

## Technical Background Article

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## The new MTU Series 1000 to 1500

**To meet the Off-Highway Emission Standards EU IV and EPA Tier 4 final, as of 2014 the Tognum Group will be offering the newly developed engines of the Series 1000, 1100, 1300 and 1500. These MTU brand diesel engines deliver outputs ranging from 100 to 460 kW and are designed to power agricultural and forestry machinery and construction as well as special-purpose machinery. Based on the medium-heavy and heavy-duty commercial vehicle engine families OM 93x and OM 47x, Daimler AG was commissioned by MTU Friedrichshafen GmbH to further develop those families as off-highway engines. This engine platform is also the base for the Detroit engines DD13 and DD16 as well as the Fuso engine 6R10.**

The engine Series 1000 to 1500 supplement the established Mercedes-Benz engines OM 924 LA, OM 926 LA, OM 460 LA, OM 501 LA and OM 502 LA. These engines were developed to comply with Emission Standards EU IIIB and EPA Tier 4i, which came into effect in 2011.

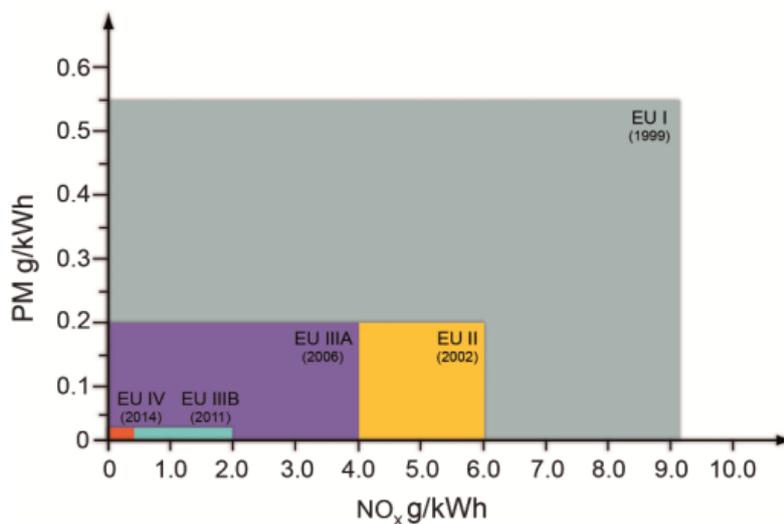
### Emission requirements

The diesel engine is the most economic drive for mobile machinery. This is why it is the preferred option in almost all commercial applications in the on- and off-highway sector. At MTU, the product portfolio of diesel engines covers a range from 75 to 10,000 kW. MTU engines have a very wide range of applications as main engines in mining vehicles, construction machines, agricultural and other off-highway applications. The off-highway engines must perform to full capacity at all times – in spite of considerable temperature and altitude variations, on inclinations and under extreme operating conditions. Apart from low fuel consumption, compliance with

exhaust gas emissions regulations is one of the greatest challenges faced in the development of these new engines.



From 1999 up to the introduction of the Off-Highway Emission Standards EU IV and EPA Tier 4 final in 2014, the limit values for exhaust emissions have been reduced drastically in several stages. Since then, the emission of nitrogen oxides and particles in industrial engines between 130 and 560kW has been reduced by more than 95% in European exhaust gas legislation (see Fig. 1).



**Figure 1: Particle and nitrogen oxide limit values for off-highway engines from 130 to 560 kW (source: VDMA)**

Emission limits such as these require the most modern exhaust gas aftertreatment systems, in particular, for engines below 560 kW – a situation where both the manufacturers of engines and vehicles are confronted with complex tasks. This includes the integration of exhaust gas aftertreatment in the vehicle concept. The design of the catalytic converters used is extremely effective in reducing the exhaust noise so that the use of an additional exhaust silencer is usually not necessary. Apart from exhaust gas aftertreatment, the new engine generation utilizes cooled exhaust gas

recirculation, the thermal load of which must also be taken into consideration for the vehicle cooling system. The exhaust gas legislations applicable as of 2014 will generally result in significant innovations to the engine and vehicle designs.



Although the formulation of the future exhaust gas legislation beyond the Off-Highway Emission Standards EU IV and EPA Tier 4 final has yet to be finalized, it can be safely assumed that emission limits will be even more stringent. The newly developed engine series 1000 to 1500 also laid the foundation to meet future emission requirements.

However, engines not only have to comply with emission legislations but, from the customer's perspective, also have to be suitable for everyday use and must be economic. The cost-effectiveness of a vehicle for the operating company is determined both by the initial cost as well as the consumption of fuel and AdBlue® – an aqueous urea solution for reducing nitrogen oxides. Added to this are costs related to maintenance and care of the engines.

### **Developing engines to meet customer requirements**

Just as the previous engines, the future engines of the Series 1000 to 1500 will also be used in agriculture and forestry and in the C&I sector (construction & industrial). Typical applications in agriculture and forestry include combine-harvesters, corn choppers, beet harvesters, forwarders, wood chippers and tree harvesters. In the C&I sector, the machinery is used, among other things, in excavators, mobile cranes, haul trucks, wheel loaders, road-building machines, landfill compactors, snow grooming machines and compressors. In harbors, for example, the engines drive gantry cranes, harbor equipment and vehicles for loading and unloading ships.



Customers of such applications expect robust, reliable engines that are easy to service. Installation space, power-to-weight ratio and operating costs also play a decisive role – high demands that are met by the new engines. Many customers are still using engines compliant with old emission levels without exhaust gas aftertreatment. With Emission Standards EU IIIB and EPA Tier 4i coming into force, exhaust gas aftertreatment systems were implemented for the first time. Starting in 2014, MTU will be offering the new engines 4R 1000, 6R 1000, 6R 1100, 6R 1300 and 6R 1500 for applications in agriculture and forestry as well as C&I. They comply with the new Off-Highway Emission Standards EU IV and EPA Tier 4 final by combining exhaust gas recirculation and exhaust gas aftertreatment without a particulate filter.

### **A question of efficiency**

Fuel consumption accounts for a large share of lifecycle costs in commercial applications. In spite of more stringent emission requirements, the consumption of fuel and AdBlue® in the EU IV engines was reduced in comparison to the predecessor engines compliant with Emission Standard EU IIIB. Since a particulate filter is not used, regeneration with additional fuel consumption is not necessary, nor is expensive low-ash oil required. Series 1000 is used as an example in chapter 4 to show a comparison of the operating material costs (see Fig. 4).

In this regard, however, allowance must also be made for the costs of integration of the engines in the target applications. Thanks to their compact design, the engines can be integrated without complex adaptations. The mechanical interfaces for integration of the engines in the vehicle and the power train are standardized in all the series. All bosses on the engine have metric threads. The media circuit requirements – for example, fuel, coolant or charge air – are harmonized in all series.

Just as the mechanical interfaces, as far as the electronics are concerned customers also demand simple integration of the drive in the vehicle. The

electronic interfaces of the individual engines are identical and facilitate the consistent application in vehicle families to a very high degree. This enables customer adaption of all engine versions to the corresponding off-highway application and diagnostics with the same tools. The new engines are supplied with a comprehensive standard control unit, which is equipped with the electronic standard interface for the off-highway market – the J1939-CAN.



### **Reliable, worldwide service from A to Z**

With regard to support, customers expect a tightly-meshed service network as well as simple and inexpensive maintenance. Important characteristics of the engines are therefore that they have a modular design and an easily accessible structure. Maintenance parts can thus be replaced quickly and easily.

Customers receive spare parts and corresponding services promptly via the joint worldwide Service network of MTU and Daimler AG, as well as the network of OEMs and dealers. This also includes customer support from MTU during the entire integration process of the engine, from the design of the power train to sign-off of the system in the target application.

### **Features of the new engine generation**

With the Series 1000 to 1500 (see Fig. 2), customers benefit from fully developed technology. The engines are developed by Daimler AG on behalf of MTU on the basis of commercial vehicle engines already in use. Production takes place at the Mercedes-Benz plant in Mannheim (Germany).

The overall power density of the engines in the Series 1000 to 1500 was increased, which makes them more compact than their predecessor engines and makes downsizing possible. Even at low speeds, the engines reach a high torque which is maintained over a wide speed range. Further advantages of the new engine generation are a favorable symmetrical

weight distribution and a power-to-weight ratio that is extremely low for the engine power class. This is achieved, among other things, by the use of correspondingly light materials, such as cast aluminum for gearcases and camshaft frame or plastic for the oil pan and cylinder head covers.



	MTU 4R 1000	MTU 6R 1000	MTU 6R 1100	MTU 6R 1300	MTU 6R 1500
<b>Displacement</b>	5.1 liters	7.7 liters	10.7 liters	12.8 liters	15.6 liters
<b>Design</b>	In-line four-cylinder engine	In-line six-cylinder engine			
	Cooled exhaust gas recirculation				
<b>Power</b>	100 to 170 kW	180 to 260 kW	280 to 320 kW	320 to 390 kW	400 to 460 kW
<b>Turbocharging</b>	single-stage turbocharging up to 129 kW, two-stage turbocharging for higher outputs	single-stage turbocharging up to 210 kW, two-stage turbocharging for higher outputs	single-stage turbocharging with asymmetrical turbine		single-stage turbocharging in combination with Turbocompound
<b>Output of Premium exhaust brake</b>	max. 170 kW @ 3,000 rpm	max. 250 kW @ 3,000 rpm	max. 340 kW @ 2,300 rpm	max. 410 kW @ 2,300 rpm	max. 435 kW @ 2,300 rpm
<b>Altitude performance</b>	no derating up to 2,500m above sea level		no derating up to 2,000m above sea level		
<b>Cold-start capability</b>	Up to -30 °C as standard				
<b>Gear train</b>	<ul style="list-style-type: none"> <li>Optional auxiliary PTO – 110 Nm / 600 Nm</li> <li>One- or two-cylinder air compressor</li> </ul>		<ul style="list-style-type: none"> <li>Optional auxiliary PTO – 110 Nm / 650 Nm</li> <li>One- or two-cylinder air compressor</li> </ul>		
<b>Belt drive</b>	Optional 2nd and 3rd belt level, high-mounted fan positions and high-powered fans				

Figure 2: Technical data of MTU Series 1000, 1100, 1300 and 1500 engines

## Development of the Series 1000

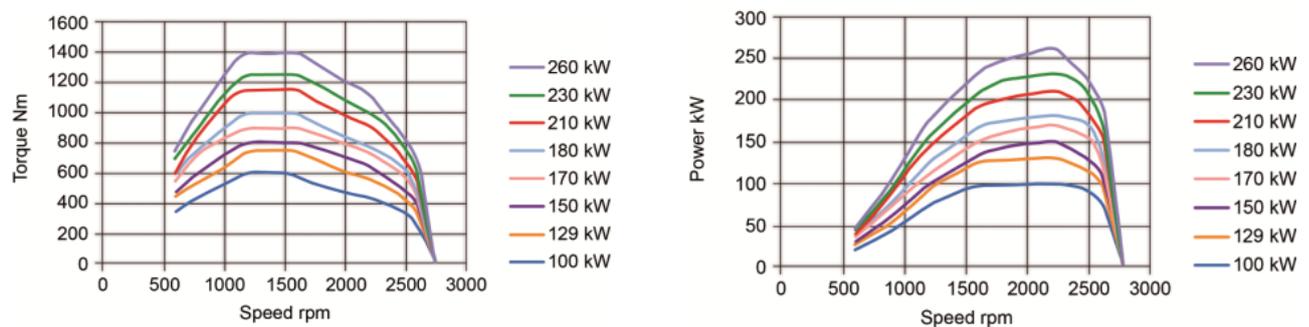
### Basic concept

The MTU Series 1000 for off-highway applications was derived from the new commercial vehicle engine family OM 93x from Daimler AG which was introduced with the Euro VI. After 15 years, this engine series will gradually replace the extremely successful OM 92x engines. The new global engine platform was developed consistently with regard to operating costs, a long service life and reliability. From the outset, the focus was not only on the



operation of the familiar vehicle applications but also on the implementation of further applications from the off-highway sector. This was achieved, among other things, by making a clear distinction between easily modifiable, application-specific interface components and highly integratable, standardized modules (for example, the oil-coolant module) that are used for different applications. To utilize the modular concept of the OM 93x on-highway engines for off-highway applications, the construction kit was extended by application-specific components and testing was supplemented by off-highway-specific requirements.

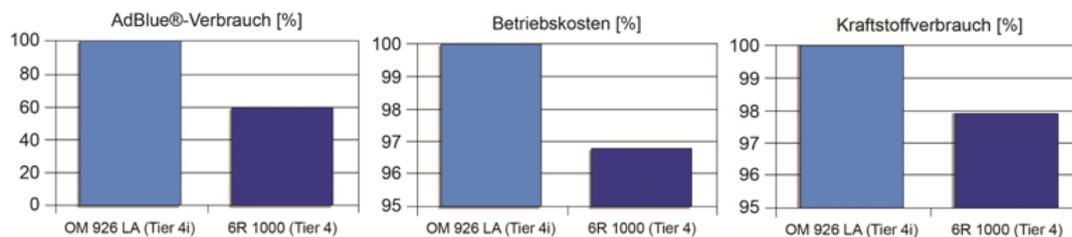
Right from the project's start, the requirements of the exhaust gas legislation for on- and off-highway applications were clearly evident. Customer and emission requirements were met from the start by using numerous nonvariable parts. The aim was to position the Series 1000 with regard to torque and power above the predecessor series OM 92x. This requirement was determined by the customers' demands for increased engine power and the need to close the gap between the engine series that existed up to now. The full-load curves for torque and power are shown in Fig. 3. A further goal during development was to increase the operational life in comparison to the predecessor series by 20%.



**Figure 3: Full-load curves of Series 1000**

To reduce operating costs (see Fig. 4), great importance was attached to the optimum design of the injection system and the combustion chamber. The

injection system with maximum injection pressure of 2,400 bar and solenoid valve injectors allow pre-injection, main injection and post-injection, which can be implemented independently of one another per cycle. Fuel consumption and exhaust gas emissions can thus be reduced to the required amount. A special piston with stepped bowl for optimum combustion management in the combustion chamber was developed.



**Figure 4: Operating costs comparison OM 926 LA (Tier 4i) / 240 kW and 6R 1000 (Tier 4) / 260 kW at the best operating point**

A further advantage of the variable injection system is that preheating of the intake air is not necessary even at very low outside temperatures. Also provided is exhaust turbocharging, which was implemented for four- and six-cylinder engines in single- and two-stage versions respectively. This further optimizes power, consumption and emissions.

The arrangement concept for the auxiliary units, circuits and air pipework was determined by the compact installation space of the in-line four-cylinder. Transferring the concept to the in-line six cylinders meant that a large number of nonvariable parts could be used in the four- and six-cylinder versions. The engine is clearly divided by the cross-flow cylinder head into a cold and a hot side, whereby, among other things, all fuel carrying components and the engine control system are arranged on the cold side.

Special design features of the Series 1000 include the two camshafts located on the top with optional exhaust brake integrated in the rocker arm frame. The principle of the exhaust brake is based on a double-clocked decompression brake. The exhaust valve is opened via an additional brake cam on the exhaust camshaft with two elevated areas near the top dead

center for reducing the gas pressure and is opened in the intake cycle to additionally increase the amount of injection. Adjustment of the braking torque is via the wastegate of the exhaust turbocharger and the exhaust gas recirculation valve. Thanks to the innovatory exhaust braking concept, it was possible to integrate a highly efficient permanent brake in the existing installation space. In comparison to the predecessor series, it has over 50% more power and brake power that amounts to up to 95% of the available drive power.



Even in the early design stages, all potential on- and off-highway applications were taken into consideration. In this manner, a standardized concept for the belt drive arrangement was found for all applications. In the standard version, the oil-water module and generator as well as the optional refrigerant compressor are positioned on one belt level. Thanks to the free front face of the engine, many fan positions and front power take-off shafts can be shown. Further belt-driven auxiliary units, such as additional generators, A/C compressors or hydraulic pumps can be positioned application-specifically on belt level two and three.

### **Special modifications for off-highway application**

The modular concept that already proved its value with commercial vehicles was extended in the Series 1000 by off-highway-specific features. These include different charge-air pipework systems that can be integrated without new EGR tuning, or different coolant nozzles that provide device manufacturers and end users with simple and robust interfaces. Solutions for increased current requirements and special oil pans were also taken into consideration. In combination with the wide-range offer of on-highway applications, almost every off-highway application can be catered for.

As the sister engine OM 93x is basically designed for use in commercial vehicles, it was tested extensively during trials for on-highway application. This included various test stand programs under concise conditions that

correspond to multiple vehicle service lives, extensive vehicle tests in a road endurance test and the application in special vehicles.



The findings and measurements from numerous existing off-highway applications were used to draft and test specific endurance tests together with the customer. These endurance tests reflect the special off-highway requirements of the engines. Parallel to this, real target applications were equipped with the engines in Series 1000 in good time to prove the superior characteristics of this new engine generation.

## **Development of Series 1100, 1300 and 1500**

### **Basic concept**

Similar to the Series 1000, the Series 1100, 1300 and 1500 engines are derived from the familiar Mercedes-Benz Euro VI engines in the OM 47x Series. The success of this new engine family began with the introduction of the exhaust gas standard EPA07 in the USA and continued with the introduction of the new emission specifications JP09 in Asia and Euro VI in Europe. The engines that were specially developed for off-highway applications and the Emission Standards EU IV and EPA Tier 4 final are thus built on a strong foundation. In this manner, the engines benefit enormously from the wide testing basis in a very wide range of vehicle applications all over the world.

The basic concept of the Series 1100 to 1500 is very similar to the Series 1000 in many respects, which offers many advantages both with regard to the vehicle integration as well as service and operation. The Series 1100 to 1500 are based on a highly integrated installed in-line six-cylinder engine. Supercharged by a turbocharger with asymmetrical turbine or, with the Series 1500, by a combination of turbocharger and turbocompound, the power spectrum ranges from 280 to 460 kW (see Fig. 5).

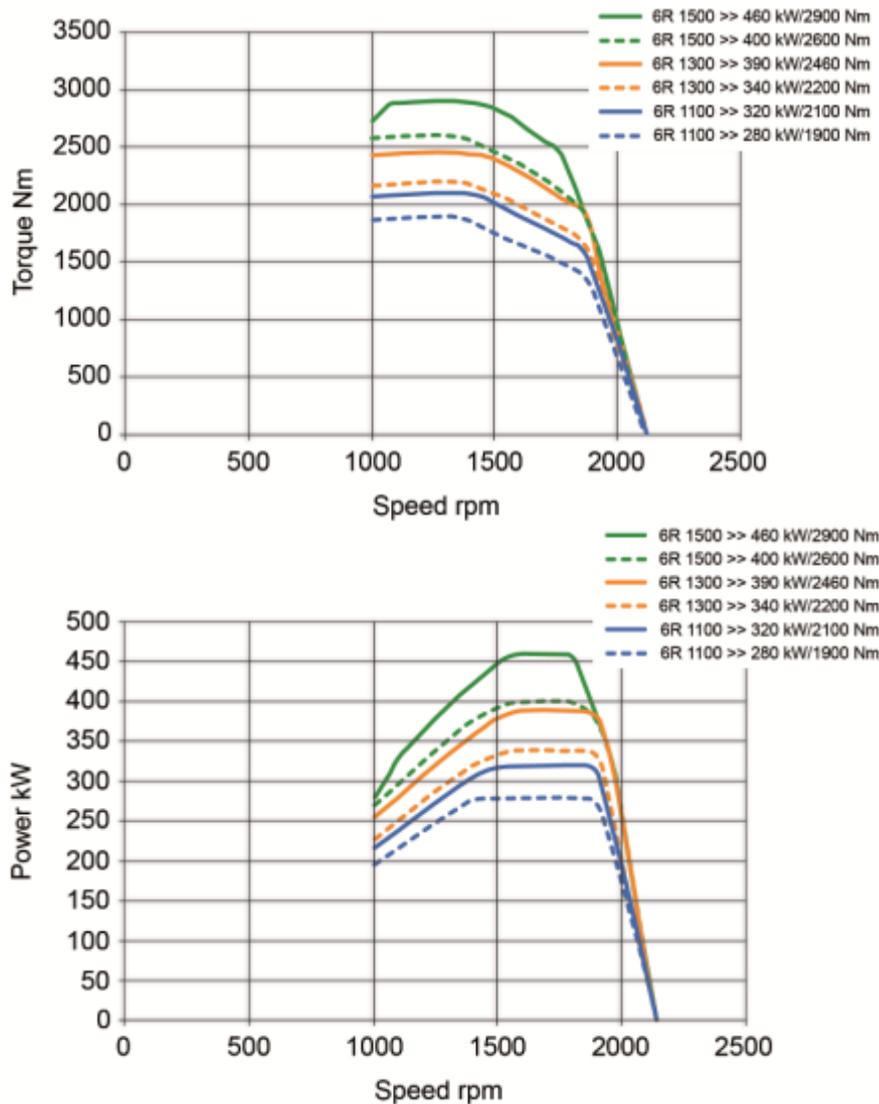


Figure 5: Full-load curves of Series 1100, 1300 and 1500

In contrast to the predecessor series, to observe the new emission limit values the new Series 1100 to 1500 use a controlled and cooled exhaust gas recirculation system. This is supplemented by the newly developed injection system in which solenoid valves are used to increase pressure within the injector from 800 bar rail pressure up to 2,100 bar injection pressure. This concept allows the injection process to be adapted individually in the different performance map areas by cutting in the pressure increase as required.



In the same manner as the Series 1000, the system permits pre-injection, main injection and post-injection. This permits, for example, an improvement in the starting behavior in cold weather or a targeted reduction in emissions. Two camshafts located on top guarantee an exact gas exchange. The highly effective exhaust brake system is controlled via additional cams and rocker arms on the exhaust side, can be regulated in three stages and generates up to 435 kW brake power at 2,300 rpm. The camshafts are connected to the crankshaft in the same manner as the HP pump and the air compressor via a gear train at the rear of the engine.

The front side of the engine can accommodate up to three belt levels, which can be used for customer-specific attachments. The coolant pump, generator and A/C compressor can be driven on the first belt level. Different fan versions can also be driven on levels two and three.

### **Special modifications for off-highway application**

The challenge here is to adapt the engine to the different off-highway customer requirements. These application cases differ from those of commercial vehicles, above all, with regard to operating conditions, which are often in the high-speed and high-utilization range.

To continue benefitting from the experience of on-highway applications, the aim was also to use as many nonvariable parts as possible in the off-highway applications. The thermodynamic design required the special adaptation of components such as injection nozzles or the turbocharger geometry. This adaptation, in turn, made it possible to limit exhaust gas aftertreatment for Emission Standards EU IV and EPA Tier 4 final to a simple SCR system. The interface to the exhaust gas aftertreatment system itself could thus be standardized for all series.

However, some modifications were also the direct consequence of the special off-highway applications, for example, activation of the

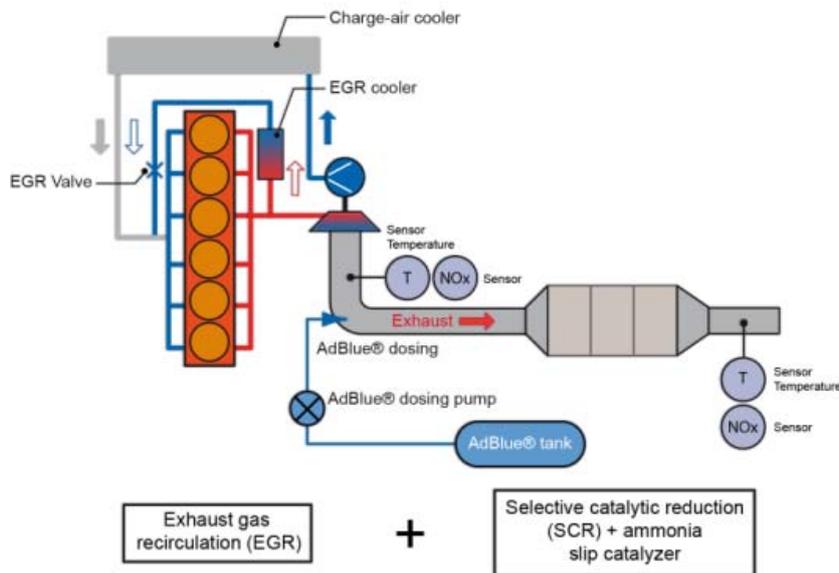
electropneumatic converter for the wastegate at the turbocharger. In commercial vehicles, air is applied to the converter via the vehicle's compressed-air system; in many industrial applications, however, an air compressor at the engine is not required. The compressed-air supply for the electropneumatic converter was therefore implemented by means of a direct connection to the turbocharger specially for the Series 1100, 1300 and 1500. Additional special adaptations were made for the vehicle interfaces. In future, MTU customers can thus choose the version suitable for their application from different versions of charge-air and exhaust-gas pipes and from a large number of oil pans.



### **Exhaust gas aftertreatment**

Since the start of development, the engine and exhaust gas aftertreatment have been regarded as an integrated system. The complete proprietary development of the engine as well as exhaust gas aftertreatment software ensured that they could be adapted specifically for Emission Standards EU IV and EPA Tier 4 final.

The basic idea during development of the exhaust gas aftertreatment system was to provide the OEM with a robust, installation space-optimized system. The result is the combined aftertreatment system ACATS (Advanced Combined After Treatment System). ACATS consists of an AdBlue® processing reactor and an exhaust box, which combines the SCR catalytic converter, ammonia blocking catalytic converter and silencer (see Fig. 6). Only four sensors are required to monitor the emissions.



**Figure 6: Diagrammatic illustration of the exhaust gas aftertreatment system**

As the engine emissions of the Series 1000 to 1500 are already very low, components of the Euro V on-highway exhaust boxes are used. They have been used successfully in the field for many years and have been tried and tested over millions of kilometers. Advantage to OEMs: They can use a matured system that does not require an additional particulate filter and is thus without active regeneration. This means that additional fuel pipework is not necessary and there are no potential hazards due to high temperatures during regeneration. Besides the more compact installation space, additional fuel consumption for filter regeneration is also not required.

To optimize operating costs, different engine operating modes are used (see Fig. 7). The control unit selects the appropriate mode as a function of ambient conditions (among other things, altitude and outside temperature), the temperature of the exhaust gas aftertreatment system and the engine operating status. If the engine and catalytic converter are in normal operation and parameters such as coldness and altitude change, this results in a performance map-controlled adaptation of normal operation. In transient operating status, an additional parameter (smoke) is added. The control is also adapted if, for example, rapid SCR heating is required after

engine start. Corresponding performance maps are saved for each individual operating mode.



	Steady state			Transient state		
	Normal	Cold	Altitude	Normal	Cold	Altitude
Normal operation						
SCR heating I		Cold	Altitude	Smoke	Smoke Cold	Smoke Altitude
SCR heating II						

**Figure 7: Operating modes for operating cost optimization with guarantee of observance of exhaust gas emissions**

### Summary and outlook

When Emission Standards EU IV and EPA Tier 4 final come into effect, MTU will offer Series 1000 and 1100, 1300 and 1500 for off-highway applications. These series continue the successful history of the Series OM 92x, OM 460, and OM 500 in all off-highway applications. The new Series 1000 to 1500 cover a power range from 100 to 460 kW and will observe the emission limit values by means of exhaust gas recirculation and exhaust gas aftertreatment without particulate filters. All of the engines are in-line engines with a compact design.

The on-highway equivalents of these series are the Daimler engines of type OM 93x and OM 47x, which meet the requirements of the more stringent exhaust gas standard Euro VI with a combined SCR and diesel particulate filter system. In the event of further tightening of the off-highway exhaust gas legislation, a fully developed system that has already proven its value in large-scale production in the on-highway sector is already available as a basis. The Series 1000 to 1500 are thus ideally equipped for future emission requirements.