Innovative Technologies in Current and Future TFSI Engines from Audi

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Summary

Over the last 7 years the turbocharged direct-injection SI engine – designated TFSI by Audi – has successfully penetrated the market for passenger car SI engines. Thanks to its many significant advantages, TFSI technology will replace most other SI engine concepts in the near future, just as TDI technology did in the past.

As the pioneer and technology leader in TFSI, Audi has continually enhanced its TFSI technology since its first production fitting of a direct turbocharged engine in Europe and NAR in 2004. In 2011 Audi launched what is already its third generation of four-cylinder inline TFSI engines onto the market. Once again, this third generation incorporates many innovative technologies applied to an SI engine for the first time anywhere in the world.

In addition to the Audi Valvelift System, for the first time the engine has a cylinder head with integrated exhaust manifold and complete cylinder firing sequence separation, an electric wastegate actuator, an innovative thermal management system and a completely new mixture preparation system in order to comply with future exhaust emission standards.

The presentation details the design and working principle of the new technologies in the third generation TFSI engine. It also looks ahead to potential further technology advances for future SI engines.

1 Introduction

Exhaust gas turbocharging has a long-standing tradition at Audi. Since the initial launch of a turbocharged petrol engine in 1979, Audi has been continually advancing its turbocharger technology.

There were two outstanding events, however, which dictated the future of Audi engines – and ultimately then also of petrol engines in general. Whereas in the period from 1979 to 1995 Audi turbocharged engines were deployed only in specialist sports designs and in a few high-end applications, the launch of the four-cylinder inline 1.8l 5VT in 1995 marked the breakthrough for the turbocharged engine as a widely accepted standard power unit for passenger cars.

The introduction of TFSI technology in 2004 then saw the beginning of a new era in petrol engine technology.

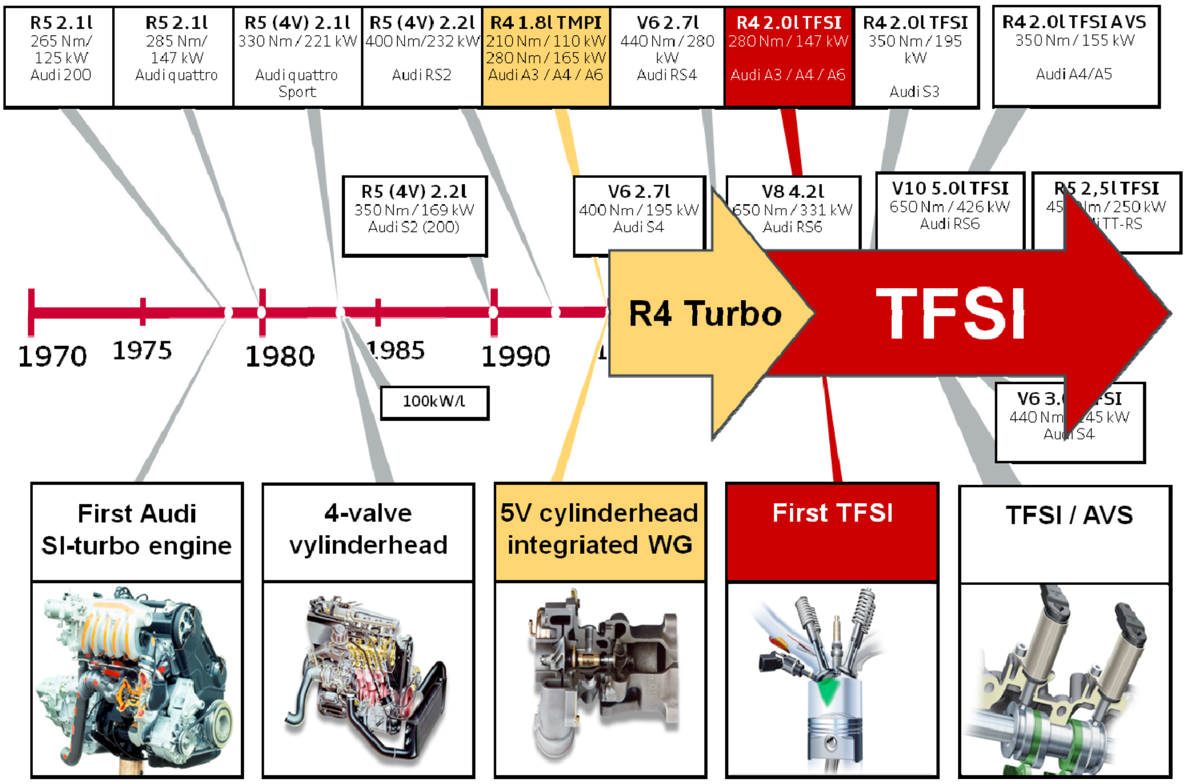


Fig. 1: History of petrol engine turbocharging at Audi

TFSI enabled torque and power output – and especially low-end torque and dynamic responsiveness – to be significantly improved, meaning that TFSI engines suffered hardly any disadvantages compared to induction engines with the same power output. Quite the contrary in fact: the high torque even at low engine speeds made TFSI engines highly appealing to drivers. The high compression ratios made possible by TFSI, and the downsizing and downspeeding advantages it delivered, brought further significant reductions in consumption both under testing and in customer applications.

In the years following 2004, Audi continually advanced its TFSI technology. Key milestones were the launch of the EA888 engine series in 2006, marking the second generation of TFSI technology and for the first time featuring a flushing charge cycle. The combination of TFSI and the Audi valvelift system implemented for the first time in 2008 represented a further major advance. This enabled a specific torque of 175 Nm/l to be realised for the first time in a non-sport design. Thanks to the significant increases in low-end torque and the improvements in dynamics, the 2.0l TFSI engine could be combined with long gear ratios and retained its good levels of driveability even from low engine speeds. Maximising downspeeding potential also enabled consumption to be greatly reduced.

Other milestones in the history of TFSI from Audi were the launch of the S3 engine in 2007 and the introduction of a TFSI design onto the North American market – the latter development also for the first time enabling compliance with stringent SULEV exhaust emission limits. In 2010 a Flexfuel version of the 2.0l TFSI engine was launched, capable of running on fuels with different ethanol contents up to and including E85.

In the summer of 2011 Audi launched the third generation of its four-cylinder inline TFSI engine onto the market. This engine generation is again characterised by a large number of innovative technologies, some of which are being deployed for the first time in mass production. The next section deals in detail with the technologies and performance data of the third generation.

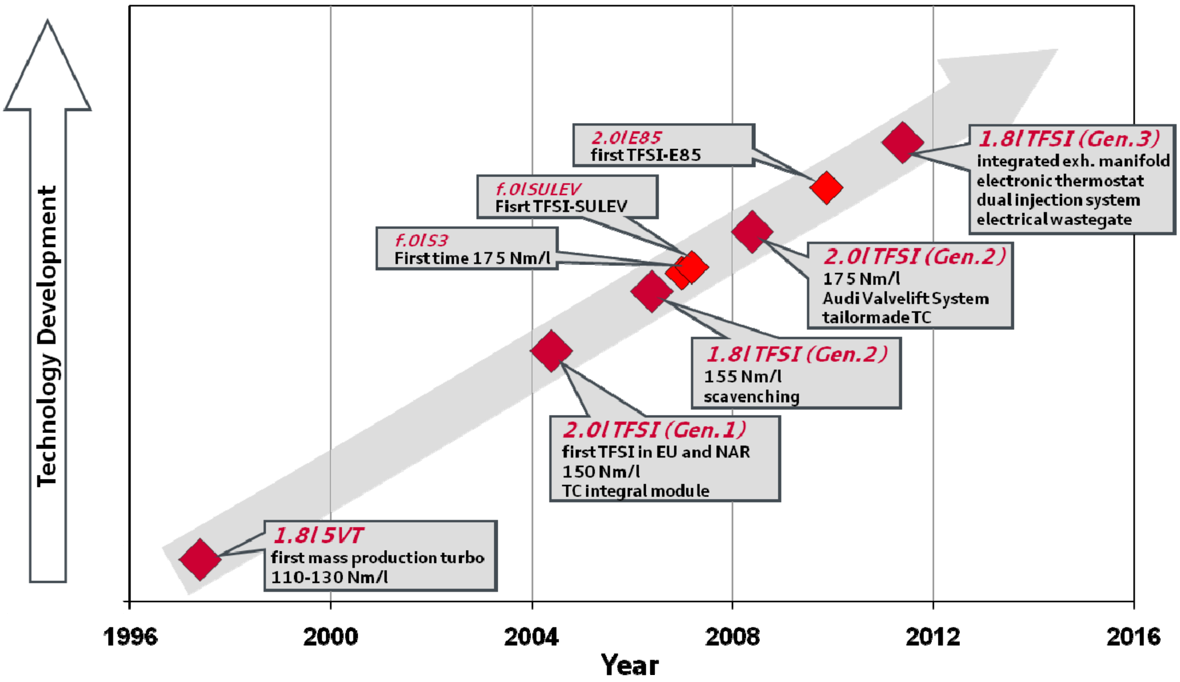


Fig. 2: Development of Audi petrol engine turbocharger technology (four-cylinder inline engines 1995-2012)

Alongside the developments in technology, the launch of turbocharged and TFSI engines also significantly reduced the fuel consumption of Audi models as well as of many other Group models. As shown in Figure 3, the NEDC consumption (presented here for a B-class saloon (Audi 80 / Audi A4) with a 6-speed manual gearbox) of the latest version of the A4 is 86 g CO_2, or almost 40%, lower than a notionally calculated 1995 model with a five-cylinder inline 2.3l induction engine. And at the same time all key performance characteristics were also improved – in some cases significantly.

The major portion of the reduction in CO_2 demonstrated (over 85%) was achieved by advances in engine development. Alongside improvements to mechanical and thermodynamic efficiency, the implementation of thermal management measures and an automatic start/stop function, most of the CO_2 improvements were brought about by the introduction and advancement of turbocharging and TFSI technology. Downsizing and downspeeding strategies alone reduced the NEDC CO_2 emissions of the B-class models investigated here by 50 g.

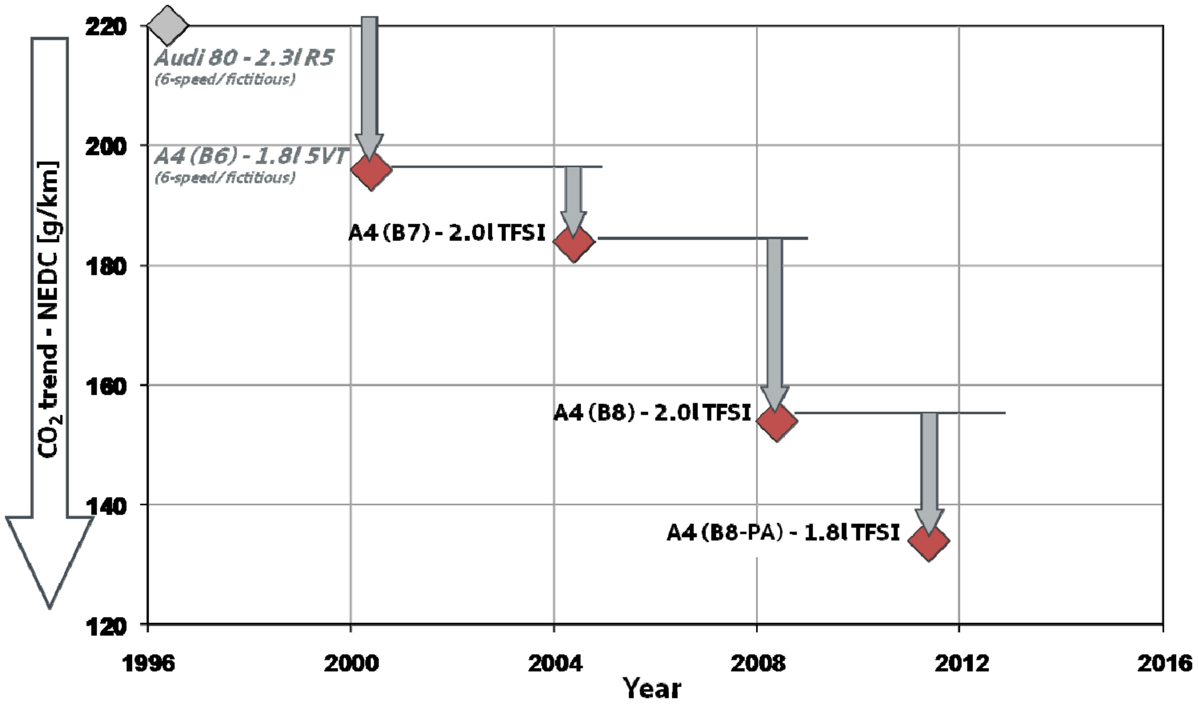


Fig. 3: Trend in CO_2 emissions of Audi turbocharged petrol engines (B-class 1995-2012)

2 The third generation 1.8l EA888 engine

As already described, in the summer of 2011 Audi put into production the third generation of its four-cylinder inline TFSI engine. The first of this new generation is the 1.8l EA888 TFSI in the new Audi A4. The 1.8l TFSI once again incorporates a large number of new and innovative technologies, some of which are being deployed for the first time in a mass production engine.

2.1 Base engine – Optimised friction and thermal management

Many new, efficiency-enhancing measures have been implemented even in the base engine model. As shown in Figure 4, the main components relevant to friction were completely redesigned. In addition to a conventional optimisation of the piston-liner friction, the balance shafts were in part mounted on roller bearings. Also, the crankshaft bearings were reduced in size and, more specifically, adapted to the load demands of the 1.8l TFSI engine. The complete oil circuit was also revised, and the pressure and volumetric flow controlled oil pump was reconfigured. For the first time switchable piston cooling nozzles are also employed, in order to realise additional potential particularly during the heat-up phase and under low loads. This represents a further implementation of variability in the crank drive as in other areas.

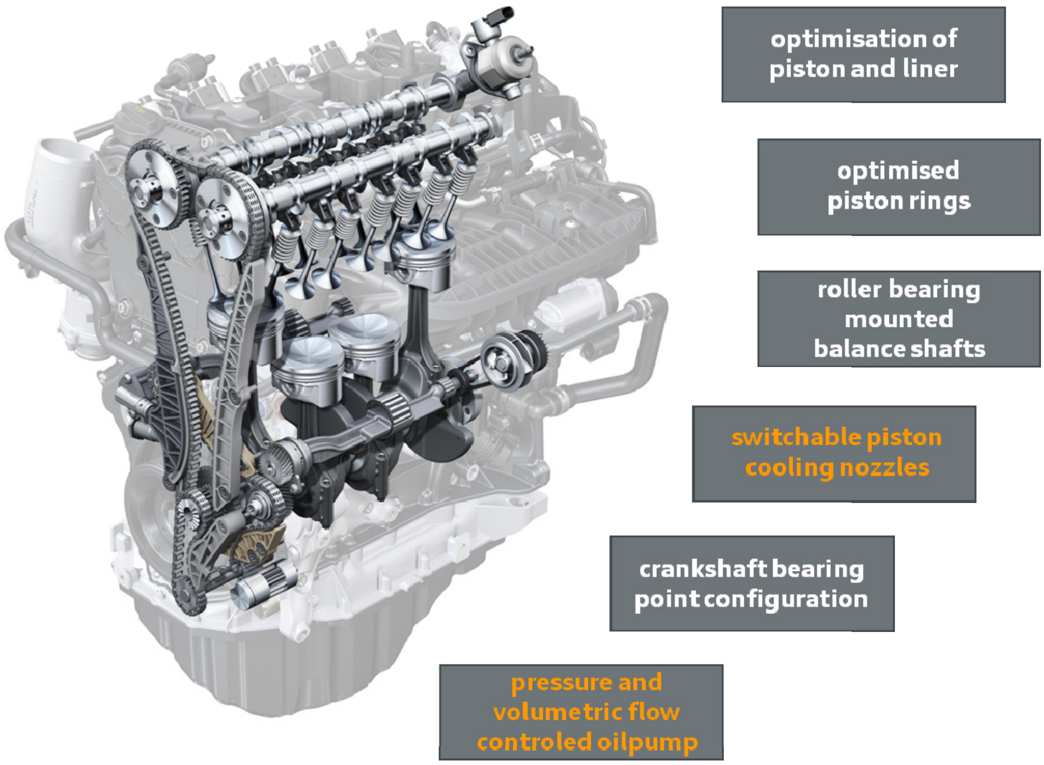


Fig. 4: 1.8l EA888 Gen.3 – Measures to optimise friction

Further significant advantages in terms of fuel consumption were achieved by means of an actively controlled thermal management system (Figure 5). One of the technical highlights of this is the first use of an electronic coolant thermostat (Figure 6). This makes it possible to leave the coolant standing after the engine starts, as a result of which the engine warms up much more rapidly. Once a modelled component temperature is reached, a first rotary slide opens a small cross-section, causing a mini-volumetric flow to slowly move the coolant. The engine continues to warm up much faster than at the otherwise normally much higher volumetric flows.

As the engine continues to warm up, in a likewise temperature-controlled sequence first the oil/water heat exchanger is activated by way of the electronic coolant thermostat and then the gear oil heat exchanger is activated by an additional switching valve. Only when the specified coolant temperature of 107°C has been reached does the coolant thermostat mix-in cold water from the main cooler, so regulating the coolant temperature under map control to the specified temperature.

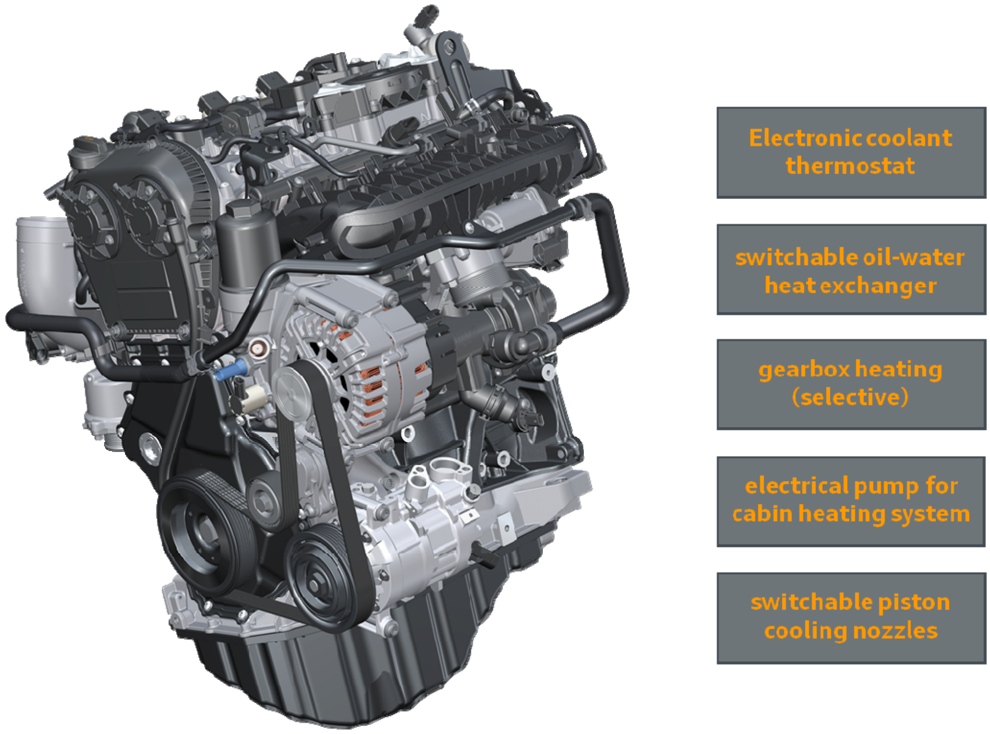


Fig. 5: 1.8l EA888 Gen.3 – Thermal management measures

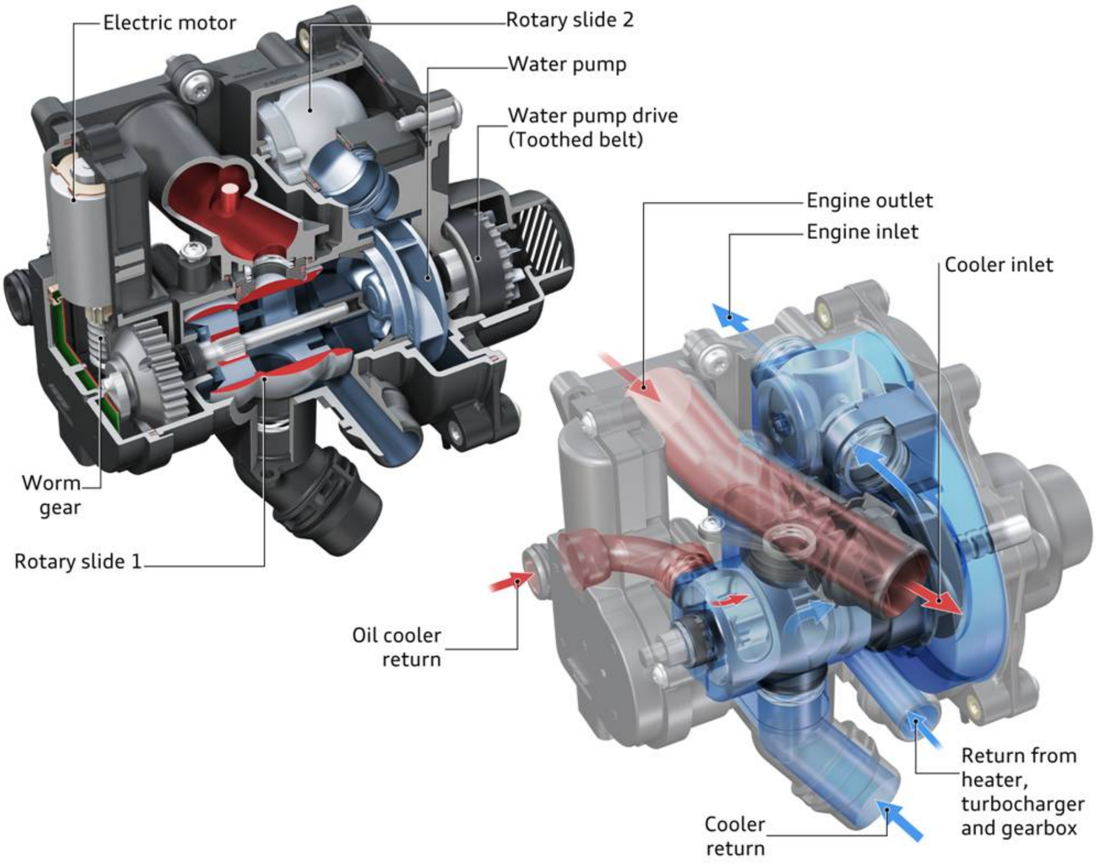


Fig. 6: 1.8l EA888 Gen.3 – Electronic coolant thermostat

As well as controlling the heat-up process in order to optimise fuel consumption, the coolant thermostat also enables demand-based engine temperature control. As already mentioned, in the lower part load range a high, fuel consumption optimised coolant temperature of 107°C is set. Under higher loads the coolant temperature is gradually reduced based on map control. Under full load, the electronic coolant thermostat can very rapidly lower the coolant temperature down to 85°C, thereby reducing the tendency to knock and so likewise delivering benefits in terms of efficiency. This means that, ultimately, the optimum coolant temperature to achieve maximum efficiency can be set for any operating point.

The thermal management system in the Audi A4 is rounded off by an autonomous heating system. A switching valve and an electric heating pump enable the heating circuit to be deactivated or, as necessary, allow heating mode to be activated while there is still coolant standing in the engine block or if the volumetric flow by the main coolant pump is low. In the latter case the heat is drawn only from the cylinder head with the integrated exhaust manifold. In both cases, the engine block in particular – and thus the piston liner assembly – heats up much faster than without the thermal management measures, resulting in further fuel consumption benefits.

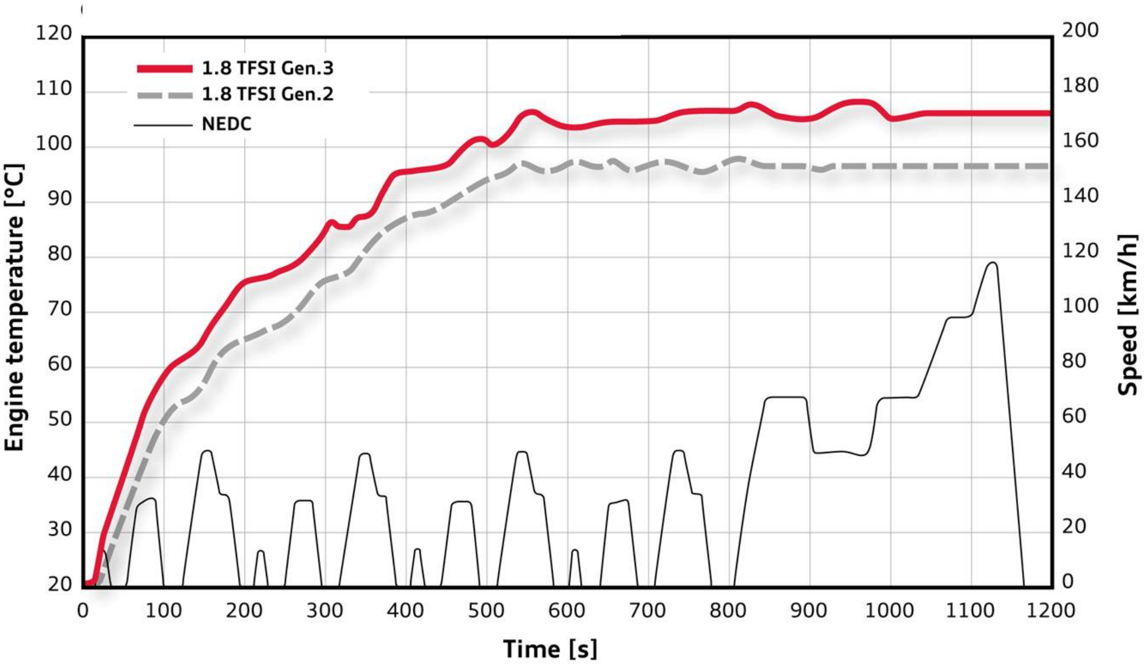


Fig. 7: 1.8l EA888 Gen.3 – Temperature curve in the NEDC with autonomous heating compared to 1.8l EA888 Gen.2

Figure 7 shows the temperature curve of the third generation 1.8l EA888 in the NEDC with autonomous heating compared to the second generation 1.8l EA888. The more rapid rise in coolant temperature and the higher operating temperature of the third generation engine are clear to see. Overall, enhancements to the thermal management system helped cut the engine's CO_2 emissions in the NEDC by approximately 2.5 g.

2.2 Combustion process and thermodynamics

For the new third generation EA888 engine the tried and proven TFSI combustion process has been optimised further in a wide variety of aspects, both to further improve robustness in terms of knocking and spark advance at mean pressures increased up to 22 bar and to optimise combustion stability under the changed conditions due to the integrated exhaust manifold in terms of residual gas behaviour and air ratio. In addition to this, the charge motion induced by the inlet port without the tumble flap activated has been increased once again. As a result of the optimised, slightly retracted position of the high-pressure injector, mixture homogenisation has been further improved, and at the same time a positive side-effect has been achieved in the reduction of the temperature load on the injector.

To achieve the required increase in power output allied to much improved spontaneity and optimised full load fuel efficiency, the Audi valvelift system (two-stage valve lift change-over of the exhaust camshaft) familiar from the 2.0l TFSI predecessor engine was adopted and for the first time combined with a camshaft adjuster on the exhaust side to provide maximum degrees of freedom in controlling the charge cycle.

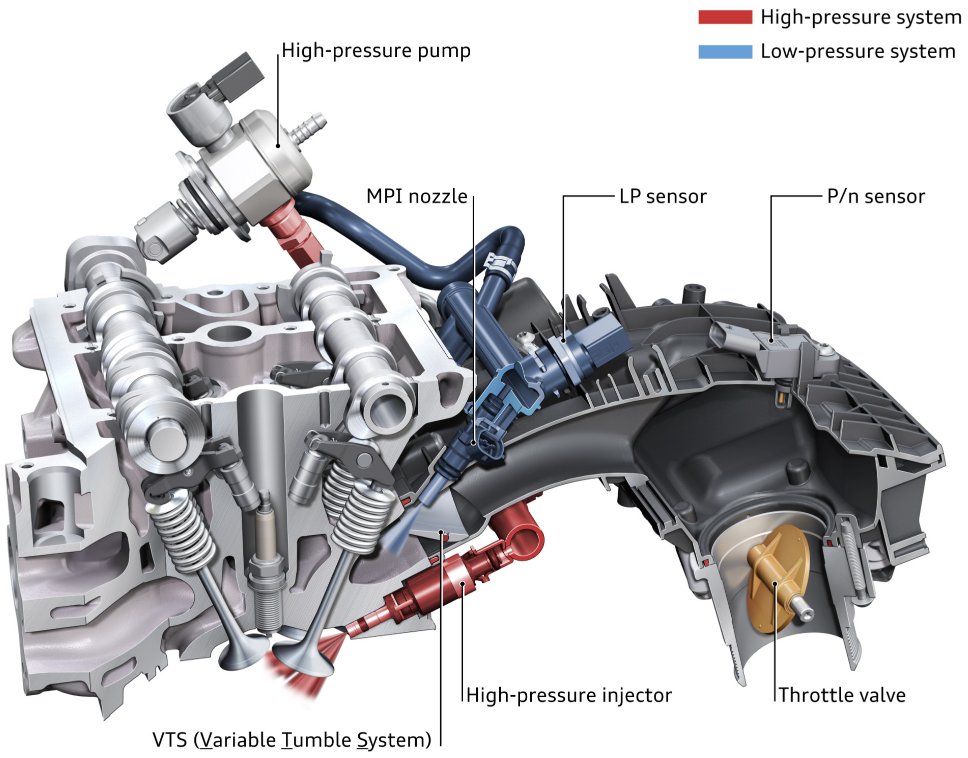


Fig. 8: 1.8l EA888 Gen.3 – Dual injection system

The third generation EA888 also for the first time features a dual fuel injection system (Figure 8). Alongside a high-pressure direct-injection system with system pressure increased from 150 to 200 bar, a low-pressure injection system has also been integrated into the VTS (Variable Tumble System) flange which injects into the upper area of the inlet ducts. Using the dual injection system allows the optimum fuel injection to be selected in every load range (intake manifold injection under low loads and direct injection under medium and high loads), so enabling a further reduction in CO_2 emissions while at the same time complying with future emission limits.

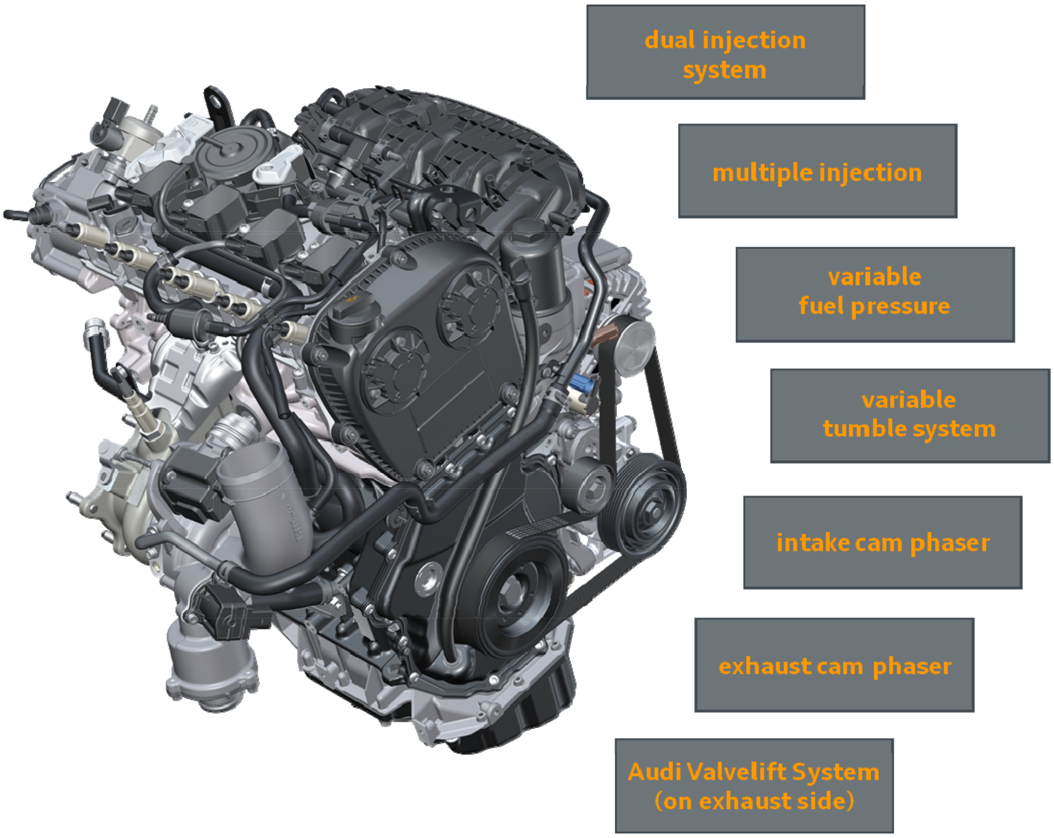


Fig. 9: 1.8l EA888 Gen.3 – Combustion process / Thermodynamics

As shown in Figure 9, alongside the usual variability in terms of ignition and injection timing and wastegate control, the third generation EA888 now exhibits seven additional variabilities so as to ensure optimum charge motion and mixture preparation, as well as attaining the ideal mixture of air, fuel and residual gas, at every operating point, thereby maximising thermodynamic efficiency. Implementing an engine with so many degrees of freedom poses an extreme challenge to the applications engineers.

2.3 Turbocharging and full-load performance

Alongside direct fuel injection, turbocharging is the core technology of the TFSI technology. In this context, too, a wide range of new technologies have been deployed alongside detail optimisation measures. Figure 10 shows the principal full load control components.

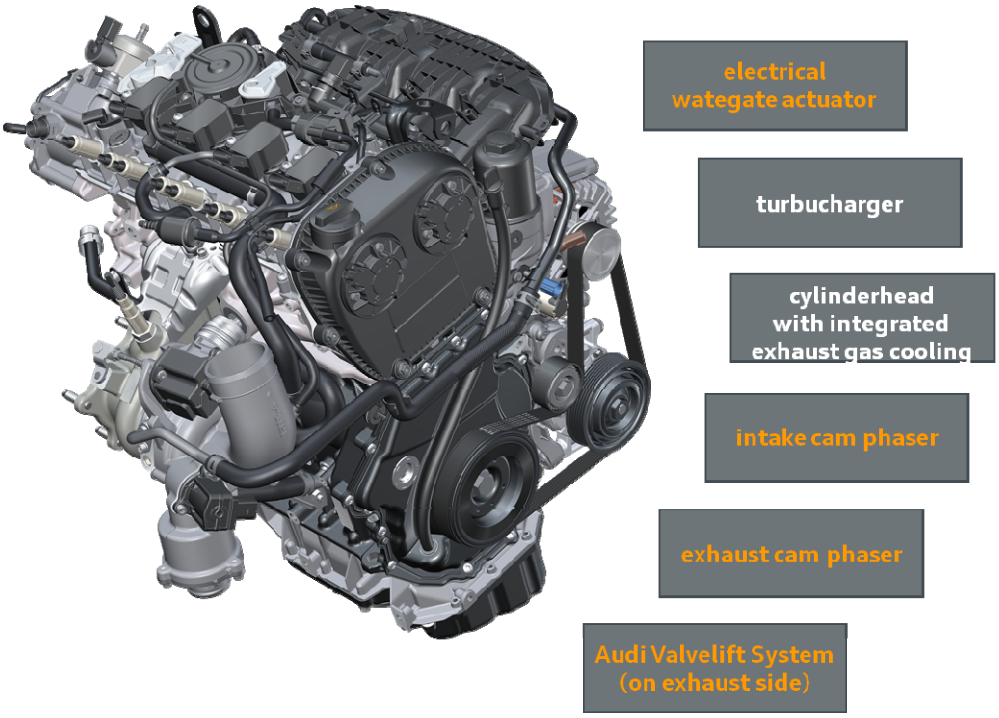


Fig. 10: 1.8l EA888 Gen.3 – Turbocharging control components

A technical 'highlight' in this respect is without doubt the cylinder head with integrated exhaust manifold (Figure 11), put into production by Audi for the first time in the third generation EA888.

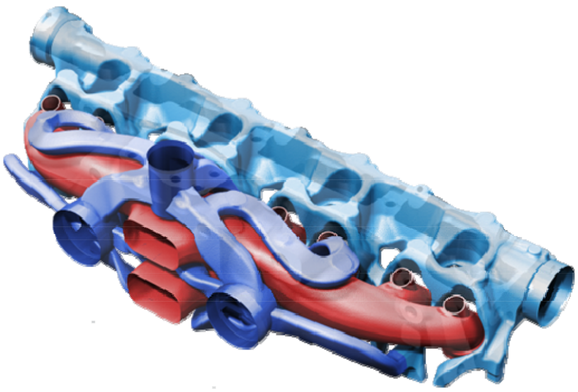


Fig. 11: 1.8l EA888 Gen.3 – Cylinder head with integrated exhaust manifold

Integrating the exhaust manifold into the water-cooled cylinder head means that the exhaust gas is cooled on its way to the turbocharger. In combination with a cast steel turbocharger, the engine can thus be run in the upper load range at approximately 100°K higher combustion temperatures, which means thermodynamic efficiency can be significantly improved and consumption under high load can be greatly reduced.

Achieving a thermodynamically and thermomechanically optimised package of gas ducts and cooling ducts posed a particular challenge during the development of the cylinder head, especially with regard to production feasibility and castability on a mass production scale.

With regard to coolant transport, a strategy of 'keeping the coolant flow under control at all times' was pursued right from the start. The coolant flows are adjusted and divided by way of defined cross-sections in the cylinder head gasket, with 75% of the total coolant flow being routed via the integrated exhaust manifold. The remaining 25% bypasses the integrated exhaust manifold, flowing directly from the cylinder block into the cylinder head. High flow speeds in the coolant ducts permit greater heat transport and thus intensive cooling, particularly of the critical web areas, and so safely prevent local boiling of the coolant.

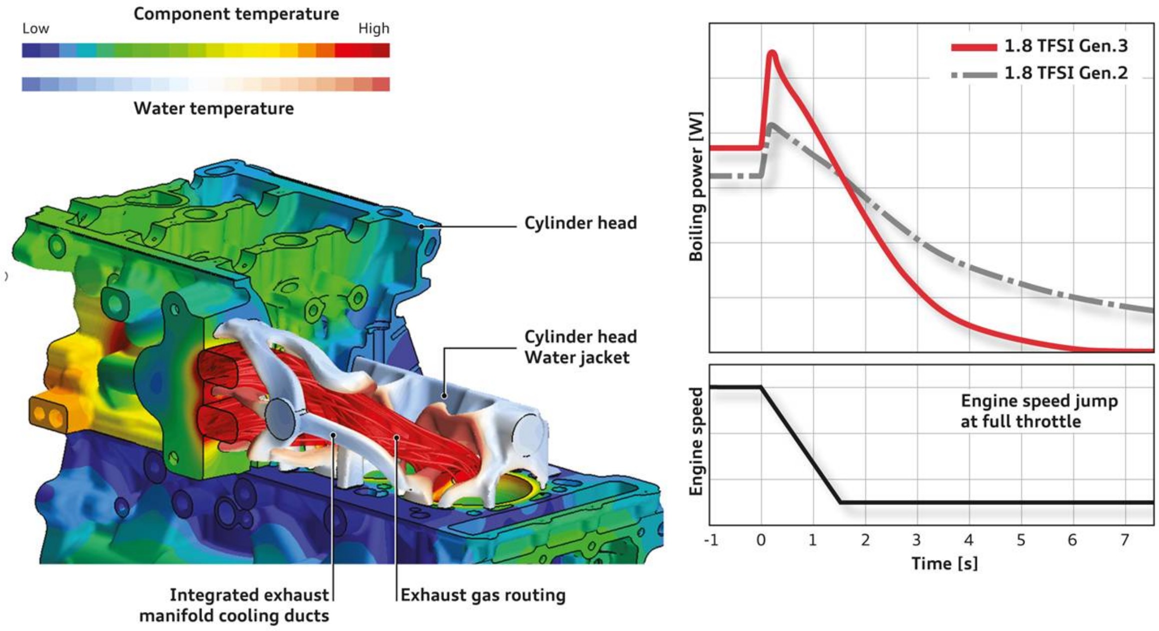


Fig. 12: 1.8l EA888 Gen.3 – Combined simulation "CCM+" (CFD and FEM)

From the very beginning, development work was supported by the intensive use of CFD calculations. To be able to simulate the complex effects inside the integrated exhaust manifold with sufficient accuracy, alongside established CFD and FEM methods a number of new simulation methods also had to be developed, enabling CFD and FEM calculations to be combined and optimisation measures to be interlinked.

First, classic CFD simulations were used to produce the basic design of the gas and water cores and combined with FEM methods to thermomechanically optimise the cylinder head. As there is intensive coupling between the exhaust gas and cooling water flows and heat transport in the aluminium within a very tight space – that is to say, involving extreme temperature gradients – in this project all three areas (gas, water, aluminium) were also calculated in a single simulation model for the first time (Figure 12, left). This methodology enables retroactive effects of the component temperatures on the fluid temperatures and the resultant heat flows to be simulated more accurately.

The development of the integrated exhaust manifold cylinder head revealed that, as well as the stationary cooling design, the load cycles involving negative load and speed changes are also a key factor. Immediately after such a change of operating state, firstly the large amount of heat stored in the material is discharged into the cooling water and, secondly, the cooling water volumetric flow and pressure decrease dramatically due to the slow water pump speed caused by the low engine revs. The hot water jacket areas are particularly at risk of boiling in this context, which in the long term may result in harm to the cooling water.

Extreme cases of such load cycles, as well as rapid shutdowns, were analysed both on the test rig and by simulation. In the final integrated exhaust manifold configuration, from an integral viewpoint a comparable level to the predecessor engine was attained in terms of short-time boiling intensity (Figure 12, right). This simulation methodology, too, was deployed for the first time in the course of the integrated exhaust manifold development.

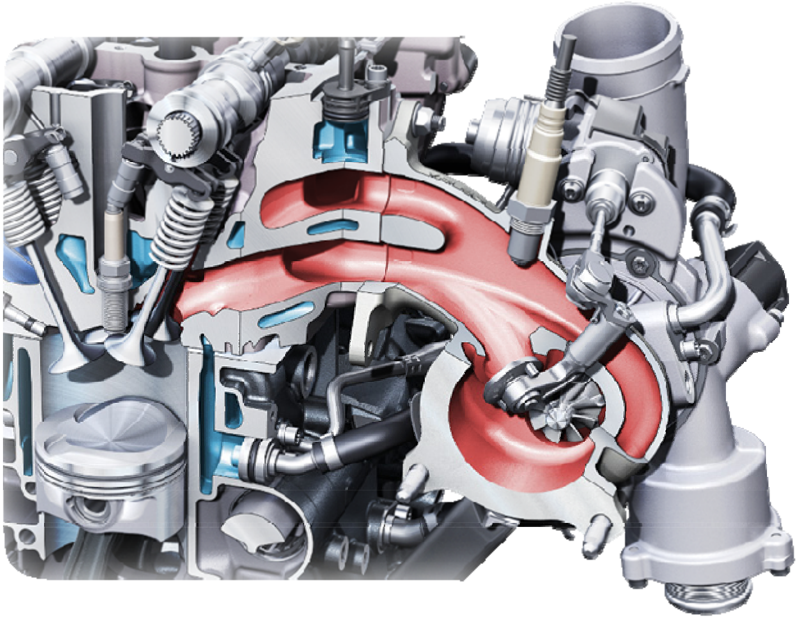


Fig. 13: 1.8l EA888 Gen.3 – Gas transport in integrated exhaust manifold and turbocharger

Extensive CFD simulations and measurements were also carried out on the fired engine in order to configure the gas ducts. To prevent interaction between the cylinders in the lower and mid engine speed ranges especially, a long ignition sequence separation, extending into the turbocharger, was implemented. At the same time, the gas ducts were configured such that the flow takes place with as little loss as possible, and is always routed directly towards the turbine (Fig. 13).

Ultimately, this reduced the flow losses and push-out work, as well as lowering the residual gas content in the cylinders, across the entire engine speed range. The impulse energy onto the turbine was also increased. Overall, despite the restrictions imposed by the package, the integrated exhaust manifold configuration delivers almost identical performance to that of an external exhaust manifold in terms of flow technics and gas dynamics.

The turbocharging system is an entirely newly developed mono-scroll turbocharger (Figure 14). The aim of the turbocharger design was to combine good low-end torque with maximum power output and very high performance. The basis for this design was the RHF4 turbocharger from IHI, with various improvements made to the rotor assembly, the spirals, the housings and to all the flow-carrying parts and components.

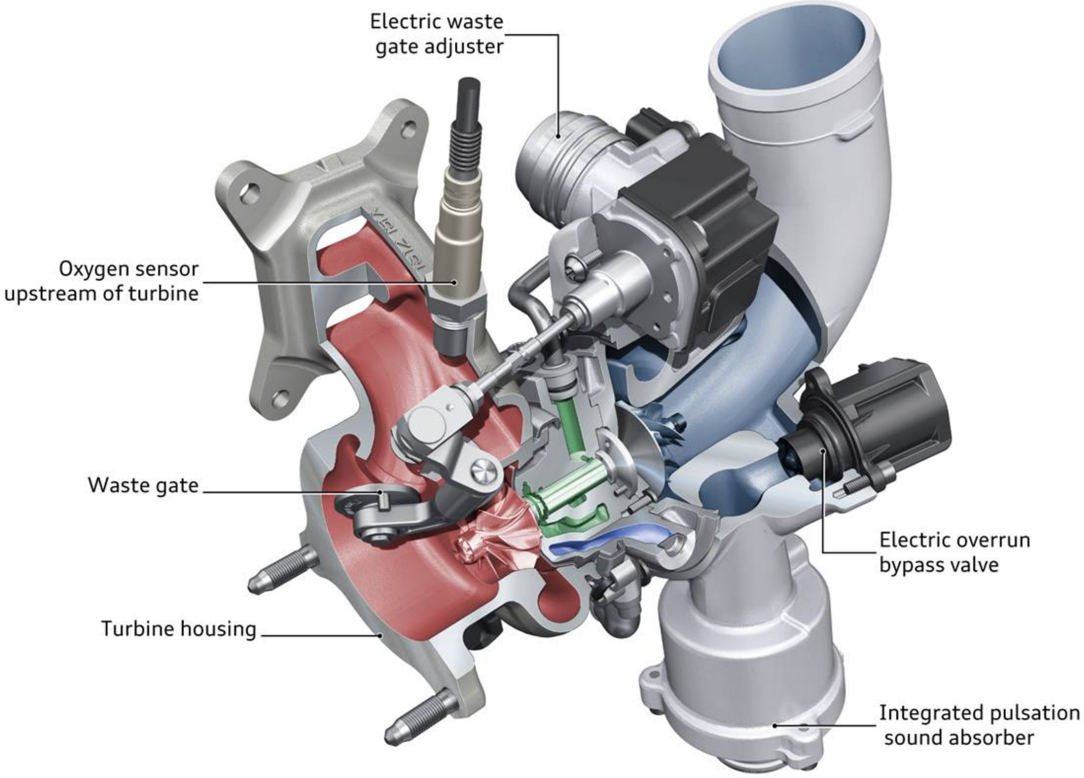


Fig. 14: 1.8l EA888 Gen.3 – Turbocharger with electric wastegate

The turbocharger turbine housing is made of cast steel 1.4837, and so permits a turbine inlet temperature of 980°C. For the first time at this high exhaust gas temperature, it was possible to fabricate the turbine wheel in Inconel 713 C instead of MAR. The compressor rotor is milled from a solid block, which delivers advantages such as greater high-speed strength and better acoustics.

The third generation 1.8l EA888 features the first use by Audi of an electric wastegate actuator. This enables even faster and more precise control of the wastegate than the previously used actuator with a pressure cell. Active opening of the wastegate under part load enables the base charge pressure to be lowered. This results in additional savings in fuel consumption both in the NEDC and in customer applications. The active opening of the wastegate also permits faster catalytic converter heat-up, resulting in lower cold-start emissions.

For the first time at Audi the oxygen sensor has been positioned ahead of the turbocharger turbine. This allows for a considerably earlier dew point end, and thus early enabling of lambda control after the engine starts, as well as providing good individual cylinder recognition.

Extensive CAE optimisation work was carried out on both the turbine and compressor sides. Figure 15 shows both CFD simulation models in one view. On the turbine side, the CFD simulations in the complete system are analysed with the integrated exhaust manifold gas routing in the cylinder head, the turbine housing (including impeller), the wastegate, the oxygen sensor upstream of the turbine and the exhaust system through to downstream of the close-coupled main catalytic converter. The aims here were to optimise the integrated exhaust manifold gas routing in conjunction with the turbine inlet, the flow to the oxygen sensor, the wastegate design, and to ensure a very good flow to the catalytic converter.

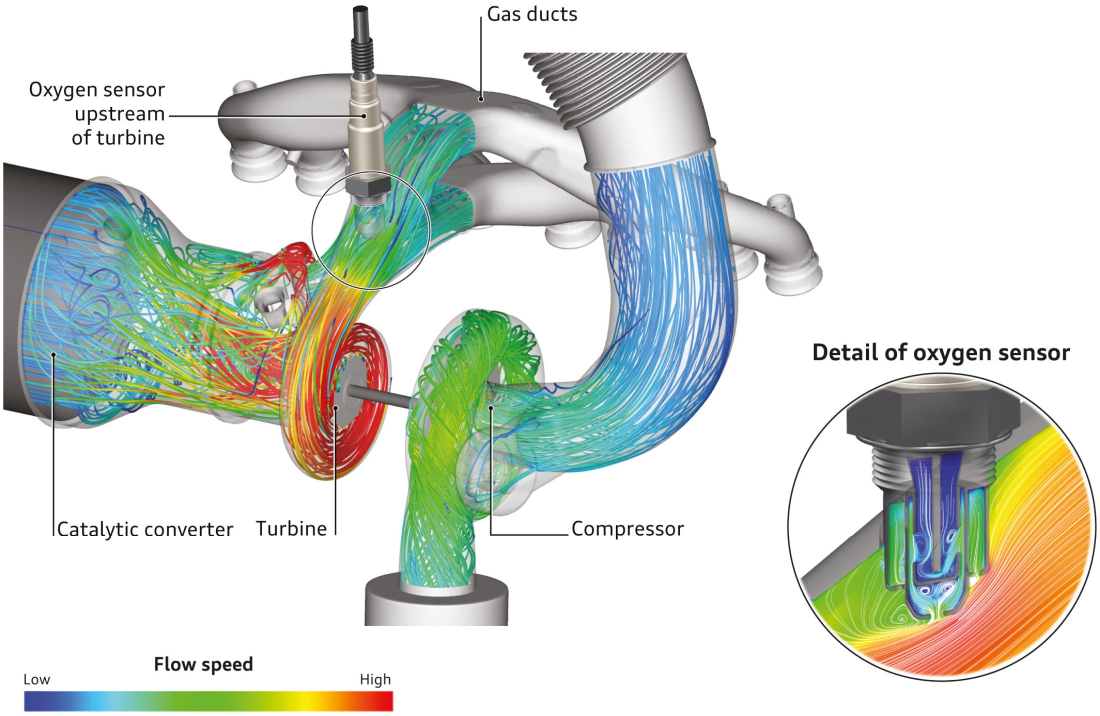


Fig. 15: 1.8l EA888 Gen.3 – CFD simulations of the turbocharger system

On the compressor side the CFD model includes the air induction, the compressor including all inlet points (e.g. from the crankcase ventilation) as well as the dump valve and the charge air duct. The aim was firstly to develop gas flow to and from the compressor that was as loss-free as possible and neutral with regard to the performance of the compressor, and secondly to find the best possible position for the inlet points and the recirculation valve. In this context the simulations identified considerable potential both with regard to reduce pressure losses and in terms of compressor efficiency.

On completion of the extensive optimisation work, the turbocharger of the third generation 1.8l EA888 engine exhibited better low-end torque, and in particular faster responsiveness, than other turbocharger design concepts currently on the market and in development, while attaining the same power and torque data. It thus represents the current benchmark in turbocharger technology.

The outstanding result is also illustrated again in Figure 16, in which the full-load torque and dynamic torque curve of the new third generation 1.8l EA888 engine are compared against the data of its predecessor and against the second generation 2.0l EA888. The significant advantages over the second generation 1.8l engine are clear to see, as is the fact that the third generation 1.8l engine is practically equal to the larger-capacity second generation 2.0l both in terms of torque level and dynamic torque curve.

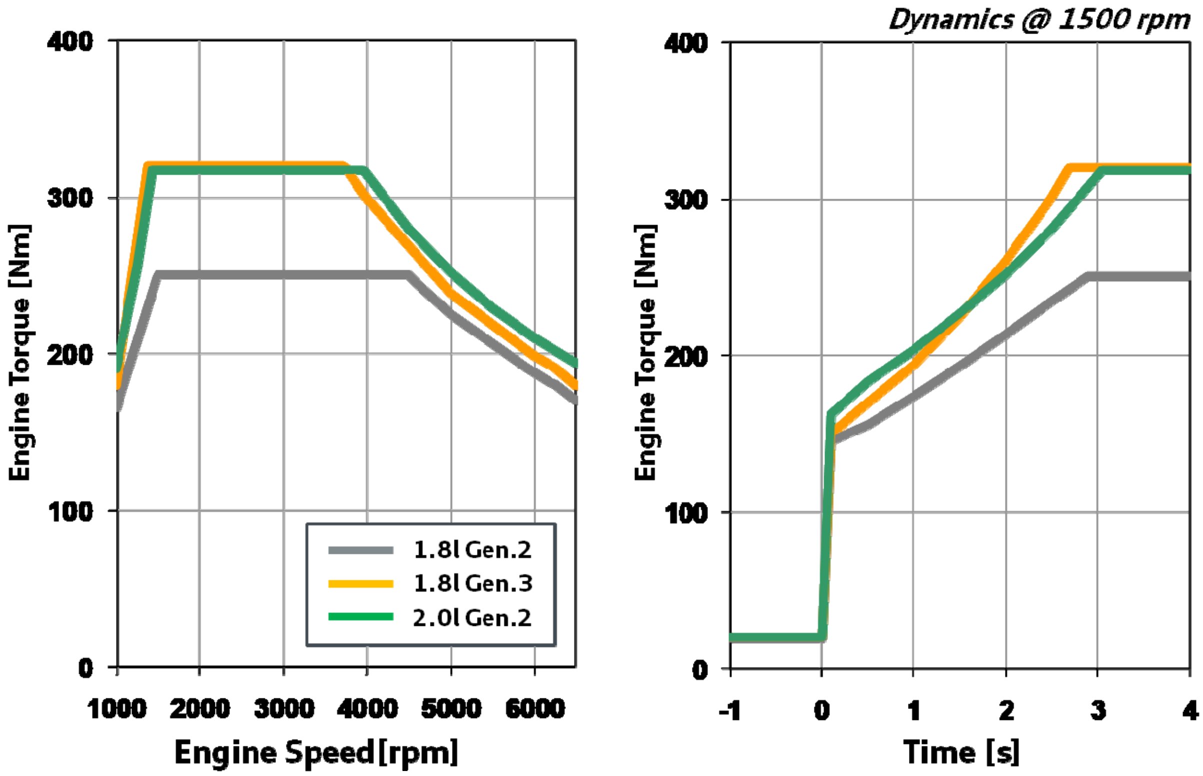


Fig. 16: 1.8l EA888 Gen.3 – Full-load torque and dynamics compared to 1.8l EA888 Gen.2 and 2.0l EA888 Gen.2

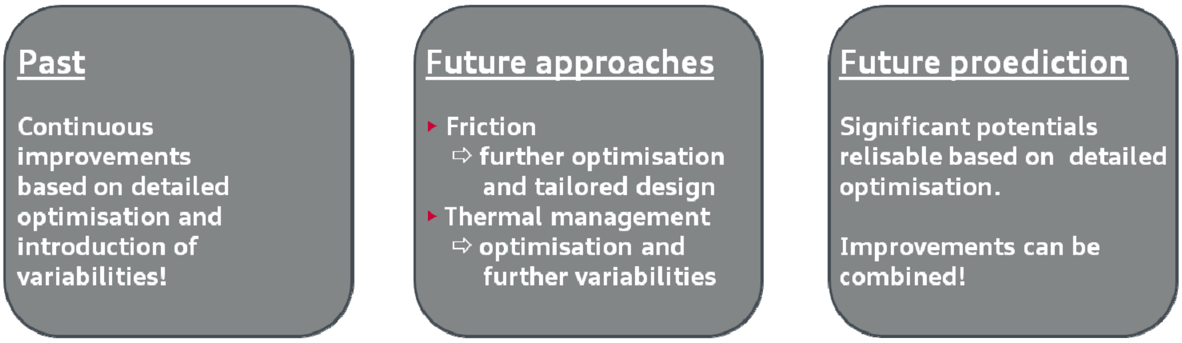
For the new Audi A4 in the 125/132 kW class, this ultimately made it possible to replace the existing 2.0l engine with the new 1.8l unit, and so not only realise the aforementioned improvements in thermodynamic and mechanical efficiency but also to achieve a further improvement in CO_2 emissions of 6 to 7 g in the NEDC by means of downsizing, without customers having to accept compromises in terms of performance.

3 Future developments in TFSI technology

The questions for the future will be how the direct-injection petrol engine will continue to be developed, and what potential it offers in particular with regard to further reductions in CO_2 emissions.

3.1 Base engine – Optimised friction and thermal management

As already demonstrated, fuel consumption improvements were achieved in the past in relation to optimisation of friction and thermal management based on continuous detail optimisation and the introduction of variability.



Past

Continuous improvements based on detailed optimisation and introduction of variabilities!

Future approaches

- Friction
  - ⇨ further optimisation and tailored design
- Thermal management
  - ⇨ optimisation and further variabilities

Future proediction

Significant potentials relisable based on detailed optimisation.

Improvements can be combined!

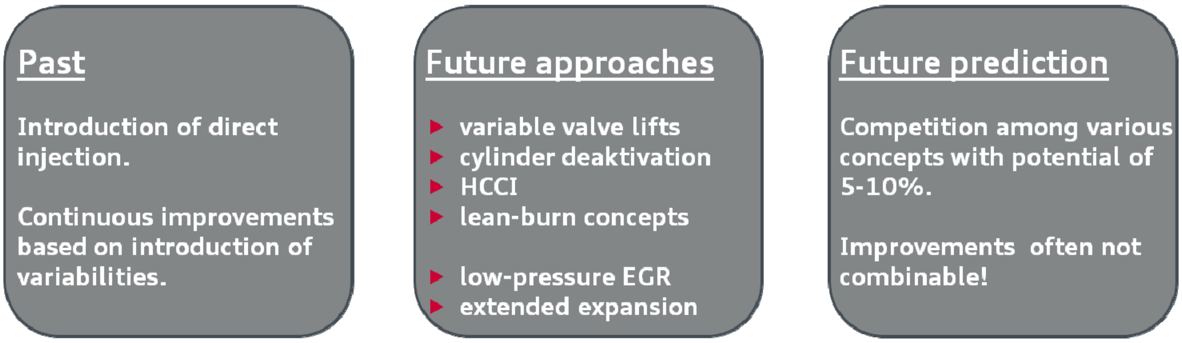
Fig. 17: Further development of TFSI technology – Friction and thermal management

There remains significant potential to be realised in future. Detail optimisation in relation to engine friction will mean that engines will be tailored ever more precisely to their specific applications. In terms of thermal management, although the early approaches implemented have realised considerable potential, there still remains significant potential for improvement. This is, however, conditional on the introduction of further variability. The improvements in fuel consumption brought by optimising friction and by thermal management fundamentally offer the benefit of reducing losses while having little cross-effect on other optimisation measures, so that the respective gains can be combined almost completely.

3.2 Combustion process and thermodynamics

With regard to the combustion process and thermodynamics, improvements in the past were achieved thanks to the introduction of direct fuel injection and large numbers of variabilities, as well as by stretching the operating parameters to their limits. In conjunction with the conventional λ=1 combustion processes, however, the existing potential in this regard has now been largely exhausted.

But for some considerable time there have been new technical ideas in circulation which seek to realise further potential based on new combustion methods or cylinder deactivation. But the lean-burn methods, homogeneous charge compression ignition (HCCI), variable valve lift control or cylinder shut-off, all target the lower part-load range and utilise similar physical effects (derestriction, reduction of heat losses). Consequently, it is in most cases pointless to combine the methods as, once a technology has delivered its advantages, few further benefits are achievable.



Past

Introduction of direct injection.

Continuous improvements based on introduction of variabilities.

Future approaches

- variable valve lifts
- cylinder deaktivation
- HCCI
- lean-burn concepts

- low-pressure EGR
- extended expansion

Future prediction

Competition among various concepts with potential of 5-10%.

Improvements often not combinable!

Fig. 18: Further development of TFSI technology – Combustion process and thermodynamics

Low-pressure EGR or methods involving extended expansion (Miller/Atkinson Cycle) tend to promise more in the way of efficiency advantages in the mid and upper load ranges. These two methods also utilise similar physical principles, so ultimately once again it only makes sense to apply one of the two. Combining them would deliver very little additional gain. The disadvantages of both methods, however, are that they require an increased charge pressure and that they reduce the full-load torque and nominal power output. To compensate for this, in order to avoid compromises in terms of performance, turbocharger design concepts involving increased charge pressure supply are required.

So, all in all, there remains significant potential for reducing consumption by thermodynamics-related measures as in other areas. The potential is estimated at 5 to 10 percent, and will doubtless be gradually realised in future.

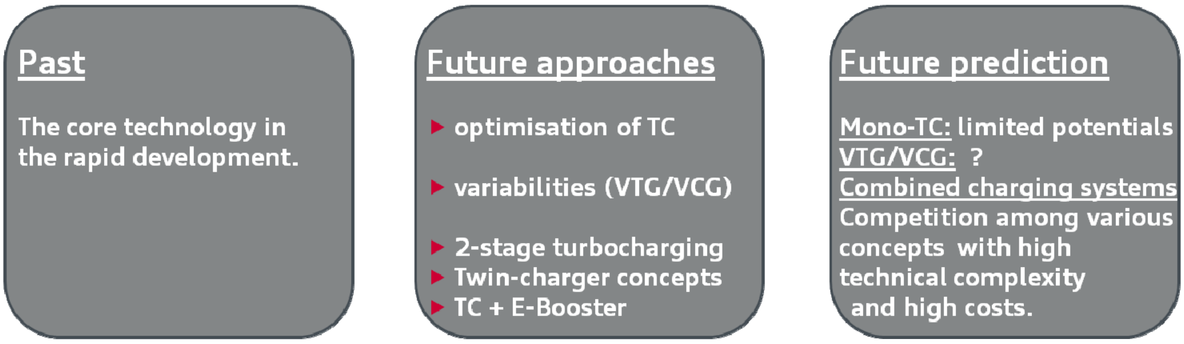
However, one point needs to be considered in this context. In the past, car-makers had great difficulty in introducing new combustion processes, as – in addition to their advantages – they in most cases also entailed a wide range of disadvantages relating to exhaust gas after treatment or combustion stability and smooth running, and as a consequence were mostly withdrawn from the market again after a short time. In this light, it is doubtless more likely that there will be an evolution of the current λ=1 combustion processes rather than any revolutionary introduction of new methods.

3.3 Turbocharging

The core technology in the rapid developments seen over recent years was without doubt turbocharging – also of course in conjunction with the introduction of variability enabling the charge cycle to be controlled ever more optimally. On the other hand, due to that rapid past development some limits have today already been reached.

As a consequence of the improvements in torque of TFSI engines, in many vehicle design concepts the gear ratios have been extended so far in recent years that further extension would bring no benefit, so little further downspeeding potential exists. For mono-turbocharger concepts, in Audi's view a specific torque of approximately 175 Nm/l today likewise represents a useful limit, in order still to safeguard adequate low-end and starting-off torque and dynamic responsiveness, thereby ensuring good driveability in all situations.

Consequently, in Audi's view the key challenges of the future in terms of turbocharging concepts are to improve starting-off and low-end torque and dynamic torque build-up – that is to say, ultimately, the rapid availability of high charge pressures even from very low engine speeds. In this respect, too, there are already a number of technical ideas in circulation for the future development of turbocharging technology.



Past

The core technology in the rapid development.

Future approaches

- optimisation of TC
- variabilities (VTG/VCG)
- 2-stage turbocharging
- Twin-charger concepts
- TC + E-Booster

Future prediction

Mono-TC: limited potentials
VTG/VCG: ?
Combined charging systems
Competition among various concepts with high technical complexity and high costs.

Fig. 19: Further development of TFSI technology – Turbocharging

However, the turbochargers themselves are today for the most part fully optimised, and as such offer only limited potential. Turbocharger developers are investigating a number of technologies in terms of aerodynamic or mechanical optimisation, but at present they are frequently revealing only minor potential improvements at still very high cost, so their application in mass production would appear unlikely at any time in the near future.

Research has likewise been ongoing for more than 10 years with regard to variability on the turbine and compressor side, though to date only in a few number of cases they have been turned into production applications, as they often offer few advantages in the totality of their properties and, again, entail relatively high cost.

The third possibility to advance turbocharger technology and the associated concepts – and the one doubtless offering the highest potential in technical terms – is a combination of charging systems, such as combining two turbochargers or one turbocharger with a mechanically or electrically driven compressor. In purely thermodynamic terms, these concepts offer considerable advantages, with no major functional cross-effects – provided the overall systems are configured appropriately. However, the integration of the overall concepts into the engine and vehicle package demands considerable effort and expense, and – for small models in particular – is often difficult or in some cases even impossible. Moreover, combination turbocharging concepts are very costly, both in terms of the turbocharger components themselves and also frequently in terms of peripheral on-board components.

But since the greatest potential in future is expected to be realised by advances in turbocharging technologies, there will no doubt be fierce competition among the various concepts, and those offering the best cost/benefit ratio will win through.

However, as turbocharging increases further, and thus more downsizing is implemented, one problem will arise. The ever greater knock limitation, reduced compression ratios and increasing charge cycle losses will almost certainly lead to a rise in consumption under high load. This may result in increased consumption in customer applications, depending on the vehicle model and driving habits, where extreme downsizing concepts are implemented. Consequently, highly charged concepts will necessitate additional measures especially in order to cut fuel consumption under high load. In view of this, a combination with some of the combustion methods presented in the previous section appears to be a most useful solution.

4 Summary and Outlook

With the introduction of TFSI technology in 2004, Audi launched a new era in petrol engine development. No engine technology other than TFSI has delivered such a boost to performance and fuel efficiency in such a short time, and no other engine technology has established itself on the market in such a short time (just five years!), practically eliminating all other competing technologies in the process.

With the aid of turbocharging and TFSI technologies, the CO_2 emissions of Audi and VW Group models have been significantly reduced over the last 15 years, while performance has been greatly improved.

The new 1.8l TFSI in 2011 marks the launch of the third generation of the successful TFSI technology from Audi. Alongside extensive modification and optimisation of the engine, in this third generation of the four-cylinder inline TFSI engines Audi has once again introduced a wide range of new and innovative technologies – some of them being put into mass production for the first time.

The technical highlights of the new engine generation:

- Electronic coolant thermostat

- Cylinder head with integrated exhaust manifold
- Electric wastegate actuator
- Dual injection system

With the third generation of TFSI engines, significant progress has once again been made compared with the already very well positioned second generation of the EA888 engine series, thus further strengthening the outstanding position of the four-cylinder inline TFSI engine range in the competitive environment. The new 1.8l EA888 TFSI engine without doubt represents a further milestone in Audi's downsizing and downspeeding strategy.

TFSI technology will continue to offer wide-ranging potential in future, particularly with regard to cutting CO_2 emissions. Key technologies in this, from Audi's viewpoint, will be advances in turbocharging technology and the introduction of new combustion methods.

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