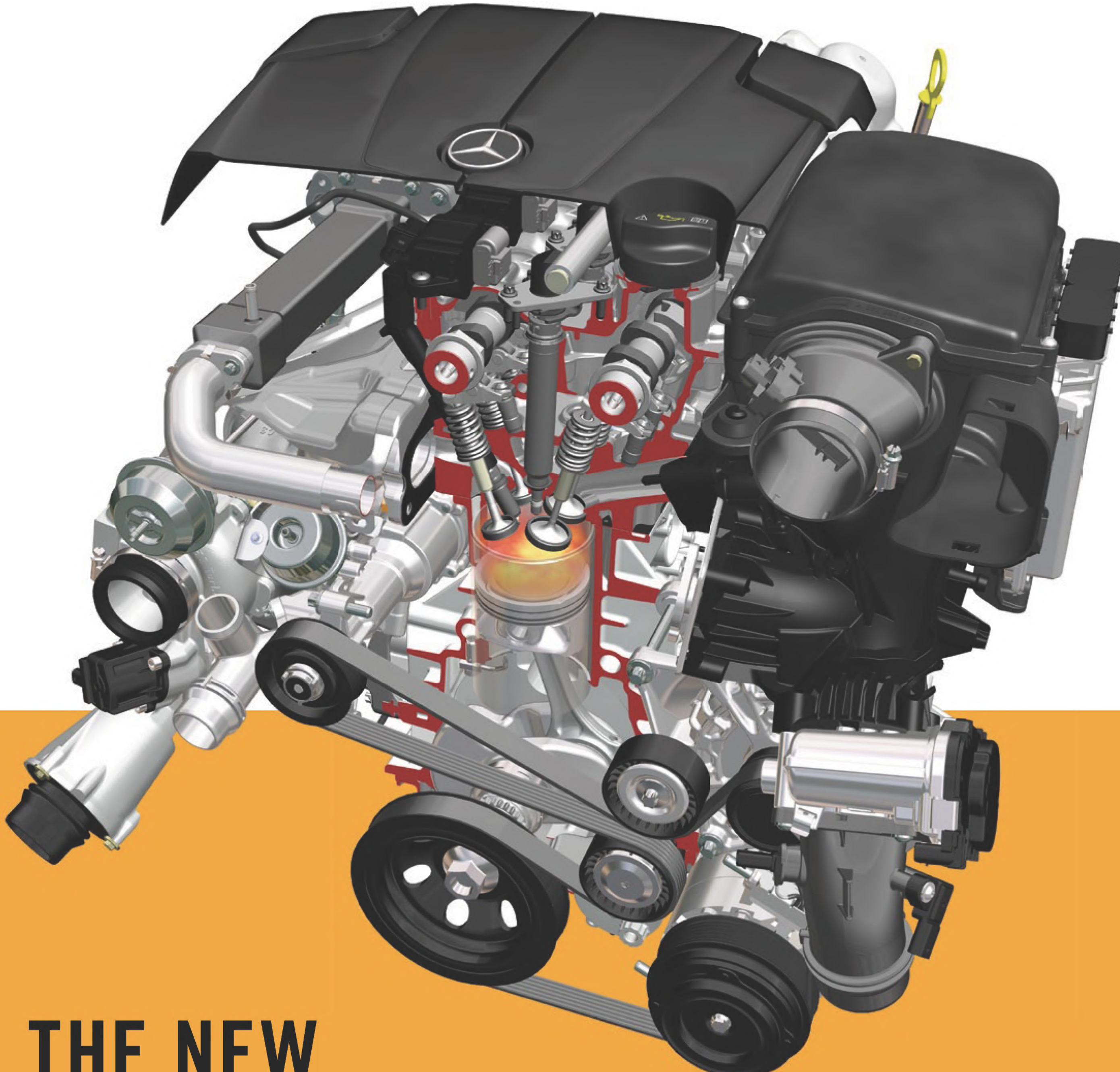


THE NEW FOUR-CYLINDER GASOLINE ENGINES FROM MERCEDES-BENZ

Mercedes-Benz has developed a completely new family of engines in the form of the M270 and M274 four-cylinder BlueDirect gasoline engines, offering maximum efficiency, dynamics, and flexibility. Market-specific CO_2 technologies in the drivetrain ensure that optimal consumption values can be attained, depending on the regional fuel availability.

AUTHORS

ING. MARIO MÜRWALD
is Head of Gasoline and Hybrid Powertrain at the Daimler AG in Stuttgart (Germany).

DIPL.-ING. ROLAND KEMMLER
is Project Manager Four-Cylinder Gasoline Engines at the Daimler AG in Stuttgart (Germany).

DIPL.-ING. ANTON WALTNER
is Head of Combustion Development and Calibration of Four-Cylinder Gasoline Engines at the Daimler AG in Stuttgart (Germany).

DIPL.-ING. FRITZ KREITMANN
is Head of Design and Mechanical Development Four-Cylinder Gasoline Engines at the Daimler AG in Stuttgart (Germany).

THE FOUR-CYLINDER FAMILY FOR TRANSVERSE AND LONGITUDINAL INSTALLATION

At the end of November 2011, Mercedes-Benz launched the new M270/M274 four-cylinder engine family for transverse and longitudinal installation, ❶, with piezo direct injection. This flexibility in terms of installation orientation allows the family of engines to be used in all vehicle segments. The performance range covered is particularly broad due to the availability of two displacement variants, 1.6 l and 2.0 l.

Many technological modules in the four-cylinder family of engines, ❷, were adopted from the six- and eight-cylinder BlueDirect engines [1]. Mercedes-Benz direct piezo injection, combined with optimal turbo design and a consistent reduced-friction basic engine meets the most exacting requirements in terms of agility, consumption, and comfort. Targeting the most ambitious CO_2 goals, this high-performance base technology portfolio is outfitted with three different consumption technologies oriented to accommodate market-specific conditions.

The two consumption technologies Camtronic and lean-burn combustion are already being used in series production for this family of engines. The third important milestone is marked by the launch of the natural gas variant NGD (Natural Gas Drive). Series production of the NGD E-Class will start at the end of 2013.

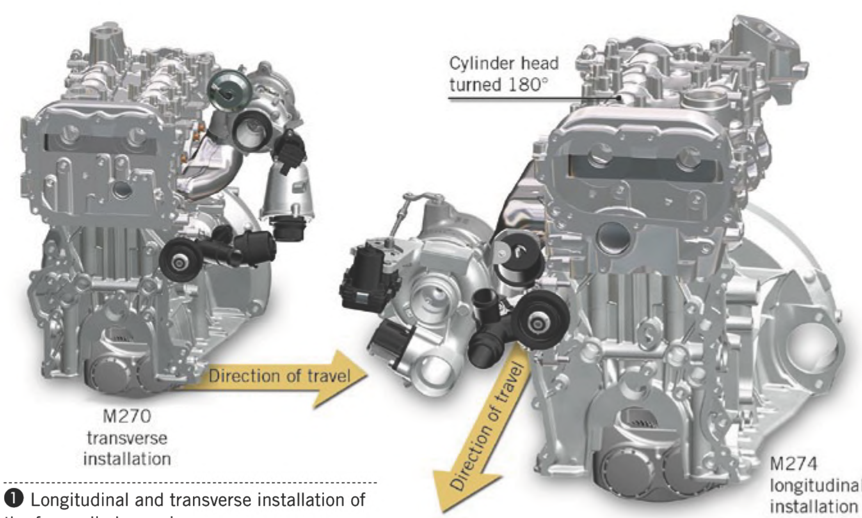
Using a flexible, innovative technology portfolio to achieve a sustainable reduction in fuel consumption and compliance with globally varying market and legal requirements ensures the viability of this new engine family and provides a foundation for extremely efficient and superior drive system performance.

ENGINE DESIGN AND MECHANICAL COMPONENTS

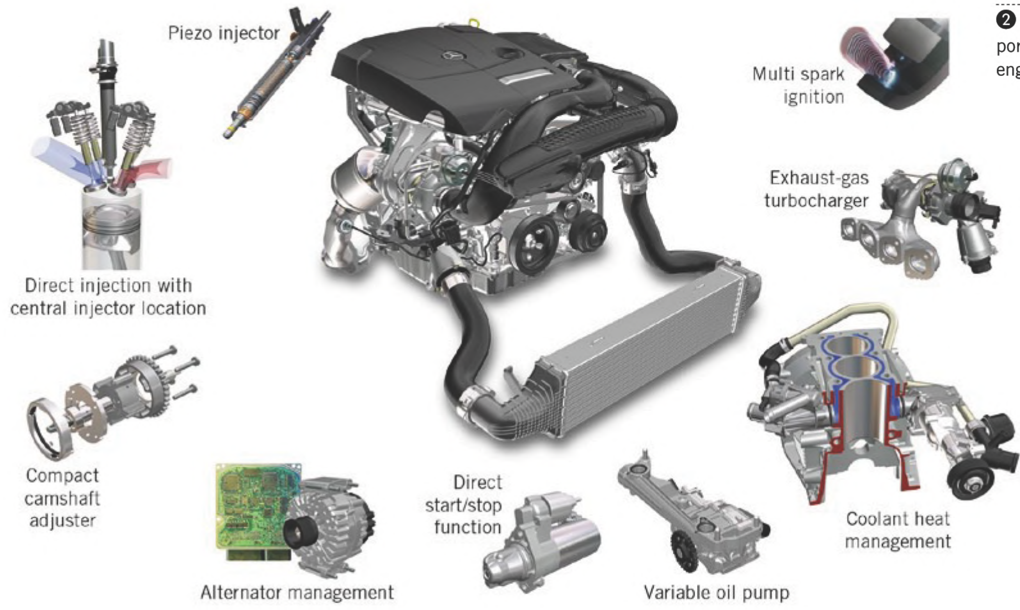
The development goals for the die-cast-aluminum cylinder crankcase and the crank assembly included significant weight savings, further reduction of friction in the crank assembly, and the introduction of a new cross-flow cooling method. Friction in the crank assembly and chain drive have been considerably reduced in comparison to the predecessor family of engines M270/M274. Friction was reduced by 16 % in the crank assembly and 9 % in the chain drive [1].

The "low-end torque" design of the turbocharger assembly has been very successful in both displacement variants of this family of engines. The 2.0-l engine achieves the maximum torque of 350 Nm at an engine speed as low as 1200 rpm. Due to high torque at low loads, an extremely compact Lanchester module is used to reduce engine NVH levels by inducing second order inertial forces, ❸. Using this module does not require any modifications to the basic engine. It is screwed onto the crankshaft bearing block from below as a complete module and is fully encapsulated to prevent churning losses in the oil sump.

The Lanchester module is mounted entirely on anti-friction bearings to help achieve the ambitious consumption



❶ Longitudinal and transverse installation of the four-cylinder engine



❷ High-performance base technology portfolio of the four-cylinder BlueDirect engines

goals. For the first time in a mass-produced car, both the radial bearing and the axial bearing are implemented via roller bearings and angular contact ball bearings respectively. This allowed the friction power values of the Lanchester to be reduced by 48 % compared to the predecessor at regular operating temperature.

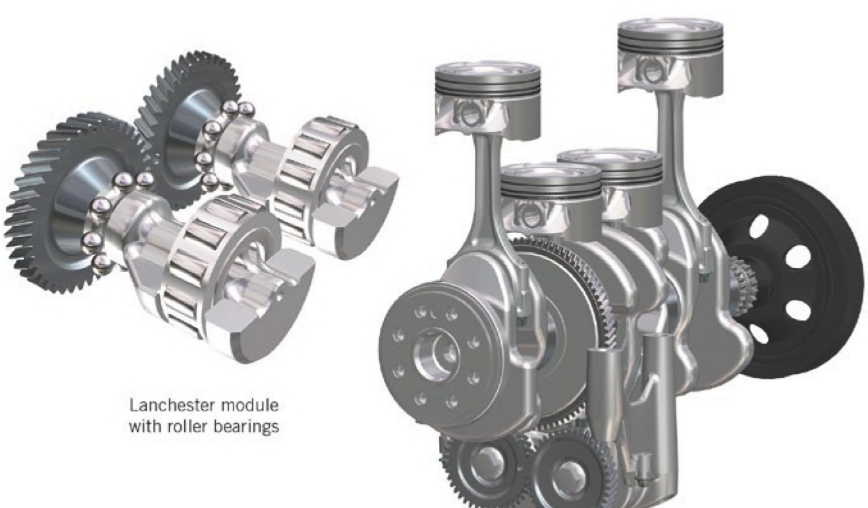
COMBUSTION PROCESS

The Mercedes-Benz BlueDirect combustion system was first introduced in 2006 with the CLS 350. The combustion system has been successively rolled out in the years that followed and has been part of the standard package for all new gasoline engines since 2012. The main feature of this system is the piezo injector, which is arranged centrally in the combustion chamber with its outward opening nozzle and spark plug positioned at a defined distance in the direction of the exhaust valves, ❹. The ultra-fast actuation of the piezo injector nozzle needle for multiple injection with minimal injection quantities per working cycle, the very good mixture formation of the A-nozzle with 200 bar of fuel pressure, and the extremely linear quantity characteristic with high static flow (Q_{stat}) allow a single injector prototype to be used for all gasoline engines. Together with the multiple ignition, this provides a basis for low-particle combustion, cold start ability even with a high ethanol content, heating of the catalytic converter for optimal consumption, as well as a range of other advantages.

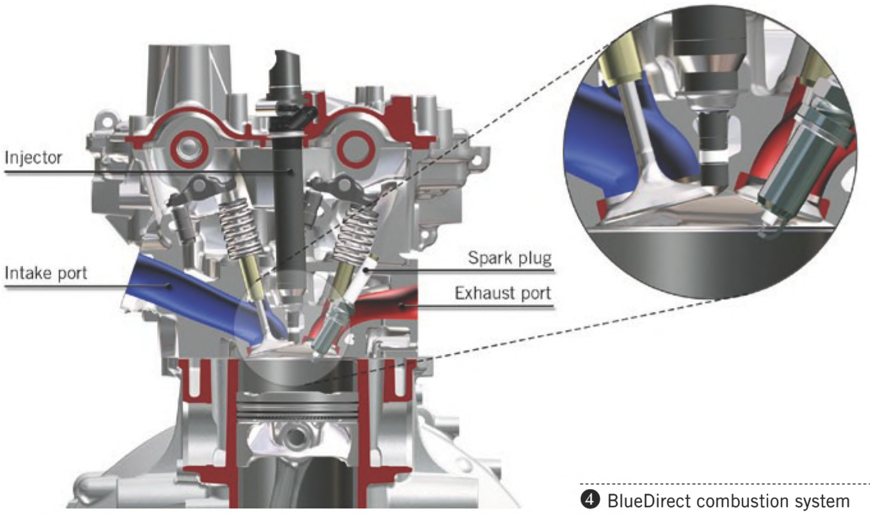
THREE MARKET-SPECIFIC TECHNOLOGIES FOR CO_2 REDUCTION

The BlueDirect combustion system and the basic technological modules already described are the starting point for achieving minimal fuel consumption. When the M274 was introduced, three consumption or CO_2 technologies, ❺, were developed, which are deployed in line with market conditions or customer demand. Valve stroke switching by means of Camtronic is used exclusively to reduce charge exchange losses. With lean-burn combustion, high-pressure efficiency is also significantly improved. The potential limit of gasoline engines is, therefore, nearly reached in gasoline mode. CNG offers enormous CO_2 advantages by virtue of its chemical composition alone. In connection with good knocking characteristics, CNG is the ideal fuel for supercharged gasoline engines.

CO_2 potentials reductions increase from approximately 3 to 5 % with Camtronic to more than 20 % with CNG. As seen in ⑤, CO_2 reducing technologies



❸ Lanchester mass balance module mounted on anti-friction bearing



❹ BlueDirect combustion system

increase from top to bottom. Despite such CO_2 reducing potentials, the availability of suitable infrastructures for these technologies is decreasing in the world market, as seen with lean-burn combustion CO_2 technology, which requires low-sulfur fuel. So far, this is only widely available at gas stations in Europe and Japan. Low-sulfur fuel will be available in the USA in the medium term [2]. The availability of natural gas on the global markets is very good, although natural gas currently plays only a rather subordinate role in terms of its use as fuel due to its more complex infrastructure in comparison to gasoline. The modular design allows the different technologies to be adapted to changing market situations relatively easily.

CO_2 REDUCTION BY MEANS OF VALVE LIFT ADJUSTMENT

Camtronic is a consumption technology that can be used worldwide and allows a consumption or CO_2 advantage of 3 to 5 % to be achieved. The camshaft design on the intake side enables a switchover from a standard cam for the upper load/speed range to a "small" cam in the partial load range. ❻ illustrates the mechanical functionality. In addition to lower friction losses on the small cam with a maximum valve lift of 3.8 mm, the main advantage is in the reduction of charge exchange losses. The early inlet end leads to nearly throttle-free operation in a relatively broad characteristic map range. The load is regulated exclusively via the continuously adjustable camshaft phase adjuster. Switchover from a small cam to a large cam and vice versa represents a considerable challenge. In addition to the high demands for comfort, exhaust and consumption aspects must also be taken into consideration for the switchovers. Here, the BlueDirect technology package allows these demands to be met in full with the enormous degree of freedom with regard to injection timing and multi spark ignition in combination with camshaft phase adjustment, throttle valve and boost pressure control [4].

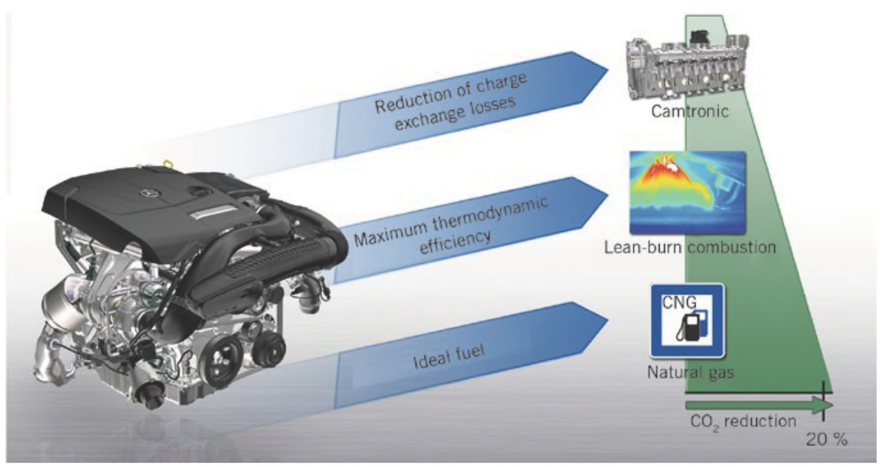
CO_2 REDUCTION BY MEANS OF LEAN-BURN COMBUSTION

Lean-burn combustion was developed for the first time in conjunction with turbocharging for the four-cylinder family of engines. This combustion method allows the maximum thermodynamic combustion potential be achieved at low loads. So far, lean-burn combustion has been limited to the European and Japanese markets. With the widespread availability of low-sulfur fuel, the technology can also be rolled out to other markets such as the US [2].

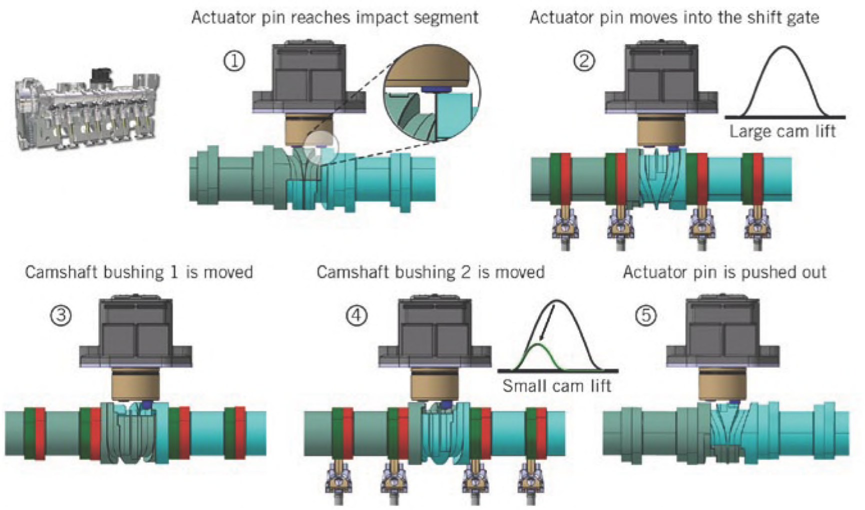
Lean-burn combustion uses a precisely timed compression stroke injection where the last injection just before ignition serves to stabilise the mixing and turbulence conditions. This produces stable and virtually stoichiometric mixtures in the area of the spark. In conjunction with multi spark ignition, optimum ignition conditions are thus created under all load and speed conditions. Lean-burn mode encompasses characteristic map ranges from idle mode up to 3500 rpm and mean pressures of up to 5 bar effective (p_{me}). This corresponds to approximately half the full load of a naturally aspirated engine.

In the load range above 5 bar p_{me}, the HOS mode (homogeneous lean combustion), which was specially enhanced for turbocharged four-cylinder engines, is used. Here, a combination of intake stroke injection and late compression stroke injection in conjunction with turbocharging are used in order to extend the lean-mixture operating range as far as the full intake load. The load range above this is operated stoichiometrically because the throttle valve is already fully open.

If lean-burn combustion is used, high demands are made on exhaust aftertreatment with regard to system and catalytic converter performance due to the low exhaust temperatures that occur in the



❺ Three market-specific CO_2 technologies



❻ Camtronic technology set (more about Mercedes-Benz Camtronic at http://youtu.be/3FHE4XTHpLI)

driving cycle. For this reason, the configuration of the single-pipe exhaust system shown in ❼ (top) was developed for the new BlueDirect four-cylinder engines with turbocharging. By consistently advancing the catalytic converter mounted near the engine, a new converter technology is made possible for mass production that not only supports three-way catalytic converter functionality but also the storage of NO_x under lean exhaust gas conditions. This involves a three-way nitrous oxide storage catalytic converter (TWNSC), which supports NO_x management in lean-burn combustion mode with low engine loads and the associated low exhaust temperatures, ⑦ (bottom). TWNSC also has a high HC reduction potential at low exhaust temperatures. Thanks to further development of the nitrous oxide storage catalytic converter (NSC) installed in the underfloor area, it was possible to further widen the NO_x storage window while simultaneously improving desulfurisation at low temperatures. In addition to improving the NO_x conversion, it was also possible to reduce the precious metal content by 30 % compared to NO_x storage catalytic converters already in series production. The overall system costs were thus significantly reduced.

CO_2 REDUCTION BY MEANS OF NATURAL GAS

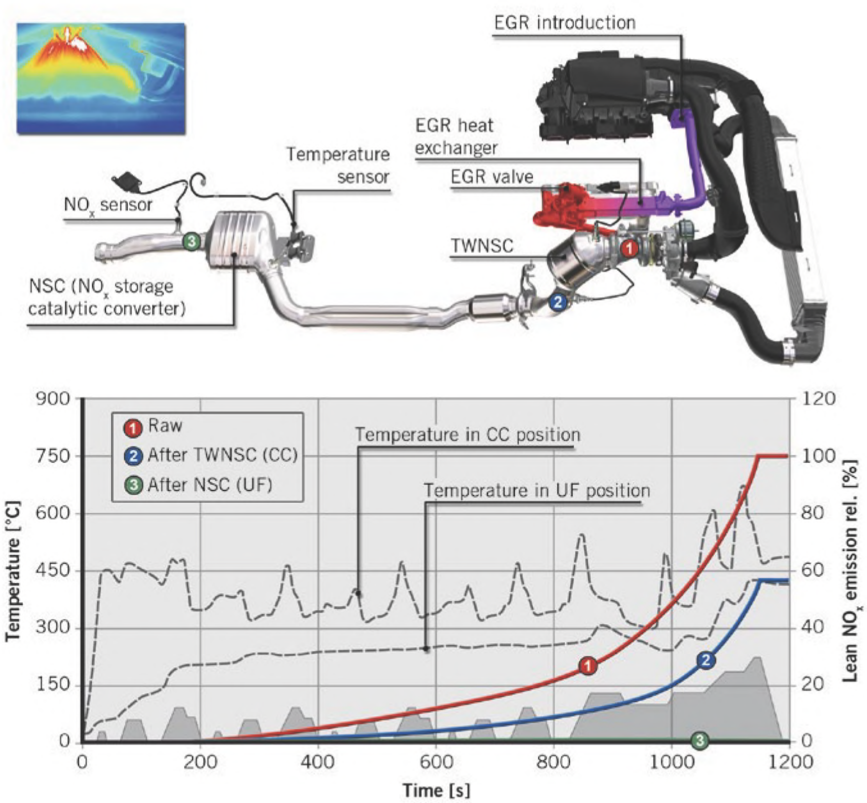
In addition to the CO_2 technologies Camtronic and lean-burn combustion, the family of engines was also developed further to support CNG Compressed Natural Gas) capability. Development of eco-friendly natural gas engines has become a successful tradition for the Mercedes-Benz E-Class. In particular, taxi and fleet operators value the low operating costs of these vehicles in natural gas mode, along with very high overall ranges thanks to the additional gasoline mode. In the dual fuel natural gas variant, a high commonisation level was achieved for the component assembly of the BlueDirect engines.

ADAPTING THE ENGINE HARDWARE TO CNG OPERATION

Operation with natural gas requires the following modifications to the crank assembly:

- adaptation of the exhaust-gas turbocharger
- piston with increased compression and coated ring supports
- cylinder head with modified seat ring and valve material.

For the purpose of injecting CNG, the charge air distributor was modified in the vicinity of the intake manifold arms to integrate a separate gas injection valve for each cylinder with corresponding nozzle cups, ❽ (top). The gas-injection valves are operated briefly with very high currents of up to 6 A (peak and hold actuation). The benefit of this strategy is that the engine can be safely and reliably started even at very low outside temperatures (down to -25 °C). To pro-



❼ Exhaust aftertreatment for lean-burn combustion (CC: Closed-Coupled; UF: Underfloor) (more about Mercedes-Benz BlueDirect lean-burn combustion at http://youtu.be/uIGe_kBhHNc) tect other components such as the pressure regulator, the engine will not start using natural gas if the outside temperature is below -15 °C. When this temperature threshold is undershot, the engine is started using gasoline only and automatically switches over to natural gas when the temperature of the coolant and natural gas permit the transition.

ENGINE CONTROL AND CNG COMPONENT NETWORKING

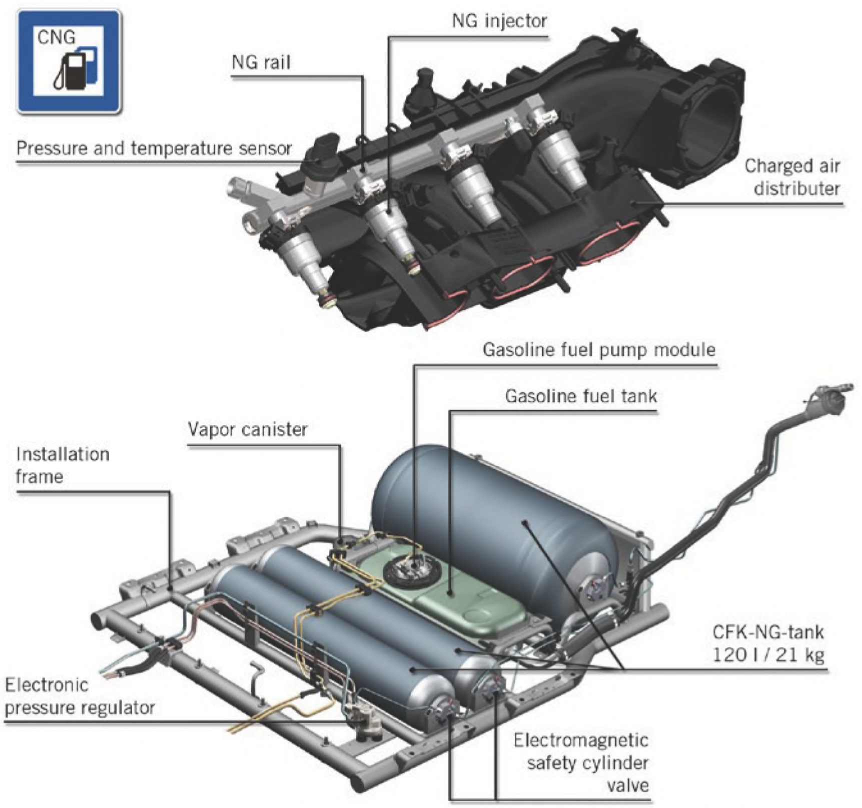
The MED17.7 engine control unit from Bosch, as used in the M270/M274, with the unassigned input and output ports, is not capable of actuating all CNG components such as cylinder valves, pressure regulator, and gas injection valves because of the modular BlueDirect component package. In addition, final stage integration would have required the architecture in the hardware of the motor control unit to be modified extensively for the gas injection valves.

The solution was realised by means of a hardware topology with an interface box as a port expander, as used across the board in Mercedes-Benz natural gas vehicles in the light-duty commercial and passenger car segments. The engine control unit hardware for the existing gasoline vehicle could then be carried over as a shared part, ❾.

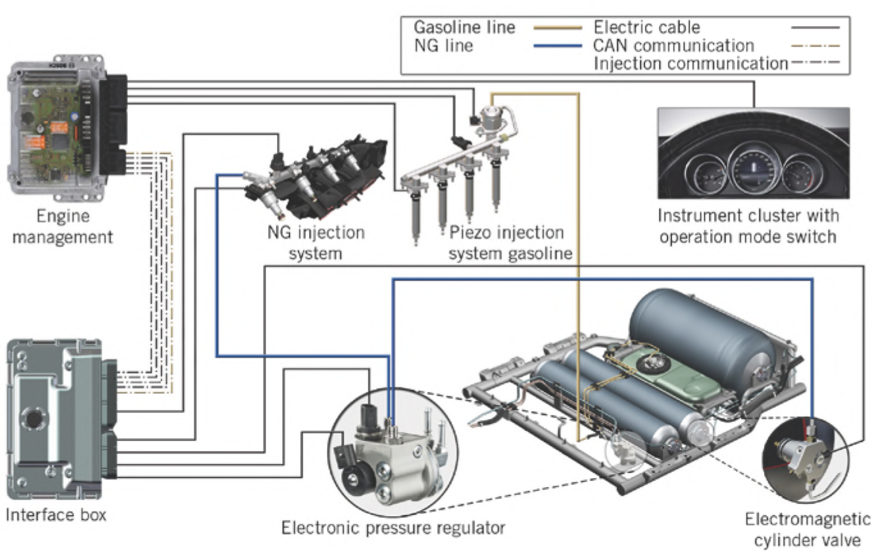
To meet the stricter requirements with respect to functionality and intrinsic safety, the interface box from Continental was redesigned with a 32-bit architecture and a separate monitoring level. Sustainability was taken into account as early as the development phase in the form of a six-channel PCB that can be expanded as required.

On one hand all natural gas functions, including logical division of the fault memory for both operation modes, are coordinated entirely by the engine control unit. The natural gas components, on the other hand, including the closed-loop control facility for the electronic pressure regulator, are managed by the interface box. This box incorporates all electrical diagnostics for the natural gas components. A separate controller area network, or CAN, is used to communicate possible fault entries and sensor values as raw values to the engine control unit. The ECU transmits the CNG release signal and the set pressure value for the respective gas pressure. Four additional control channels output a digital signal from the engine control unit to the interface box for actuating the gas injectors. Independent actuation of the piezo gasoline direct injection system is also coordinated by the engine control unit.

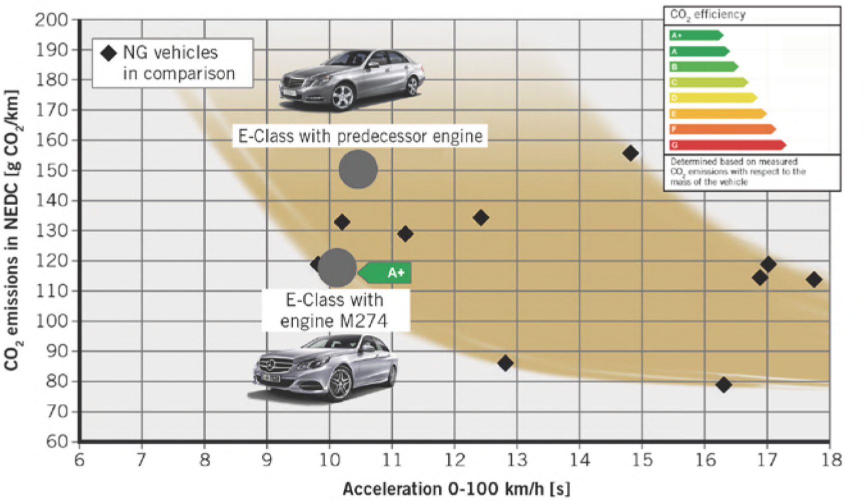
The knock-free fuel natural gas allows operation with an ideal combustion at 8 to 10 °CA after top dead centre (50 % mass fraction burnt point) despite the increase in compression ratio from 9.8:1 to 11:1 throughout the entire characteristic map. The early end of combustion and the prolonged expansion lead to



❽ Charge air distributor with gas injection nozzles (top) and natural gas tank module (bottom)



❾ Hardware topology



⑩ Competitive comparison of performance and consumption of E-Class NGD

extremely low exhaust temperatures. In conjunction with the heat sink of the exhaust turbocharger, the exhaust temperature level under full load is significantly lower than the permitted limit temperature for the catalytic converter. In the best case scenario, a specific consumption of 195 g/kWh can be identified in CNG mode. Thanks to the favorable C/H ratio of the methane molecule CH_4 in combination with the ideal combustion properties, significantly less CO_2 is emitted in comparison to gasoline operation. The E-Class, for example, thus achieves an NEDC consumption of 116 g CO_2/km and is, therefore, awarded the A+ label as consumption certificate.

The sum of all engine and vehicle measures for the E-Class compared to the predecessor vehicle results in improvements with regard to consumption of up to 22 % accompanied by a simultaneous improvement in acceleration. With these values, the E-Class is clearly at the lower end of the scatter band compared to the competition, ⑩ [3].

CONCLUSION AND FURTHER DEVELOPMENT

The M270/M274 family of four-cylinder engines is optimally equipped thanks to the flexible consumption technologies Camtronic, lean-burn combustion and natural gas capability. Due to stricter CO_2 legislation expected in the future around the world, Mercedes Benz is pursuing two strategic approaches. The first of these involves promoting the use of lean-burn combustion and CNG technologies in other markets [2]. This infrastructural challenge can only be realised if suitable fuel is readily available. The second approach builds on the solid basis established with the conventional family of four-cylinder gasoline engines, which can be further optimised by means of hybridisation of the powertrain in the face of stricter CO_2 legislation.

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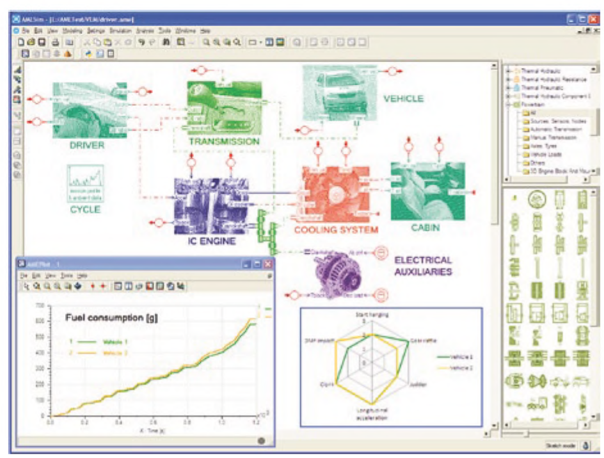

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