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# Audi future lab: mobility

**Audi future engines**

Introduction Audi future engines

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**Future mobility will be very diverse, and Audi plans to offer the right drive concept at the right time to every customer on every market. To this end, the brand is developing a broad-based portfolio of new technologies: in its TDI and TFSI engines, hybrid drives and electrified vehicles – the Audi e-tron models.**

The internal combustion engine will continue to assume primary importance in the automobile for a long time. TDI and TFSI engines are the classic pillars of the brand with the four rings, and it is further extending its leadership position with them. In recent years, Audi succeeded in making great progress in both of these technical areas; currently, over 100 model versions emit less than 140 g/km of $CO_2$ *(225.31 g/mile)*, and 33 versions even emit less than 120 g/km *(193.12 g/mile)*. Further considerable efficiency potential will be tapped in the future as well – without detracting from the emotion-packed driving experience.

A good example of Audi's innovative power is the electrically boosted turbocharger for TDI engines, the electric biturbo. Among TFSI engines, "rightsizing" will assume crucial importance in the future. This concept refers to a bundle of innovative technologies for optimizing gasoline engines that target a 15 percent reduction in fuel consumption over the next several years. The predictive efficiency assistant offers further potential. The intelligent use of navigation data makes it possible to coast the car longer, i.e. to shut off the engine in an anticipatory fuel-saving way.

A third cornerstone of future mobility is electrification of the powertrain. The new hybrid models – the A6 hybrid, A8 hybrid and Q5 hybrid quattro – are already on the streets today. They impress with their high efficiency and their electric driving range of up to three kilometers *(1.86 miles)*.

The next significant step will be cars that can cover longer distances in pure electric mode and can be charged from an electrical outlet – the e-tron models. Audi is simultaneously branching out in many directions: from the city compact with range extender to the serial-parallel plug-in hybrid (Dual-Mode Hybrid) and finally the purely electric-powered Audi R8 e-tron high-performance sports car, which will make its appearance on the streets at the end of this year.

For Audi, electrification is a crucial technology – the brand with the four rings is rethinking and reinterpreting its motto "Vorsprung durch Technik" here. Engineers are working intensively on all aspects of the technology chain. They include new types of energy storage technologies, intelligent operating strategies and an electrified all-wheel drive vehicle – the e-tron quattro, the technical concept vehicle implemented in the "e performance" research project.

The goal is to develop uncompromising vehicle concepts that offer maximum utility and convey all of the brand's strengths. Fascination and emotion will define the character of electric-powered Audi vehicles as well. The brand with the four rings will already be offering its first plug-in hybrid models starting in 2014. Over the mid-term, e-tron technology will grow to become one of the supporting pillars of the company. By the year 2020, Audi wants to be the leading premium manufacturer of electric vehicles.

Even today, the brand has already been demonstrating the dynamic potential of the electric drive – with the world record of the R8 e-tron on the North Loop of the Nürburgring race course and with the overall victory of the R18 e-tron quattro at the 24 Hours of Le Mans. Future drive systems at Audi will be sustainable and highly efficient as well as very emotional and dynamic.

<u>Engines Audi TFSI and TDI</u>

## Rightsizing strategy at Audi

**Audi has made great progress in the engineering of its TFSI gasoline engines in recent years. However, considerable efficiency potential continues to exist. Audi engineers plan to tap this potential with a series of new technologies that will be implemented under the "rightsizing" concept.**

For many years now, Audi has been a pioneer of progress in gasoline engines. At the end of the 1970s, the first gasoline engine with turbocharging already made its debut – a sporty five-cylinder unit. The next great milestone was the 1.8-liter four-cylinder turbo in 1995. In 2004, the brand with the four rings rose to the top of the competitive field with the world debut of TFSI technology that combined charging and gasoline direct injection.

The strategy of downsizing – replacing engine displacement by charging – led to large boosts in torque. This let developers implement downspeeding, i.e. the use of transmissions with fuel-saving long gear ratios. Audi is still pursuing this successful course today, and only now are its key competitors following suit.

The four-cylinder engine series with development code EA888, which made its debut in 2006, marked another advance in TFSI technology. In its latest development stage, now its third, the 1.8-liter and 2.0-liter TFSI engines are now appearing with a large bundle of high-tech solutions. They include the Audi valvelift system (AVS), integration of the exhaust manifold in the cylinder head, turbocharger with electric wastegate control, an innovative thermal management system with an electric coolant regulator and a dual fuel-injection system that combines direct injection with injection into the intake manifold.

Altogether, these solutions lead to some very impressive results. In the A4 with a manual transmission, the 1.8 TFSI with 125 kW (170 hp) has a combined fuel consumption of just 5.7 liters per 100 km *(41.27 US mpg)* – which equates to $CO_2$ emissions of 134 grams per km *(215.65 g/mile)*. The A4 of model year 2000 with a 1.8 T engine that produced 110 kW (150 hp) of power was still emitting 197 grams $CO_2$ per km *(317.04 g/mile)*. Improvements contributing to this better fuel economy come from many areas. However, they primarily involve engine optimizations.

The latest innovation from Audi increases efficiency noticeably – the cylinder on demand system. In the new 4.0 TFSI and 1.4 TFSI engines, four or two cylinders are shut down at part-load. This is another aspect of rightsizing. It aims for the right ratio of engine displacement to charging at all times.

A central work field of rightsizing is advanced development of engine charging. Audi developers especially want to further optimize torque and its dynamic buildup in the lower engine speed range. Very promising approaches already exist here. Two-stage charging concepts, for example, offer distinct performance enhancements. Materials used in the turbochargers now include high temperature-resistant steel alloys and turbine wheels made of titanium-aluminide.

The use of new combustion methods is another key topic in advanced development of engine charging technology, especially in efforts to increase charge pressure. Especially interesting in this context are low-pressure exhaust gas recirculation and the Miller and Atkinson cycles, which enable a longer expansion phase. Both of these technologies significantly boost efficiency under mid- to high-load conditions. At the other end of the load spectrum, homogeneous charge compression ignition (HCCI), lean combustion methods and variable valve drives offer potential new ways to further boost efficiency.

In addition, future fuels such as Audi e-gas and e-ethanol play a supportive role. Their use promises great potential on the path towards $CO_2$-neutral mobility. The classic areas of internal friction, engine materials and thermal management round out the work of gasoline engine developers.

Audi's large-scale use of new technologies will once again significantly improve the fuel economy of TFSI engines – its magnitude should be a full 15 percent by 2020. The goal of the brand with the four rings is to offer a mid-class sedan with a TFSI engine that emits less than 100 grams of $CO_2$ per km *(160.93 g/mile)* by the end of the decade.

## Electric biturbo from Audi

**Audi is taking another big step forward with the electric biturbo. In this future technology, a secondary compressor boosts the main turbocharger at lower engine speeds.**

Nearly a quarter century ago, Audi provided a decisive impetus to international diesel engineering – in 1989, the first diesel with direct fuel injection, turbocharging and electronic control made its debut in the Audi 100. Since then, the TDI has enjoyed remarkable success.

Turbocharging makes a lot of sense especially in combination with diesel engines. It enhances performance and substantially reduces fuel consumption and emissions – this represents downsizing par excellence compared with naturally aspirated engines. Referenced to their displacement, TDI engines have realized power gains of over 100 percent and torque gains of 70 percent since 1989. Over the same time period, emissions have been reduced by 95 percent.

The latest development stage from Audi is a biturbo version of the 3.0 TDI – it has a power output of 230 kW (313 hp) and a maximum torque of 650 Nm *(479.42 lb-ft)* between 1,450 and 2,800 rpm. Its specific power output is 77.5 kW (105.5 hp) per liter displacement. However, its combined fuel consumption in the A6 is only 6.4 liters of fuel per 100 km *(36.75 US mpg)*, equivalent to $CO_2$ emissions of 169 grams per km *(271.98 g/mile)*.

What all turbocharged engines have in common is that the turbocharger is driven by energy from the exhaust. This means that starting from very low revs, the rise in boost pressure and therefore torque becomes gradually greater only as the exhaust energy increases.

A new development stage is the electric biturbo. This makes it possible – independently of the exhaust energy available – to build up charge pressure quickly and achieve high levels of torque even at very low revs.

In advanced diesel development at Audi's site in Neckarsulm, a 3.0 V6 TDI was built and calibrated with an electric biturbo. It is a combination of a conventional gas-driven turbocharger with a secondary electrically driven compressor – whose exterior appearance is almost identical to that of a conventional turbocharger.

Instead of a turbine wheel driven by the exhaust gas stream, this is an auxiliary charging stage arranged in line with the gas-driven turbocharger. It integrates a small electric motor that can accelerate its turbine to very high speeds in an extremely short time. The electrically driven compressor is placed after the main turbocharger and intercooler in the charge air path. In most operating states, the charge air is routed around it via a bypass. However, when the flap integrated in the bypass closes – i.e. when the main turbocharger's energy output is low – the air is directed into the electric compressor and is compressed there a second time.

The results of the new concept are impressive. Torque buildup occurs significantly earlier in every drive-off, which the driver perceives as a distinct boost in performance.

The energy required to drive the electric compressor is largely offset by battery regeneration during coasting phases, so that the end effect is essentially neutral with regard to energy consumption.

The flexible and compact charge air path enables two-stage turbocharging with just one turbine that is driven by exhaust gas. The reduced heat demand enables earlier activation of the catalytic converter.

## The predictive efficiency assistant from Audi

**Audi is developing new, intelligent solutions in order to further reduce fuel consumption. One of these is the predictive efficiency assistant (PEA) – it uses route data from the navigation system and the vehicle's surround sensors to promote a predictive style of driving and so lower the amount of fuel used by the customer.**

Speed limit or place-name signs around a curve or over a hill often force the driver to brake sharply. However, braking in conventional vehicles involves the conversion of kinetic energy into heat. It would be much more efficient if the driver could step off the gas early on and steadily roll towards the speed limit. To make this possible, we need to be able to identify what is lying ahead as accurately as possible, i.e. "events" such as bends, traffic signs and road conditions.

This capability is the focus of the predictive efficiency assistant (PEA), a pre-development project from Audi: the objective is to use route information provided by the navigation system – predictive route data – for drivetrain management. In addition to fixed speed limits, the new major development stage of the MMI navigation plus system also provides gradient data.

The drivetrain management system can use this information to decide whether it is better to drive the route with the drivetrain connected or disconnected. The PEA also takes into account changes in vehicle mass or additionally attached parts such as roof boxes, cycle racks or trailers. The system is assisted by the adaptive cruise control (ACC), which monitors traffic in front of the vehicle using a radar sensor.

The efficiency assistant informs the driver at the pre-calculated moment that now is a good time to start coasting. This takes him or her comfortably and without affecting following traffic to the next "event" – a speed limit, for example. The information can be given in the form of a message in the driver information display or as a haptic signal such as a vibration in the gas pedal. Alternatively, the driver can use the functions in conjunction with the adaptive cruise control. In this case, coasting periods are initiated independently, allowing the vehicle to reach the required speed for speed limit zones or bends. Comfort and efficiency are ideally intertwined.

The information helps the driver to adopt a more efficient driving style and therefore to significantly reduce actual consumption. Depending on the model and the equipment fitted, the vehicle may coast with an engaged (overrun fuel cut-off) or disengaged (freewheel) drivetrain. In both cases, the combustion engine is still running. In a further development stage, it will be possible to switch off the combustion engine if the drivetrain is disengaged (freewheel – engine off).

When the gas pedal is released, conventional vehicles respond by activating overrun fuel cut-off. However, the hybrid models in the A6, A8 and Q5 model series frequently coast without engine drag torque – even if the driver steps off the gas at higher speeds the drivetrain is disengaged and the engine is switched off. Only the electric motor brakes lightly to recharge the lithium-ion battery and to reproduce typical deceleration behavior.

The freewheel function on the S tronic, available in conjunction with some engine versions for the Q3 and A3, has a similar effect. Depending on engine and transmission configuration, the freewheel mode saves more fuel than conventional overrun fuel cut-off – especially when the freewheel phase takes place over as long a distance as possible while anticipating the road ahead.

In order to enhance efficiency even further in conventional vehicles, the predictive efficiency assistant can be combined with the iHEV system. When the freewheel function is activated, the internal combustion engine is switched off (freewheel – engine off). The restart is performed by a powerful 48V electric motor which is located in the belt drive. While the engine is switched off, energy is supplied via a high-cycle-strength 48V lithium-ion battery.

Together with the predictive efficiency assistant, iHEV vehicles can unleash their full energy potential, as comparative test drives in a vehicle with the new technology have shown. The A7 Sportback 3.0 TFSI iHEV several times completed a 61 km (*37.90 mile*) stretch of winding country roads north of Ingolstadt, with a normal, everyday style of driving.

During the tests without the predictive efficiency assistant, the driver covered 28 percent of the route with the engine switched off. With activated assistance, this figure rose to 43 percent; at the same time, fuel consumption dropped by around ten percent, yet the driving time increased by merely two minutes (three percent) – a virtually neutral impact.

In future, the networking functions of Audi connect will ensure that the data available is always up to date. If an Audi vehicle identifies a traffic sign with a speed restriction using its video camera – at recently started roadworks, for instance – it will send the location and speed limit via the cell phone network to a server in the Audi IT center. From there, following a plausibility check, the information will be transmitted to all suitably equipped vehicles that subsequently drive along the same route – a concrete example of the upcoming car-to-X-technology, which the brand is working on intensively.

<u>Audi electrification strategy</u>

## Audi e-tron

**At Audi, the term e-tron refers to all cars that can cover longer distances purely on electric power. By 2020, the brand with the four rings intends to offer an e-tron model in every segment. Together, they should achieve an annual sales volume in the six-figure range. Today there are already various test cars featuring the new technology. At the end of the year, a limited production R8 e-tron model will hit the road.**

Audi is working on all aspects of electric mobility – with the aim of fulfilling the varying demands of customers worldwide. The resulting concepts offer maximum benefits without compromise – with innovative ideas and with sporty, progressive and sophisticated automobiles that convey all the qualities of the brand. Fascination and emotion will also define the character of an electrically powered Audi.

Audi's wide-ranging electrification strategy incorporates all the relevant concepts. One of these is the electrically powered high-performance sports car, the R8 e-tron, a limited production model that will hit the road towards the end of the year.

At the same time, the brand's engineers have created test cars that represent various approaches to the new technology, such as the Audi A3 e-tron concept. Conceived as a parallel plug-in hybrid, it will go into series production in 2014. The Q7 and A4 with plug-in hybrid drive will follow a short time later.

An alternative to the parallel hybrid concept involves splitting the power of the combustion engine and the electric drive between the axles. The e-tron quattro study based on the Audi A5 takes this approach. Two electric motors complement the 2.0 TFSI – one is mounted at the front axle, the other at the rear.

The LMP1 prototype R18 e-tron quattro, the winner of the 24 Hours of Le Mans, follows a similar concept. A centrally mounted V6 TDI with a capacity of 3.7 liters delivers a good 275 kW (510 hp) to the rear wheels. The front wheels can be driven for a short time on electric power, with 75 kW (102 hp) per wheel. The energy, which is recovered during braking maneuvers, is provided by a flywheel accumulator.

The compact A1 e-tron, on the other hand, is a specialist for the urban jungle and comes with an additional range extender. Its electric motor also drives the front wheels with 75 kW of peak power; the range in electric mode is around 50 km *(31.07 miles)*. A rotary engine at the rear, which displaces 254 cc and produces 15 kW of electric power, makes trips of up to 250 km *(155.34 miles)* in total possible by recharging the 12 kWh battery via an alternator. Audi has conducted an extensive fleet test with the first A1 e-tron models in Munich, during which more than 50,000 km *(31,069 miles)* have been covered to date.

The test consisted of two phases. The first involved a group of drivers who were able to charge the car at public charging stations and at their place of work. In the second phase, it focused on users who could “refuel” the A1 e-tron via a wall box at home. Prior to both, a pilot phase took place in which Audi provided every participant with an A1 1.4 TFSI as a reference vehicle to enable direct comparisons to be made between driving a gasoline and electric-powered car.

The fleet test will be completed at the end of September. Important results on customers’ usage behavior, the charging infrastructure and the vehicles’ performance are already available.

At the beginning of the test, according to the findings, the majority of the A1 e-tron users first and foremost had to learn how to maximize the driving range of the electric car. However, they managed to do so quickly; many drivers took trips out onto the freeways and far beyond Munich’s city boundaries – they did not use the A1 e-tron any differently from the A1 1.4 TFSI they had driven previously. After a short time, the participants were very happy with the electrically powered compact car and the driving feel it provided; they saw themselves as trendsetters for a new form of mobility.

During the course of the test, the distances travelled on electric power rose from 76 to 91 percent, shifting the energy mix to a more cost-effective level.

The sustainably produced “green” electricity, which powered the Audi A1 e-tron models in the Munich area, and the low amount of fuel that was required to run the range extender, worked out at between four and seven euros per 100 km *(62.14 miles),* depending on the individual driving profile.

Audi will continue its tests with the A1 e-tron – the company is taking part in a program called “Schaufenster Elektromobilität,” a showcase for electric mobility, which starts at the beginning of 2013 and is funded by the Federal Ministry of Education and Research. The brand with the four rings will be involved in the model regions of Bavaria/Saxony, Berlin-Brandenburg and Baden-Württemberg, and will focus on various themes in each area.

The holistic approach that Audi is adopting in the field of electric mobility includes another promising concept – the Dual-Mode Hybrid technology. At present, the project is at the pre-development stage: tests have begun with the first prototypes based on the A1. The layout of the drive system essentially comprises a combustion engine, two electric motors and a single-speed transmission.

The combustion engine is a specially developed three-cylinder TFSI with a capacity of 1.5 liters, based on the two-liter four-cylinder version. It generates 95 kW (130 hp) of power and 200 Nm *(147.51 lb-ft)* of torque. The three-cylinder unit is combined with an electric motor (EM 1), which mainly functions as a starter and alternator. It produces a peak output of 50 kW (68 hp) and a maximum torque of 210 Nm.

The electric traction is provided by the second electric motor (EM 2) in the drivetrain; it delivers a peak output of 85 kW (116 hp) and a peak torque of 250 Nm *(184.39 lb-ft)*. The drastically streamlined single-speed transmission enables the combustion engine, including the alternator, to be engaged or disengaged as required from the rest of the drivetrain by means of a claw clutch.

The Dual-Mode Hybrid concept allows various operating modes. In the urban speed range between standstill and 55 km/h *(34.18 mph)*, the vehicle is driven exclusively by electric motor 2 (electric mode), the required energy coming primarily from the traction battery. In addition, a serial mode is available. In this case, the combustion engine and the alternator (EM 1) produce electrical energy to support, relieve or substitute the battery should it be discharged.

The electric mode is possible up to 130 km/h *(80.78 mph)*. From a speed of around 55 km/h *(34.18 mph)*, the drive system permits the combustion engine and the alternator (EM1) to be directly coupled with the drivetrain – hybrid operation offers the flexibility of combining the drive units to maximize efficiency or performance. Above 130 km/h *(80.78 mph)*, the vehicle is driven primarily by the combustion engine. If required – for instance to reduce fuel consumption or to briefly raise system performance – electric motor EM 1 can support the three-cylinder TFSI.

In addition to the operating modes mentioned, which are selected by the drive management system according to each situation, the driver can choose an economical or performance-oriented setting; when driving at city speeds, he/she can also activate the electric mode via an EV button. Regardless of operating mode, the driving feel is similar to that of a battery electric vehicle – the driver does not experience any gear changes or notice the engine or motors cutting in.

The Dual-Mode Hybrid concept cars based on the Audi A1 e-tron, which Audi has developed, have a system output of 130 kW (177 hp); this permits acceleration from zero to 100 km/h *(62.14 mph)* in less than 9 seconds. The 17.4 kWh battery, the major part of which is installed under the rear bench seat, offers a range of around 90 km *(55.92 miles)* on electric power, resulting in standard consumption of around 1.0 liters per 100 km *(235.21 US mpg),* which is equivalent to 23 grams $CO_2$ /km *(37.01 g/mile*).

## Hybrid technology from Audi

**Audi is one of the leading premium producers of hybrid technology. The brand with the four rings offers full hybrid cars with advanced lithium-ion technology in the B, C and D segments – the Q5 hybrid quattro, A6 hybrid and A8 hybrid. All three models are configured as parallel hybrids that combine the performance of a six-cylinder engine with the fuel economy of a four-cylinder.**

The parallel hybrid powertrain from Audi is a straight-line concept with high efficiency and a modular layout. The only difference between the three hybrid models is that the Q5 hybrid quattro drives all four wheels, while the power in the sedans is only directed to the front wheels. System power is a uniform 180 kW (245 hp), while system torque is 480 Nm *(354.03 lb-ft)*.

Propulsion is provided by a 2.0 TFSI developing 155 kW (211 hp) and an electric motor developing up to 40 kW of power and 210 Nm *(154.89 lb-ft)* of torque. Power transmission is handled by a highly modified eight-speed tiptronic, which operates without a torque converter. Taking its place is a disc-shaped electric motor that is paired with a multiplate clutch. It engages and disengages the electric motor and the TFSI; they operate precisely, smoothly and fast in all situations.

A lithium-ion battery system serves as the electrical storage device. Weighing just 36.7 kg *(80.91 lb)*, it supplies 1.3 kWh of nominal energy and has a power output of 39 kW. It is air-cooled in two different ways as needed – by a blower from the car's interior and by a coolant circulation loop that is coupled to the deluxe automatic climate control system. This technology maintains the battery within a suitable temperature window over a broad range of conditions. This assures a relatively long electric driving range of up to three kilometers *(1.86 miles)* at a constant speed of 60 km/h *(37.28 mph)*. The peak speed of 100 km/h *(62.14 mph)* in electric mode also sets standards.

Compact and lightweight power electronics, which are water-cooled like the electric motor, convert the direct current from the battery into alternating current. The power electronics integrate a DC/DC converter that couples electrical consumers in the 12-Volt electrical system to the high-voltage network.

The brake servo is also supplied via an electric vacuum pump. A complex control strategy adapts braking processes to the conditions of electric driving and energy recovery (battery regeneration). The air conditioning compressor has an electric drive; an electric auxiliary heater completes the climate control system. In total, the hybrid-specific components represent less than 130 kg *(286.60 lb)* of additional weight.

The performance of the three hybrid models is as impressive as their efficiency. They handle the sprint from zero to 100 km/h *(62.14 mph)* in between 7.1 and 7.7 seconds, and their top speeds are between 225 and 240 km/h *(139.81 and 149.13 mph)*. Combined fuel consumption is only 6.2 to 6.9 liters per 100 km *(37.94 to 34.09 US mpg)* – with $CO_2$ emissions of 145 to 159 grams per km *(233.35 to 255.89 g/mile)*.

The hybrid models from Audi can be driven with just the internal combustion engine, just the electric drive or in hybrid mode; they can also regenerate the battery and provide boost. The driver selects one of three programs: the EV mode prioritizes electric driving, the D mode controls both power sources efficiently, and the S mode is configured for a sporty style of driving.

The most important gauge is the Powermeter in the instrument cluster. Its needle indicates the total system power in percent over a scale from zero to 100. Another instrument visualizes the battery’s charge state. In parallel, the color display of the driver information system and the monitor of the MMI navigation plus system show power flow paths and operating states in elegant graphics.

Audi can look back on over 20 years of experience in hybrid technology. The first generation of the Audi duo made its debut early on, in 1989 – this was a technology concept car based on the Audi 100 Avant. A five-cylinder gasoline engine powered the front wheels, while a connectable electric motor developing 9 kW drove the rear wheels. Nickel-cadmium batteries served as the energy source. This was followed two years later by another duo variant based on an Audi 100 Avant quattro.

In 1997, Audi became the first European carmaker to build a hybrid vehicle in a limited production run – the Audi duo based on the A4 Avant. Its drive power was supplied by a 1.9-liter TDI developing 66 kW (90 hp) and an electric motor developing 21 kW, which was supplied by a lead gel battery at the rear. Both power sources drove the front wheels.

Like the two concept cars before it, the limited production car was also a plug-in hybrid – its battery could be charged from an electrical outlet, and the electric motor recovered energy during braking. The Audi duo reached a top speed of 80 km/h *(49.71 mph)* in electric mode and 170 km/h *(105.63 mph)* with the TDI engine.

<u>e performance</u>

## The Audi F12 from the e performance research project

**Audi is systematically working out all aspects of electric mobility from the ground up. The e performance research project – a think tank within the company – has developed a modular component system for electrically powered vehicles. This has resulted in a sporty research vehicle, the F12, in the framework of a research project sponsored by the German Federal Ministry of Education and Research (BMBF).**

In its exterior appearance, the F12 research vehicle resembles the Audi R8 e-tron, which will appear on streets at the end of this year. The high-performance R8 sports car with its lightweight aluminum Audi Space Frame body served as the starting point for both projects. The research vehicle, which weighs around 1,650 kg *(3,637.63 lb)*, also attains sporty performance values. It accelerates from zero to 100 km/h *(62.14 mph)* in less than seven seconds. Its top speed is electronically limited to 180 km/h *(111.85 mph)*, and its driving range is around 200 km *(124.27 miles)*.

Developers working on the e performance research project took entirely new approaches to the car’s drive technology. They were not concerned with the production maturity of the car, but rather with taking a broad-based and comprehensive approach to its design. Key components of the F12, all custom fabricated parts, can be interchanged with minimal effort to enable many new configurations. The system matrix is scalable – when engineers make suitable modifications to the parts they can also be used to configure a sedan or a city car with an electric or plug-in hybrid drive.

Two large, separately housed battery blocks with a total energy capacity of 38.9 kWh serve as the car’s energy storage devices. The front battery block is longitudinally mounted in the center tunnel that was specially adapted for this purpose, and the rear block is mounted transversely in front of the rear axle. The liquid-cooled batteries weigh around 400 kg *(881.85 lb)*; they consist of a total of 5,200 cylindrical lithium-ion cells of the type commonly used in consumer electronics.

Each set of 26 cells forms a battery module; they are embedded in a poured high-strength structural foam and are protected by aluminum profiles integrated in the package as well. The modules can be shifted next to one another with their diagonally slanted walls. This forms the basis for the safety design which, according to calculations, can withstand a pole side impact. The rear battery is installed in an ultra-lightweight pan made of carbon fiber reinforced polymer (CFRP).

Three electric motors of different types work together to drive the research vehicle. Each rear wheel is coupled to an asynchronous motor via a single-stage gearbox; each motor outputs 50 kW of power and 200 Nm *(147.51 lb-ft)* of torque. An intelligent control system distributes drive forces based on demand – this “torque vectoring” makes handling even more stable and sporty. A synchronous motor is installed in the front section of the car; it delivers its 50 kW and 150 Nm *(110.63 lb-ft)* to a newly developed mechanically locking differential via a two-stage gearbox – so the F12 is a fully electric quattro.

The three motors can be driven separately to utilize energy as efficiently as possible. During slow driving, only the synchronous motor is active; it achieves a very high level of efficiency. At higher speeds, the performance-optimized asynchronous motors come into play at the rear axle.

Another innovation in the F12 is the switchable high-voltage electrical system. Following the basic idea of scalability, the two batteries can produce different output voltages at either 148 or 222 volts. A high-performance direct current converter (DC/DC) regulates the desired uniform system voltage. Under part-load, the voltage is around 200 volts to maximize efficiency; with increasing power demand, it can be boosted up to 440 volts.

The advanced development team of the e performance research project targeted a maximum level of integration in designing the control modules. With this goal in mind, they utilized valves similar to those used in building technology for the heat pump that handles thermal management of the drive system and the interior. In many situations, the heat pump is used to heat up the batteries; this heat is stored and is available to heat the interior on the next drive.

The driver of the F12 controls basic drive functions – P, R, N and D – by operating buttons on the center tunnel. An iPad in a mounting bracket on the center console is used to perform all other operating steps, including the degree of energy recovery and settings for the synthetic e-Sound. When the driver arrives at his or her destination, the iPad can be removed and used to configure the car remotely. A user-programmable instrument cluster displays all important information in virtual digital graphics with very high resolution and quality.

The F12 research vehicle was created as part of a three-year research project sponsored by the German Federal Ministry of Education and Research. The project budget was 36 million euros. Engineers from Audi, its subsidiary Audi Electronics Venture GmbH (AEV) and scientists from the ika, ISEA and IEM institutes of the RWTH Aachen university formed the core team of the e performance research project. Other external specialists from the technical universities in Munich, Dresden and Ilmenau, Hanover's Leibniz University and the Fraunhofer IISB and IESE institutes provided scientific support. Key industrial partners involved in the project were Robert Bosch GmbH and Bosch Engineering GmbH.

The e performance research project has the freedom to explore entirely new approaches. Advanced development tools and a new type of knowledge management helped to create an atmosphere characterized by engineering ingenuity, creativity, open discussions and flexible networking. Cameras document every step in construction, and all findings flowed via a ticket system onto a server that was available to all participants across Germany.

This high level of transparency and networking based on the principle of "open innovation" allowed the research project to have a very positive influence on Germany's entire higher education system and industry. Partnerships are continuing even after completion of the F12 – the first follow-up projects that focus on special technical issues have already begun. Individual solutions, such as the CFRP housing for the rear battery, show good prospects for later production use.

## The Audi R8 e-tron

**To Audi, electric mobility means emotion, sportiness and driving pleasure – a principle that has been emphatically demonstrated by the Audi R8 e-tron. On the Nürburgring Nordschleife in June, it achieved a record time for a production vehicle with an electric drive system. Professional driver Markus Winkelhock piloted the car around the 20.832-kilometer track *(12.94 miles)* in 8:09.099 minutes.**

"The record drives were a fantastic experience for me", said a beaming Markus Winkelhock after the event. The 32-year old from Swabia has a high standard for comparison – the Audi R8 LMS ultra, in which he, together with Marc Basseng, Christopher Haase and Frank Stippler, won the 24-hour race at the Nürburgring in May 2012.

The drive system of the record-setting vehicle corresponds in every detail to the production model that will hit the road at the end of the year. Its ultra-light body primarily consists of aluminum based on the ASF construction principle (Audi Space Frame) as well as CFRP components; it is the main reason why the high-performance sports car has a curb weight of just 1,780 kilograms *(3924.23 lbs)*, despite the hefty battery.

Together, the two electric motors in the R8 e-tron transmit 280 kW (381 hp) of power and 820 Nm of torque to the rear wheels. They can be activated individually, which enables targeted "torque vectoring" – torque displacement depending on the driving situation. The R8 e-tron sprints from zero to 100 km/h *(62.14 mph)* in 4.6 seconds; its top speed is normally limited to 200 km/h *(124.27 mph)*. For the record-setting lap, completed by the high-performance sports car on cup tires, a speed of 250 km/h *(155.34 mph)* was approved.

The T-shaped lithium-ion battery is mounted transversely in the center tunnel, in front of the rear axle. The 48.6 KWh of energy it stores is enough for a distance of around 215 kilometers *(133.59 miles)* of everyday driving. On the extremely tough Nürburgring Nordschleife, where a conventional high-performance car can use up to 65 liters of gasoline per 100 km *(3.62 US mpg)*, the available power was sufficient for two fast laps in succession.

The energy recovery system proved to be useful here – when the vehicle decelerates, the electric motors act as powerful alternators that take most of the load off the electromechanical brakes at the rear wheels.

In addition to the fast single lap on the Nordschleife, the R8 e-tron - with Markus Winkelhock at the wheel - also set an impressive record for two back-to-back laps. Limited to 200 km/h *(124.27 mph)* and equipped with standard tires, it completed the task in 16:56.966 minutes.

“The R8 e-tron is a production car, of course, with no aerodynamic aids”, said Winkelhock. “But with its low center of gravity and rear-biased weight distribution it has a lot of sporty qualities. The torque with which the electric motors propel the car out of tight bends is incredible – even if they hardly make any noise in the process, which initially was a completely new experience for me.”

R18 e-tron quattro

## The Audi R18 e-tron quattro

**The e-tron technology from Audi offers fascinating potential. In June, the sports prototype - the R18 e-tron quattro - won the 24-hour race at Le Mans – with an innovative, specially developed hybrid drive.**

The Audi R18 e-tron quattro is a vehicle concept packed with progressive technology. With it, Audi has realized a drive technology never before seen in motor sport. At the rear axle, a 3.7-liter V6 TDI engine delivering more than 375 kW (510 hp) and more than 850 Nm *(626.93 ib-ft)* of torque provides powerful and efficient propulsion. A six-speed transmission made of ultra-light carbon fiber reinforced polymer (CFRP) transmits the power to the road.

At the front axle sits the innovative motor generator unit (MGU), developed by Audi in conjunction with its system partners. A generator and a converter transform energy recovered during braking phases into direct current; this powers a flywheel accumulator, which is located in the cockpit next to the driver. The electricity accelerates an ultra-light CFRP flywheel, which runs in a vacuum, to up to 45,000 rpm.

When exiting the bend, the driver can retrieve the energy from the accumulator. It then supplies the MGU’s two electric motors that drive the front wheels with up to 150 kW (204 hp) of power – for a short time the Audi R18 TDI is a quattro with four driven wheels. So that this did not become too much of an advantage, the organizers of the 24-hour Le Mans race restricted the use of the MGU to the speed range above 120 km/h *(74.56 mph)*, to a maximum of 500 kilojoules of energy and to seven zones on the circuit.

In Qualifying, André Lotterer put the 900-kilogram *(1,984.16 lb)* R18 e-tron quattro – designated as car number 1 - in pole position. “It runs like it’s on rails”, enthused the driver, born in Duisburg, after completing the fast lap in 3:23.787 minutes.

The Audi with chassis number R18-208 took the checkered flag on Sunday at 15.00 after 378 laps and 5151.762 km (*3,201.16 miles)*. Runner-up was the R8 e-tron quattro with Dindo Capello, Tom Kristensen and Allan McNish, one lap behind. The two purely TDI-powered Audi R18 ultra cars rounded off the brand’s success by taking third and fifth position – the eleventh overall victory at Le Mans in 14 attempts since 1999.

The consumption results for Lotterer/Fässler/Tréluyer underline the potential of hybrid technology from Audi. The winners were considerably faster than in the previous year – with an average of 214.468 km/h *(133.26 mph)* compared with 201.266 km/h *(125.06 mph)*. Even so, their R18 e-tron quattro consumed an average of around ten percent less than the R18 TDI competing in 2011.

“With the e-tron quattro in combination with ultra lightweight construction, we have put a completely new technology on the grid and have immediately won with it”, said Rupert Stadler, Chairman of the Board of Management at AUDI AG after the race. “Our engineers have demonstrated their high technical expertise with this vehicle”. Victories with innovations have already become a tradition at Audi: In 2001, the brand with the four rings won at La Sarthe with the TFSI engine, which was new at the time; in 2006, it amazed the public with the first TDI triumph at Le Mans.

“The regulations, which we have collaborated on intensively, are a big step in the right direction”, commented Dr. Wolfgang Ullrich, Head of Audi Motorsport. “They promote the development of new technologies that are also of relevance to production cars. This is the very reason why we are so heavily involved in Le Mans.”

From 2014, there will be some changes in the classic endurance race. The organizers will specify a certain amount of energy from which every participant must extract maximum performance; in terms of engines and hybrid systems, there will be more room for maneuver. The aim is to cut fuel consumption by a further 30 percent. Audi is already looking forward to this new challenge.

# Audi future energies

**Audi is striving for a leadership role within the automotive industry with regard to the sustainable use of raw materials – its goal is to make the vision of $CO_2$-neutral mobility a reality. The company is thinking on a broad scale and is making very specific contributions in the development of renewable materials, recycling concepts and new energy sources. The first step is the Audi e-gas project; the project facility is currently being built in Werlte in the Emsland region and will begin operations in 2013.**

Anyone planning for future sustainable mobility first needs to adopt a new and broader perspective. For example, Audi no longer just considers the $CO_2$ emitted while driving. Rather, it analyzes the entire life cycle of a car – from its development and production to the phase of customer use and finally recycling.

A central issue in this comprehensive analysis relates to the origins of the types of energy used to drive vehicles. In the case of electrically powered cars, for example, environmental impact is only really improved if the electricity they consume was generated from renewable resources. Following this idea to its logical conclusion, it becomes clear that the focus must shift towards new types of fuels.

This realization has motivated Audi to pursue two courses of action. Firstly, the brand with the four rings is actively engaged in projects with third parties involved in the sustainable production of electricity. Secondly, Audi is the world's first carmaker to become directly involved in the development and production of renewable fuels that do not rely on biomass. Audi is addressing the entire range of drive technologies here, and the future fuels are called Audi e-power, Audi e-hydrogen, Audi e-gas, Audi e-ethanol and Audi e-diesel.

The first step is the Audi e-gas project, in which the Ingolstadt company is producing an entire chain of sustainable fuels. They begin with wind, water and carbon dioxide sourced from a biogas plant. The end products are renewably generated eco-electricity (Audi e-power), hydrogen (Audi e-hydrogen) and synthetic methane (Audi e-gas) which can power vehicles like the new A3 Sportback TCNG that will launch in 2013.

Over the mid-term, Audi also wants to create options for replacing liquid fuels by innovative renewable fuels that are no longer energy crop-based and do not compete directly with food production.

Right now, the brand is working with a specialist partner from the USA to produce synthetic ethanol (Audi e-ethanol) and synthetic diesel (Audi e-diesel).

## The Audi e-gas project

**In the Audi e-gas project, the brand with the four rings will be the world's first carmaker to synthesize a chain of sustainable fuels by 2013. Its end products are hydrogen and the synthetic Audi e-gas.**

The Audi e-gas facility that is currently being built in Werlte in the Emsland region will be operated with renewable electricity (e.g. from wind energy and solar energy). Expansion into the area of renewable energies is increasing the share of volatile energy sources – sometimes there is a surplus of electricity while at other times a shortage exists. The facility with its electrical power consumption of about 6,000 kW will preferably draw electricity whenever there is an electrical surplus. Then the facility could serve as a means for long-term storage of renewable energies, and this would solve one of the central problems of the transition to new energy sources.

The first step involves converting the electricity to produce renewably generated hydrogen by electrolysis – Audi e-hydrogen – which will be the fuel used to power future cars with fuel cell drive systems such as the Audi Q5 HFC technology platform. In this car, two high-pressure cylinders store the hydrogen under 700 bar pressure; a polymer electrolyte membrane fuel cell (PEM), which produces 98 kW, supplies the energy for the electric drive. Two electric motors output a system power of 90 kW and 420 Nm *(309.78 lb-ft)* of torque.

However, the infrastructure needed to supply hydrogen is lacking today. Audi is solving this problem by adding another innovative process step: combining hydrogen with $CO_2$ in a methanation system (downstream of electrolysis) to synthesize renewable methane – Audi e-gas. This natural gas substitute can be locally fed into the natural gas network to store the energy.

The Audi e-gas facility in Werlte, which Audi is now constructing with system builder SolarFuel, will be the world's first facility to convert renewable electricity and $CO_2$ into a synthetic natural gas that can be fed into the natural gas network on an industrial scale.

The Audi facility obtains its $CO_2$ from a biogas plant. The input material for the biogas plant is not energy crop plants, rather it is organic waste. This avoids any sort of competition with food production. The $CO_2$ is a waste product of the biogas plant that would otherwise be released into the atmosphere. The Audi e-gas facility uses the $CO_2$ as a feedstock for the fuel. This makes Audi e-gas a climate-neutral fuel – when it is combusted in the engine, the amount of $CO_2$ emitted is precisely the amount consumed by the e-gas facility beforehand.

Audi e-gas is an energy-rich fuel that is chemically identical to the fossil fuel methane, the primary constituent of natural gas, and it is excellently suited for powering internal combustion engines. According to forecasts, beginning in 2013 the facility in Werlte will produce about 1,000 metric tons *(1102.31 US tons)* of methane per year, and in the process it will chemically bond 2,800 metric tons *(3086.47 US tons)* of $CO_2$. That amount of renewably generated Audi e-gas could power 1,500 Audi A3 Sportback TCNG vehicles for 15,000 kilometers *(9320.57 miles)* per year in $CO_2$-neutral driving. In 2015, Audi plans to launch a second TCNG model on the market that is based on the A4.

The German energy industry could also benefit from the conceptual approach of the Audi e-gas project over the mid-term, because it must address the open issue of how to store eco-electricity efficiently and independent of location. When a lot of sea breeze is blowing, electrical overcapacities could be converted to Audi e-gas and be stored in the public gas network – with its 217 Terrawatt-hours of energy capacity, it is by far the largest energy storage network in Germany. If desired, it would be possible to convert the energy from the gas network back into electricity at any time.

The potential of electricity-gas coupling to store large amounts of wind or solar energy can provide tremendous impetus to renewable energies. The Audi e-gas project could easily be implemented in any countries in which natural gas networks exist.

<u>Audi A3 Sportback TCNG</u>

## The Audi A3 Sportback TCNG

**Audi is taking a large step towards sustainable mobility with the A3 Sportback TCNG. The compact five-door car that will make its debut in 2013 can use Audi e-gas – a $CO_2$-neutral fuel. It innovatively combines ecological balance, economy and high-tech solutions.**

The Audi A3 Sportback TCNG represents the most advanced level of natural gas powered technology in all aspects, beginning with storage of the fuel. Its two pressure tanks, placed under the cargo space floor, each hold about eight kilograms *(17.64 lb)* of natural gas.

In keeping with Audi's ultra lightweight design principle, polymer composite pressure tanks are used. They store gas at pressures of up to 200 bar and weigh around 70 percent less than conventional natural gas tanks – each tank is some 27 kilograms *(59.52 lb)* lighter. Their structure consists of a new type of matrix. The inner layer consists of gas-impermeable polyamide polymer, while a second layer of carbon fiber reinforced polymer (CFRP) gives the tank its extremely high strength; a third layer of glass fiber reinforced polymer (GFRP) provides rugged protection against damage from the outside. A high-strength epoxy resin is the adhesive which is used to join the CFRP and GFRP materials.

A second highlight of the Audi A3 Sportback TCNG is its electronic gas pressure regulator. This compact and lightweight component reduces the high pressure of the gas flowing from the cylinders down to around five to nine bar in two stages. It ensures that the right pressure is always present in the gas rail and at the injector valves – low pressure for efficient driving in the lower speed range, and higher when the driver calls for more power and torque. If the pressure in the tank drops below around ten bar, the engine management system automatically switches over to gasoline operation. The Audi A3 Sportback TCNG is bivalent; despite the engine being optimized for natural gas operation, it offers the same power and torque values when gasoline is used.

The car can cover over 400 km *(248.55 miles)* in natural gas mode and, if necessary, another 780 km *(484.67 miles)* with gasoline. This adds up to a total driving range equivalent to that of an Audi A3 TDI. Two indicators in the instrument cluster inform the driver of fuel tank levels at a glance. The filler necks are placed under a common fuel door.

The engine is based on the newly developed 1.4 TFSI. Key modifications relate to the cylinder head and turbocharging; the injection system and catalytic converter are specially configured for natural gas operation as well. With 81 kW (110 hp) and 200 Nm *(147.51 lb-ft)* of torque, the A3 Sportback TCNG accelerates to a top speed of over 190 km/h *(118.06 mph)*. The five-door premium compact car embodies Audi’s full technological expertise. The ultra lightweight design technology gives it a low weight, and it sets new standards in its segment in terms of its infotainment and driver assistance systems.

The highly efficient Audi A3 Sportback TCNG consumes a mere 3.6 kg *(7.94 lb)* per 100 km of natural gas or Audi e-gas – the fuel that is created in the Audi e-gas project. With either fuel, $CO_2$ tailpipe emissions are less than 100 grams per km *(160.93 g/mile)*. The greenhouse gas balance is even more attractive in a well-to-wheel analysis that accounts for all factors from the fuel source to the car’s wheels. When the A3 Sportback TCNG is powered by Audi e-gas, no more $CO_2$ is released than was chemically input in its production beforehand – creating a closed loop. When the energy required to build the e-gas facility and wind power generators is included in a comprehensive analysis, $CO_2$ emissions are still less than 30 grams per km *(48.28 g/mile)*.

Buyers of the Audi A3 Sportback TCNG will presumably obtain the e-gas at a public CNG refueling station via a certified ecological accounting method, similar to the method currently in existence for obtaining eco-electricity. When paying for the e-gas with a special fueling card, the transaction is centrally recorded, and the amount of e-gas purchased is debited from the amount of e-gas that the e-gas generating facility has fed into the natural gas network.

## Audi e-diesel and Audi e-ethanol

**$CO_2$-neutral mobility – of the type that Audi is striving to attain – is only feasible with new sustainable forms of energy that can replace fossil fuels over the long term. Audi is promoting the development of a fundamentally new technology, in which microorganisms produce diesel and ethanol without agriculture feedstock. This technology is at the core of the Audi e-diesel and Audi e-ethanol projects.**

The problem is very familiar: the combustion of conventional fuels based on petroleum releases carbon dioxide into the atmosphere. Current ethanol and diesel from renewable raw materials such as corn and rapeseed, generally achieve a better environmental balance, because the plants previously absorbed the $CO_2$ that is released in combustion. But these fuel sources require costly processing and compete with food agriculture. Over the long term, they cannot be a solution in a world witnessing steady population growth.

A radically new solution is needed to produce fuels for future $CO_2$-neutral mobility where the ‘feedstock’ for the fuel is entirely renewable. Audi is developing such a solution in a partnership with Joule, a US-based company producing fuels in a patented process that involves special microorganisms in a highly-scalable modular system.

The process is relatively simple: use the energy from the sun to convert $CO_2$ and non-potable water into liquid fuels. At the heart of this process are photosynthetic microorganisms (each one of around three thousandths of a millimetre in diameter). However, instead of using photosynthesis to grow more cells, the microorganisms continuously produce fuel. The inputs for this process are sunlight; industrial waste $CO_2$ from sources such as industrial plants and brackish or sea water. Critically, there is no need for agricultural land or fresh water.

The special microorganisms have been engineered to directly produce ethanol and diesel-range paraffinic alkanes – important components of diesel fuel – directly from the carbon dioxide. The fuel is secreted by these organisms, which is then separated from the water media and concentrated. No further manufacturing steps are required.

This technology makes Audi e-diesel and Audi e-ethanol come to life. For example, the e-ethanol project delivers a product with the same chemical properties as the bioethanol that is already established on the market, with the decisive advantage that it is produced without biomass. It will be used as a blend with fossil-fuel gasoline at percentages up to 85% in the case of vehicles able to use E85 fuel.

Along with the development of the Audi e-ethanol project, Audi is also working with Joule to produce a sustainable diesel fuel to support the Audi e-diesel project. A great strength of this product is its purity. In contrast to petroleum-based diesel, which is a mixture of a wide variety of organic compounds, this ‘drop-in’ fuel is free of sulfur and aromatics. Moreover, thanks to its high cetane number, a high-performance parameter, the fuel is very easy to ignite and its chemical composition permits unlimited blending with fossil-fuel diesel.

Audi e-diesel will result in a fuel that works seamlessly with existing Audi TDI clean diesel systems, posing no additional automotive engineering challenges.

Audi and Joule have commissioned a demonstration facility in the US state of New Mexico – in an unfertile region with a high level of annual sunlight. The facility is soon to begin operations with the production of sustainable ethanol. The productivity rates have shown decisive advantages over bioethanol. In addition, regions that are unsuitable for agriculture, e.g. desert regions, could be utilized for energy production.

The partnership between Audi and Joule has been in place since 2011. Joule has protected its technology with patents for which the brand with the four rings has acquired exclusive rights in the automotive field. Collaborative work includes technical support as well. Audi engineers with extensive know-how in the area of fuel and engine tests are helping to develop marketable fuels.

## Audi e-power

**In its vision of sustainable mobility, Audi is looking far beyond the usual timeframes of the automotive industry. The company is now engaging in initiatives related to the production of sustainable electric energy under the key concept of Audi e-power.**

In April 2010, Audi joined the international consortium Desertec Industrial Initiative (Dii GmbH). Its long-term goal is to generate climate-friendly solar energy in the deserts of North Africa and the Middle East. Audi is the only automotive manufacturer in the world to be named an Associated Partner of the consortium; the brand is initially working on creating suitable conditions and building up infrastructure.

In the deserts of the Middle East and North Africa alone, the sun radiates an energy equivalent to about 630,000 TWh over the course of a year – which is 30 times the total amount of electricity generated worldwide in 2010. It has been calculated that solar-thermal generating plants operating in the earth’s most sun-intensive regions could meet current global electrical requirements with an operating area of 83,000 square kilometers *(34,046 square miles)* – approximately the land area of Austria.

The industry initiative has set a goal of supplying most electrical needs for North African countries and the Middle East and a smaller share for Europe from solar and wind power. Audi sees great potential for sustainable energy supplies in this project.

The brand with the four rings wants to use a portion of the electricity from the Desertec project to manufacture and drive its e-tron vehicles. If necessary, excess generating capacity from solar plants could be stored in the natural gas network – based on the principle of electricity-gas coupling that will be implemented in the Audi e-gas project in Werlte starting in 2013. Another Audi e-power strategy is to partner with companies that produce components for solar-thermal power plants – a technology that enables flexible electrical production.

Life cycle assessment

## Environmental footprint

**Audi keeps a close eye on environmental factors even during the development of vehicles. An assessment is made of each model's environmental impact over all phases of its life cycle – development and production of the vehicle, recycling and – the most important factor – its operating phase. It is here in particular that the lightweight and efficient Audi models play out their strengths, especially when they are powered by renewable fuels that Audi is driving for the future.**

This environmental footprint, also known as an eco-balance or life cycle assessment (LCA), analyzes the environmental effects of a product over the course of its entire life cycle. It serves to quantitatively assess such environmental aspects as greenhouse gas emissions (including $CO_2$), energy consumption, acidification and summer smog. In generating its life cycle assessments, Audi applies a standardized process that conforms to the international ISO 14040 series of standards.

Today, the general public is very critically evaluating cars based on their fuel economy. Audi is taking an even longer view and is no longer simply concerned with $CO_2$ emissions that escape from the exhaust system while driving. Rather, all aspects are considered: the procurement of raw materials, production of individual parts and their composition, and the energy flows in production facilities, recycling and the operating phase.

In its production area, Audi strictly adheres to the principle of sustainability. Large building roofs are equipped with photovoltaic systems. Many efficiency and energy recovery technologies are at work at plants in Ingolstadt and Neckarsulm; both production sites make use of district heating distribution systems on a large scale. Car trains to the port of Emden are powered by sustainably produced electricity, and recycling efforts have been exemplary for many years now – every Audi is 95 percent recyclable.

The customer use phase is crucial to the environmental balance of a vehicle, since about 80 percent of emissions occur in this phase. Large improvements can be realized by optimizing vehicle weight, increasing drive efficiency and in producing fuels and electricity.

This is where Audi's strengths play a crucial role – in ultra-lightweight design, efficient drive systems and future renewable fuels. In the new Audi A3 – which has been made up to 80 kg *(176.37 lb)* lighter than the previous model, depending on the engine version – greenhouse gas emissions have been reduced by up to nine percent (in the 1.4 TFSI). For the first time at Audi, the A3 is being equipped with a new drive version – a natural gas engine. The TCNG model can be powered by Audi e-gas, the first representative of Audi e-fuels that achieve an even better environmental balance. When the A3 Sportback TCNG is powered by Audi e-gas, no $CO_2$ is released that was not first input in its production – achieving a closed loop. Even in a comprehensive analysis that considers the energy expended to build the e-gas production facility and the wind power generators, $CO_2$ emissions are still under 30 grams per km *(48.28 g/mile)*.

The weight of the Audi A6 was also trimmed by up to 80 kg *(176.37 lb)* – its body consists of over 20 percent aluminum. Although initial production of this lightweight material requires a higher energy input than steel sheet metal, improved fuel economy overcompensates for this effect after just a short number of miles driven. In the A6 3.0 TDI quattro with S tronic, the bottom line on greenhouse gas emissions is a 13 percent reduction, which represents a seven metric ton *(7.72 US ton)* reduction in $CO_2$ equivalents.

At the end of a vehicle's life, the aluminum components can be recycled with low energy input and no compromises in quality. The ASF body contains 38 percent secondary aluminum – a prime example of eco-friendly lightweight design as Audi understands it.

**Audi urban future**

Introduction Audi urban future

# Audi urban future

**A question that often plays a central role in Audi projects is the issue of the future development of global metropolises. Audi designers are providing answers with innovative vehicles and fresh ideas. At the same time, the Audi Urban Future Initiative, a company think tank, is seeking intelligent ways to give shape to the urban mobility of tomorrow.**

For years now, Audi has been setting benchmarks in vehicle design with its innovative show cars and technical concept cars – including quite recently. The Audi e-bike Wörthersee, for example, was conceptualized as a radical piece of sports equipment, while the Audi urban concept Spyder took the form of an ultra-light sports car with an electric drive. Whether on two or four wheels – what the two vehicles have in common is a concentrated, taut design language. Audi designers are thinking many years ahead in systematically evolving this design language. Always central to this thinking are the Audi core competencies e-tron, ultra and connect, which are also expressed in design.

The role of the car will change in future mobility. It will acquire even more capabilities and intelligence and become a “mobile device” – a tool for mobility with smart networking and communication solutions. New lightweight and efficient vehicles will increasingly populate the big cities. In some projects, Audi designers are working closely with students from international design colleges, to learn from young creative people how they perceive the mobile world of the future and to then transfer these findings to the Audi brand.

The Audi Urban Future Initiative, founded over two years ago, is a global forum that brings together experts from different cultures and disciplines. This is a place where architects, sociologists, urban planners and trend researchers meet to discuss new approaches to finding mobility solutions for rapidly growing metropolises. The range of topics is diverse. In some cities, the focus is on seamless mobility that interconnects different transportation modes, while in other metropolises the goal is to achieve flexible use of urban space. Intelligent communication between car and city is another theme.

An important component of the initiative is the Audi Urban Future Award that Audi created in 2010. It is Germany’s largest monetary prize for an architectural competition, and it is awarded every two years. In this year’s competition, five international architectural firms will address issues within their respective metropolitan areas: CRIT (Mumbai), Höweler & Yoon Architecture (Boston/Washington), NODE Architecture & Urbanism (Pearl River Delta), Superpool (Istanbul) and Urban-Think Tank (São Paulo).

The core topics of the Award are underpinned and discussed in research partnerships and workshops. At the Summit, a large symposium for networking knowledge that was held in advance of the Frankfurt International Motor Show in 2011, Audi brought experts from across the globe together at a roundtable. The Audi Insight Team, a small, active group of Audi employees from different work areas, transfers the many ideas of the Audi Urban Future Initiative into the company.

Audi Urban Future Initiative

## Audi Urban Future Initiative

**The world is changing at a rapid pace, and populations are growing more quickly. According to forecasts, 60 percent of all people will live in metropolitan areas with populations of over eight million people by the year 2030, primarily in Asia and South America. Audi is working to develop answers to the questions resulting from this trend, and in this context it created the Audi Urban Future Initiative over two years ago.**

The initiative is an interdisciplinary forum that networks creative thinkers – architects, sociologists, city planners and trend researchers – across the whole world, bridging the gaps between experts of various disciplines, cultures and perspectives. Their joint discussions target an analysis of mobility in the megacities of the world and seek to find possible solutions.

Besides covering technical aspects, the findings and ideas resulting from this process also incorporate social, environmental and aesthetic aspects. The goal is to merge actual local conditions and possibilities for a sustainable mobile future. The range of topics is as multifaceted as the megacities themselves: In some cities what is needed is flexible, spontaneous use of public space, while in others the focus is on seamless mobility that combines different modes of transportation.

Grand futuristic visions also have their place in the Audi Urban Future Initiative – such as the idea of the city as a continual flow of movement without stationary traffic. Another topic is intelligent communication between car and city. Today, Audi is already developing technologies for such scenarios – solutions for piloted driving as well as car-to-X-communication under the heading of Audi connect.

An important component of the Audi Urban Future Initiative is the Award that Audi created in 2010; with a prize of 100,000 Euros, it is the most lucrative architectural competition in Germany. This year, Audi will be offering the Award for the second time; the competition revolves around the question of how mobility can become an engine of urban development.

The five participating architectural and urban planning firms are: CRIT (Mumbai), Höweler & Yoon Architecture (Boston/Washington), NODE Architecture & Urbanism (Pearl River Delta), Superpool (Istanbul) and Urban-Think Tank (São Paulo).

All of these firms are drawing up concepts for the metropolitan regions in which they reside. In May, the participants already met for an introductory workshop in Ingolstadt – the "Metropolis & Mobility Dialogue" – where they presented their ideas and discussed them with Audi experts. In October, an international jury will announce the prize winner in Istanbul.

Core topics of the Award are underpinned by research partnerships and workshops and are discussed with Audi employees. At the Summit that was held in advance of the Frankfurt International Motor Show in 2011, Audi experts from across the globe were summoned to a roundtable. The ensuing discussion addressed the need to overcome entrenched thinking and take up new sustainable paths towards a mobile urban future. The topic was "Energies – what are the forces that will reshape the cities of the future?"

The current research program consists of two projects with Columbia University in New York. The Audi Urban Future Initiative is creating a global network of experts here that is developing an academic knowledge base for future mobility scenarios while always relating this knowledge to local circumstances and discussing these relationships.

<u>Audi Design</u>

## Audi Design

**In the future there won't be just the automobile, but rather various forms of mobility, for which the Audi designers are developing new concepts and creative ideas. All of these follow the line of progressive sportiness that defines the brand's character. Audi constantly seeks to engage young design students in dialogue to get as many ideas as possible for the mobile world of the future.**

Audi designers are working today to shape the mobility of tomorrow, in all kinds of ways. A sport machine like the Audi e-bike Wörthersee is a bicycle technology concept intended to explore the limits of technical feasibility through the application of Audi's brand competences "design," "ultra," "connect" and "e-tron." A high-end pedelc show bike made by Audi for sport, fun and tricks. The Audi urban concept Spyder is an ultra-lightweight, electric-powered sports car featuring a radical concept and great versatility. Both technology studies have one important element in common: the taut, concentrated design language that characterizes the brand.

To further expand this global leadership role, the Audi designers are on the constant lookout for new impulses and approaches. Creative ideas are more important today than ever before, as the significance of the automobile will change greatly in the diverse mobility of the future.

For young customers, particularly those in Europe and the United States, the significance of the automobile as an individual status symbol is changing. Its expression of achievement and luxury will become secondary as new values gain increasing importance: those of sharing rather than owning, and integration into sustainable mobility. New needs, such as seamless networking with the community and wide-ranging interaction with the surroundings, have already been created and will become more firmly established. In the medium term, these requirements will lead to a new architecture for the automobile. At the same time, electric drive systems enable innovative packaging concepts that will make these changes possible.

The new role of the automobile in society will create space in major cities for other forms of individual mobility: for lean, lightweight and efficient vehicles with two, three or four wheels; for e-pedelecs, e-skateboards, e-trikes and e-quads. For now the ideas and possibilities are boundless. Audi designers are working to integrate these still young trends into a cohesive image, on the basis of which they will then develop the appropriate solutions for Audi.

A key tool for these innovations are the partnerships that Audi regularly engages in with renowned design schools throughout the world, most recently with Pforzheim University, the Royal College of Art in London and the Italian schools Milan Polytechnic University and Scuola Politecnica di Design.
The creative, open dialogue that the Audi designers engage in here with the students offers numerous advantages to both sides. The Design department learns from the young designers how they see the mobile world of the future and how they would like to see the brand’s design evolve. Together they develop design concepts for tomorrow. This can even help the young creative talents land a contract with Audi. The company regularly awards internships and diploma project positions, offering the best young designers an opportunity for a career at Audi. A dialogue with friction, so to speak, that ultimately provides both sides with many creative impulses.

## Audi urban concept Spyder

**The technology study Audi urban concept Spyder – the star of the Frankfurt International Motor Show in 2011 – makes a tangible statement about the mobility of tomorrow. It is a vehicle for contemporary people who live in urban metropolitan areas. The show car, powered exclusively by electricity, embodies the elements of a race car, roadster, fun car and city car.**

The look of the technology study, painted in white, is dynamic and emotional, and ultra-lightweight design by Audi keeps its unladen weight at just 480 kg *(1058 lb)*. The lean body, with a hexagonal single-frame grille at the front, combines a monocoque made of carbon fiber reinforced polymer with an aluminum structure; its exterior skin consists entirely of CFRP. A low band of windows that descends towards the rear surrounds the occupant cell on three sides.

Protective body panels with turn signal light strips made of LED light conductors cover the free-standing 21-inch wheels; they are suspended by wishbones that are also made of aluminum and CFRP. The springs and shock absorbers were designed in pushrod technology, as in race cars, while four disc brakes handle the braking.

A lithium-ion battery is mounted transversely behind the seats; it stores 7.1 kWh of energy. The two electric motors between the rear wheels produce a combined 15 kW (20 hp) of continuous power and 47 Nm *(34.67 lb-ft)* of torque. The car’s driving range in the European driving cycle is a full 70 km *(43.50 miles)*. The urban concept Spyder is a forerunner of new smart mobility from Audi.

The seating concept also breaks from convention. It seats two persons in a slightly offset layout, and they sit in low, sporty positions. The long doors open forward and upward, and handles on the A-pillars make entry easier. Along with the open body version, Audi has also developed a closed coupé. Its roof can be slid open, and it can remain open underway.

All user controls and materials were subject to the strict dictate of ultra-lightweight design, so they convey a very special fascination. For example, the steering column is suspended in free space – it consists of a strong profile in elegant design, is mounted nearly horizontally and has a long adjustment range. The small, hexagonal steering wheel contains control buttons and rollers, including controls for the driving programs of the electric drive. A display directly in front of the driver shows all key information.