Technology for Ecology
Medium speed engines for cleaner air

Engineering the Future — since 1758.
MAN Diesel & Turbo
MAN Diesel & Turbo
Powering the world – responsibly

MAN Diesel & Turbo is the world’s leading provider of large-bore diesel engines and turbo-machinery. Our portfolio includes two-stroke and four-stroke engines for marine and stationary applications, turbochargers and propellers, as well as gas and steam turbines, compressors, and chemical reactors.

Our commitment to minimizing fuel consumption while meeting even the most advanced emissions regulations plays a vital role in safeguarding the environment for future generations.

State-of-the-art technology
The diesel engine has always been the most efficient system for converting fuel into mechanical energy and MAN Diesel & Turbo will ensure it stays that way. For more than 20 years, we’ve also concentrated on achieving reductions in NO\textsubscript{x} and CO\textsubscript{2}. Our technologies for efficiency and ecology enable us to provide medium speed diesel engines which comply with the most stringent emissions limits.

IMO NO\textsubscript{x} limit curves according to engine speed

![Graph showing IMO NO\textsubscript{x} limit curves according to engine speed]
Solving Tomorrow’s Challenges Today
With progressive diesel engine technology

With us, years ahead of time
MAN Diesel & Turbo has the relevant technologies for IMO Tier III, which even enable our clients to benefit from attractive incentives. Norway, for example, initiated a scheme which rewards every kg of NO\textsubscript{X} that is not emitted. With MAN Diesel & Turbo technology, ship owners and operators can adopt NO\textsubscript{X} reduction systems in their fleets at an early date and benefit from this incentive.

MAN Diesel & Turbo: a foresighted decision.

The requirements are growing stricter
A growing number of regions already prescribe emissions limits tighter than IMO Tier II, especially in coastal areas. But that’s only the beginning of a global trend. The International Maritime Organization (IMO) decided to introduce new IMO Tier III limits in so-called Emission Controlled Areas (ECAs). Among other projected locations, ECAs are already established along the east and west coasts of the USA and in Hawaii. Other areas under discussion include the Baltic Sea and North Sea.
Benefit from overall system competence

MAN Diesel & Turbo unites comprehensive technologies and competencies under one roof: injection systems, turbocharger, control and after-treatment systems. This enables us to design and implement highly efficient emission-reduction packages for both new buildings and retrofits.

Targeting all important emissions

NO\textsubscript{x} is one of the primary emissions caused by combustion engines. It can be efficiently minimized by using selective catalytic reduction and exhaust gas recirculation.

The SO\textsubscript{x} emission, on the contrary cannot be influenced during the combustion process. One option to reduce this harmful exhaust gas constituent is using low-sulfur fuels. Another option consists of custom-tailored after-treatment packages, offered by MAN Diesel & Turbo.

CO\textsubscript{2}, the third major emission, is directly related to the fuel consumption. Due to the comprehensive system competence, MAN Diesel & Turbo is able to increase the overall efficiency of the propulsion system. From propeller to blue sky, all of the components complement one another perfectly. This subsequently leads to a significant reduction in CO\textsubscript{2} emissions.
Effective NO\textsubscript{X} reduction off the shelf
Temperature peaks during combustion are the principle cause of NO\textsubscript{X} formation. Therefore it is our primary goal to prevent excessively high temperatures during the combustion process. Built-in features and capabilities, integrated into the new design of our engines, are our approach to accomplish this.

The engines vary in their operating parameters, but all of them reduce NO\textsubscript{X} efficiently. There is no additional work required at the shipyard, and the engine itself does not require any additional consumables.

Additional measures available
Additional measures can be applied to further increase the NO\textsubscript{X} reducing effect of MAN Diesel & Turbo’s engines in order to comply with tighter emissions regulations. This can be achieved by means of systems that condition the fuel and combustion air to eliminate combustion temperature peaks or remove NO\textsubscript{X} from the engine’s exhaust, i.e., after-treatment devices.

One option in this context consists of so-called wet technologies, such as fuel water emulsion and charge air humidification, another option is selective catalytic reduction as a state-of-the-art after-treatment technique.
Optimizing Engines for a Blue Sky
Primary NO\textsubscript{x} measures on the engine

IMO Tier II compliance and beyond
The following primary measures form the basis for compliance with the IMO Tier II limits and can be used to attain NO\textsubscript{x} abatement levels beyond this milestone.

Combustion chamber geometry
Optimizing the fuel-air mix in the cylinder achieves more complete, homogeneous combustion and avoids temperature peaks that cause NO\textsubscript{x} to form. Our new low-swirl cylinder heads and high compression reentrant pistons assure a more favorable gas flow and a corresponding decrease in NO\textsubscript{x} formation.

Common Rail technology
The Common Rail fuel injection system developed by MAN Diesel & Turbo allows a very precise and flexible control of injection pressure, timing, and duration throughout an engine's entire operating range. Engine performance, emissions, and fuel consumption can be optimized accordingly.

Optimized injection
Combustion temperature and NO\textsubscript{x} formation can also be decreased through retarded fuel injection. The corresponding increase in specific fuel oil consumption (SFOC) – the so-called Diesel Dilemma – can be eased by MAN Diesel & Turbo’s technologies.

Miller Cycle and Variable Valve Timing
The intake air expands and cools during the Miller Cycle. Combustion temperature peaks and NO\textsubscript{x} formation are reduced. MAN Diesel & Turbo’s own system of Variable Valve Timing (VVT) enables a variable Miller process. It ensures the elimination of the particle matter (PM) penalty which arises under partial load.

High efficiency turbocharging
MAN Diesel & Turbo turbochargers with increased pressure ratios compensate for the shorter inlet valve opening times of the Miller cycle. This ensures that the quantity of combustion air entering the cylinder – and thus the engine’s performance and efficiency – all remain unaffected.

The fuel injection features of our Common Rail systems are perfectly complemented by the air management flexibility of our high-efficiency turbocharger systems with variable output. These include the Variable Turbine Area (VTA) turbocharger and the MAN Diesel & Turbo Sequential Turbocharging (STC) systems. These technologies allow the quantity of air entering the cylinder to be more precisely matched to the quantity of fuel throughout the engine’s entire operating spectrum.

VTA technology can be retrofitted for turbochargers already in the field. Vane position is electronically controlled via closed-loop (with feedback) or open-loop control (mapped vane adjustment).

Interacting technologies
Depending on the engine type, MAN Diesel & Turbo uses combinations of the above primary measures. Their interaction achieves IMO Tier II compliance along with optimized fuel consumption and enhanced engine performance.

Easing the diesel dilemma: “The SFOC-NO\textsubscript{x} trade-off”
More Solutions for Less $\text{NO}_x$
Secondary $\text{NO}_x$ reduction measures in detail

**Catalytic after-treatment**
Selective Catalytic Reduction (SCR) is the most tested and approved system for achieving $\text{NO}_x$ reduction rates up to 90%. Due to different chemical reactions taking place in the exhaust gas system, harmful substances are transformed into ecologically benign constituents.

MAN developed an SCR system optimized for marine operation, capable of running with HFO and diesel oil. The system has a modular design, enabling us to deliver the engine + MAN SCR from a single source, with MAN taking the full IMO Tier III responsibility.

The well-known SaCoS control system is used for both technologies. This intelligent control system and the integration of engine and exhaust gas reduction technology results in an optimized package with the highest efficiency at the lowest operational expenditures. A smart combination of a minimum SFOC engine and an environmentally friendly SCR is no longer just a dream.

**Selective Catalytic Reduction of $\text{NO}_x$**
SCR involves the injection of ammonia or urea into the diesel engine’s exhaust stream. The urea decomposes into ammonia and carbon dioxide. The ammonia reacts with $\text{NO}_x$ and oxygen in the presence of a catalyst and transforms into water and nitrogen.

In order to ensure reliable and efficient SCR operation, MAN Diesel&Turbo has developed a new SCR control strategy. A turbocharger bypass is used to temporarily increase the exhaust temperature in order to regenerate the catalysts if required, enabling the engine to run with improved fuel efficiency most of the time.

As the leading engine builder in the marine sector, MAN Diesel & Turbo provides all the know-how needed to design and implement highly efficient and reliable SCR systems for new engines and retrofit applications for engines already in the field.
Selective Catalytic Reduction in principle

\[ 4 \text{NO} + 4 \text{NH}_3 + \text{O}_2 \rightarrow 4 \text{N}_2 + 6 \text{H}_2\text{O} \]

Exhaust temperature after turbine (e.g. HFO usage) [°C]

<table>
<thead>
<tr>
<th>Operation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conv. MAN SCR</td>
</tr>
<tr>
<td>MDT-SCR</td>
</tr>
</tbody>
</table>
Tailored to the Engine
The MAN Diesel & Turbo SCR system

The MAN Diesel & Turbo SCR system standard is available in fourteen different sizes. In this way, it fully covers the entire portfolio of MAN medium speed diesel engines. Furthermore, customized SCR systems can be offered on demand.

Main components of the SCR system:
- SCR reactor
- Catalyst elements
- Soot blowing system
- Dosing unit
- Mixing device
- Urea injection lance
- Control unit
- Compressed air reservoir module

Diesel engine MAN 6L32/44CR

Power:
3,600 kW

SCR dimensions:
3,100 x 1,750 x 1,750 mm
Exhaust gas with a benefit

The exhaust gas recirculation concept (EGR) uses exhaust gas to decrease the oxygen concentration in the charge air. This leads to slower combustion and a lower peak temperature, therefore reducing NO\textsubscript{X} emissions.

The high level of NO\textsubscript{X} reduction is also sustained during part-load operation. It can be combined with other engine-internal measures to achieve the most efficient and most reliable solution. MAN’s EGR system is therefore one of the options to comply with IMO Tier III in the future.

Installed engines, new technology

MAN Diesel & Turbo has the expertise to offer the optimum emissions reduction solution for each specific engine application. This also applies to engines that are already in the field. Depending on engine application and technical and economic viability, the latest primary NO\textsubscript{X} reduction measures from MAN Diesel & Turbo will be made available for retrofit.
Solutions beyond the Combustion Process

SO\textsubscript{x} reduction in the exhaust tract

The MAN V32/44CR includes the full range of primary NO\textsubscript{x} reduction measures currently used on MAN Diesel & Turbo four-stroke engines with Common Rail fuel injection.

The benefits of low-sulfur fuel

Using a low-sulfur fuel cuts the amount of sulfur in the exhaust. It simultaneously reduces the formation of Particulate Matter (PM) and increases the potentials for recovering waste heat.

Exhaust gas scrubbing

Operation with HFO is initially less costly, but after-treatment is needed in order to comply with emissions laws and to assure the beneficial use of the vessel.

Two main principles are currently used in marine applications: scrubbers, based on the use of seawater or freshwater with an alkaline reagent such as caustic soda. These principles are well-known and already installed on several vessels.

The wet scrubbing process

SO\textsubscript{x} is absorbed in water and then neutralized. In open loop, this happens through the seawater’s carbonate system. In closed loop, caustic soda must be added to ensure proper desulfurization. The combination of both systems, so-called hybrid scrubbers, maximizes the operation’s efficiency depending on boundary conditions and thus keeps operating costs low. This enables the ship to run on HFO while continuing to comply with the IMO sulfur limits.
Freedom in the choice of technologies
The Energy Efficiency Design Index (EEDI) sets a limit for the maximum CO₂ emissions for ships of different types and sizes. This performance-based mechanism lets the industry decide which technologies to use in each specific ship design. As long as the required energy efficiency level is achieved, ship designers and builders can select the most cost-efficient solution.

SaCoSone for maximum efficiency
Reduced fuel consumption results in lower CO₂ emissions. But the NOₓ-SFOC tradeoff limits the potential increase in fuel efficiency. MAN Diesel & Turbo’s SaCoSone electronic management system delivers a superior solution. In this respect, it optimizes engine output, fuel consumption, and emissions at all engine loads and speeds. Both CO₂ and harmful emissions can be minimized in applications subject to varying loads. One example: marine generator sets or vessels operating at below their designed cruising speed, so-called “slow steaming”.

Energy recovery for more power
The charge air cooler, the oil cooler, the engine coolant and the exhaust gases are rich sources of recoverable thermal and kinetic energy. Building on its advanced turbocharger turbine technology, MAN Diesel & Turbo offers a range of Thermal Efficiency Systems (TES). They effectively convert exhaust gas energy into mechanical, hydraulic or electrical power.

Holistic solutions from one supplier
MAN Diesel & Turbo supplies all the main parts of propulsion and onboard power generation systems. Our ability to treat the ship as a complete system enables us to develop a concept that will reduce CO₂ and yield substantial energy savings. As a competent simultaneous engineering partner, MAN Diesel & Turbo can collaborate closely to optimize a vessel’s overall efficiency.
Innovative Power Source at Sea
Gas for propulsion and onboard power

**Turn to gas**
Faced with stricter emissions regulations, the shipping industry demands alternative fuel sources. Natural gas, made viable through proven technologies, represents an environmentally friendly power source that even contributes to profitability. MAN Diesel & Turbo caters for this by providing dual fuel engines that run on both gas and diesel. This fuel combination provides all the benefits of gas and adds high fuel flexibility and built-in redundancy.

**Made-to-measure solutions**
Whether it’s a new engine, a retrofit or a complete gas system, MAN Diesel & Turbo examines your specific needs and then tailors a solution that will yield reliable returns on your investment. You also benefit from a global service network that provides expert advice and assistance whenever and wherever you need it. With our expert in-house knowledge, we can provide you with everything you need to run your ship on gas, including storage tanks and supply systems. Furthermore, combination of a DF engine and SCR is also possible in order to enable reliable IMO Tier III operation in gas and liquid mode.