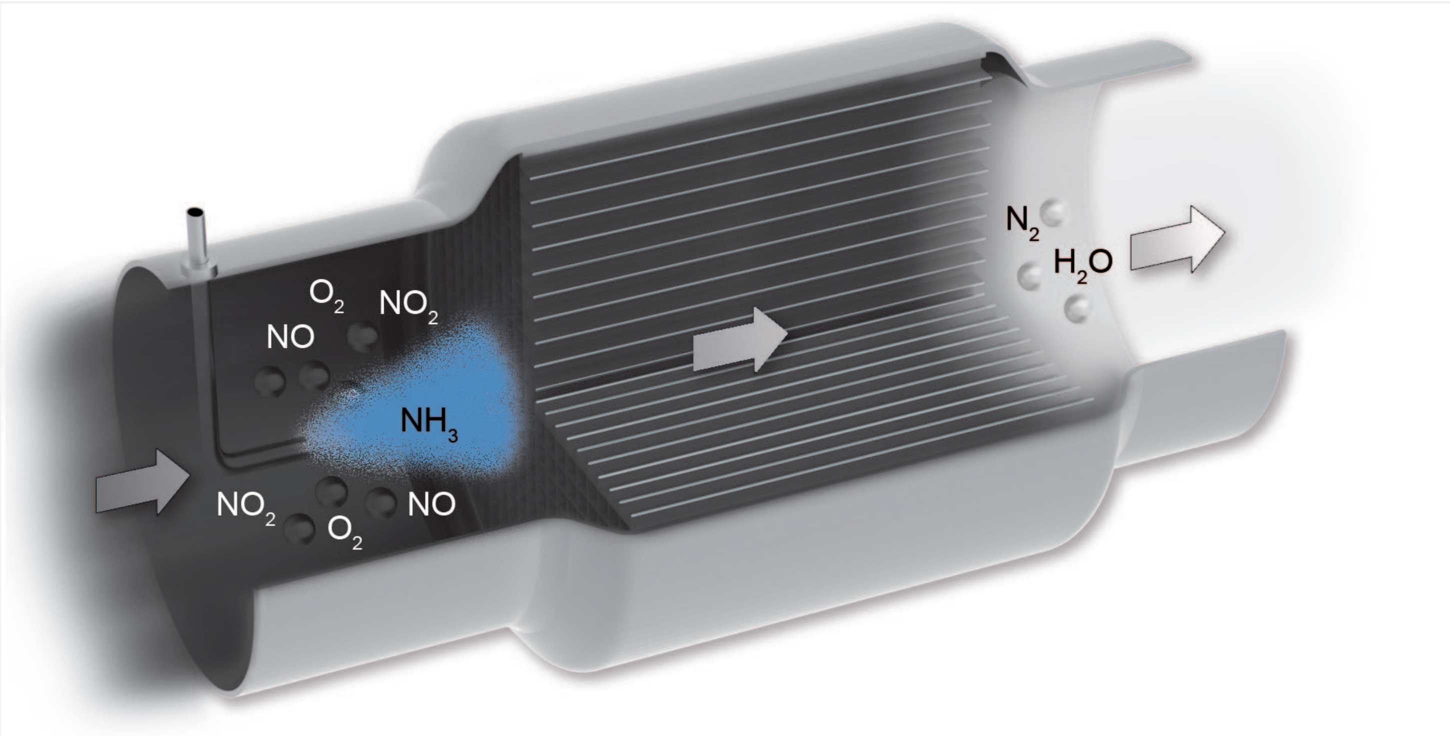
Engine technology

Selective Catalytic Reduction: Exhaust aftertreatment for reducing nitrogen oxide emissions



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The term Selective Catalytic Reduction (or SCR) is used to describe a chemical reaction in which harmful nitrogen oxides (NO_x) in exhaust gas are converted into water (H_2O) and nitrogen (N_2). In combination with internal engine technologies, such as exhaust gas recirculation (EGR), extremely low nitrogen oxide emissions can be achieved with low fuel consumption.

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 particulate matter (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.

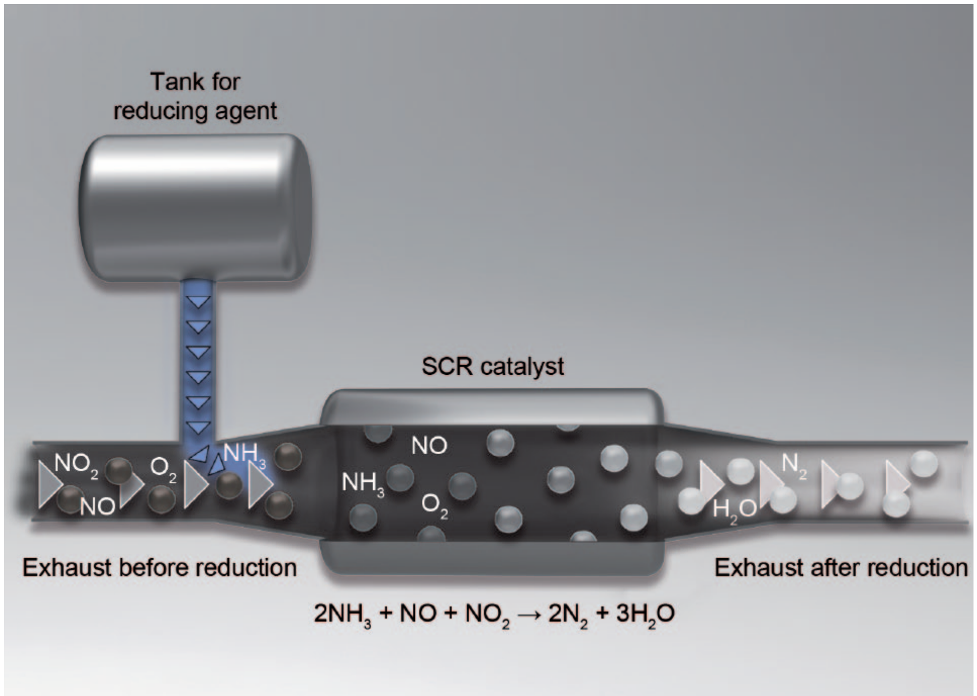
The second way of reducing nitrogen oxide emissions is to use exhaust gas aftertreatment with an SCR catalytic converter. Very low limits for both nitrogen oxide and diesel particulates can make the use of such an SCR system necessary, as it removes subsequently up to 90 percent of the nitrogen oxide produced during the combustion process from the exhaust gas. Depending on the application, even higher reduction rates are possible.

This gives engine developers more scope to configure the combustion process for extremely low fuel consumption and at the same time to comply with the limits required by law (see Figure 1). An added benefit of the SCR system is a reduction in particulate emissions of up to 60 percent. This frequently means that – depending on the emission standard applicable – the need for an additional diesel particulate filter (DPF) in the exhaust system can be eliminated.

Examples of SCR use in MTU drive systems
One example of particularly low emission limits is the US EPA Tier 4 final emission standard. As from 2015, it will limit the nitrogen oxide emissions of engines for gensets with power outputs exceeding 560 kW to a maximum of 0.67 g/kWh and particulate emissions to 0.03 g/kWh. MTU will comply with these stringent environmental regulations using a SCR system (see Figure 2).

For drive systems with power outputs below 560 kW used in construction and industry, the regulation specifies a maximum of 0.4 g/kWh for nitrogen oxides and 0.02 g/kWh for soot particulates as from 2014. In order to comply with these tough legal limits, MTU is using a technology package for the new Series 1000, 1100, 1300 and 1500 engines consisting of exhaust gas recirculation and SCR catalytic converter.

In the combustion process inside the cylinder, in addition to the relationship between the production of nitrogen oxide and particulates, there is one between fuel consumption and nitrogen oxides. Generally speaking, high combustion



H_2O	Water	N_2	Nitrogen	NH_3	Ammonia
NO	Nitrogen Monoxide	NO_2	Nitrogen Dioxide	O_2	Oxygen

Fig. 1: **Schematic of the SCR system**
Selective catalytic reduction describes a way to minimize the amount of nitrogen oxide contained in the exhaust gases. A urea-water solution is injected into the exhaust gas flow upstream of the SCR catalytic converter, thus producing nitrogen and water during the selective catalytic reduction process.

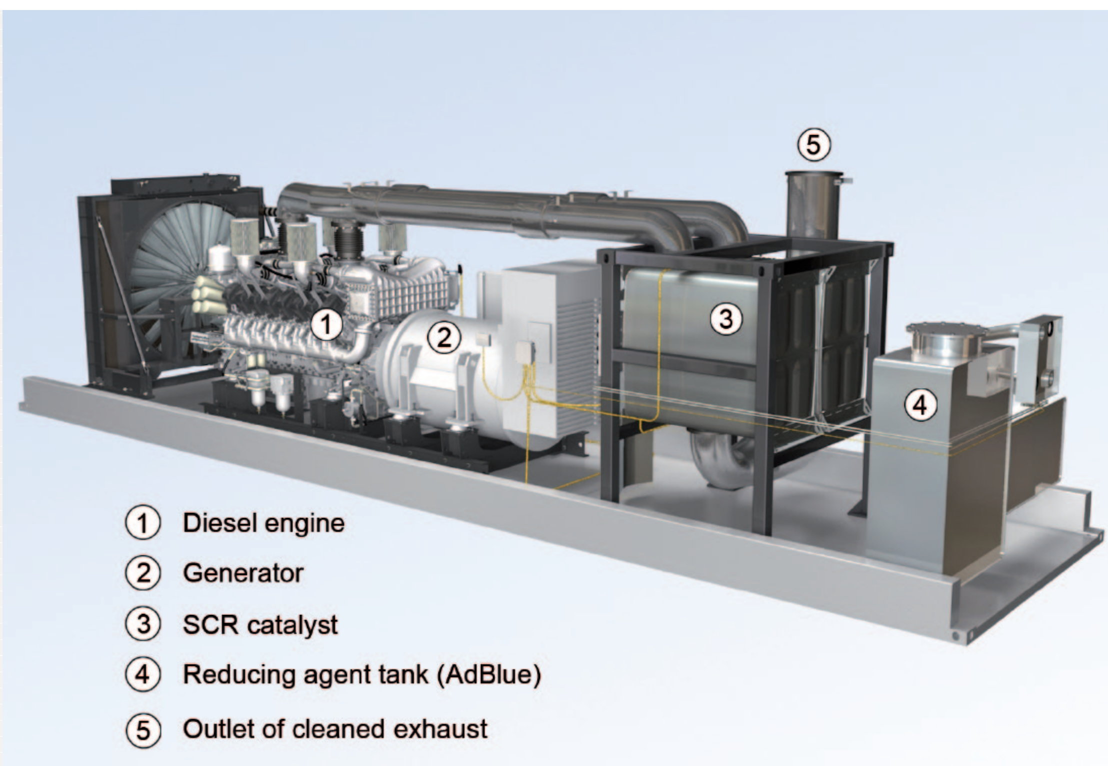


Fig. 2: **Genset with a 16 cylinder Series 4000 engine equipped with SCR system**
To comply with the stringent US EPA Tier 4 final emission standards for gensets with a power output above 560 kW that will come into force in the USA as from 2015, MTU will be equipping its gensets with a SCR system.

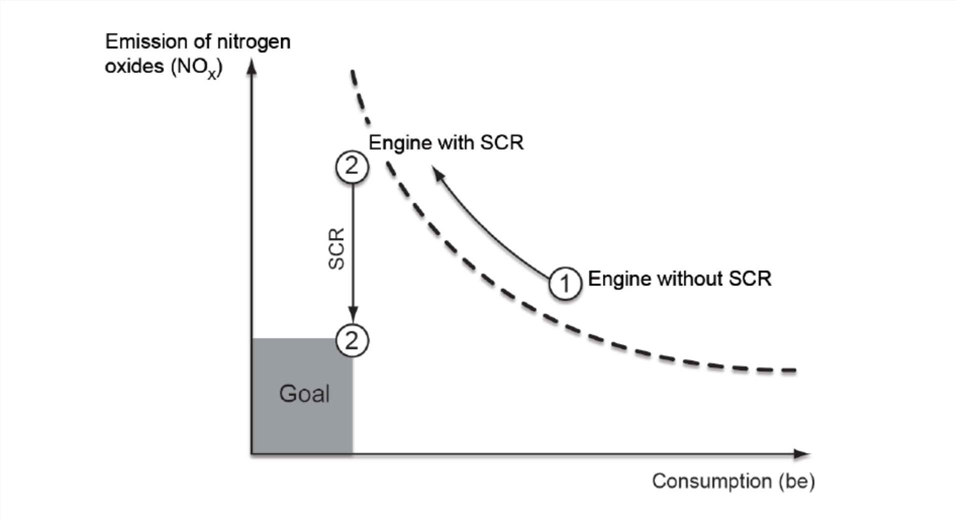


Fig. 3: **Diagram of fuel consumption and nitrogen oxide emissions relationship**
High combustion temperatures result in economical fuel consumption, but also to high levels of nitrogen oxide. A SCR system can subsequently remove up to 90 percent of the nitrogen oxide produced during the combustion process from the exhaust gas.

temperatures lead to economical fuel consumption and low particulate levels, albeit with greater nitrogen oxide production. Since the SCR catalytic converter subsequently removes the nitrogen oxide from the exhaust gas, the development engineers can use this to configure the combustion process for extremely low fuel consumption while still remaining within the legal emission limits (see Figure 3). An additional advantage of the SCR system is a reduction in particulate emissions of as much as 60 percent.

Benefits of MTU's SCR system

MTU individually matches the SCR system to the specific engine and the application. At the same time, the drive system is optimized for low fuel consumption and a minimal space requirement for the SCR components. As far as possible, MTU uses proven SCR components from the commercial vehicle sector. Customers subsequently benefit from a tried and tested standard production solution with a long service life which is optimally adapted to the engine package. MTU drive systems are designed to be very robust in terms of changes in the operating conditions, which means that customers are very flexible in terms of how they employ their systems in a wide range of applications.

Compared with other ways to reduce emissions, by using a diesel particulate filter, for example, an SCR catalytic converter does not increase backpressure in the exhaust system to the same degree. Consequently, the turbocharging system has to work against a lower backpressure and can be operated at a higher efficiency level. Depending on the performance and dynamic response requirements of the drive systems, MTU for this reason uses the more cost-effective single-stage turbocharging system for engines equipped with the SCR system instead of a two-stage system.

Operating principle of the SCR system

In the case of selective catalytic reduction, a catalytic converter converts the nitrogen oxides contained in the exhaust gas into water vapor and nitrogen. For this purpose, a reducing agent is continually injected into the exhaust gas flow using a metering module. In the exhaust gas flow, the fluid reacts within a fraction of a second to produce ammonia (NH_3). This chemical compound then converts the nitrogen oxides in the SCR catalytic converter (see Figure 4).

The non-toxic and odorless reducing agent is widely used in commercial vehicle applications and has been available throughout Europe since 2004, and the USA since 2010. It is marketed in Europe under the trade name of “Ad Blue”. It consists of a 32.5 percent solution of extra pure grade of urea in de-ionized water. The amount of reducing agent added is between five and seven percent of the fuel consumption. It is stored as a second consumable fluid in a separate tank and fed to the metering device via pipelines. To ensure the high nitrogen oxide conversion rates of as much as 90 percent in some cases in every operating state of the propulsion system, the electronic control system calculates the precise quantity of reducing agent needed based on key engine parameters such as operating temperature and engine speed.

System development at MTU

MTU has acquired extensive expertise in SCR systems. This has enabled the company to optimally exploit the potential of exhaust aftertreatment in combination with the engine. Using modern simulation tools, MTU matches parameters such as the exhaust gas flow through the

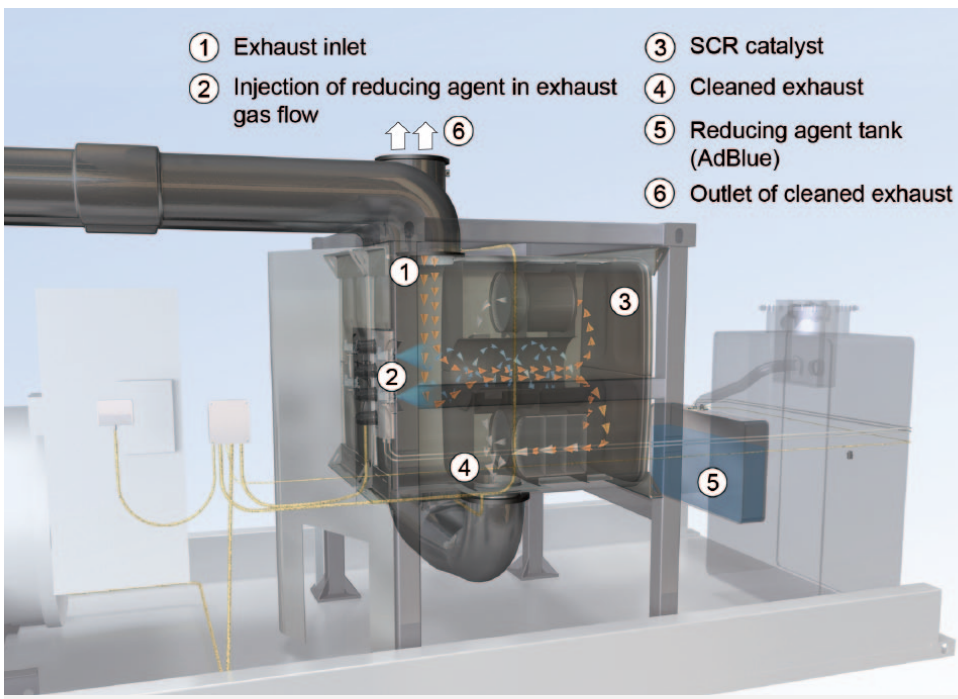


Fig. 4: **Schematic of the operating principle of the SCR system**
In the SCR catalytic converter, ammonia converts the nitrogen oxides into water vapor and nitrogen. For this purpose, a reducing agent is continually injected into the exhaust gas flow using a metering module. In the exhaust gas flow, the fluid reacts within a fraction of a second to produce ammonia. This chemical compound then converts the nitrogen oxides in the SCR catalytic converter.

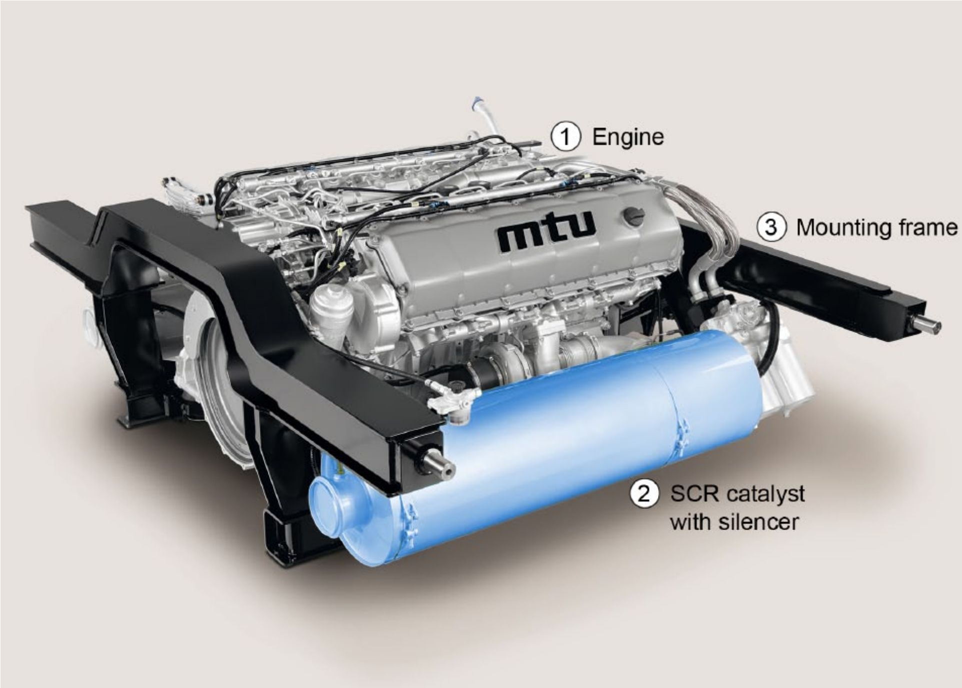


Fig. 5: **Underfloor rail powerpack equipped with SCR**
MTU also assists its customers in the design of the reducing agent supply system for the SCR system. For the underfloor rail powerpack equipped with a 12V Series 1600 engine, MTU is developing a complete SCR system that, in addition to the catalytic converter and metering system, includes a reducing agent tank, heater and piping.

catalytic converter precisely to the engine's operating conditions. The results of those calculations are then used in the design of the catalytic converter casing. MTU also improves the packaging by using computer simulations. Since MTU supplies the drive and SCR system from a single source, it is able to optimally match the engine technologies such as combustion and turbocharging to the needs of exhaust gas cleaning system. This ensures, for example,that the operating temperature of the SCR system remains at an optimal level.

In the case of drive systems in the lower power range, such as Series 1000, 1100, 1300, 1500 and 1600 engines, MTU uses reliable SCR components from the commercial vehicle sector that are adapted to the specific requirements of their use in industry. MTU has also transferred this high-volume production expertise to larger engines with power outputs of up to 3,000 kW and has developed an economical modular concept for SCR metering devices and catalytic converters, with each module using two metering devices. As is the case with the smaller engines, they originate from proven high-volume commercial vehicle applications.

MTU is currently advancing the development of its flexible modular concept for Series 2000 and 4000 engines: one module will completely cover Series 2000 engines, while two identical modules will be used for 12 and 16-cylinder versions of the Series 4000 engines and three modules for the 20-cylinder Series 4000 engine. In addition to lower costs and high reliability, the benefits of the modular concept include a modest space requirement, since smaller individual modules can be better integrated into the engine package than one large unit.
MTU also assists its customers in the design of the reducing agent supply system for the SCR system. For the underfloor rail powerpack equipped with the V12 Series 1600 engine, MTU is even developing a complete SCR system that, in addition to the catalytic converter and metering system, includes a reducing agent tank, heater and piping (see Figure 5).

Summary
An SCR system can remove as much as 90 percent of the nitrogen oxides from the exhaust gas. In addition, the engine can be configured for very low particulate emissions. That ensures compliance with stringent emission limits for diesel engines. At the same time, operators save on fuel costs with an SCR system, because internal engine parameters can be configured for ultra-low fuel consumption. Compliance with extremely low emission limits, however, requires a combination of internal engine optimization using exhaust gas recirculation and external optimization by means of exhaust aftertreatment with an SCR catalytic converter and, if necessary, a diesel particulate filter.

MTU supplies the engine and the SCR system from a single source and can therefore ensure that the two components are ideally matched, with the key development objectives focusing primarily on low fuel consumption and low space requirement for the SCR components. MTU will be using SCR systems for genset engines with a power output exceeding 560 kW, for example, and in drive systems for construction and industrial applications below 560 kW in order to meet the very strict requirements of the US EPA Tier 4 final standard.

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