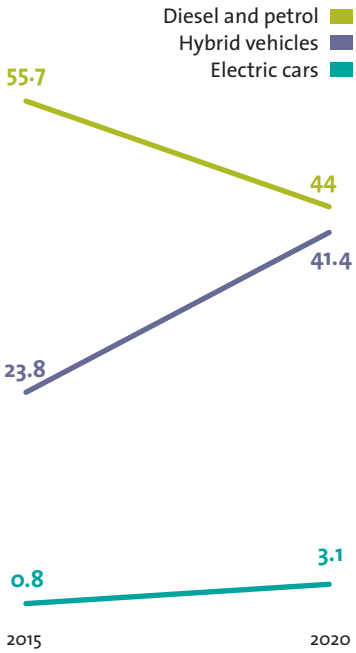
In a mild hybrid the electric engine supports the combustion engine. It is usually used in parallel hybrid drives.

More than 20
Full hybrid

The electric engine is the only drive. The combustion engine supplies on-board electronics and charges the batteries. Applicable to serial drives.

Source: Dietrich Naunin, „Hybrid-, Batterie- und Brennstoffzellen-Elektrofahrzeuge: Technik, Strukturen und Entwicklungen" (as of 2010)

Projected sales of engine types:
(in millions)



According to estimates, global sales of electric cars will increase fourfold between 2015 and 2020.
Source: PRTM Management Consulting

Plug-in hybrid

The plug-in hybrid works like a full hybrid but offers the possibility of externally charging the e-engine's battery, for instance using a plug. The combustion engine is only used when the battery has run dry, otherwise only the electricity needs to be replenished.

Serial hybrid

The combustion engine drives a generator which either supplies the on-board electronics or charges the battery of the electric engine. However, it does not move the vehicle itself and therefore requires only limited cylinder capacity, resulting in extremely low consumption.

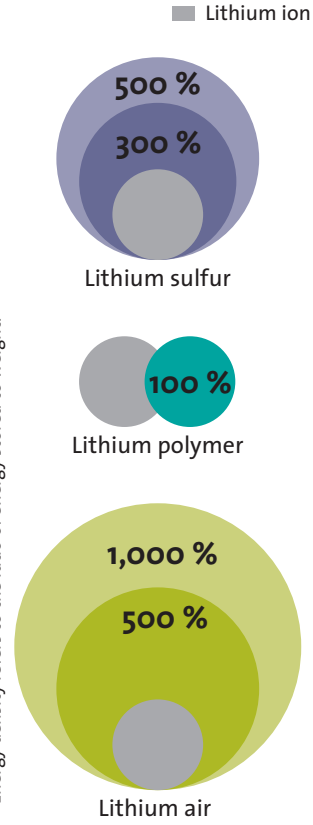
Parallel hybrid

Both engines are connected via the drive axle and support each other throughout the journey. They are significantly smaller than conventionally installed engines and this reduction in weight saves fuel.

Series-parallel hybrid

Here serial and parallel drives are combined. The combustion engine can, as required, either charge the battery or be used for propulsion.

Energy density* of new batteries:
(in comparison to a lithium ion battery)



* Energy density refers to the ratio of energy stored to weight.

Lithium air batteries have especially high potential: They will have up to ten times the performance of lithium ion batteries at market maturity.

Sources: Fraunhofer Institute for Systems and Innovation Research ISI; Fraunhofer Institute for Chemical Technology ICT; Münster Electrochemical Energy Technology (MEET)

Battery of the Future

New Technologies for Increased Range

Even though battery performance has steadily improved, it is still not yet sufficient to make the electric engine a serious alternative to the combustion engine: Charging times are too long, range and life span too short, and the costs too high. This is about to change – intensive research is currently taking place into new batteries.

Lithium sulfur

The energy density of lithium sulfur batteries is three to five times higher than that of lithium ion batteries. Additionally, they react less sensitively to changes in temperature. However, they can currently only be charged a few hundred times. Experts estimate the technology will be ready for use in commercial products by about 2020.

Lithium polymer

Lithium polymer batteries do not contain liquids, such as battery acid, which makes them adaptable to any shape – an advantage for car construction. Problems though are low conductivity as well as poor performance when cold. Their energy density and life span will be equivalent to those of lithium ion batteries when market maturity, expected in 2020 to 2025, has been reached.

Lithium air

The energy density of lithium air batteries is five to ten times higher than that of lithium ion batteries. At present these batteries can only be charged a few times and do not react well to changes in temperature. Market maturity could take ten to twenty years.

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