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The Audi e-tron GT: Production and sound development

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Condensed Information

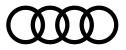
Passion for quality and progressiveness: the new Audi e-tron GT

Passion for detail, maximum precision, and top quality: The new Audi e-tron GT reflects all the passion with which Audi develops and builds cars. For the production of the electrically powered Gran Turismo at Audi Böllinger Höfe at the Neckarsulm site, the company uses customized new technologies – however, the finishing touches are applied by highly skilled hands. And since the dynamic work of art must also sound good, Audi has brought musical flair and technical competence to bear in composing a unique sound for the e-tron GT. It sounds powerful and progressive – just as an Audi should.

Production of the Audi e-tron GT

The Audi e-tron GT is the brand's first fully electric car to be built in Germany. The Gran Turismo will start rolling off the production line at Audi Böllinger Höfe at the Neckarsulm site at the end of 2020. The small-series production facility has been expanded, upgraded, and converted for its new role. The skilled craftsmanship from the previous facility has been retained and is supplemented by digital processes and smart technologies. During the expansion, production planners made use of new virtual methods. The tests of the work procedures on the assembly line and the logistic processes were conducted in the virtual domain for the first time, with container planning also performed with the help of VR technology. Production of the e-tron GT was designed without physical prototypes – a first at Audi.

Large areas of the body of the all-electric Gran Turismo are constructed from ultra-highstrength steel and aluminum. To produce this material mix in the planned quantities, a body shop was established that combines the skilled craftsmanship of the employees with the full potential of automated production technology. It consists of an innovative body assembly line along which each body passes twice. It is constructed around what is called the two-way framer, in which ten robots are used to attach the inner and outer side panels. It combines all manufacturing steps involved in joining the sides in a single system – thus making production of the Audi e-tron GT possible on the existing floorspace.



The inline measuring procedure for the bodies is also new. It guarantees even greater accuracy and can respond very quickly to minute deviations. At the end of the body assembly line is where precise craftsmanship comes into play: Experienced workers fit the add-on parts and check the finish of the completed body. The expressive design of the Audi e-tron GT places unusually high demands on production quality – the side wall frame, for instance, has a remarkably large draw depth of 35 centimeters (*13.8 in*) between its highest and lowest point.

The expanded assembly line includes 36 instead of the previous 16 cycles. The e-tron GT shares it with the R8 – this integration of two technically completely different cars is unique in the Volkswagen Group. Both models are moved using the same driverless transport vehicles and an electrically powered monorail system. At one station of the line, humans and robots work side by side. A 3D printer is also on hand to produce customized assembly aids at the employees' request. Once completed, every car is driven for 40 kilometers (24.9 mi) on public roads, which also includes sections on the highway and in urban traffic.

"With the integration of the Audi R8 and Audi e-tron GT, a unique combination of craftsmanship and smart factory technology is coming to life at Böllinger Höfe," says Production Head Wolfgang Schanz in summary. "I am especially proud of the passion and spirit of our team."

The e-sound of the Audi e-tron GT

Whether it's quality, design or technical characteristics – the Audi e-tron GT is a car packed with all the passion of Audi. This also applies to the sound of the electrically powered Gran Turismo. Engineers Rudolf Halbmeir and Stephan Gsell conceived and designed the progressive electronic sound – on the computer, in the sound laboratory, inside the moving car, and in customer studies.

As with every electric car, the e-tron GT also features the statutory acoustic vehicle alerting system (AVAS), although embedded within a broader acoustic spectrum. A loudspeaker fitted in the front of the vehicle emits the AVAS sound. For customers ordering the optional sound package, a second, large loudspeaker is added in the rear. In parallel, two loudspeakers in the interior provide an emotional sound experience. Two control units continuously remix the e-tron GT sound based on variables such as speed or accelerator position. The Audi drive select system allows drivers to set whether and how intensively they wish to experience the sound.

<mark>Audi</mark> MediaCenter



Facts and figures

Production

- Production of the Audi e-tron GT at Audi Böllinger Höfe, which opened in 2014 at the Neckarsulm site; expansion and conversion 2019; new virtual planning methods
- Head of Production Wolfgang Schanz: "Here, we are bringing a unique combination of craftsmanship and smart factory technology to life"
- The body shop for the e-tron GT is around 85 percent automated; ten stations with a total of 34 robots
- Optimum area management with a body assembly line along which each body passes twice; two-way framer combines multiple manufacturing steps on limited floorspace
- Correlation-free inline measurement is a new technology offering the highest precision, with a maximum possible deviation of just +/-0.20 millimeters
- The joint assembly line for Audi e-tron GT and Audi R8 despite their different technology concepts is unique in the Volkswagen Group
- Different conveyor technologies on the assembly line: 20 driverless transport vehicles, new electrically powered overhead conveyor rail, autonomous transfer station
- > Human-robot cooperation for bonding the front and rear windows
- > Customized assembly aids from the 3D printer based on employee ideas

e-sound

- Development of the e-sound for the Audi e-tron GT with musical creativity and technical competence; designed on the computer, in the sound laboratory, and in the car
- 32 individual sound elements; weighted and modulated based on drive management data
- Optional sound package: two control units in the luggage compartment, two external loudspeakers on the car and two internal loudspeakers in the rear doors
- > Sound characteristics can be adjusted across multiple stages using Audi drive select





The information in detail

High-tech meets craftsmanship: production of the Audi e-tron GT at Böllinger Höfe

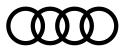
At the end of 2020, series production of the Audi e-tron GT will commence at Böllinger Höfe, where the R8 high-performance sports car is already being built. Although the facility uses customized new technologies, the finishing touches are applied by experienced workers with a keen eye for detail and a steady hand. The production layout is also unusual. Although the bodies of the two very different models are constructed separately, they are assembled on a joint line. With this concept, which is unique in the Volkswagen Group, Audi is demonstrating the flexibility of its production setup at Böllinger Höfe.

Production of the Audi e-tron GT

Unique in the Group: the production layout at Audi Böllinger Höfe

Wolfgang Schanz, a car enthusiast through and through, has spent over 20 years working on premium vehicles and sports cars for Audi and Porsche. Around four years ago, Schanz took over as the Head of Production at Böllinger Höfe, where he knows every manufacturing step and every part of the R8. This experienced engineer is not easily impressed – but when he talks about the e-tron GT, his enthusiasm is immediately apparent. "Production as it is done here does not exist anywhere else in the Group," says the production manager. "We have successfully brought together two completely different vehicles on a joint assembly line: The R8 high-performance sports car with a V10 internal combustion engine is joined by the e-tron GT as an all-electric powered Gran Turismo."

According to Schanz, this was only possible because of highly flexible planning and a policy of bringing together the best of both worlds. "We retained the skilled craftsmanship from the R8 facility and supplemented it with new, smart technologies. Our employees also immediately transferred all of their passion for the R8 to the e-tron GT."



The Audi Böllinger Höfe facility in Heilbronn forms part of the Neckarsulm site. Designed from the outset as a small-series production facility with innovative and flexible processes, production of the Audi R8 commenced there in the fall of 2014. To integrate the e-tron GT, production operations were not only expanded but also upgraded and converted: Ultra-modern systems were installed in the body shop and assembly areas. In addition, new logistics halls were constructed with approximately 10,000 square meters (107,639.1 sq ft) of space on the ground floor as well as a further 800 square meters (8,611.1 sq ft) in the basement. Most of the conversions at Böllinger Höfe were completed while the site was in operation. The first all-electric Audi car to be produced in Germany will roll off an assembly line shared with the R8 from the end of 2020. However, the upstream body shops will be kept separate.

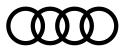
Once production of the e-tron GT starts, the energy supplied to Böllinger Höfe will come 100 percent from renewable sources, with biogas providing a climate-neutral heat supply. Since the start of the year, the site has been using exclusively eco-electricity for its automobile production operations, and this applies equally to the Neckarsulm plant and Böllinger Höfe.

Headset and controller: new VR tools saved time and resources

By also relying on resource-saving procedures for its production planning activities, Audi was able to plan and realize the production of a new vehicle with unprecedented speed. Employees used virtual reality headsets and controllers to test all assembly processes and the associated logistics processes in digital form – even the container planning was supported by VR. Audi developed its own VR software for this purpose – a pioneering project in the Volkswagen Group. It is based on 360-degree scans that provide a three-dimensional indoor map of the virtual space. The e-tron GT is the first vehicle in the Group to undergo tests of all assembly sequences entirely without a physical prototype.

Thinking big in a small space: the body shop

Large areas of the passenger compartment of the all-electric Gran Turismo are constructed from ultra-high-strength steel, and the outer skin is made entirely of aluminum. This material concept differs fundamentally from the Audi Space Frame (ASF) of the R8 high-performance sports car and its motorsports derivatives, which are almost entirely built by hand. Therefore, a new body shop for the Audi e-tron GT was set up on the existing floorspace.



It begins with an ultra-modern body assembly line incorporating 34 robots that is approximately 85 percent automated – almost like a conventional volume production line. A total of nine "warm" and "cold" joining techniques are used, ranging from resistance spot welding to screws all the way to rivets and bonding. Christoph Steinbauer, Head of the Body Shop, explains the principle: "The body of the e-tron GT passes through ten stations on our body assembly line. It runs in a loop twice around the line because we want to use the available space as efficiently as possible."

Ten robots and 32 tools: the two-way framer

The two-way framer, a large clamping and attachment system, acts as a central station in the body assembly line. During the first pass, this is where the inner side panels are precisely positioned and joined. The outer side panels are attached during the second pass. The framer integrates ten robots, which use 32 high-tech tools to perform all joining techniques. Between the two passes and during the work steps, they switch between tools automatically.

The two-way framer exemplifies the flexible and innovative nature of the manufacturing process at Audi Böllinger Höfe. It is also what makes production of the e-tron GT there possible in the first place. A conventional body shop would have required two separate framers and therefore two body assembly lines, which would have used up much more space. "The double pass concept is a smart solution," says Steinbauer.

Ushering in a new era of precision: correlation-free measuring

Another new addition to the Audi Group is the station at which correlation-free measuring is performed – it represents an evolution of the previous inline measuring procedure. At the end of the two passes, two robot-guided optical measuring heads check the exact dimensional accuracy of the body. They do so by approaching 150 measuring points during the first pass and even 200 during the second. Ten room cameras calibrated to one another detect the exact position of the measuring heads; this comparison reduces the possible deviation from +/-0.30 millimeters to +/-0.20 millimeters. The volumes of ultraprecise data generated in the process make it possible to react quickly and predictively to even the smallest deviations.

In addition to high-tech systems, the body assembly line includes two manual stations. Here, welded connections are created with levels of precision and quality that call for specialist skills. The employees here profit from their expertise gained through many years working with the ASF for the Audi R8.



With a keen eye and a steady hand: the mounting stage

Following the largely automated body assembly line, the body enters what is called the mounting stage, where trained body manufacturers mount the fenders, the doors, and the engine hood. Group spokesman Marc Rickert focuses on the precise, uniform gap dimensions and the quality of the surfaces. On the outer skin parts, even minute tolerances in the dies or slight carelessness during transport and handling can cause tiny minute imperfections – this demands the greatest care and attention.

Traditional craftsmanship is indispensable in the construction of the e-tron GT, which is also clear from Rickert's professional career. The group spokesperson is a trained carpenter and joined Audi eight years ago. "At the time, the transition from the first to the second Audi R8 generation had been initiated, and Audi was looking to bolster its team for the body shop," he reports. "As a carpenter, you develop a keen eye and good intuition in dealing with surfaces – it's not much different with metal than it is with wood. It's an ability that you never lose, and it even gets better over time as a result of continuous training."

"A draw depth of 35 cm (13.8 in) – this has never been done before"

After completing the mounting stage, the bodies enter the finishing area, where they undergo yet another meticulous investigation by production and quality assurance specialists. Christoph Steinbauer knows the particularly challenging areas, such as the transitions between the doors and the adjacent surfaces. The expressive design of the Audi e-tron GT places maximum demands on production quality; it also fills the specialist with enthusiasm: "The side wall frame has a draw depth of 35 centimeters (*13.8 in*) between the highest and the lowest point – and we're using aluminum, which is a far more brittle material than sheet steel. Even for Audi, this is new. This is also the limit of what can be achieved with the current state of technology."

Autonomously from basement to assembly line

After being painted at the Neckarsulm plant, the bodies of the e-tron GT are briefly stored alongside those of the R8 in a high bay in the basement of Böllinger Höfe. Driverless transport vehicles bring them to the joint assembly line on the ground floor. They orient themselves automatically with the help of a navigation map that contains a digital representation of the surroundings. Two laser scanners at the front and rear detect the surroundings – ensuring that each driverless transport vehicle knows its exact position at all times. The 20 vehicles that together complete the distance of around 23 kilometers (*14.3 mi*) on each working day are used not only for transportation but also for assembly purposes during the cycles. Every driverless transport vehicle can carry both body types, and it adjusts its height to enable ergonomic working.



Audi e-tron GT and R8 on a single line: assembly

The small-series production facility at Böllinger Höfe also shows its flexibility at the assembly stage. The Audi e-tron GT and R8 pass down the same line, precisely coordinated like a good orchestra. The same is true of the parts supply: The logistics experts control the two complex chains in such a way that all parts arrive at the right moment and in the required sequence at the corresponding assembly cycle.

During assembly, three conveyor systems manage the flow of vehicles: the driverless transport vehicles, a newly installed electric overhead conveyor rail system, and a conveyor belt at the end of the line. Driverless transport vehicles convey the painted bodies through the first cycles. They then hand over the burgeoning car to the overhead conveyor rail at a fully automated transfer station. This system takes the car through a closed loop, which ends up back at the station after 15 cycles. The driverless transport vehicles now take over again and transport the vehicles through the other cycles of the assembly line.

For the e-tron GT, Audi has extended the assembly process by 20 to 36 cycles, with a cycle time of 15 minutes. "All our employees have mastered the work steps on the R8 and on the e-tron GT. This means that they perform many different steps in a single cycle," explains Assembly Head Sascha Koch. All employees in the assembly hall have a raised awareness of high voltages and have received instruction on how to deal with high-voltage electrical components and drives. Other employees have completed higher-level training depending on the nature of their role.

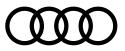
74 screw fittings: the marriage of drive, suspension, and body

During the first cycles of the electric overhead conveyor rail, employees install the interior of the e-tron GT. This is followed by the marriage of the assembled bodies with the battery, electric motors, and suspension. These major technical modules are placed on a workpiece carrier, which is positioned below the body with millimeter precision. The marriage is performed as a meticulously choreographed engineering ballet: Employees screw the battery and the drive components to the body at 74 points. They do so using intelligent, self-positioning power screwdrivers.

Humans and robots side by side: fitting the windows

The assembly process relies on precise and skilled handiwork supported in some areas by employees of steel. One example of this is the installation of the front and rear windows in the body – which is carried out by human-robot cooperation without the need for safety barriers. Two workers place the window onto a fixture with automatically adjustable retainers. They then step aside while the robot applies the adhesive. After that, the employees take over again and fit the window to the body with extreme precision.





Many stations use assembly aids – specially created tools – to ensure ergonomic working. Employees who come up with good ideas to improve these can turn to the in-house <u>3D</u> <u>printing center</u>. The team of experts from Böllinger Höfe joined forces with a start-up from Berlin to develop a piece of software that reduces the design time for pre-assembly jigs and fixtures by 80 percent. Generally, all that's required is a sketch, which can often be transformed into a finished printed part in a matter of hours.

On the final stretch: commissioning and tests

The final stations on the conveyor belt are devoted to the commissioning processes where the highly integrated systems are finally activated. Employees drive the car over the dynamometers and calibration stands for the suspension, headlights, assist systems and braking systems. After that, the Audi e-tron GT completes its first kilometers on the road. Every car is driven along a test and vibration track with different surfaces at the Böllinger Höfe premises, after which it completes a journey of around 40 kilometers (24.9 mi) on public roads, which includes driving on the highway and in urban traffic. During these tests, trained drivers focus on the smallest details. Do all the moving parts – from the air vent to the lid of the glove compartment – fit together exactly? Or can creaking sounds be heard somewhere when the car is driven on cobbled streets? Can leather or plastic parts be heard rubbing against each another? And do all systems and displays function flawlessly?

Up to 60 bar of pressure at 40 nozzles: monsoon rain in the chamber

Back in the assembly hall, the all-electric Gran Turismo must undergo a leak test in the rain chamber, which simulates heavy monsoon rainfall. For eight minutes, water is fired at the car through 40 nozzles, each of which can deliver up to 25 liters (0.9 cu ft) per minute at a pressure of 60 bar. The cycle is closed: Water is circulated, processed, and reused by internal pumps.

The final station through which the e-tron GT passes at Audi Böllinger Höfe is the finish check in two consecutive light tunnels. It takes place under the close supervision of production and quality assurance specialists. This is where the manual skills that no camera and no robot can replace are required one last time. A total of 44 light cassettes are installed in the first tunnel – twelve each provide light from above and from the sides while a further eight cassettes are mobile. This configuration helps detect minute deviations in the paintwork. The focus in the second light tunnel is on the joins and gaps, and the employees can make the last-minute fine adjustments if necessary.

All checks and finishing measures on the e-tron GT serve the same goal: ensuring the premium quality of Audi and providing every customer with a perfect car. And that, as Production Head Schanz explains, is a very personal matter for every employee in Böllinger Höfe.





Six statements by Wolfgang Schanz Wolfgang Schanz, Head of Production, Audi Böllinger Höfe, about...

... the character of the production line: "The fact that the Böllinger Höfe plant was conceived in the design phase as a small-series production facility with innovative and flexible production processes gives us the ideal conditions to produce the e-tron GT. What is created here is the result of a unique combination of craftsmanship and smart factory technology."

... the evolution of craft-scale production: "We are retaining the strengths of craft-scale production and will continue to use them in the future. At the same time, we are expanding our expertise with the e-tron GT by adding new competencies in the fields of electrification, automation, and digitalization. In doing so, we are combining the best of two worlds at Böllinger Höfe."

... the flexibility of production: "We have used the available space to implement production that is both lean and flexible. Everything goes hand in hand here. This allows us to assemble the e-tron GT and the R8 with the same employees on a joint assembly line."

... on the interaction between large-scale and small-series production: "In our small-series production facility at Böllinger Höfe, we are adapting and scaling various methods from large-scale production. At the same time, we are developing and using completely new solutions, which in turn provide us with important insights for large-scale production."

... on Industry 4.0: "We have established a lot of new methods, starting with the planning of assembly sequences, which was done virtually for the most part. We have introduced correlation-free measuring in the body shop. And the assembly aids from the 3D printer are already proving to be a great asset."

... on the motivation of the employees: "The team's enthusiasm fills me with great joy. In many respects, building our cars is a craft that requires a lot of attention to detail. Our employees have transferred the great passion with which they have been building the R8 so far to the e-tron GT."

Experience Böllinger Höfe interactively: In the Audi MediaCenter, interested persons will find texts, photographs, videos, graphics and other information on the production of the e-tron GT.



Creativity and classic engineering work: e-sound of the Audi e-tron GT

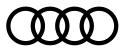
Powerful and progressive – all cars by Audi produce sound signatures that are balanced and harmonic in keeping with the brand. This also applies in particular for the e-tron GT. Engineers Rudolf Halbmeir and Stephan Gsell "composed" its digital sound.

The sound of a car is a unique quality – one that can be physically described but must above all be experienced live. We feel sound in our gut, and it touches our heart; it sends signals. Low frequencies create an impression of serene power, while mid-range frequencies express sportiness and agility. High frequencies provide a degree of brilliance and go well with the sonic backdrop of an electric car. The way the pedestrian on the street hears the external sound of a car is completely different from how the driver and front passenger experience the interior sound. They are only consciously aware of it in certain situations, yet it has a powerful influence on their driving experience.

Basic research: violin, guitar or didgeridoo? Plastic pipe!

"In principle, the sound of a car has much in common with music," says Rudolf Halbmeir. The Audi sound designer is a dedicated musician who writes songs in his spare time and plays all the instruments himself in his private recording studio. Halbmeir reports: "To find the basis for the sound of the e-tron GT, I tried all sorts of instruments – from the violin to the electric guitar all the way to the didgeridoo, a wind instrument from Australia. But none of them were really suitable. Then I came across a piece of plastic pipe lying in the garden, it was 3 meters (9.8 ft) long and had a cross-section of 80 millimeters (3.1 in). I attached a fan at one end and listened to the sound coming out the other end. It was a very specific, deep growl – and I knew straight away that I had discovered the foundation of the sound."

This creative moment was followed by traditional engineering work conducted both in the Audi sound laboratory and on the computer in the office. As a tool, he used a program that the team of Audi sound designers had written themselves, inspired by commercial software used for creating music. Halbmeir and his colleague Stephan Gsell used it to continuously develop the frequency structure into a finely balanced sample of 32 sounds. These include processed synthesizer sounds and, for instance, sounds made by a cordless screwdriver. The repertoire also features recordings of a model helicopter, and several variants of the plastic pipe can also be heard in the sound of the e-tron GT.



It is a synthetic sound that authentically conveys the work of the drive system

Another part of the development work was completed over many kilometers spent inside the car. After all, it is only here that real everyday conditions can be experienced – the movement, the wind and tire noises, the other vehicles. "Our sound is continuously recreated as the algorithm mixes and prioritizes the individual sounds differently," explains Stephan Gsell. This is based on data about the rotational speed of the electric motors, the load, the vehicle speed, and other parameters supplied by the drive management. When the car is driven slowly, the e-sound is discreet, becoming fuller and more dynamic as speed increases. Although synthesized, it creates an authentic and finely nuanced impression of the work performed by the drive system.

"The sound of the e-tron GT must be appealing in every driving situation," adds Gsell. "And naturally, one can't rely on the preferences of individuals like us." With this in mind, the Audi engineers invited 130 guests to participate in a customer study during the development phase. They sat behind a curtain and evaluated the sounds generated by passing cars – providing valuable input for the development work.

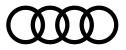
And how does the electric powered Gran Turismo from Audi sound? "We deliberately avoided imitating an internal combustion engine or a spaceship from a science fiction movie," explains Halbmeir. "Instead, we developed a sporty, expansive and sophisticated sound that also comes across as clear and distinctive. It combines familiar sound patterns with new, futuristic elements." The sound of an Audi is more than just motor or engine noise. It is the acoustic expression of sportiness, sophistication and a progressive character – all the more so in the world of electric mobility.

Entirely up to the customer: the sound package in the e-tron GT

Customers of the Audi e-tron GT can decide for themselves whether and how they wish to hear the e-sound. Standard equipment includes the statutory warning sound at low speeds, known as AVAS (Acoustic Vehicle Alerting System). It is emitted by a loudspeaker positioned in the front area of the car. At high speed – from 20 km/h (*12.4 mph*) in the EU and from 32 km/h (*19.9 mph*) in North America – it becomes gradually quieter and is inaudible at 60 km/h (*37.3 mph*). Even in this standard version, the statutory sound components are embedded within a broader sound palette that exceeds the legal requirements.

The optional sound package delivers a far more emotional sound experience. Two control units and amplifiers positioned in the luggage compartment generate the exterior and interior sounds. In this configuration, the front exterior loudspeaker is joined by a counterpart in the rear end along with two loudspeakers in the rear doors for the interior sound. Their comparatively large dimensions allow them to accurately reproduce frequencies down to 65 Hz.





In the Audi drive select dynamic handling system, the driver can set how the e-sound is delivered. In efficiency mode, it is restricted to the AVAS warning sound. In the comfort profile, the rear exterior loudspeaker comes into play – delivering full and sophisticated exterior sound and remaining active up to the top speed. In dynamic mode, both exterior loudspeakers become louder, and the interior sound is added. The e-tron GT is the first electrically powered Audi model in which customers can configure the listening experience themselves – from the silence of the electric drive all the way to the fascinating sound backdrop.