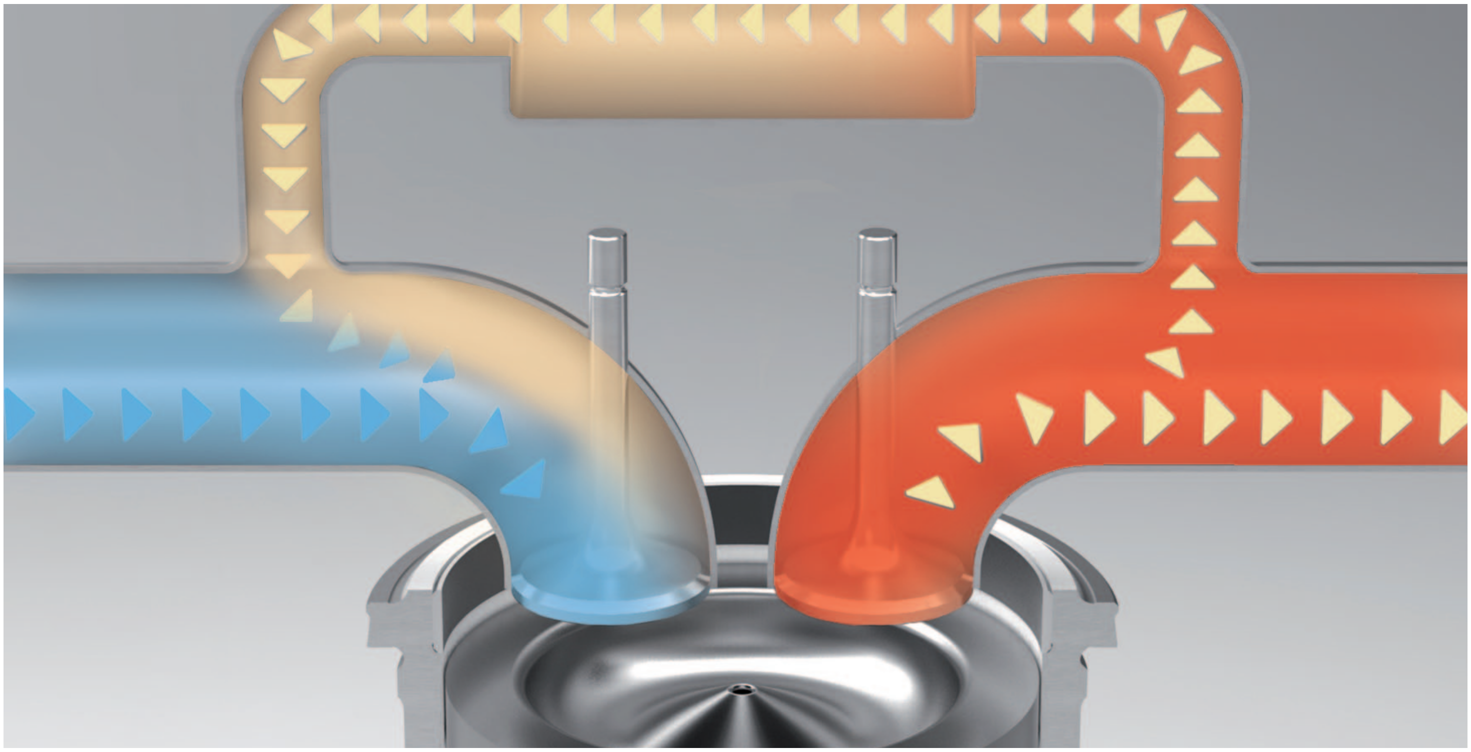
Engine technology

# Exhaust Gas Recirculation: Internal engine technology for reducing nitrogen oxide emissions

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**Nitrogen oxide ($NO_x$) emissions can be reduced using internal engine technology by cooling some of the exhaust gas, which is then redirected back into the charge air. This results in the reduction of the combustion temperature and less nitrogen oxide is produced. This process is known as exhaust gas recirculation (EGR) and is one of the principal methods used to reduce nitrogen oxide emissions from diesel engines. MTU has been testing this key technology for years. As a standard feature, it will be included for the first time in Series 4000 engines – starting mid-2011 in oil & gas engines for hydro frac applications to ensure compliance with EPA Tier 4 interim emission standards, followed by rail applications who need to meet EU Stage IIIB emission standards which come into force in 2012.**


### Ways to reduce nitrogen oxide emissions

In order to comply with the increasingly tough emission standards worldwide, engine manufacturers are forced not only to substantially reduce emissions of soot particulates (PM), but also emissions of nitrogen oxides. The main approach pursued by MTU is low-emission combustion, in other words an internal engine solution. However, this means taking into account a basic principle that governs the process of combustion – if the fuel burns at a higher temperature inside the cylinder, little soot is produced, but a large amount of nitrogen oxide. At lower combustion temperatures, nitrogen oxide emissions are low, but the production of soot particulates is high. To find the right balance, therefore, all the key technologies that affect combustion must be perfectly matched. When combined with fuel injection and turbocharging in particular, the use of exhaust gas recirculation results in a combustion process that produces significantly lower levels of nitrogen oxide.

The second way of reducing nitrogen oxide emissions is to use exhaust gas aftertreatment with an SCR catalytic converter (selective catalytic reduction, short: SCR). Very low limits for both nitrogen oxide and diesel particulates can make the use of such an SCR system necessary, as it removes up to 90 percent of the nitrogen oxide produced during the combustion process from the exhaust gas. Exhaust gas recirculation can reduce nitrogen oxide emissions by around 40 percent. An even greater reduction requires the use of an SCR system, which – depending on the application – removes up to 90 percent of the nitrogen oxide from the exhaust gas. In the case of particularly stringent emission standards, exhaust gas recirculation and a SCR system must be combined to ensure the limits are met.

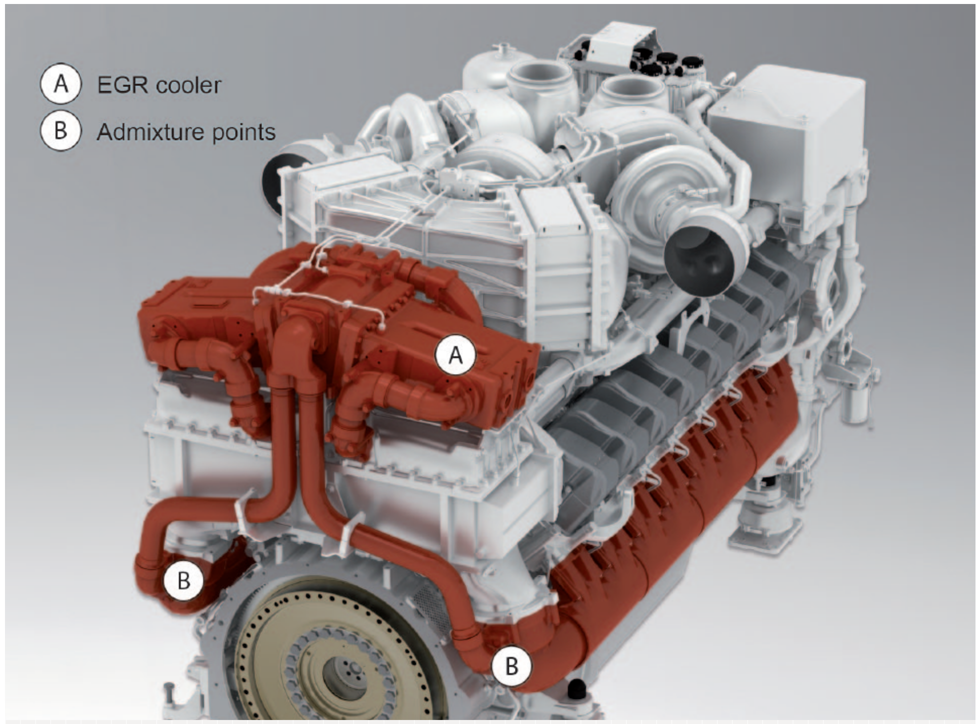



Fig. 1: **Integration of exhaust gas recirculation in engine design concept**
MTU has integrated the exhaust gas recirculation system into the engine design so that it has very little effect on space requirements.

**Examples of EGR use in MTU drive systems**

The US EPA Tier 4 interim emission standard, which came into force as from 2011, limits nitrogen oxide emission levels for mobile applications above 560 kW to a maximum of 3.5 g/kWh. At MTU, this will affect Series 1600, 2000 and 4000 engines, which will meet this limit with exhaust gas recirculation. The Series 1600 and 4000 locomotive engines for the EU Stage IIIB emission standards that come into force in 2012 will be equipped with this technology, too. Nitrogen oxide and hydrocarbon (HC) emissions combined may not exceed 4.0 g/kWh. By contrast, the limit for $NO_x$ emissions for railcars in the same EU Stage IIIB emission standard is only 2.0 g/kWh. For this reason, MTU is equipping its Series 1600 engines for underfloor drive systems with an SCR exhaust aftertreatment – with no exhaust gas recirculation.

The US EPA Tier 4 final standard for non-road mobile engines with power outputs below 560 kW, which will come into force as from 2014, is extremely challenging. In this case, the nitrogen oxide limits are down 90 percent to 0.4 g/kWh compared with EPA Tier 3 regulations. In order to comply with these tough limits, MTU will incorporate both exhaust gas recirculation and an SCR system.

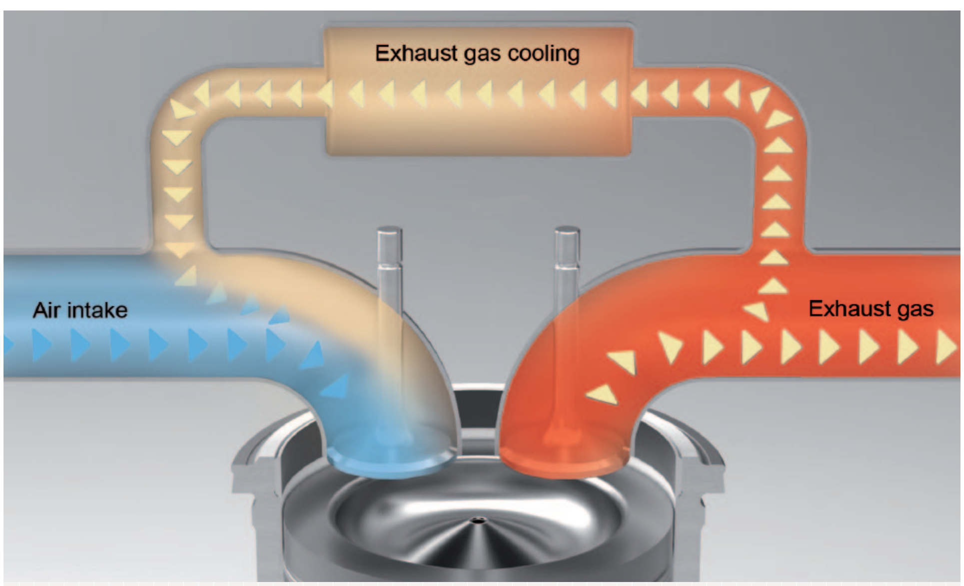



Fig. 2: **Schematic diagram of exhaust gas recirculation**
In exhaust gas recirculation, some of the exhaust gas is returned to the fresh air intake. The resultant mixture of fresh air and exhaust gas has a lower calorific value in terms of the volume. This lowers combustion chamber temperatures, thus reducing the production of nitrogen oxide ($NO_x$).

**Benefits of exhaust gas recirculation from MTU**

Generally speaking, systems designed to reduce emissions must be modified to match the drive systems. MTU has produced a very compact design that permits all the exhaust gas recirculation components to be integrated into the engine concept (see Figure 1), so that any modifications to the engine have relatively little effect on space requirements and the exhaust system. It is necessary to modify the radiator, however, in order to cope with the increased cooling capacity of the engine. Compared with an engine application requiring an SCR system, it is now much easier for customers to upgrade their application to comply with a new emission standard. Furthermore, exhaust gas recirculation requires no additional consumables to reduce nitrogen oxide levels, which would otherwise result in costs for an additional fuel tank and piping. The customer benefits in terms of reduced costs for handling and maintenance.

**Principle of operation**

In exhaust gas recirculation, some of the exhaust gas is drawn off from the exhaust system, Info

### High and low-pressure exhaust recirculation

The exhaust gas recirculation system widely used today draws off part of the exhaust flow upstream of the turbocharger turbine and feeds it back into the air intake system downstream of the compressor. It works at the level of the boost pressure generated by the turbocharger and is therefore referred to as high-pressure exhaust gas recirculation. In the case of low-pressure exhaust gas recirculation, the exhaust is drawn off downstream of the turbocharger turbine and returned upstream of the compressor, so that the pressure level is roughly equivalent to ambient pressure. Compared with high-pressure exhaust recirculation, low-pressure recirculation has serious drawbacks: the compressor has to work harder, with the result that the heat to be removed from the intercooler increases. In addition, the system requires a diesel particulate filter, as otherwise particulates in the exhaust gas could damage components of he recirculation system or the compressor and intercooler. By comparison, high-pressure exhaust gas recirculation is inherently more robust so that no particulate filter is required. Low-pressure exhaust gas recirculation could be a means of subsequently upgrading an existing engine design to comply with stricter emission standards. Due to the considerable drawbacks of the system, particularly with regard to the maintenance requirement for the customer, MTU is not currently working on this version.

cooled and redirected back into the cylinders (see Figure 2). Although the exhaust fills the combustion chamber, it is not involved in the combustion reaction that takes place in the cylinder due to its low oxygen content. The speed of the combustion process overall is thus reduced, with the result that the peak flame temperature in the combustion chamber is lowered. This dramatically reduces the production of nitrogen oxides.

### Patented solution from MTU: the donor cylinder concept

Exhaust gas recirculation places higher demands on exhaust gas turbocharging, since higher boost pressures have to be achieved with reduced mass flow in the turbocharging system. These high boost pressures are required to direct the increased mass flow resulting from the exhaust gas recirculation rate into the cylinder during the gas cycle. In addition, the exhaust gas can only be redirected back into the cylinders when there is a pressure drop between the exhaust and the charge air systems. This pressure drop must be established with an appropriately configured turbocharging system, which results in a reduction in turbocharging efficiency. The pressure drop between the exhaust and the charge air systems leads to gas cycle losses. These factors tend to result in lower engine performance or higher fuel consumption. To improve the combined effect of exhaust gas recirculation and turbocharging, MTU has developed what is known as the donor cylinder exhaust gas recirculation system (see Figure 3).

MTU's patented system only uses some of the engine's cylinders as the donor for exhaust gas recirculation. An exhaust valve (donor valve) holds back the exhaust gas flow downstream of the donor cylinders and thus creates the necessary pressure drop between the exhaust and the charge air systems. This means that the turbocharging system can be optimized to a very good efficiency level, with gas cycle losses only affecting the donor cylinders. Compared with conventional high-pressure exhaust gas recirculation (as in the case of the Series 1600 engine), the donor cylinder concept (Series 2000 and 4000) achieves lower fuel consumption, since it reduces the gas cycle losses in the engine and permits higher turbocharger efficiency levels. For this purpose, an additional donor cylinder exhaust valve is required in comparison with high-pressure exhaust gas recirculation.

Dirt build-up on components and the amount of servicing required over the service life of the application are lower with the donor cylinder concept, as is the case with high-pressure exhaust gas recirculation: unlike the situation with low-pressure exhaust gas recirculation, the exhaust gas is not fed into the intake air until immediately before it enters the cylinder, which means that only clean air flows through the compressor impeller and the intercooler and not exhaust gas containing particles as well.

### Cooling system for exhaust gas recirculation

The exhaust gas drawn off for recirculation has a temperature of around 650 degrees Celsius. It is therefore far too hot to be fed directly into the cylinders; it would increase the temperature of the combustion chamber even further, thereby defeating its actual purpose – that of reducing nitrogen oxide formation by lowering the combustion temperature. For this reason, the exhaust gas is first cooled to around 120 degrees Celsius (see Figure 4). In the case of industrial engines with high intake air and exhaust mass flow rates that requires high cooling capacities, which have to be supplied by high-performance heat exchangers. Basically speaking, standard commercial vehicle

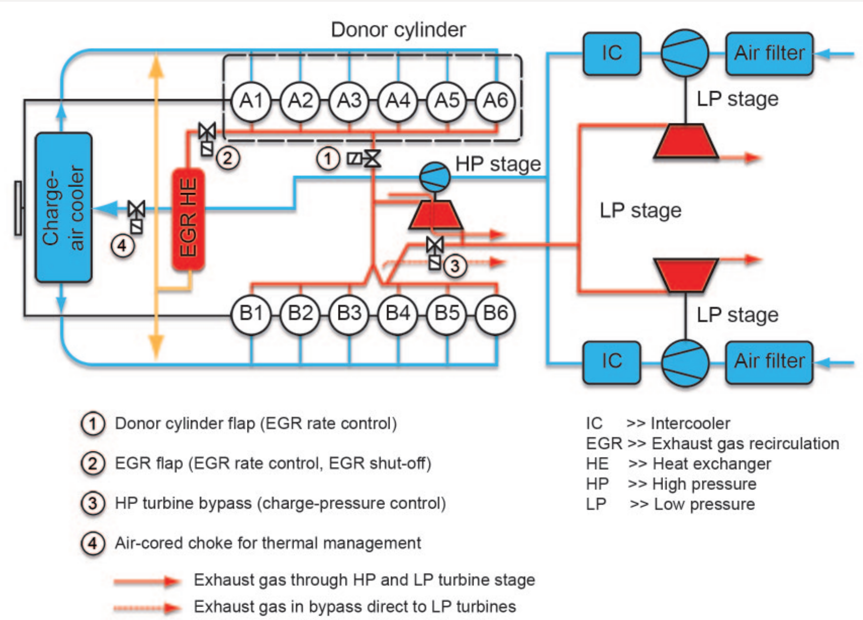



Fig. 3: **EGR donor cylinder concept**
Compared with conventional high-pressure exhaust gas recirculation, MTU's patented system achieves lower fuel consumption, since it reduces the gas cycle losses in the engine and permits higher turbocharger efficiency levels. This requires an additional donor cylinder exhaust valve.

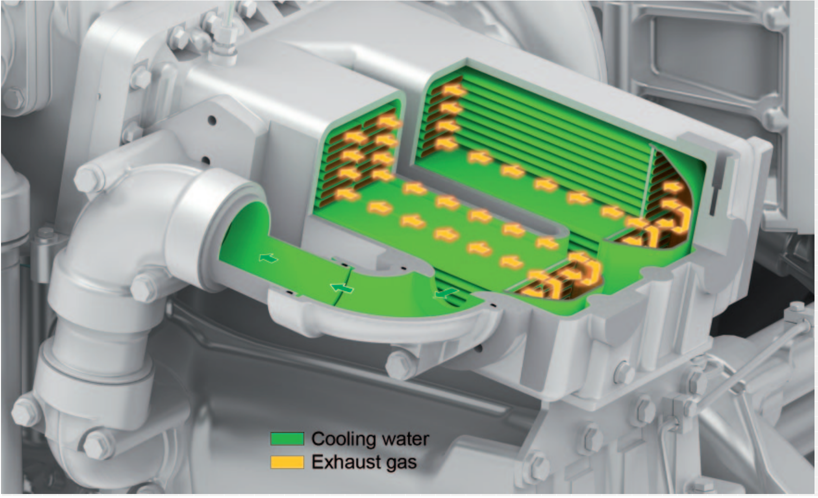



Fig. 4: **Section through a radiator**
The exhaust gas drawn off for recirculation at a temperature of around 650 degrees Celsius is far too hot to be fed directly into the cylinders. For this reason, the exhaust gas is first cooled to around 120 degrees Celsius. The cooling system is optimally integrated into the engine design concept, so that the customer needs only to allow for a very small space requirement.

radiators can be used in such cases. However, to cover the cooling capacity required for a 16-cylinder engine with a capacity of 4.8 liters per cylinder, depending on the supplier, four to eight conventional commercial vehicle radiators of the highest capacity available would be needed for exhaust gas recirculation. Using this number of single radiators with the required mechanical strength is not possible in a mobile application.

For this reason, MTU works with the suppliers to develop integrated radiator solutions in which only the internal components of the heat exchangers are adopted from proven commercial vehicle applications and the highly integrated cast body is developed in-house. The heat exchanger body is designed to match the contours of the engine perfectly and incorporates all connecting pipes. The benefits for the customer are a smaller space requirement, high functional reliability and low maintenance. MTU uses as many common parts as possible for engines within the same series with different numbers of cylinders. Due to the advanced stage of development maturity, this also results in a high level of functional reliability.

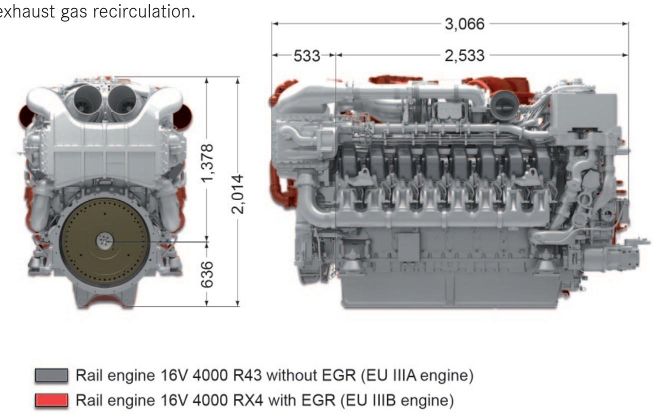
### Interaction with other key technologies

Although exhaust recirculation results in lower nitrogen oxide emissions, soot particulate emissions increase to an undesirable degree if no counter-measures are taken. To prevent this happening, MTU has further refined both fuel injection and turbocharging. Whether a diesel particulate filter (DPF) is needed in addition to these internal engine modifications to further reduce emissions depends on the limits specified in the emission standard applicable to the individual application.

### Summary

Exhaust gas recirculation is one of MTU's key internal engine technologies for reducing emissions. It can be used to reduce nitrogen oxide formation inside the cylinder by 40 percent and more, with the result that many applications – depending on the applicable limits in each case – can meet the required emission standards without the need for additional exhaust aftertreatment for $NO_x$ removal. In cases where emissions legislation is particularly strict, an SCR system or even a combination of exhaust gas recirculation and SCR system is required. MTU has produced a compact solution to integrate all the exhaust gas recirculation components into the engine design concept so that no additional installation space is required (see Figure 5). It means that customers can upgrade their applications to comply with new emission standards with no great effort involved. The system also requires no additional consumables.

Fig. 5: **Comparison of 16V 4000 R43 engine for rail applications with no EGR and 16V 4000 RX4 with EGR**
MTU is including exhaust gas recirculatino for the first time as a standard feature in Series 4000 engines – starting mid-2011 in oil & gas engines for hydro frac applications to ensure compliance with EPA Tier 4 interim emission standards, followed by rail applications who need to meet EU Stage IIIB emission standards which come into force in 2012. Since the compact design permits the individual components to be integrated into the engine concept, additional space is hardly required, which can be seen in the comparison of the Series 4000 engines for rail applications with no exhaust gas recirculation.

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