Technology for ecology

MAN Energy Solutions
Future in the making

Medium-speed engines for cleaner air

Future in the making

Contributing to a carbon-neutral economy

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

For more than 30 years, we have also concentrated on achieving reductions in NO_x and CO_2. Our technologies for efficiency and ecology enable us to provide medium-speed diesel engines which comply with the most stringent emission limits and even reach levels significantly below the regulatory requirements.

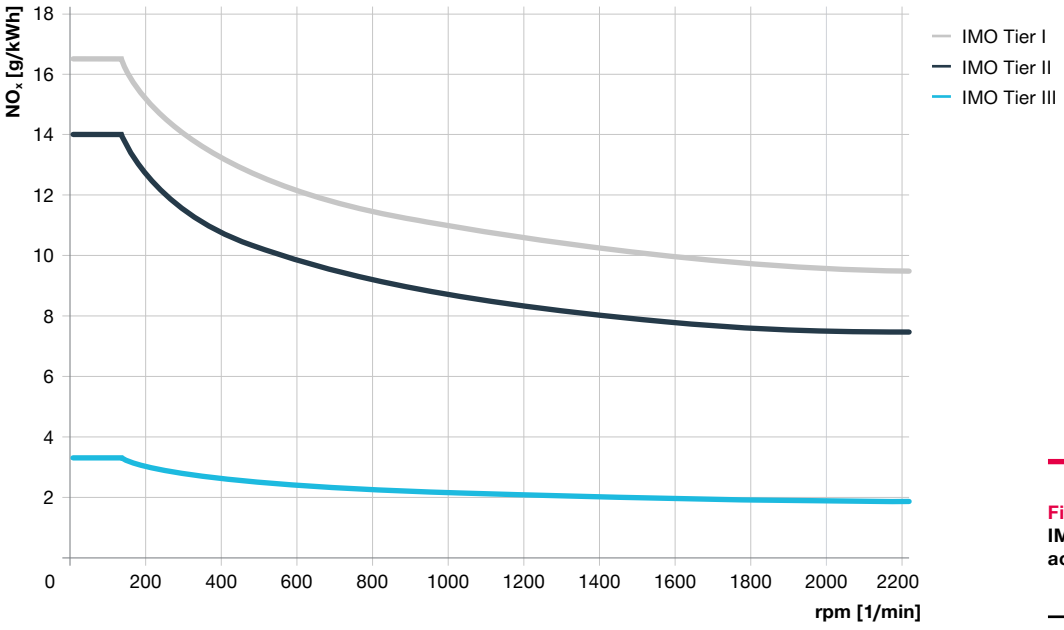


Fig. 1
IMO NO_x limit curves according to engine speed

Solving tomorrow's challenges today

Reducing emissions at sea

With us, years ahead of time

MAN Energy Solutions has all the relevant technologies for IMO Tier III and significant emission reduction experience in every market segment. MAN adopted the new NO_x regulation as early as 2015 and received the first IMO Tier III approval by several major classification societies. Since then we have provided SCR solutions for over 200 systems and have proven our system competence and reliability to a wide share of customers.

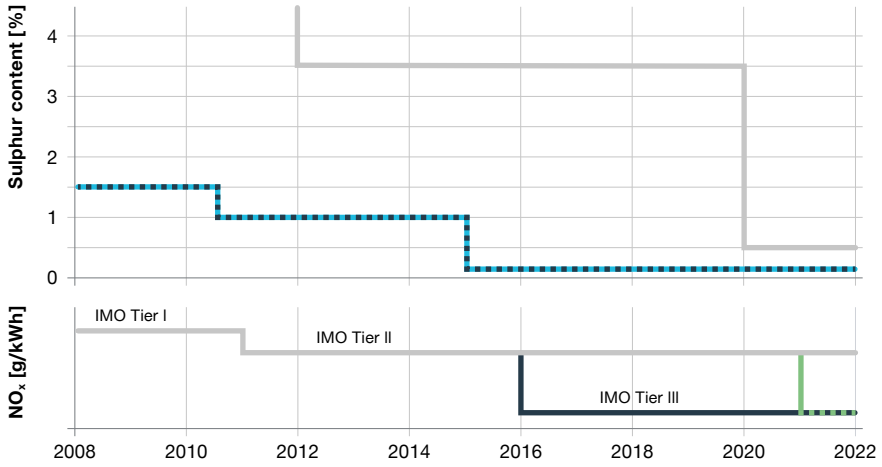


Fig. 2
Implementation schedule
SO_x and NO_x limits according to IMO MARPOL 73/78 Annex VI

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 control areas (ECAs). ECAs are already established along the east and west coasts of the USA and around Hawaii. The Baltic and North Sea will follow in 2021.

Fig. 3
Schematic world map of emission control areas (ECA)

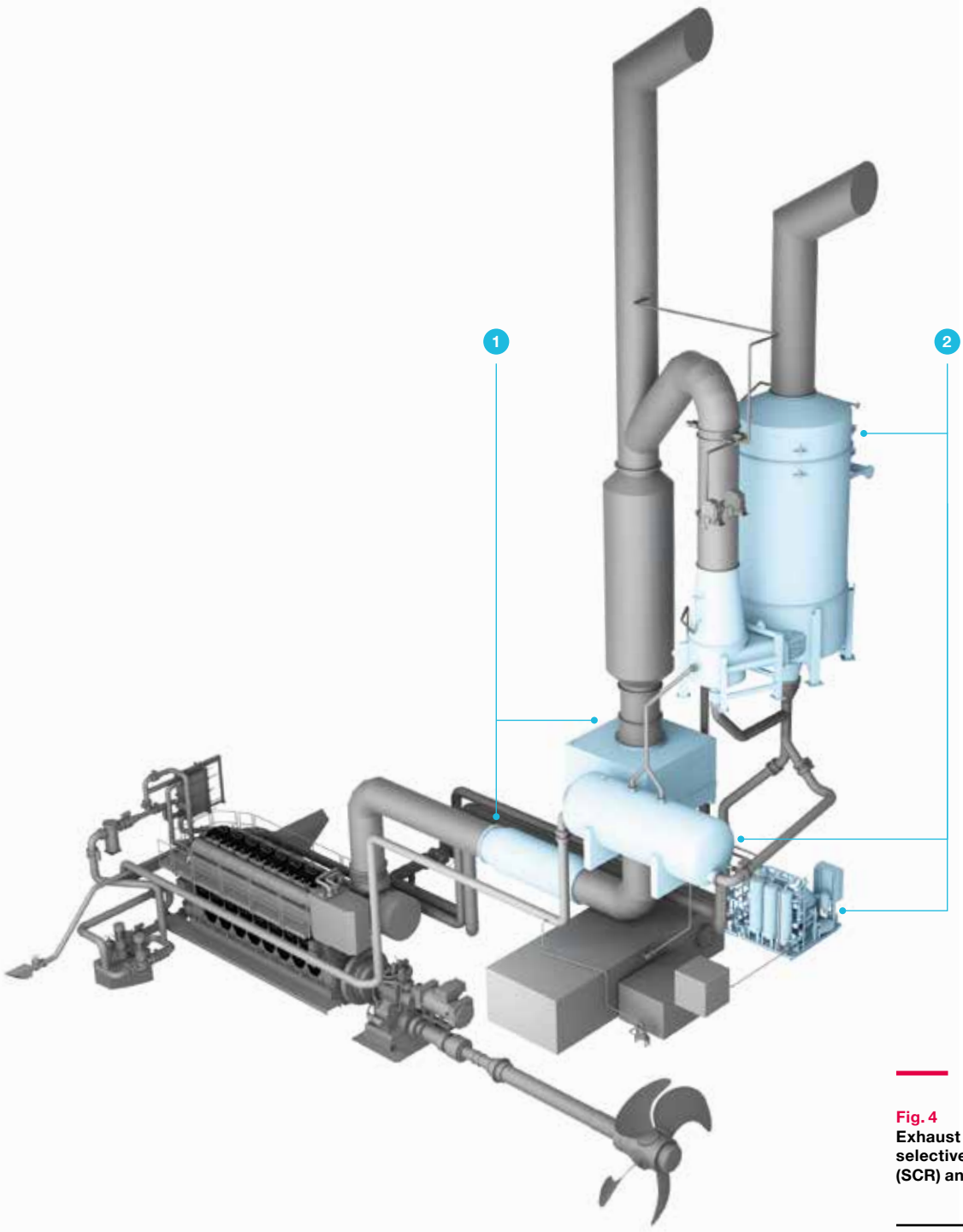


Fig. 4
Exhaust gas after-treatment with selective catalytic reduction (SCR) and scrubber

Benefit from overall system competence

MAN Energy Solutions unites comprehensive technologies and competencies under one roof: Injection systems, turbochargers, control and after-treatment systems. This enables us to design and implement highly efficient emission reduction packages for both new builds and retrofits. On top of that, the complete propulsion train can be optimized by integrating an energy storage system. This improves the loading behavior of the engines and lowers emissions.

Targeting all important emissions

Nitrogen oxide (NO_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.

Sulphur oxide (SO_x) emissions, on the contrary, cannot be influenced during the combustion process. One option to reduce this harmful exhaust gas constituent is using low-sulphur fuels. Another option consists of custom after-treatment packages, offered by MAN Energy Solutions.

Carbon dioxide (CO_2), the third major emission, is directly related to the fuel consumption. Due to its comprehensive system competence, MAN Energy Solutions is able to increase the overall efficiency of the propulsion system. From propeller to exhaust, all of the components complement one another perfectly. This leads to a significant reduction in CO_2 emissions.

NO_x abatement

Available solutions

Effective NO_x reduction included

Temperature peaks during combustion are the principle cause of NO_x formation. Therefore, we design our engines with features that prevent excessively high temperatures during the combustion process. The engines vary in their operating parameters, but all of them reduce NO_x efficiently. There is no additional work required at the shipyard, and the engine itself does not require any additional consumables.

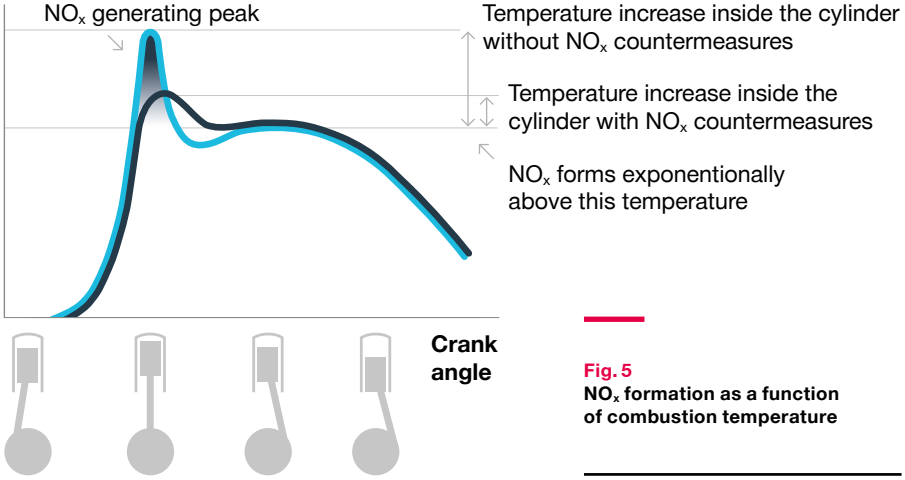


Fig. 5
NO_x formation as a function of combustion temperature

© Courtesy of Austal

Additional measures available

Additional technologies can be applied to further increase the NO_x reducing effect of our engines and 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 by removing NO_x from the engine's exhaust with after-treatment devices. The state-of-the-art solution is selective catalytic reduction (SCR).

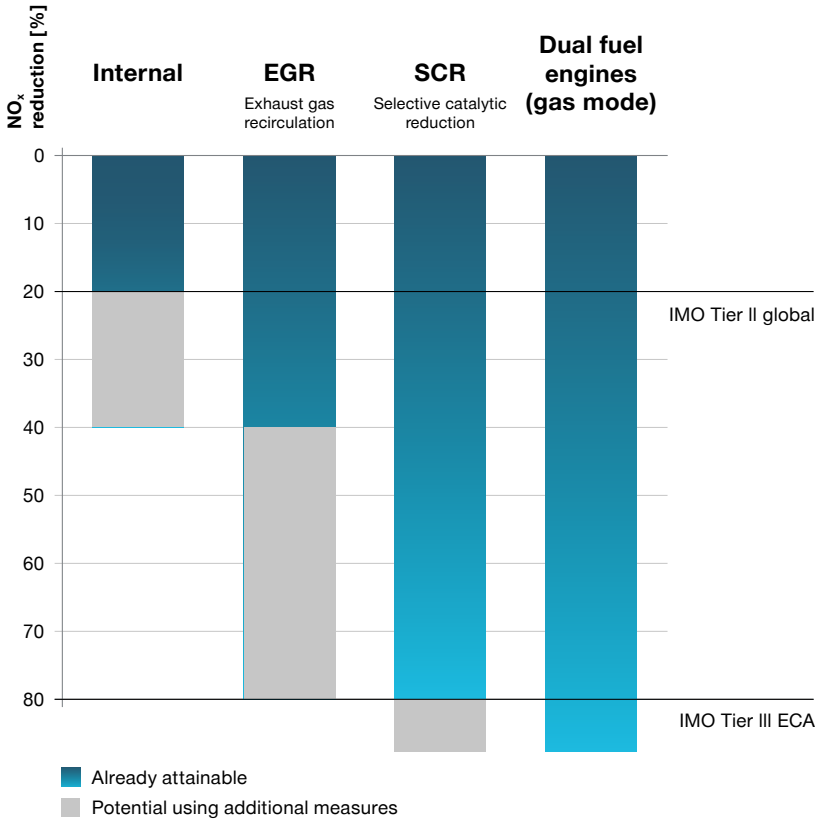


Fig. 6
NO_x reduction technologies and their potential – primary estimations

Internal solutions

IMO Tier II compliance and beyond

We use different combinations of internal engine solutions as the basis for compliance with the IMO Tier II limits and to attain NO_x abatement levels beyond this milestone. The following primary measures depend on the engine type. Their interaction not only reduces emissions but optimizes fuel consumption and enhances engine performance.

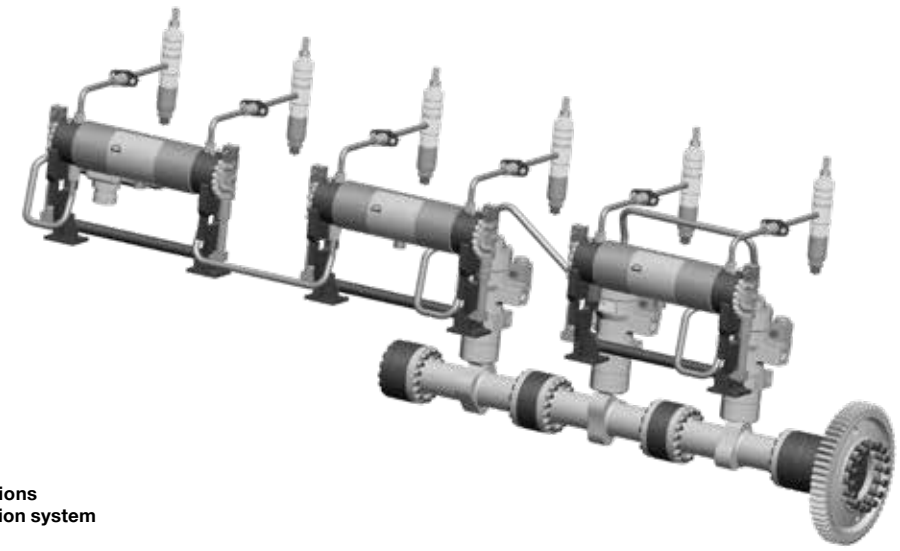


Fig. 7
The MAN Energy Solutions common rail fuel injection system

Combustion chamber geometry

Optimizing the fuel-air mix in the cylinder achieves more complete, homogeneous combustion and avoids temperature peaks that cause NO_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_x formation.

Common rail technology

The common rail fuel injection system developed by MAN Energy Solutions 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_x formation can also be decreased through retarded fuel injection. The corresponding increase in specific fuel oil consumption (SFOC) can be eased with MAN technologies.

Miller Cycle and variable valve timing

The intake air expands and cools during the Miller cycle. Combustion temperature peaks and NO_x formation are reduced. MAN'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 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 MAN variable turbine area (VTA) and the MAN 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. The vane position is electronically controlled via closed-loop control (with feedback) or open-loop control (mapped vane adjustment).

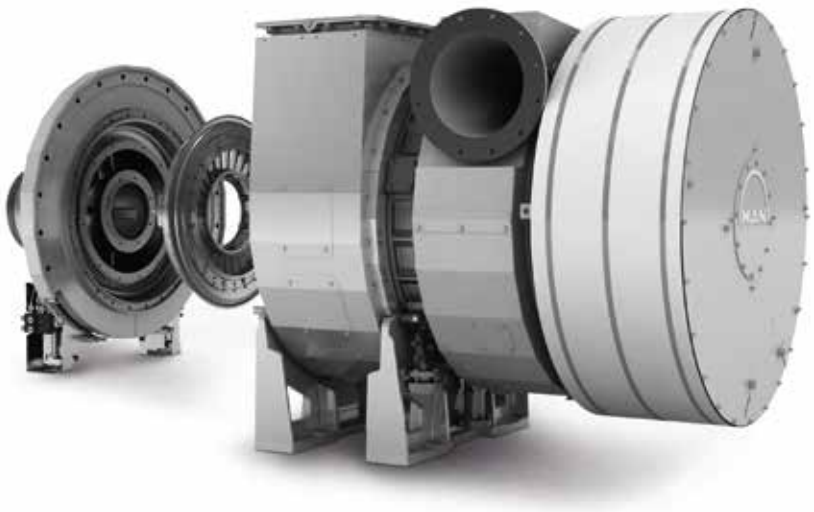


Fig. 8
Turbocharger with variable turbine area (VTA)

Exhaust gas recirculation (EGR)

For efficient NO_x reduction

Exhaust gas recirculation (EGR) is a method to significantly reduce the formation of NO_x in two-stroke diesel engines. By using this method, the Tier III requirements in NO_x ECA can be met.

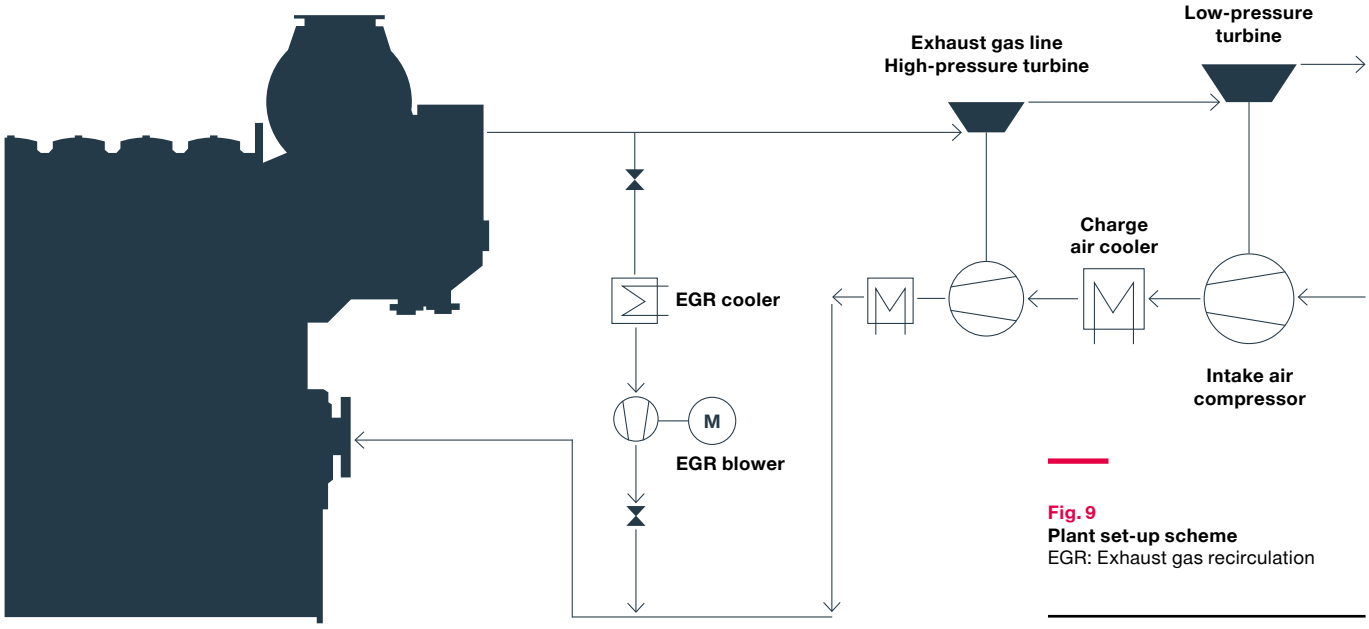


Fig. 9
Plant set-up scheme
EGR: Exhaust gas recirculation

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_x emissions.

The high level of NO_x reduction is also sustained during partial load operation. It can be combined with other internal engine 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.

MAN has researched the benefits and drawbacks of SCR and EGR on its two- and four-stroke engine portfolio. The results show that, for medium-speed engines, the negative effects of EGR outweigh the potential benefits. Therefore, SCR has been chosen as the best solution.

For low-speed engines, a project-specific evaluation can determine which of the two technologies is the way to go.

MAN SCR

Selective catalytic reduction tailored to the engine

Selective catalytic reduction (SCR) is a tested and approved system for achieving NO_x reduction rates up of to 90%. By inducing chemical reactions in the engine's exhaust gases, harmful substances are transformed into ecologically benign constituents.

Modular components

The MAN SCR system standard is available in fourteen different sizes. In this way, it fully covers the entire portfolio of MAN Energy Solutions four-stroke medium-speed engines. Furthermore, customized MAN SCR systems can be offered on demand. The modular design lets us take the full IMO Tier III responsibility by delivering both engine and SCR together.

Catalytic reduction

SCR involves the injection of urea into the diesel engine's exhaust stream. The urea decomposes into ammonia and carbon dioxide. The ammonia reacts with NO_x and oxygen in the presence of a catalyst and transforms into water and nitrogen.

Optimized for marine operation

The SCR system developed by MAN is capable of running with every marine fuel type. As the leading engine builder in the marine sector, MAN Energy Solutions 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.

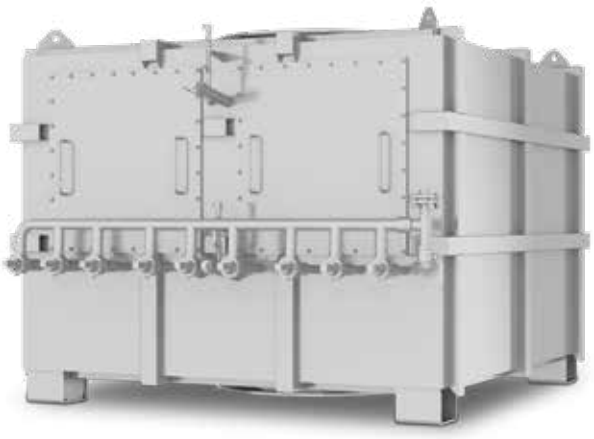
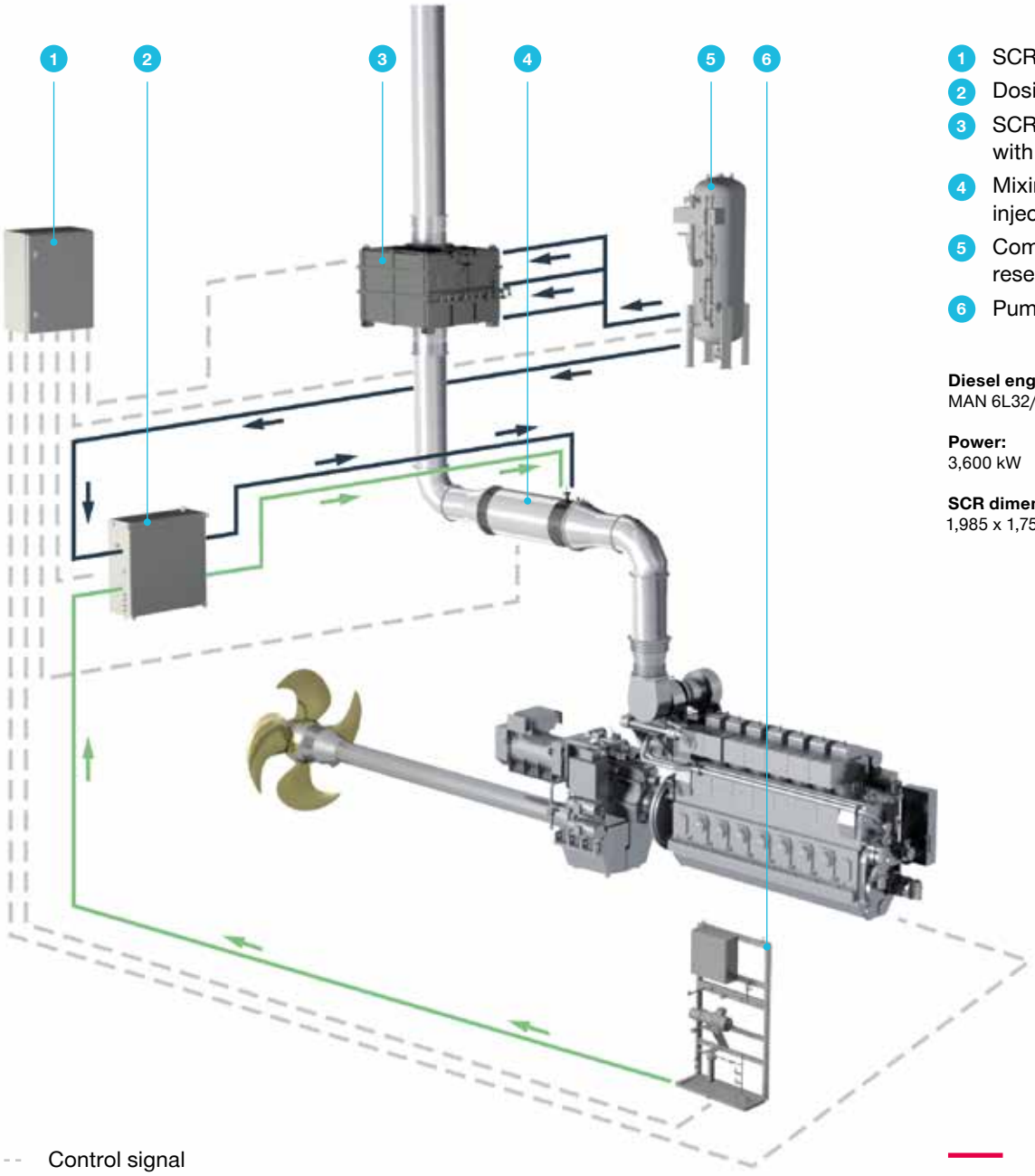


Fig. 10
LPC reactor housing



1. SCR control unit*
2. Dosing unit
3. SCR reactor housing with catalyst modules
4. Mixing unit with urea injection lance
5. Compressed air reservoir module
6. Pump module

Diesel engine:
MAN 6L32/44CR

Power:
3,600 kW

SCR dimensions:
1,985 x 1,752 x 1,752 mm

- - Control signal
— Aqueous urea solution
— Compressed air
* not true to scale

Fig. 11
Main components of the SCR system

Strengths of the integrated solution

Our core competence in engines and SCR

Engine and SCR set as core competence

- Quick response time for changes in boundary conditions
- Up to 2.5 g/kWh of fuel oil consumption savings during SCR operation through integrated and optimized control strategies (compared to combinations using different engine and SCR suppliers)
- Exhaust gas temperature control to optimize fuel efficiency
- Turbocharger layout
- Fuel injection optimization
- Closed-loop control: Urea consumption is adjusted automatically to the engine operation mode
- Modular components system

IMO Tier III compliance guaranteed

- 12,000 running hours without loss of emission compliance
- MAN takes care of certification
- Online condition monitoring

Proven SCR and catalyst know-how

- Long-term experience
- Reliable and cost-effective component design
- Standardized supply chain with premium availability
- Approved quality standards throughout the design and production process
- Reliable state-of-the-art solutions

System flexibility

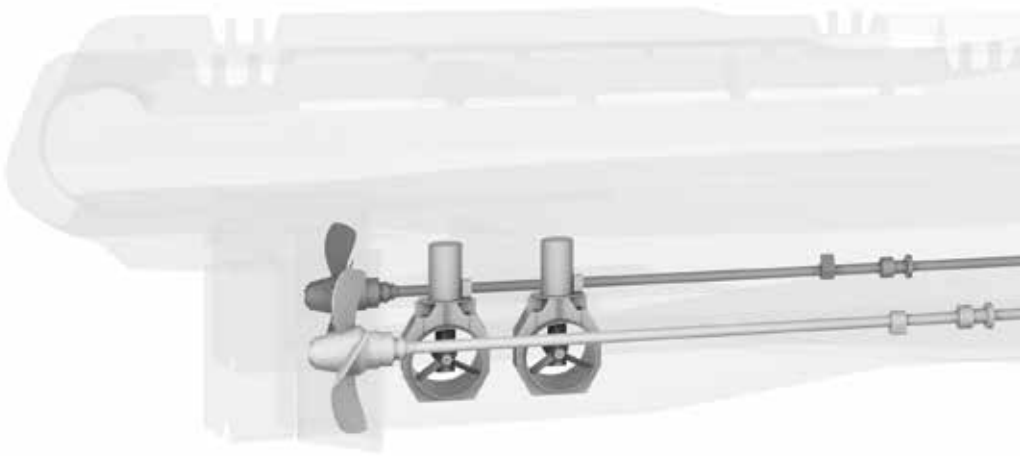
- Different reactor variants available (slim or compact)
- Integrated spark arrestor function and secondary sound attenuation potential
- Synergies for multi-engine plants: Combined use of compressed air reservoir module, pump module and control unit

Worldwide service network

- Support for engine and SCR from a single source
- Synchronized service intervals for engine and SCR
- Short reaction times to customer requests

Single point of contact

- No additional supplier interfaces
- Auxiliary system engineering by MAN experts



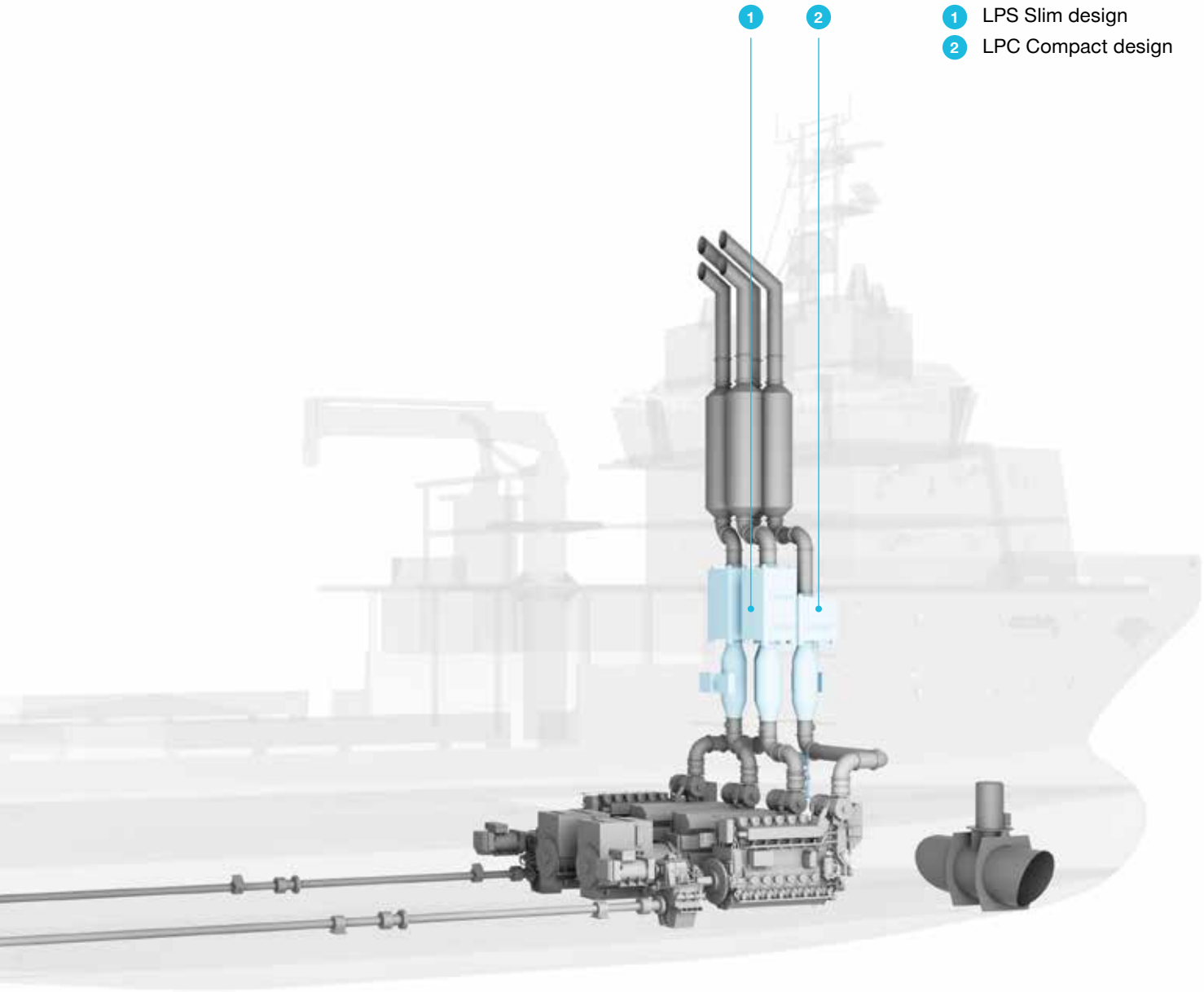


Fig. 12
SCR integration in engine system

Dual fuel gas propulsion

Innovative power source at sea

Faced with stricter emissions regulations, the shipping industry demands alternative fuel sources. Natural gas, made viable through proven technologies, is an environmentally friendly power source that contributes to profitability. MAN Energy Solutions caters for this by providing dual fuel (DF) 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.

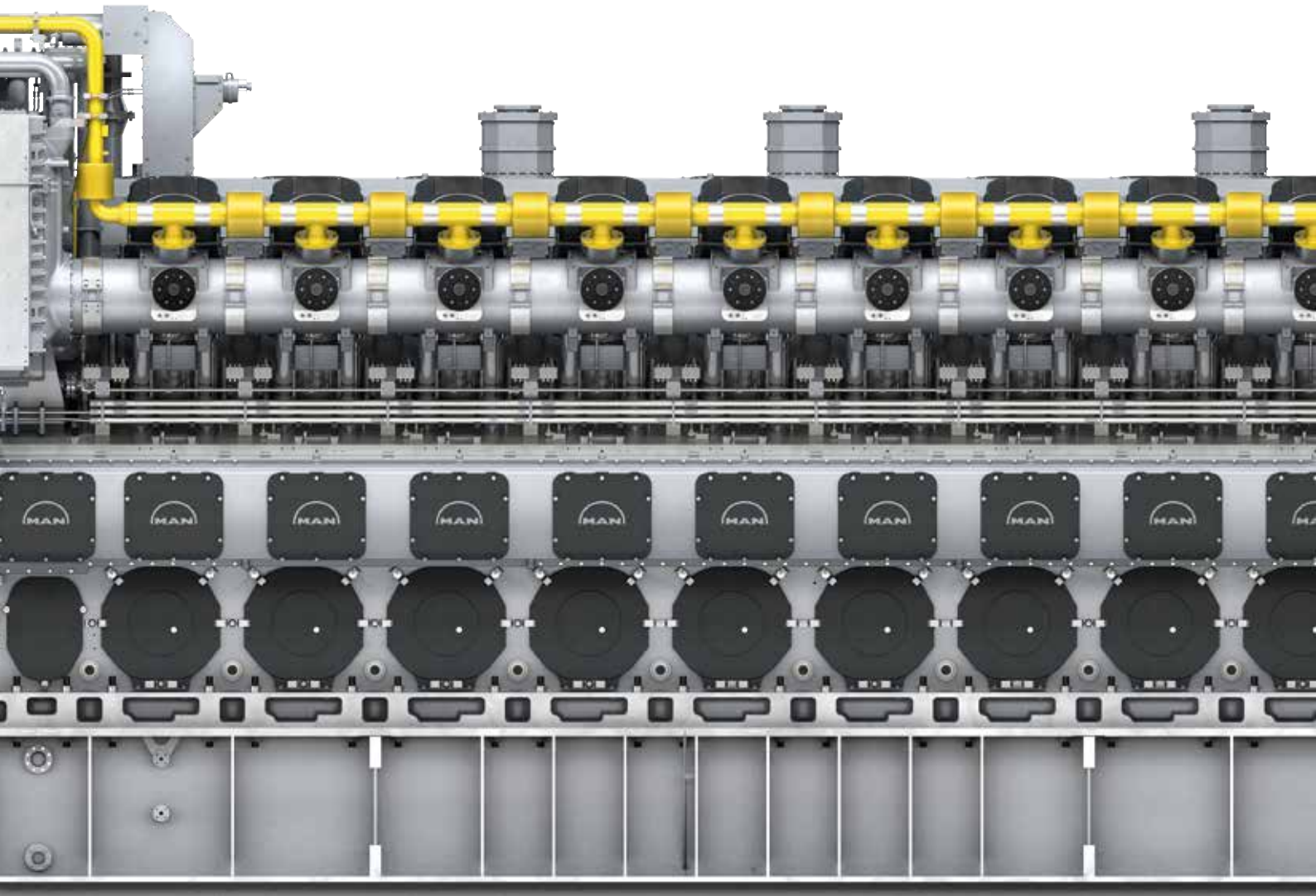
Fig. 13
MAN 51/60DF

MAN dual fuel and gas supply systems

Our dual fuel systems reduce emissions, raise fuel efficiency and power density and keep operation economical. The possibility to switch over seamlessly from gas to diesel operation and vice versa ensures full flexibility. As we now supply both the engines and the complete fuel gas supply system equipment, we can work with ship designers to perfectly integrate engines, tanks and systems.

Made-to-measure solutions

Whether it's a new engine, a retrofit or a complete gas system, we will examine your specific needs and then tailor 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 in-house expertise, 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.



Decarbonization

Reducing your CO_2 footprint

Shipping is by far the most efficient way of transportation, with the lowest production of CO_2 per weight moved. However, there are many possibilities of increasing the efficiency and reducing emissions with innovative methods.

Emission reduction through automation and optimization

Engine automation and optimization

MAN Energy Solutions integrates common rail, the MAN SCR system and SaCoSone for the fuel-saving ECOMAP 2.0 concept. While in harbor and offline, one of up to four different injection maps can be selected for the engines. Each map is designed for a different operation scenario to ensure the highest flexibility. During the voyage, by using the best map for each engine, significant shares of fuel can be saved.

Plant automation and optimization

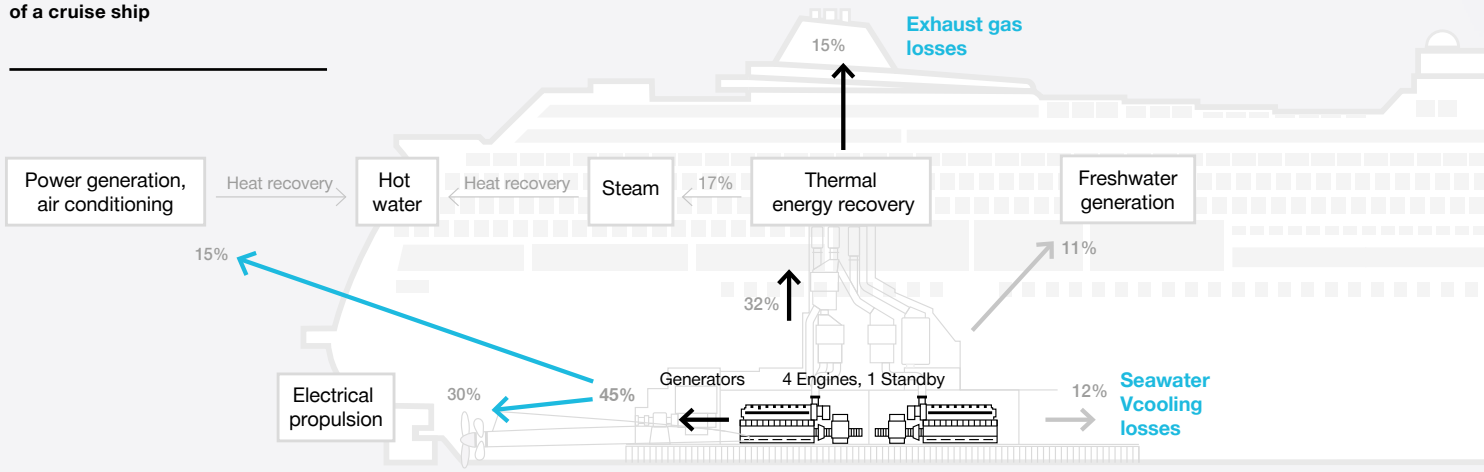
Aside from optimizing the prime movers, significant potential also lies in the surrounding plant equipment.

EcoLoad advisory tool
Flexible engines and integrated exhaust gas after-treatment within diesel electric propulsion systems have massive saving potentials. Fuel price fluctuations and varying boundary conditions may yield different optimal system settings in various situations. Finding the best plant operation mode is becoming an increasingly complex task.

The EcoLoad advisory system is designed by MAN for MAN propulsion systems, helping to achieve their full potential, for full support in route planning and online operation optimization.

ECOS (Engine Cooling Optimization System)
By controlling the seawater- and LT-cooling water pumps to supply no more than the actually needed coolant flow, notable fuel and CO_2 savings can be realized. Due to flow control, no harbor pumps are necessary and wear on the pumps is reduced while maintaining performance and leaving operational safety margins untouched, resulting in an optimized plant automation setup.

Fig. 14
Typical energy/heat balance of a cruise ship



Emission reduction through future fuels and PtX

Creating carbon-neutral fuels

Power-to-X is an energy transformation technology that converts electricity into synthetic fuels (gas or liquid) which can be stored and later used to propel ships. By using electricity from renewable sources, we can create carbon-neutral fuels for a sector that is difficult to electrify like international shipping. MAN offers turnkey Power-to-X plants, converting CO_2 from other processes and hydrogen produced from water into green fuels.

MAN power-to-gas

Renewable energy is used to run an electrolysis plant that breaks water down into hydrogen and oxygen. The hydrogen is then put into a methanation reactor with carbon dioxide, resulting in synthetic methane – also known as synthetic natural gas (SNG) or e-gas. The SNG can be stored and then be used directly as fuel for DF engine powered ships.

MAN power-to-liquid

Hydrogen can also be converted into methanol, ammonia and synthetic liquid fuels, which can play a key role in the sustainable production of fuels for shipping.

New ships without CO_2 emissions

The combustion engine is the solution of choice for marine applications – it is flexible, dynamic, cost-efficient and robust. The question now is how to reduce CO_2 by using cleaner fuels. Power-to-X enables shipbuilders to design new ships with engines that run on both fossil and synthetic fuels, or engines that eliminate CO_2 completely by running exclusively on fuels such as e-hydrogen, e-methanol, e-methane or synthetic diesel. The option of blending synthetic and fossil fuels allows an adoption of increasing carbon emission regulation also with existing assets.

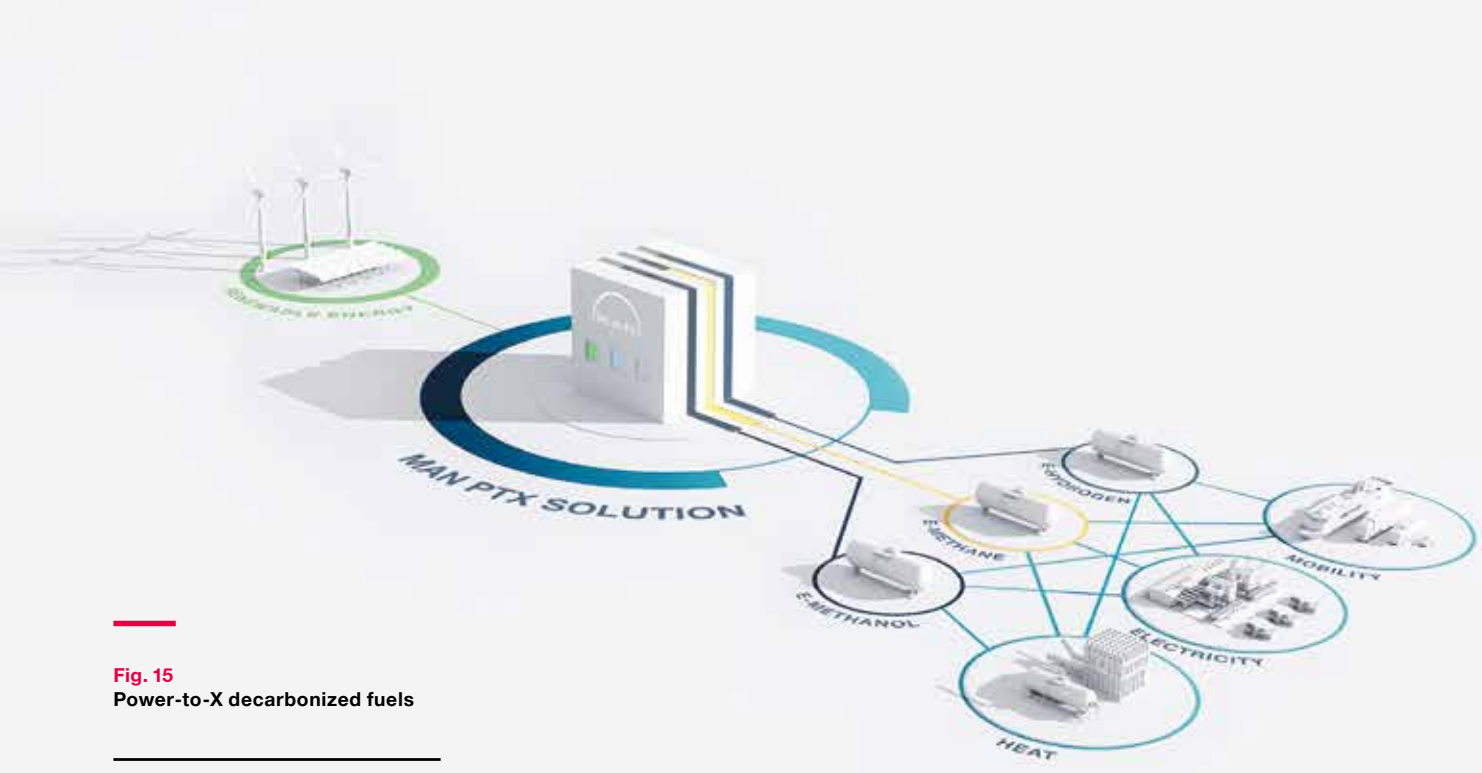


Fig. 15
Power-to-X decarbonized fuels

Battery-hybrid systems

Batteries for reduced emissions

Battery-hybrid propulsion systems combine combustion engines with battery power. The result is more energy efficiency, optimized engine operation and reduced emissions. These systems are ideal for vessels with flexible operation profiles and running hours and with varying power demands.

Batteries for reliability and flexibility

MAN offers fully tailor-made propulsion and power generation solutions, including all components such as main engines, GenSets, switchboards, energy storage systems, converters, electrical motors, gear boxes and propellers. Battery-hybrid propulsion optimizes fuel efficiency as well as the reliability of the propulsion plant. At a strategic level, an energy management system (EMS) decides if the power needed is taken from the diesels and/or from the batteries. This assures that the vessels have a broad operational capability.

Integrated system solutions

Together with our partner Aspin Kemp & Associates (AKA), we provide integrated system solutions for electric and battery hybrid propulsion. AKA's specialized expertise is the integration of electric propulsion and energy storage systems as well as providing power management and controls.

Benefits of hybrid propulsion

- **Strategic loading**
  Diesel engines are always operated at optimal load, so their SFOC is minimal
- **Dynamic support**
  Instant power for propulsors and hotel load in case of sudden demands
- **Peak shaving**
  Prevents transient loads on the diesels, which also lowers the maintenance costs
- **Electric spinning reserve**
  No standby GenSet required, it is often possible to reduce the number of running engines
- **Fewer cylinders**
  Less installed engine power necessary thanks to battery power support
- **Boost support**
  Increased system performance via electric boost
- **Zero emissions**
  When operating on batteries

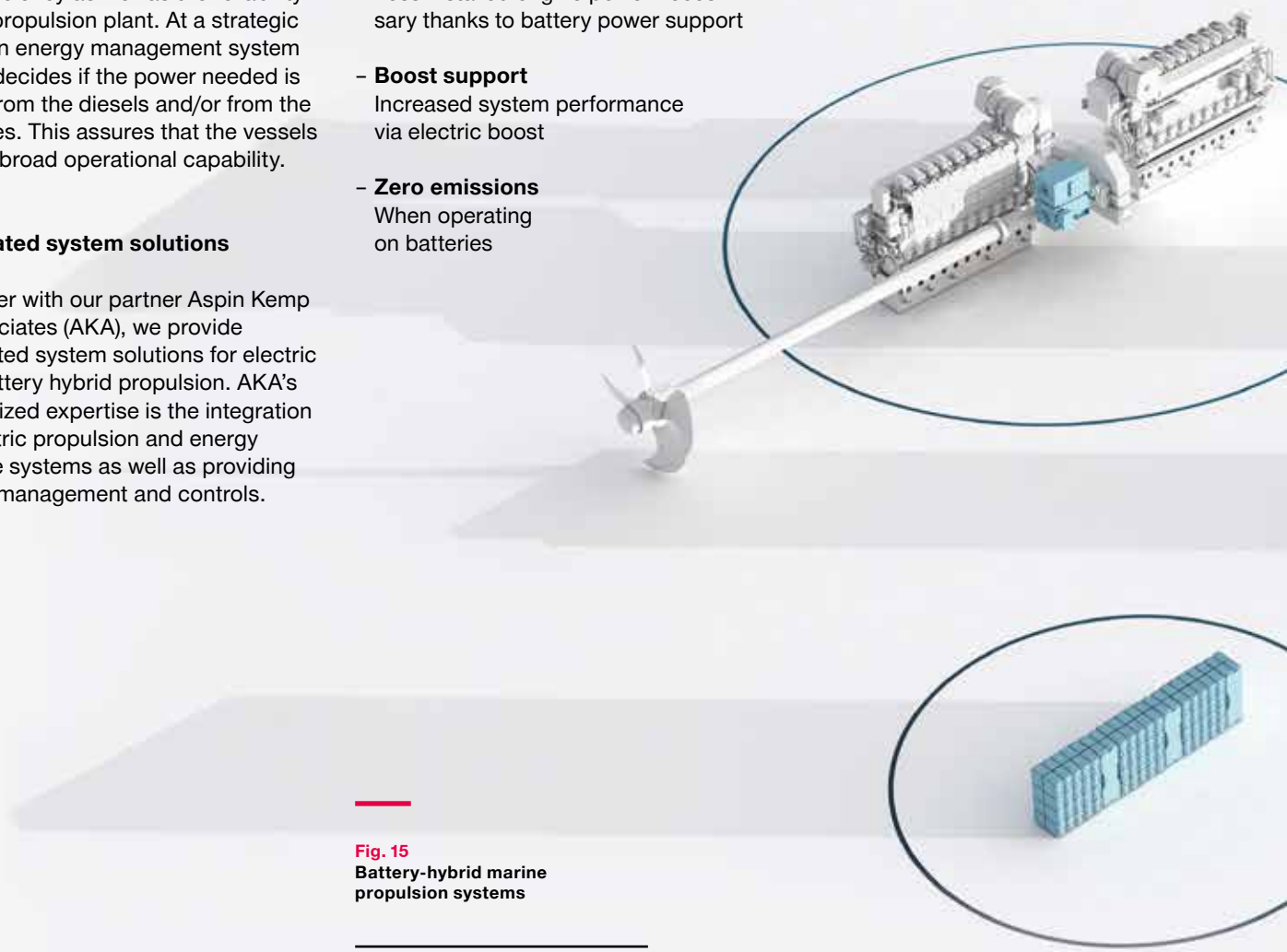


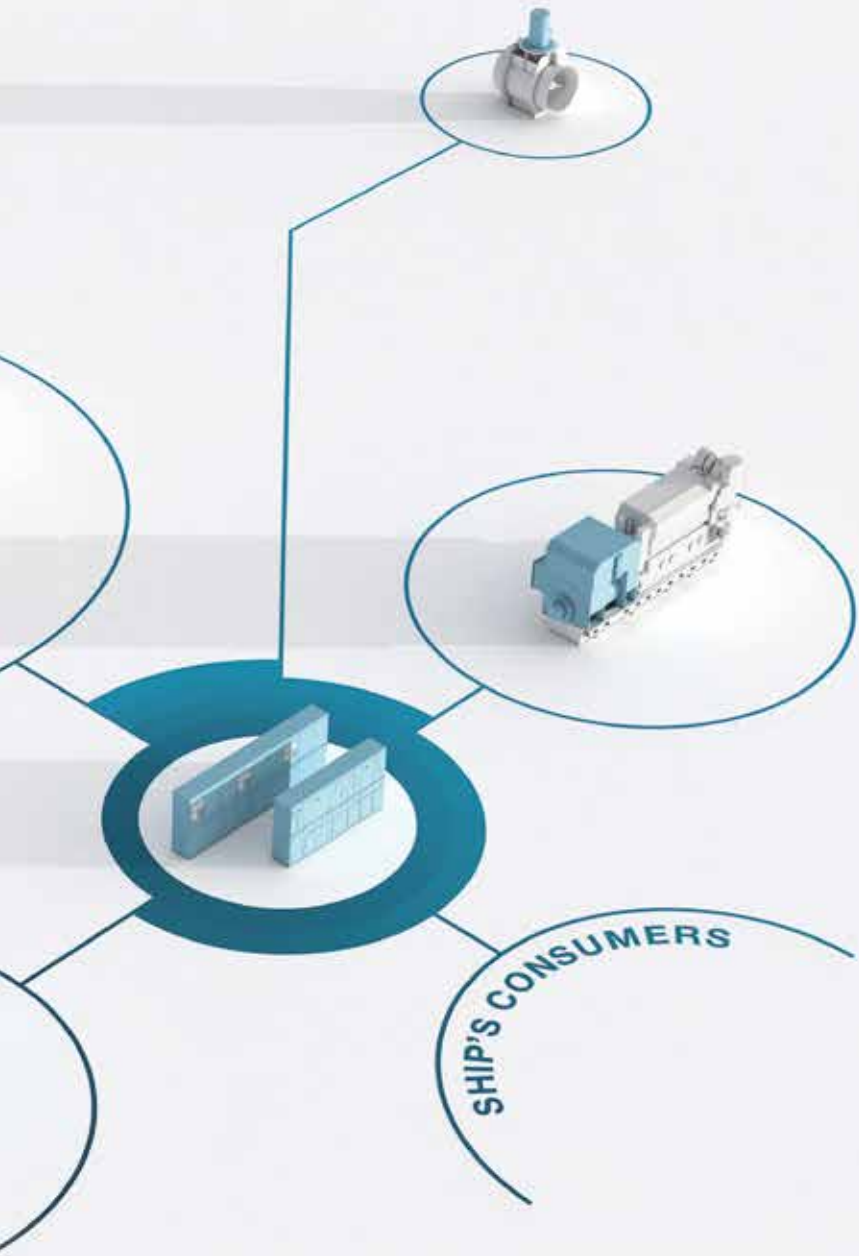
Fig. 15
Battery-hybrid marine propulsion systems

Freedom in the choice of technologies

The energy efficiency design index (EEDI) sets a limit for the maximum CO_2 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.

Holistic solutions from one supplier

MAN Energy Solutions 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 CO_2 and yield substantial energy savings. As a competent simultaneous engineering partner, MAN Energy Solutions can collaborate closely to optimize a vessel's overall efficiency.



Sulfur cap 2020

Compliant alternatives to high-sulfur heavy fuel oil

Global 0.50% sulphur cap in 2020

From January 1, 2020, the new global limit of 0.50% sulphur (S) will apply. Under the new global cap, all ships have to use fuel oil with a sulphur content of no more than 0.50% S or an approved equivalent SO_x reduction alternative solution such as exhaust gas cleaning.

This landmark decision helps to reduce the environmental footprint of global shipping by cutting the sulphur in the exhaust gas. However, the sulphur cap will change the marine fuel oil landscape remarkably and poses a major challenge for the marine industry.

Therefore, a sound fuel strategy is key and the following options can be chosen:

- Distillate marine fuels (e.g. DMA) with maximum 0.50% S content
- Very low-sulphur fuel oil (VLSFO) with maximum 0.50% S content
- Dual fuel (DF) engine for liquefied natural gas (LNG)
- High-sulphur residual fuels and application of approved SO_x reduction method

It is anticipated that very low-sulphur fuel oils (VLSFO) will be the dominant option as no major modifications (e.g. retrofit of scrubber or fuel gas system) are required. Those fuels will range between distillate and residual types and hence have a high variety in their properties and quality.

The following key challenges should be considered:

- The VLSFOs will be blended out of many different refinery products, which can result in incompatibility problems with different fuel batches.
- The varying properties of different fuel batches might need a constant adaption of the fuel oil system.

MAN Energy Solutions helps to overcome those challenges with comprehensive fuel oil analyses and extensive know-how on the design and operation of fuel oil systems.

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. The two main types of cleaning system are known as wet scrubbers and use either 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_x is absorbed in water and then neutralized. In an open loop, this happens through the seawater's carbonate system. In a closed loop, a reducing agent like caustic soda must be added to ensure proper desulphurization. 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 sulphur limits.

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