The new 2.0l turbo engine from the Mercedes-Benz 4-cylinder engine family

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Summary

The new Mercedes-Benz four-cylinder engine family presented for the first time at the end of 2011 with the 1.6l turbocharged four-cylinder engine will be extended at the end of 2012 to include a displacement and technology variant featuring the new 2.0l engine designed to reduce fuel consumption. The combination of third-generation Mercedes-Benz direct injection with piezo injectors, called “ Blue Direct “, an optimum turbocharger design and a consistently friction-reduced basic engine also complies with the most exacting requirements in terms of agility, fuel consumption and comfort and, in conjunction with the Mercedes-Benz dual clutch transmission, enables sports-car-like driving performance.

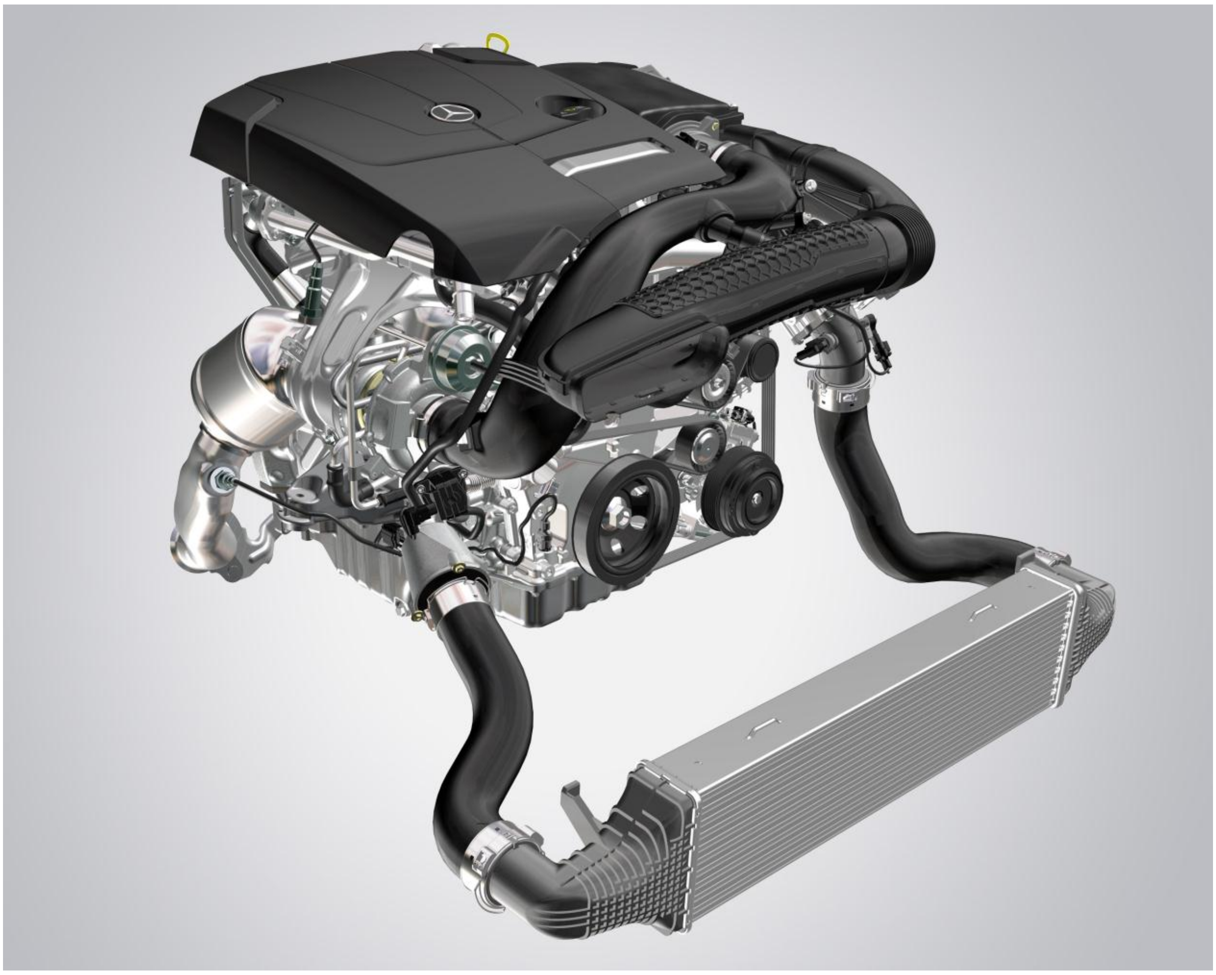

Figure 1: Mercedes M274 2.0l engine

1 Concept development and technology transfer

In fall 2011, alongside the new Mercedes-Benz B-Class, a new turbocharged R4 gasoline engine generation was also launched, starting with a displacement of 1.6l and an output of 90 to 115 kW. This new engine was designed based on systematic downsizing, modularization and advanced technologies and replaced the highly successful predecessor engines.

The displacement and technology variants presented here are a systematic addition to the new R4 gasoline engine family, which is used in the entire Mercedes-Benz passenger car and van product portfolios. The aim was, in light of the different requirements such as north-south and transverse installation, passenger car and van applications as well as 4x4 drive in all the vehicle model series covered, to find a uniform platform for the new engine family in terms of product design.

This aim was achieved with a high degree of commonality by establishing a modular production concept across all variants and for all components of the basic engine - particularly the cylinder head, crankcase and drive unit - and by using shared parts and generic elements. However, the focus was always on the engine family's performance targets and on the sustainability with regard to modular technology enhancement possibilities. [8]

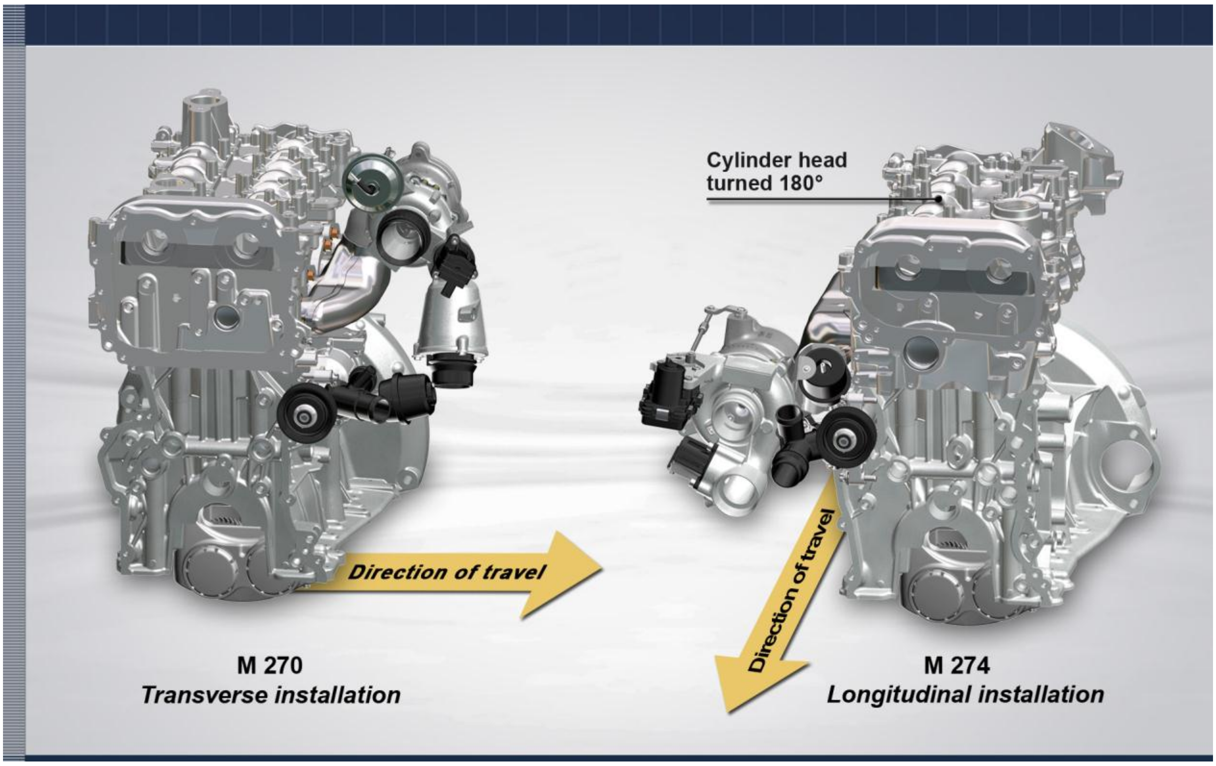

Figure 2: Platform concept for north-south and transverse installation

Therefore, for the first time within an engine family that is installed in both a north-south and a transverse manner, a front exhaust design was implemented for transverse installation. The cooling concept implemented in each case was specifically adapted to the respective application. The 2.0l variant presented here has a modular Lanchester design that is extremely compact and friction-optimized and has a neutral effect on the 1.6l basic engine in terms of the cost and weight.

The use of a flexible, innovative high-performance technology portfolio in order to achieve a sustainable reduction in the fuel consumption and compliance with globally varying market and legal requirements ensures the viability of the extended engine family and forms the basis for a superior and comfortable drive system performance. Modular implementation of this technology portfolio is particularly important, not only from a financial point of view but also in terms of being the prerequisite for the implementation of the Mercedes-Benz brand's high standard of quality for our customers.

In 2010, for the new V6 and V8 engines [8] with exhaust-gas turbocharging and direct injection, an enhanced downsizing strategy was launched across the market with a technology portfolio involving spray-guided combustion with third-generation direct injection, multiple-spark ignition and an ECO start/stop function. This technology portfolio and the Mercedes-Benz combustion system developed from it were transferred to the new R4 gasoline engine generation in all its derivatives and further optimized for the 4-cylinder-specific requirements. This standard technology portfolio includes the use of a twin-pipe turbocharger exhaust manifold with 1050°C turbocharger, a water pump optimized for the installation space with a mixed-flow impeller as a complete mounting pump, a pressure-loss-optimized ball thermostat, a 2-stage regulated vane-type oil pump, integrated ancillary component and coolant heat management and the reduction of the friction power in the drive unit and chain drive. However, the central technology module is the Mercedes-Benz BlueDIRECT direct injection combustion system, which is characterized by a central injector position, a piezo injector with an outward-opening tapered jet nozzle and a multiple-spark ignition.

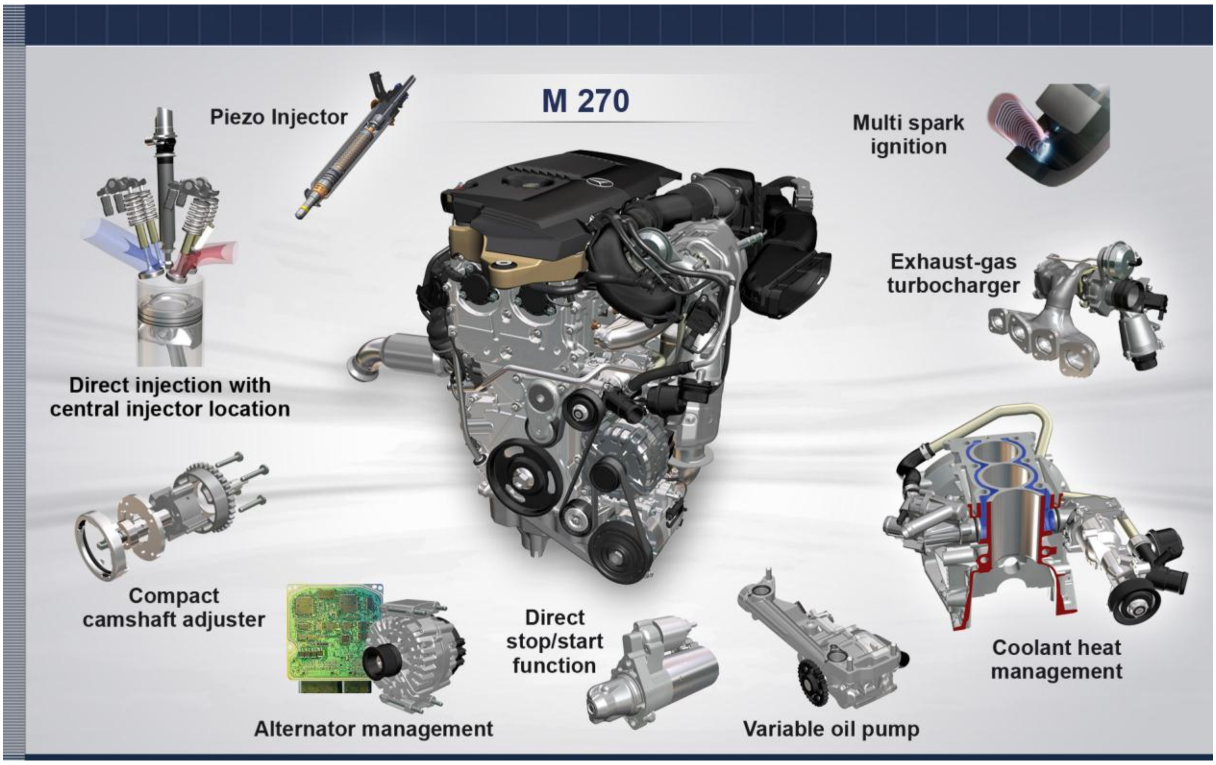

Figure 3: Technology portfolio for the M 270/ M274

2 Layout and function of the Camtronic for 1.6l

2.1 Camtronic system components

Based on the M270 engine with a displacement of 1.6l, which was presented in 2011 with the launch of the current B-Class and achieves optimum values with respect to fuel consumption and emissions thanks to its systematically friction- and cooling-optimized design, an additional cost-optimized fuel consumption technology was developed and will be launched for the first time in the new A-Class in September 2012 with the 1.6l M270.

The basic concept of this fuel consumption technology is valve stroke switching in conjunction with fast camshaft positioners, which makes it possible to drive a very large share of the partial load with optimum fuel consumption with a small cam while almost completely dethrottled.

Camtronic was also designed in a modular way so that it was possible to adopt the important basic components 1:1 from the already familiar engine. These components are the complete crankcase, the basic cylinder head or the camshaft adjusters.

Figure 4 shows the basic Camtronic layout with all the relevant components. Based on the standard cylinder head with the fast hydraulic camshaft adjusters that are also used in the conventional cylinder head, the main changes are:

- The multi-part camshaft,
  composed of a support shaft with engagement elements and gearing to adjust the two hollow-bored cam parts, each with two double cams for small and large valve strokes.
- The shift gate for actuating the stroke switching.
- The cam for the high-pressure pump is fixed securely to the support shaft.

Actuation of the stroke switching is carried out by a dual-pin actuator for all cylinders. This moves both cam parts axially within a combustion cycle in each case.

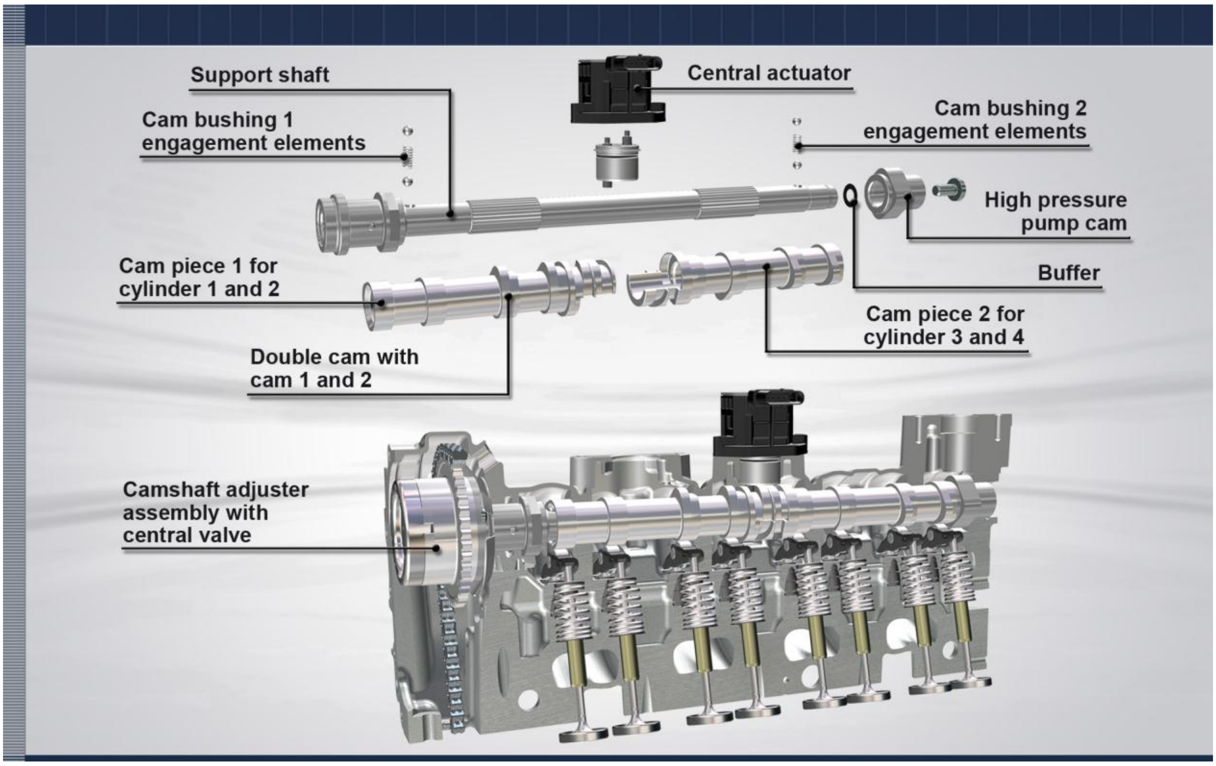

Figure 4: Camtronic layout

Thanks to the layout with very few parts, it was possible for the first time to create a system that enables an operating mode with thermodynamically optimized fuel consumption using early inlet closure (FES) by the addition of just one extra actuator. The mechanical functioning of the dual-pin actuator is very simple. In each case, one of the pins is responsible for switching from the large stroke to the small stroke while the other pin is responsible for switching from the small stroke to the large stroke. The switching procedure shown in Figure 5 shows how the pin for switching to the small stroke moves into the shift gate of cam piece 1 (in the image on the right) at the beginning of the switching. The pin then slides in the gate and, based on the predefined curved path in the shift gate, exerts an axial force on cam piece 1 at exactly the time when the valves on the cam piece are all located in the zero stroke area. The valve stroke switching is then carried out by the axial movement of the cam piece. The complete switching procedure for this cam piece takes place in approximately half a camshaft rotation in the first cycle after the valve stroke switching is requested. During the continued camshaft rotation, the same pin moves into the shift gate of the second cam piece. The basic stroke switching procedure follows the pattern for the first switching, with the second cam piece moving in the same direction, i.e. to the right in the figure. After the movement of the second cam piece and the valve stroke switching for the remaining two cylinders, the pin is automatically disengaged by the shift gate of the second cam piece and held in its rest position. This means that valve stroke switching for all cylinders takes place within one working cycle.

Switching from the small stroke to the large one follows the same pattern. Here, the other pin is always used, causing the cam pieces to move axially in the opposite direction. As a result, switching from the small stroke to the large one is again triggered in the same time frame.

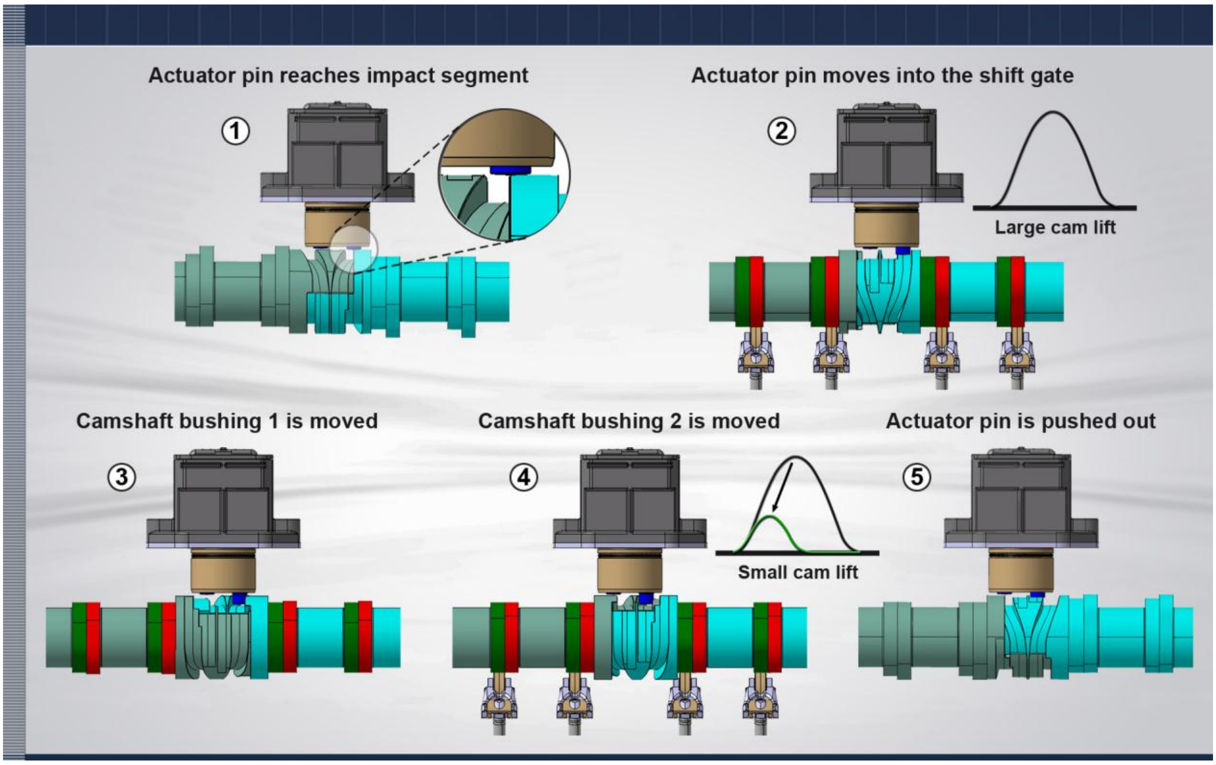

Figure 5: The function principle of Camtronic with dual-pin actuator

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2.2 Fuel consumption advantages of Camtronic

Besides the very compact and modular design of Camtronic to optimize the function and costs, a maximization of the fuel consumption advantage was also an important development objective.

Particular attention was paid not just to obtaining the maximum customer benefit, which besides optimization of the best point - achievable here at approx. 10% at low loads and engine speeds - also has a very good specific value for a system like this, but also to achieving an operating range that is as wide as possible with respect to load and engine speed. The characteristics map shown in Figure 6 shows large areas with fuel consumption advantages >4% compared with the basic engine. At the same time, the system is active in a wide engine speed range from idle to 3,500 rpm and in a load range from zero load to almost the full intake load (with the large valve stroke). This technology thus covers large areas of the operating ranges currently used by customers and shows its major potential in exactly those areas which are important in modern traffic conditions.

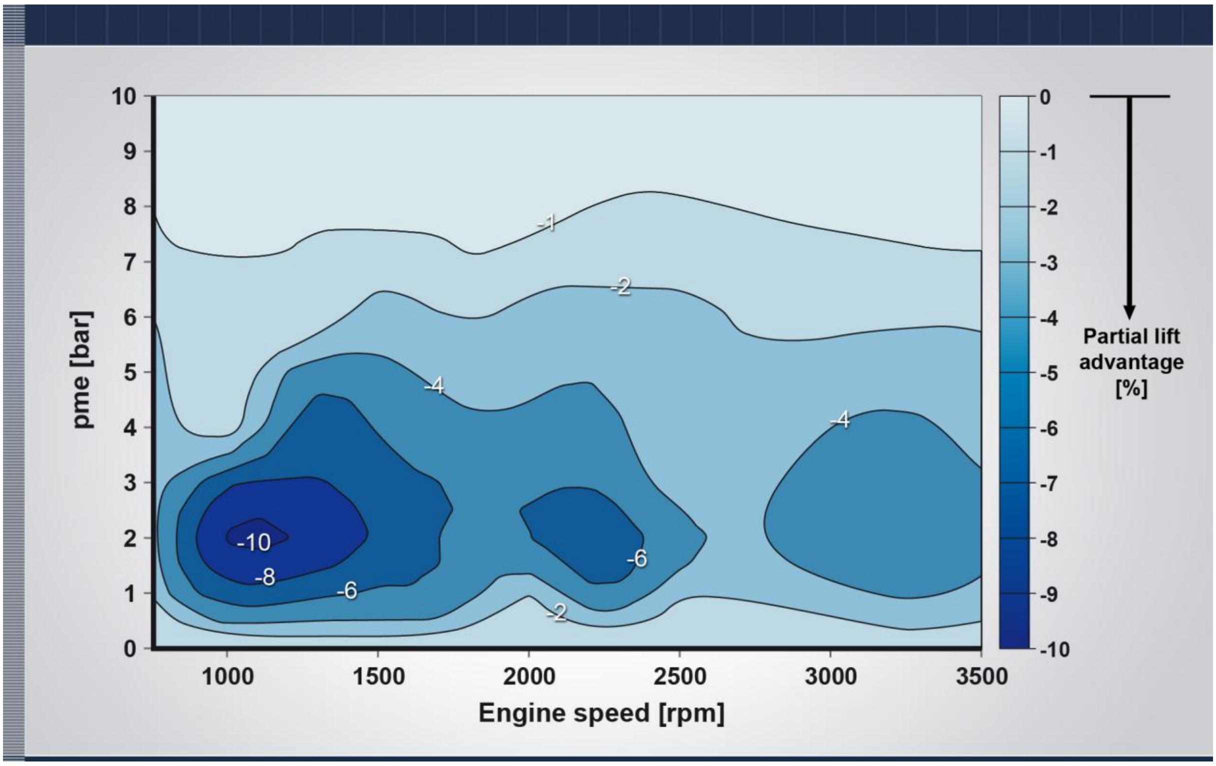

Figure 6: Fuel consumption advantages of Camtronic on the characteristics map

When comparing this engine with others in its displacement class, it has an absolute best fuel consumption with an effective fuel consumption of 350 g/kWh at an operating point of n = 2,000 rpm and pme = 2 bar not only within this class but also compared with many other stoichiometrically operated engines with differing displacements. However, in the view shown in Figure 6, this operating point does not represent the best point with respect to fuel consumption improvement.

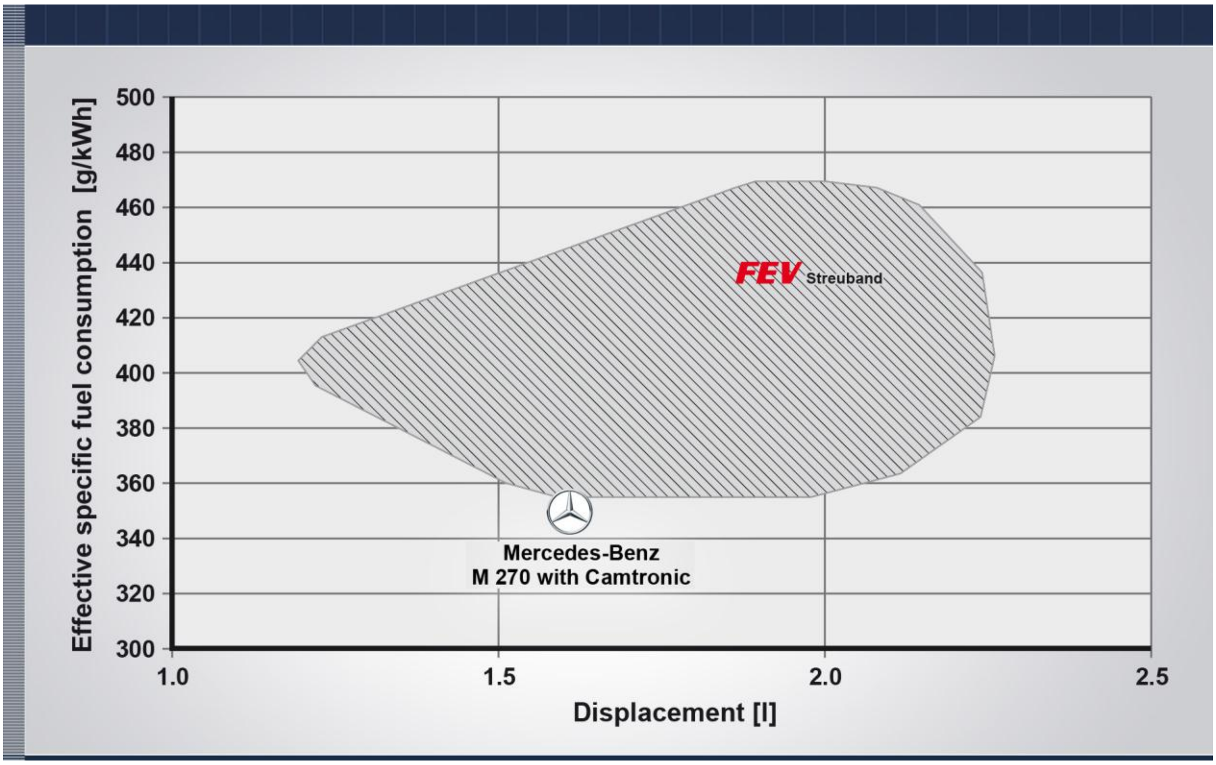

Figure 7: Fuel consumption in the scatter band where n = 2,000 rpm, pme = 2 bar

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2.3 Camtronic operating modes

Extensive reworking of the entire load control of the engine was required to achieve an operating range that is as large as possible while retaining the typical Mercedes driving comfort where the stroke switching is not perceptible for the customer. To do so, an inverse calculation of the air path based on the engine specified torque is used for the targeted regulation of all air-path-relevant components such as throttle valve, camshaft adjuster, stroke switching and turbocharger.

Figure 8 shows all the important Camtronic engine operating modes. If the engine load control for the small valve stroke was controlled only in conjunction with the throttle valve, this would result in significant restrictions with respect to the load range and engine speed range that could be covered. A maximum of an eighth of the entire engine characteristics map could be covered, meaning that the technology would only be able to achieve usable fuel consumption advantages for the customer in ranges close to idling.

For this reason, all of the other components already mentioned above were included in the load control, making a complete in-house redevelopment of the air path model and new calculation methods necessary.

After the load control has reached its limits for the small valve stroke via the throttle valve and it is no longer possible to increase the load and engine speed any further, the camshaft adjusters are used in such a way that adjusting the inlet valve timing continually increases the engine load without adjusting the throttle valve at the same time. This almost doubles the operating range.

If the upper load limit is reached here, too, the engine is turbocharged with the small valve stroke. Only once a load limit representing the same fuel consumption for large and small valve strokes with turbocharging is reached on the characteristics map while in turbocharged mode does the valve stroke switching take place within a working cycle in order to comply with the driver's higher load wishes.

This enhancement to the operating range made it possible on the one hand to maximize the operating range and on the other hand to achieve a minimization of the number of switching operations in the Camtronic system.

The large operating range created in this way can generate corresponding fuel consumption advantages particularly for customers in inner-city traffic or inter-city traffic on country roads.

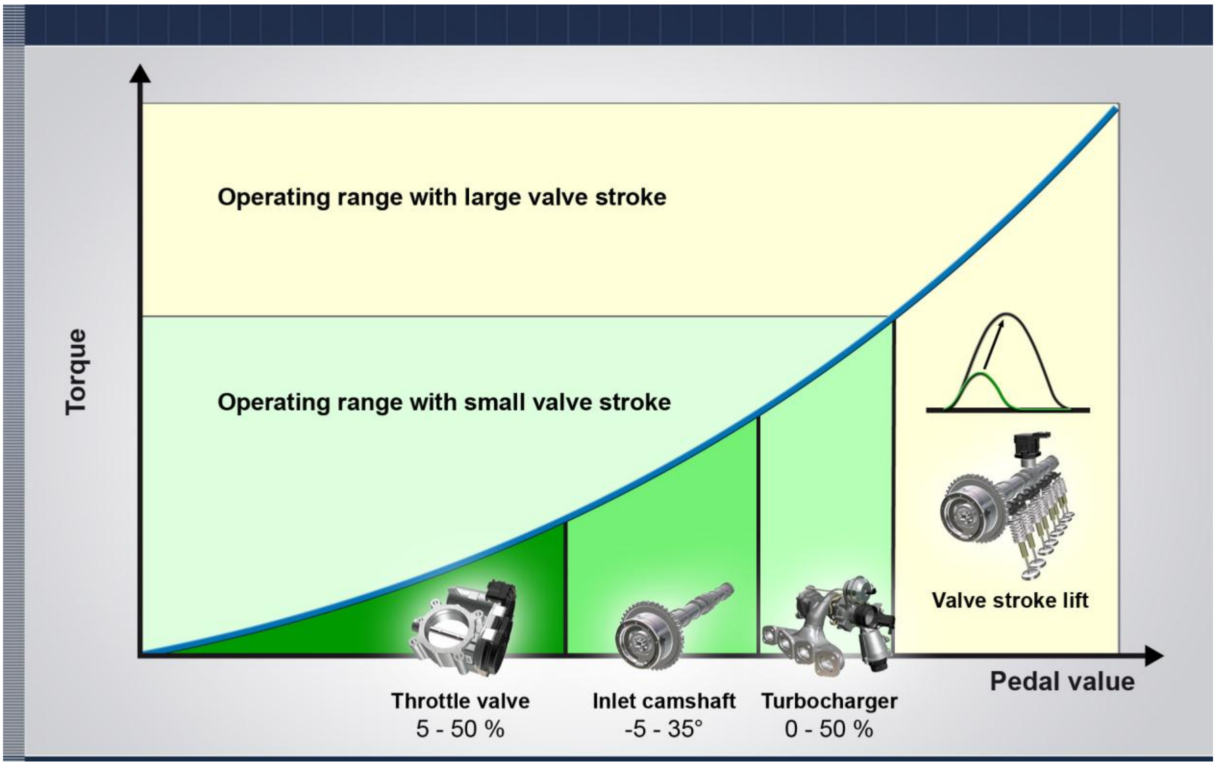


Figure 8: Camtronic operating modes on the characteristics map

4 The new 2.0l four-cylinder M270/M274 engine

Since the new engine family is not only installed in a transverse manner with front-wheel drive, but represents a modular design that is also used in north-south installation with rear-wheel drive, the use in the different vehicle platforms results in performance and engine torque requirements that cannot be covered by a displacement of 1.6l alone. For this reason, a displacement derivative with 2.0l, an output of 155 kW and a torque of 350 Nm was part of the engine family as well as the 1.6l variant with 90 kW and 115 kW output and a torque of up to 250 Nm.

This engine with increased displacement and performance is in a position to fulfill the enhanced performance requirements of a C-Class and an E-Class while also being the perfect basis for a sporty version of the A-Class that has just been presented.

The modular design of the engine family was also systematically used to enlarge the displacement. The bore from the short-stroke 1.6l engine was adopted to enlarge the displacement and the stroke lengthened accordingly. To fulfill the increased unit load of the engine, the crankshaft was changed from a cast crankshaft with hollow-bored crank pins to a steel crankshaft without hollow crank pins.

As this reduces the free inertial forces and therefore the NVH level of the engine, a completely newly developed, extremely compact Lanchester module was used to compensate for the second order inertial forces (Figure 9). No modifications to the basic engine are required in order to use this module. It is attached to the crankshaft bearing bracket from below as a complete module and the module is completely encapsulated to prevent hydraulic losses in the oil sump.

In light of the ambitious fuel consumption targets for this engine, the use of the Lanchester module should only have a minimal impact on the specific consumption of the engine. For this reason, a Lanchester module with complete roller bearings used for the first time in large-scale production was selected. This means that as well as radial mounting using roller bearings, axial mounting also takes place using angular contact ball bearings. This made it possible to reduce the frictional force caused by the Lanchester compensation by almost half (48%) when the engine is at operating temperature compared with the already very good frictional force values of the M271evo predecessor engine.

The further engine modifications are restricted to a change to the turbocharger group. A turbocharger made by ICSI with vacuum-controlled WG and 1050°C technology is also used here to optimize high-load fuel consumption. Charge-air cooling is carried out by an air-to-air intercooler, which has no disadvantages with respect to cooling efficiency compared with water-to-air intercoolers but has significant advantages as far as weight and cost are concerned.

For north-south installation, only the turbine casing and the charge-air piping were modified for the different package situation, and all other engine components were kept the same with the aid of the turning head concept.

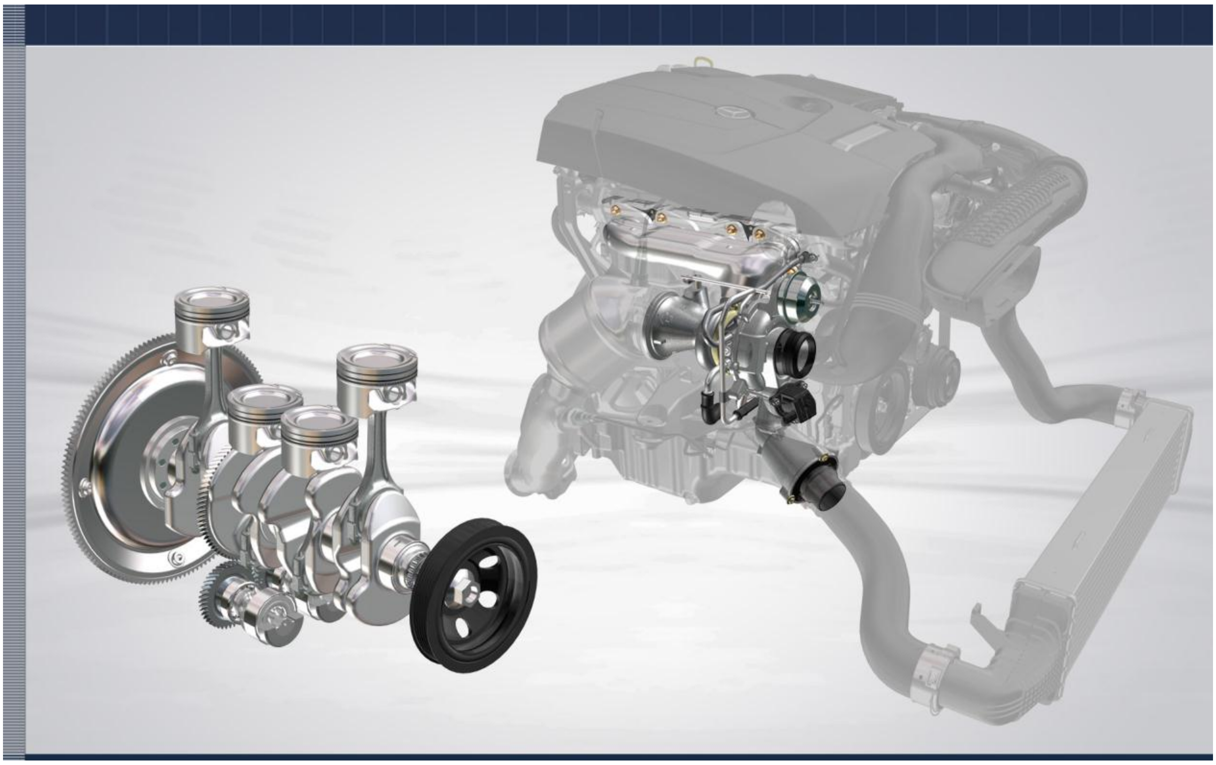


Figure 9: Change scope for 2.0l M274/270 engine

As was already the case for the small displacement variant, one development goal was the systematic implementation of a downsizing concept. For customers, the main focus here is on achieving an identical dynamic performance with equally powerful naturally aspirated engines. The achievement of low-end torque in particular plays an important part. While the maximum possible torque in the 1.6l displacement variant of 250 Nm, which is also identical for engines equipped with Camtronic, was already possible starting at 1,250 rpm, it was possible to further reduce the lower engine speed limit for the 2.0l engine. As a result, the 2.0l engine achieves the maximum torque of 350 Nm at an engine speed of as low as 1,200 rpm and an output of 155 kW at 5200 rpm. At the same time, it was possible to significantly reduce the specific engine consumption compared with the predecessor model using the fuel consumption measures already presented, whereby Camtronic is not used in the 2.0l engine. (Figure 10)

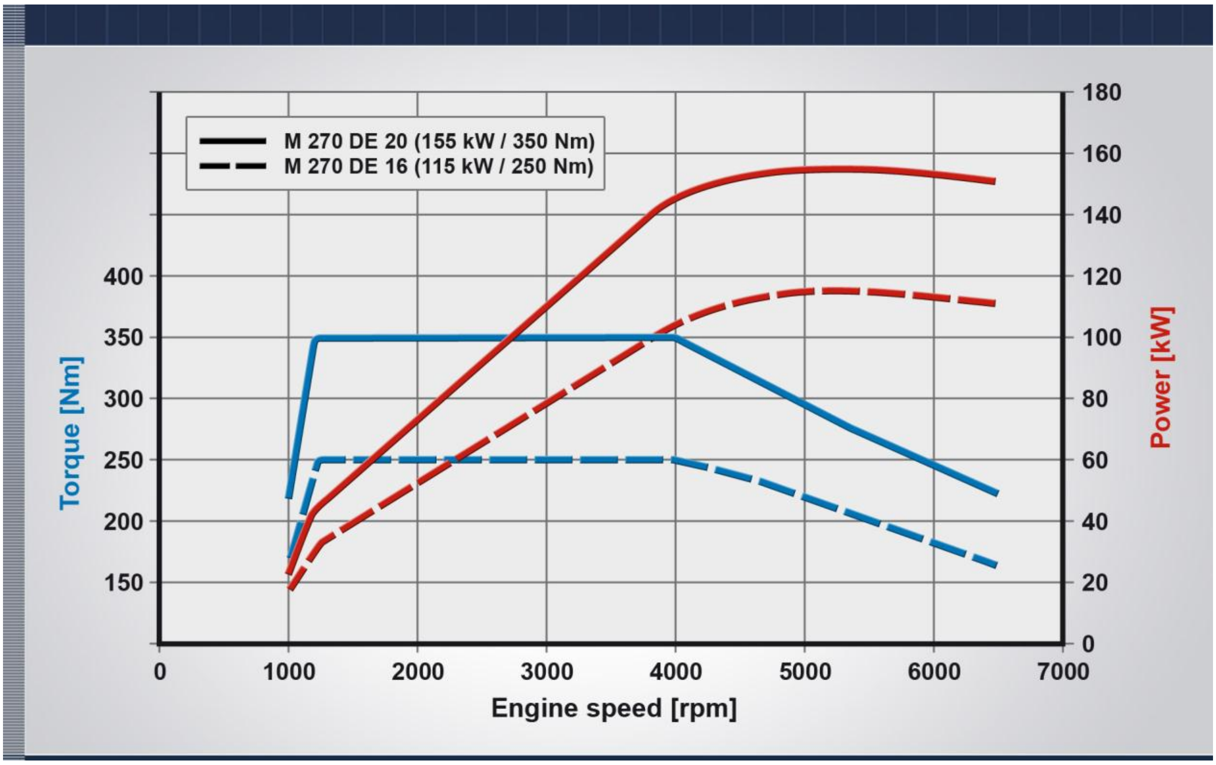


Figure 10: Output and torque of the new M270/274 engine generation

The 2.0l displacement variant of the M270/M274 engine family will be used for the first time in the A-Class in 09/2012 with the technology portfolio shown so far.

Figure 11 shows the comparison with the predecessor model. The new engines make a significant contribution to the performance increase in the vehicles as far as the fuel consumption and driving performance disciplines are concerned. While the W169 predecessor A-Class model still needed almost 10 seconds for the 0-100 km/h sprint with the 100 kW engine, the driving performance was improved to an outstanding 8.4 seconds for the sprint using manual transmission with the new turbo engine and the corresponding torque curve. At the same time, the fuel consumption also improved from 157 gCO2 to 129 gCO2 in the NEDC, equivalent to a reduction of approx. 15%.

If you consider the top 2.0l engines for both vehicle types, the output may have increased only slightly, but the driving performance was improved significantly by almost a second. Fuel consumption was also significantly improved here, representing a best-in-class value of 143 gCO2 and also advancing into the sports car sector with acceleration of 6.6 seconds.

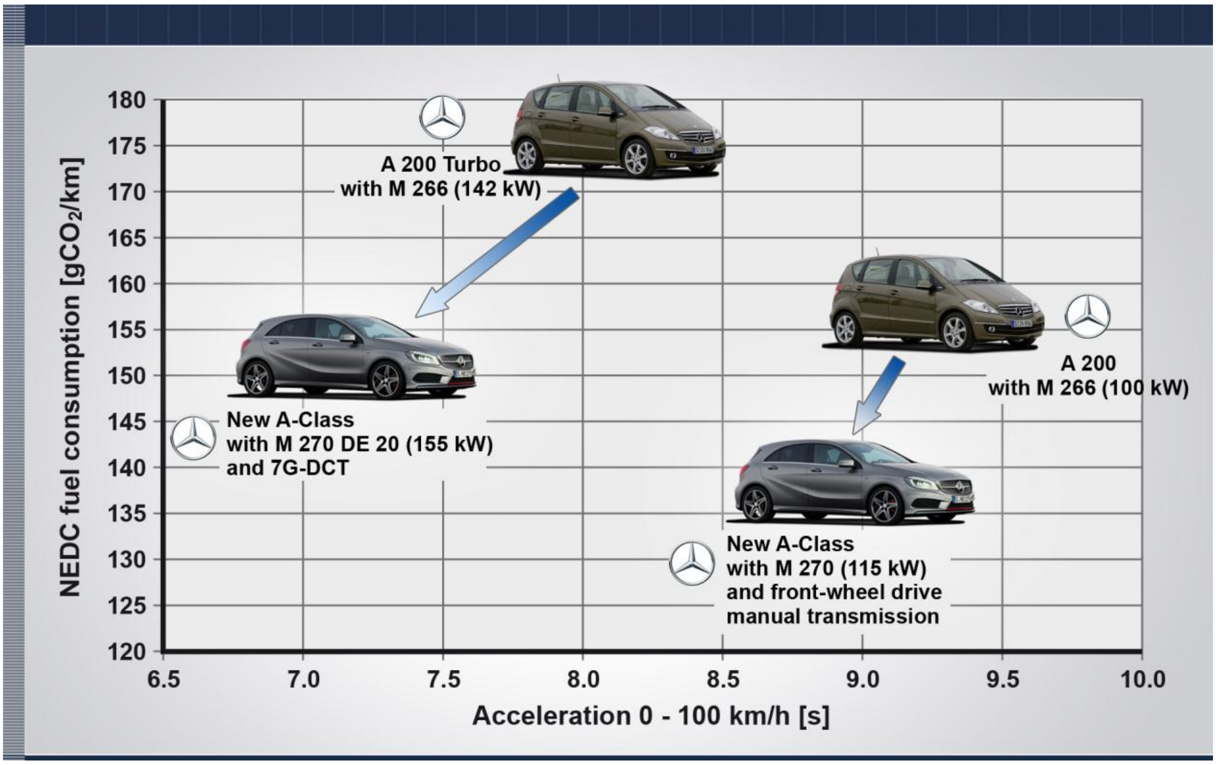


Figure 10: Driving performance comparison with the predecessor model

5 Combustion and exhaust-gas aftertreatment

5.1 Mercedes-Benz combustion system

Besides the electrification of the powertrain, discussion about reducing the climate-affecting CO_2 emissions is leading to sustainable further development of conventional combustion engines. The focus here is on the reduction of fuel consumption in almost all markets worldwide. At Mercedes-Benz, the course has been set within gasoline engine development over the last few years for an innovative and sustainable technology portfolio that is the optimum base for the implementation of maximum fuel efficiency in all vehicle segments without sacrificing comfort or superior drive performance [Aachen 2011, 4, 5].

Starting with the new V6 and V8 engine generation with the designation BlueDIRECT, the Mercedes-Benz combustion system, comprising the technology portfolio with third-generation direct injection, spray-guided combustion system, multiple-spark ignition (MSI) as well as integrated ancillary component and heat management, was launched [3].

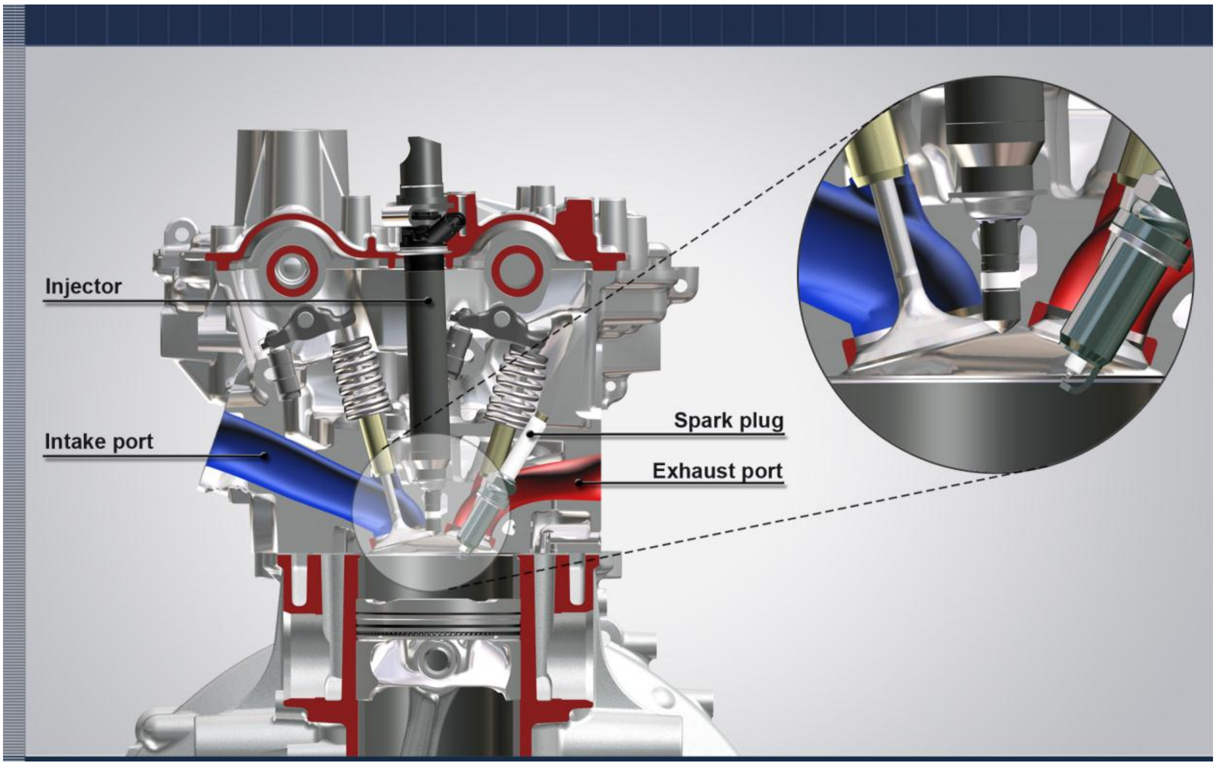


Figure 11: Mercedes-Benz combustion system with centrally arranged piezo injection [Aachen 2011]

The centrally arranged injector represents the design base of the Mercedes-Benz spray-guided combustion system. This is an outward-opening injector with a piezo actuator. It stands out primarily due to two characteristic benefits: Firstly, that the outward-opening nozzle enables very good mixture formation properties in conjunction with simultaneously high spray stability and the lowest possible fuel wetting of the combustion chamber surface. Secondly, the injection system is very flexible as far as the minimum and maximum possible injection quantities are concerned thanks to the directly controlled outward-opening nozzle. Injection times of between 80 µs and 5 ms can be set with the piezo actuator valve used and therefore a very large quantity spread from under 1 mg to over 150 mg can be realised. As a result, both the areas of supercharged wide open throttle and the microquantity requirements of the deceleration-like characteristics map area are covered without problems for the most varied single-cylinder volumes and all standard fuels up to E100. The injection pressure can remain at a high level almost constantly in order to ensure particularly good atomization and therefore mixture formation even in the lowest load range. In this way, one standard component can be used for the entire Mercedes-Benz gasoline engine portfolio, from the 5.5l eight-cylinder engine to the 1.6l four-cylinder engine [6].

The high stability of the mixture formation together with the ability to inject well prepared, very small quantities of fuel into the combustion chamber results in a very stable combustion system with appropriate local mixture composition. This is the basis for rapid and complete combustion, which means a low tendency to knock towards the end of combustion and low emissions.

Besides the benefits for conventional stoichiometric combustion systems already mentioned, this combustion chamber configuration also makes it possible to implement the lean-mixture stratified combustion system already implemented in the Mercedes-Benz V6 engines. This combustion system represents the thermodynamic optimum to date and is the basis for specific and best vehicle fuel consumption values.

Since it is no longer possible to use conventional exhaust gas technology with a three-way catalytic converter for exhaust gas after treatment in lean-mixture combustion systems, changes to the engine itself and the exhaust system are required in order to make it possible to sustainably comply with the exhaust gas limit values in the triad in addition to the very good fuel consumption values.

In order to be able to reduce the exhaust-gas after treatment effort on the one hand and to design the combustion system suitably on the other, it is essential that cooled exhaust gas recirculation is used. In the case of the M274, Mercedes-Benz will be implementing an engine with turbocharging and spray-guided direct injection as a lean-mixture combustion system for the first time in the E-Class in the spring of 2013. This is simultaneously the first use of spray-guided direct injection in a four-cylinder engine and thus of an engine in very high quantities.

5.2 Design changes compared with the homogeneous engine

For this reason, new strategies had to be explored when implementing the combustion system in conjunction with turbocharging, particularly when designing the EGR system. To ensure the necessary EGR rates, the EGR system's extraction point was placed upstream of the turbine. The EGR valve consequently installed upstream of the EGR cooler had to be designed to be suitably temperature-resistant. The EGR cooler that then follows reduces the EGR temperatures so that the cooled exhaust gas can be fed to the plastic intake pipe via a large flange and a suitably designed mixing tube without any risk of damaging the components. Particular attention was paid to good mixing and even distribution over the cylinders.

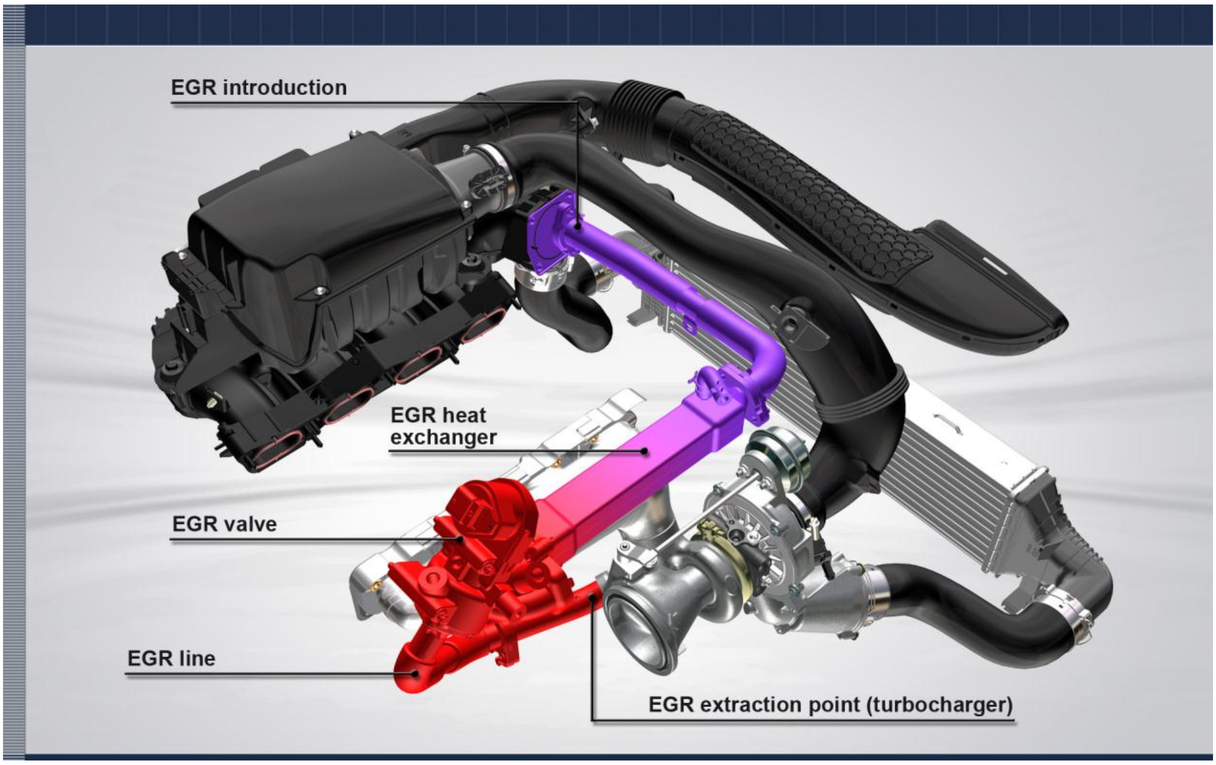


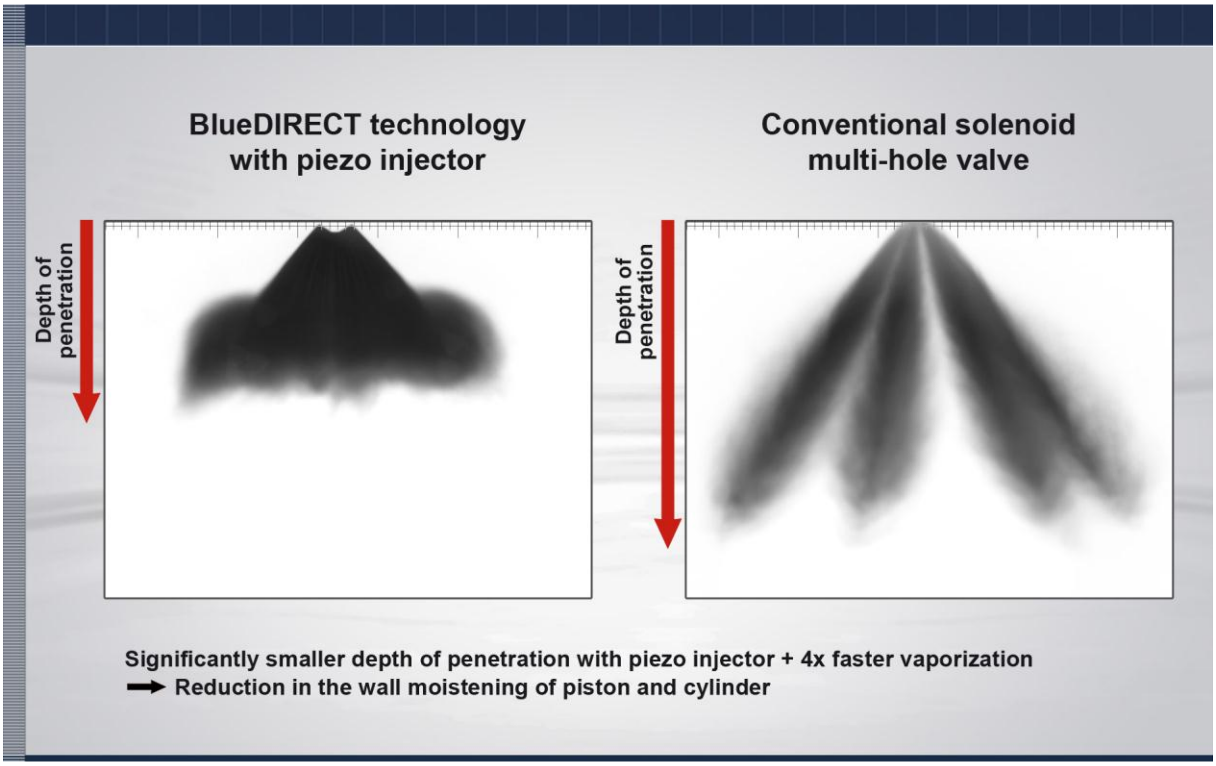
Figure 12: EGR system of the stratified engine

5.3 Mercedes-Benz BlueDIRECT combustion system

The key element of the spray-guided combustion system is the piezo injector with outward-opening nozzle, which can distribute the shortest of injection impulses extremely precisely and stably. It is extremely robust with respect to carbonization and has an almost unchanged spraying pattern over the operation life.

These are the basic prerequisites for stratified combustion. Since the last injection takes place immediately before ignition in the case of the spray-guided combustion system, this results in further requirements to be fulfilled by the mix controller compared with homogeneous operation. In order to prevent the moistening of pistons and walls, the requirements concerning depth of spray penetration and vaporization behavior are much higher than for intake stroke injection. The possible free spray length is reduced significantly, particularly in conjunction with optimally efficient high compression rations. This is because the piston is located almost in the top dead center position.

Figure 13 impressively shows the potential of the outward-opening piezo nozzle compared with the standard multi-hole valves. It shows a completely dethrottled operating point with 200 bar injection pressure for the piezo injector versus 130 bar for the multi-hole valve. The high injection pressure in conjunction with the outward-opening nozzle with a very small valve gap produces a tapering hollow spray, for which the depth of penetration is only about 50% of that of a conventional multi-hole valve. The small droplet spectra thus produced with minimum quantity injection cause vaporization to take place four times faster than with multi-hole valves of the type currently used. On the one hand, this reliably prevents wall moistening, which is the basis for extremely low particle emissions and thus compliance with the EU6 Stage 2 exhaust gas standard. On the other hand, it also creates increased robustness with respect to carbonization and residue build-up.


BlueDIRECT technology with piezo injector

Conventional solenoid multi-hole valve

Significantly smaller depth of penetration with piezo injector + 4x faster vaporization

→ Reduction in the wall moistening of piston and cylinder

Figure 13: Comparison of injector technologies

The resulting advantages are not only used to implement combustion in the spray-guided stratified combustion system but are also already being used in homogeneous combustion system mode. This means that in homogeneous mode, in addition to just intake stroke injection, a short injection impulse is also applied shortly before ignition. This leads to higher turbulence in the ignition spark area, thereby stabilizing the flame core formation and ultimately the combustion. Using this injection stabilization also made it possible to implement Camtronic without valve masking and thus to achieve systematic implementation of the module concept and a standard combustion chamber.

On the other hand, just pulsed compression stroke injection is used in stratified combustion systems. Here again, the last injection impulse is also shortly before ignition to stabilize the mixture and turbulence conditions at the time of ignition. This results in the production of stable, almost stoichiometric mixtures in the spark area and, in conjunction with multiple-spark ignition, misfire-free operation is made possible under all load and engine speed conditions even in stratified operation. The characteristics map area covered in this way extends from idling to 4,000 rpm and up to approximately half the full intake load.

In order to enhance the fuel consumption benefits of lean-mixture operation for the customer, possibilities to expand lean-mixture operation further were investigated. The HOS (homogeneous stratified mode) operation mode developed on the V6 engines was enhanced for use in turbocharged four-cylinder engines. Here, a combination of intake stroke injection and late compression stroke injection are used in order to extend the lean-mixture operating range almost as far as the full intake load. The load range above this is, in turn, operated stoichiometrically and since the engine is already being operated almost dethrottled due to the high loads, it results in a thermodynamic optimum even without lean-mixture operation.

The characteristics map area that this covers means that a significant fuel consumption potential can still be achieved, even with a dynamic driving style.

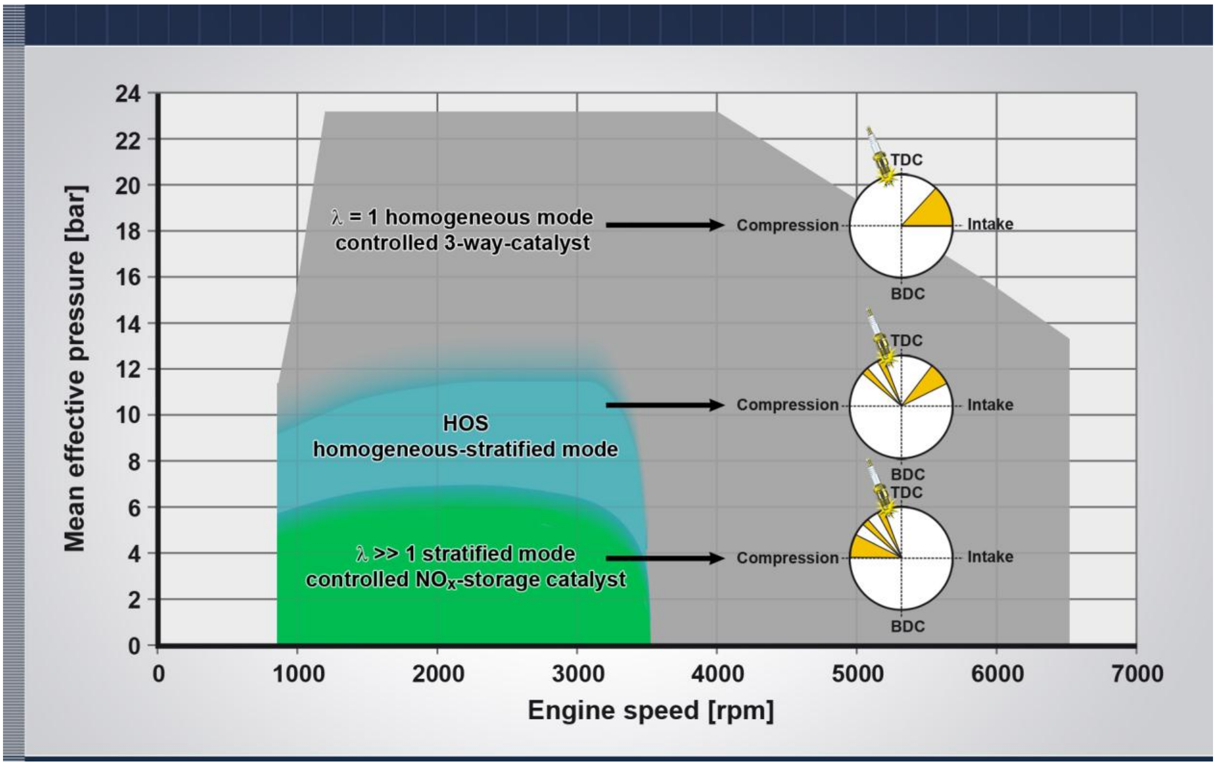


Figure 14: Operation strategies on the characteristics map

On the fueleconomy map, this results in fuel consumption benefits of more than 18% compared with purely stoichiometric operation at low loads and engine speeds; however, fuel consumption benefits in the range of up to 6% can still be achieved even at high loads with a bmep of 12 bar. This is therefore perfectly suited to modern traffic conditions.

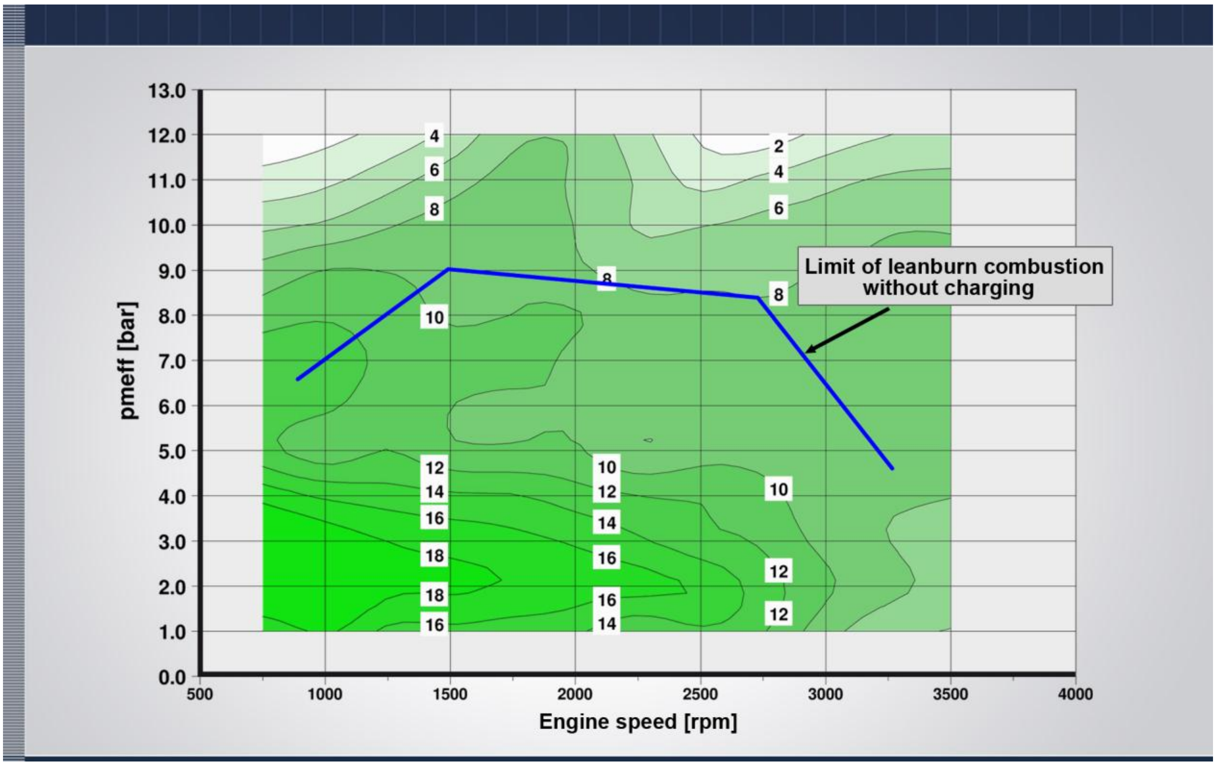


Figure 15: Delta fuel consumption characteristics map for lean-mixture homogeneous mode

Within figure 15 the blue line marks the border for leanburn combustion without charging, given by the stoichiometry of the lean mixture. The leanburn operation range could be increased by using the turbocharger also at partload in order to get higher AFR´s without penaltys in fuelconsumption.

Figure 16 shows how these operation strategies are implemented in real vehicle operation. After the engine is started, the catalytic converter is first heated in the conventional manner with a slight lean-mixture displacement in order to achieve the light-off of the closed-coupled catalytic convertor as quickly as possible. The light-off is achieved before the second acceleration phase in the cycle and the engine is running in stochiometric mode until the third acceleration period. After this acceleration phase the whole system , engine, sensors, and exhaust aftertreatment are in a stable condition. Now the lean operation mode and start stopp is engaged. The diagram now shows that almost the entire test can be driven with a lean mixture, since the characteristics map fields that can now be achieved extend to the full intake load. As Figure 16 clearly shows, the stratified combustion system alone can already be used to cover about 80% of the time of the test. The time could be extended to almost 90% using the development of what is known as the HOS operating mode for the high load ranges in vehicle operation. The fuel consumption benefits achieved there may be smaller in absolute terms; however, they are of great importance for the real fuel consumption that can be achieved in the vehicle due to the high-load operation ranges with correspondingly high fuel flows.

This operation strategy means that reductions of up to 10% are possible in the NEDC depending on the vehicle and engine combination. A fuel consumption benefit of approximately 8% is achieved here for the E-Class.

Significantly higher fuel consumption benefits can be achieved by customers with this technology and the corresponding driving style.

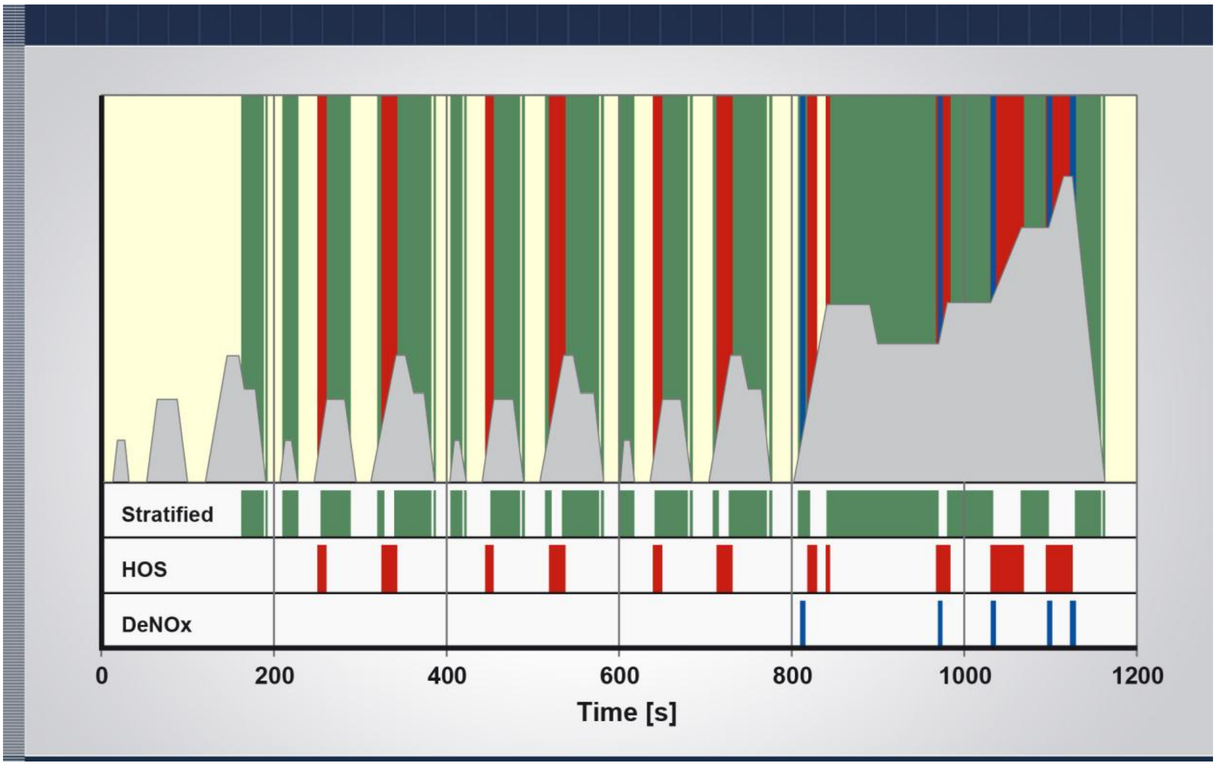


Figure 16: Vehicle operation strategy in the NEDC

5.4 Changes to the exhaust system

The lean exhaust flow now created is subject to a large number of additional requirements with respect to its aftertreatment compared with stoichiometric exhaust. The high efficiency of the combustion in conjunction with the high excess air leads to a high exhaust flow with very cold exhaust gas at diesel-like level. Exhaust gas temperatures from 250°C are typical here. This condition places particularly high requirements on the light-off behavior of the catalytic converter coatings, both for the components to be oxidized, such as HC and CO, and for the components to be stored, such as NOx. Simultaneously, the high possible exhaust gas temperatures in the range close to full load place high requirements on the aging resistance of all components. Finally, the overall system also has to fulfill all OBD requirements in a stable manner and fit into the modular design of the respective model type.

For this reason, intensive further development of the exhaust gas system already familiar from the six-cylinder naturally aspirated engines was necessary.

Using this double-pipe system proved to be the best compromise between temperature reduction in the high-load area and package and temperature reduction in the catalytic converter's light-off area, which is important for stratified operation. As a result, it was possible to significantly improve the aging stability of the NOx storage catalytic converter. In the high-load area, the exhaust gas temperatures are reduced by approx. 50°C without any noteworthy temperature reductions in stratified operation that would have a negative effect on the light-off behavior.

In closed-couple-position there is a new developed three-way NOx-storage catalyst, which works as a TWC during stoichiometric mode as well as NOx-storage catalyst during lean and cold phases with low exhaust temperatures. The coating is optimized regarding light-off behaviour which enables also a stable conversion of HC and CO during lean phases. [9]

The closed-couple catalytic convertor takes on the three-way function in homogeneous mode. Here, a coating optimized with respect to the light-off behavior was also used, enabling safe HC and CO conversion in lean-mixture operation.

The NOx storage catalytic converter for the reduction of nitrogen oxides in the lean-mixture operation modes is located downstream of the cooling path in the underfloor position.

To monitor exhaust-gas after treatment and to control the NSC, a continuous sensor and a binary sensor are used to monitor the firewall catalytic converter, and a thermocouple upstream of the NSC and an NOx sensor downstream of the NSC to monitor the NOx storage catalytic converter.

Finally, the exhaust system was also optimized with respect to NVH, which is why a soft decoupling element was used downstream of the closed-coupled catalytic convertor to reduce the transmission of engine excitations.

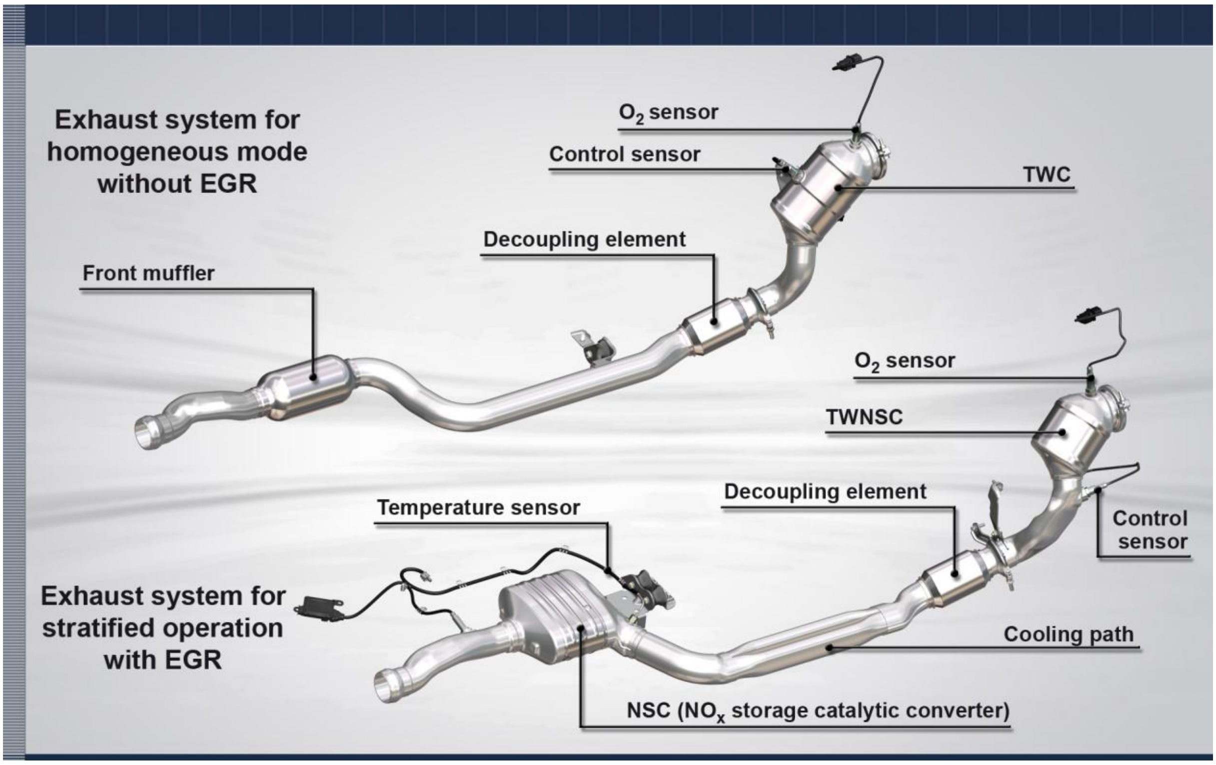


Figure 17: Comparison of stoichiometric exhaust system and stratified/lean-mixture operation

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