



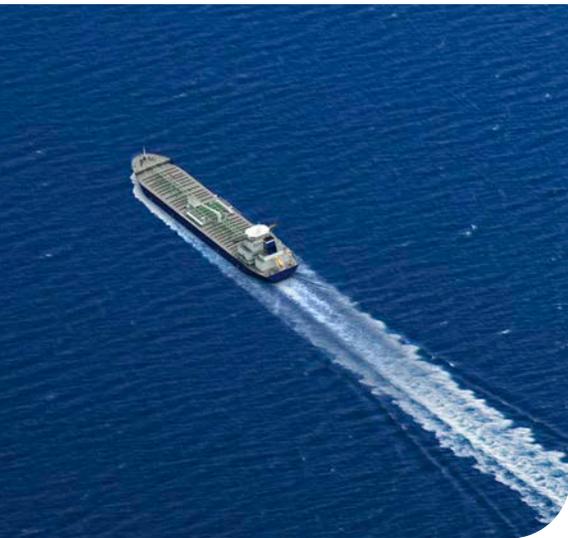
White paper



Reducing NO_x emissions from ship exhaust

An Alfa Laval white paper on exhaust
gas recirculation

January 2020



1. Why reduce NOx now

Air pollution is the single largest environmental health risk and responsible for the premature deaths of an estimated 7 million people worldwide each year. Air pollution contributes to the global burden of air pollution-related disease, the World Health Organization reports. Nine out of 10 people breathe air containing high levels of air pollutants.

Ship exhaust emissions contain three main pollutants: sulphur oxides (SOx), nitrogen oxides (NOx) and particulate matter. A University of Rochester study published 2018 in Nature magazine estimates the number of cases of childhood asthma a year due to ship emissions at 14 million and the number of premature deaths a year at 400,000¹. To curb air pollution from ships, the International Maritime Organization (IMO) adopted in 2008 the NOx Technical Code, Regulation 13 of MARPOL Annex VI.

By 2010, MAN Energy Solutions and Alfa Laval had developed exhaust gas recirculation (EGR) technology to prevent the formation of NOx during combustion. The prototype clocked 3,500 operating hours at sea. Two years later, Alfa Laval became the first company in the world to be approved by MAN Energy Solutions to supply a water treatment system, Alfa Laval PureNOx, for cleaning effluent from the MAN EGR scrubber intended for use on MAN B&W two-stroke engines. PureNOx in combination with the MAN EGR scrubber provided a 50% reduction in NOx emissions and bleed-off water in compliance with IMO criteria for Tier III ships.

¹ Source: <https://www.nature.com/articles/s41467-017-02774-9>

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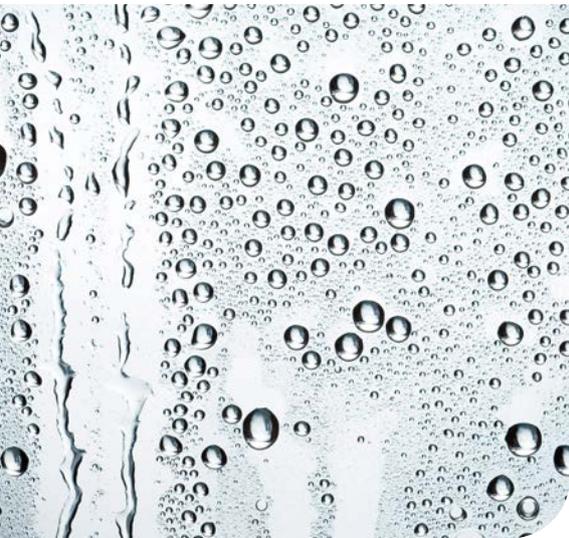
Since then, Alfa Laval has continuously improved PureNOx, reducing its footprint as well as its capital and operating costs. In 2018, the IMO adopted Marine Environment Protection Committee (MEPC) Resolution 307(73), which details guidelines for the overboard discharge of exhaust gas recirculation (EGR) bleed-off water. The latest iterations, PureNOx LS and PureNOx HS, ensure compliance with the MARPOL Annex VI Tier II and Tier III NOx emission reductions.

What is NOx?

Combustion of fossil fuels on board ships produce carbon dioxide (CO₂), sulphur oxides (SOx), nitrogen oxides (NOx), soot and water. Nitrogen oxides in ship exhaust emissions form when nitrogen reacts with oxygen at high combustion temperatures. This occurs almost independent of the fuel type and depends on the peak engine flame temperature. The resulting nitric oxide and nitrogen dioxide, collectively known as NOx, must be reduced before releasing ship exhaust into the atmosphere. Nitric oxide is a colourless, odourless gas while nitrogen oxide is a reddish-brown gas with a pungent odour.

NOx, its environmental impact and health issues

NOx reacts with other substance and therefore plays a role in forming smog, acid rain, ground level ozone, and increased levels of fine particles (PM), which are associated with deforestation, surface water acidification, reduced crop yield and adverse health effects. Health effects are mostly related to the human respiratory system causing inflammation of the airways and increased sensitization to allergens.



The legislation: IMO legislation MEPC.307(73)

Since its adoption in 2008, the IMO MARPOL Annex VI and the NOx Technical Code have been amended. Tier II and Tier III controls set respective NOx limits for ship operation using low-sulphur fuels (< 0.1%) and high-sulphur fuels (> 0.5%), both outside and inside NOx Emission Control Areas. For operation inside NOx Emission Control Areas, a ship engine must be able to switch operation to meet Tier III controls.

Most recently, in 2018, MEPC.307(73) adopted 'Guidelines for the discharge of exhaust gas recirculation (EGR) bleed-off water', valid for ships with an engine international air pollution prevention (EIAPP) certificate issued after June 2019. The EGR wastewater handling regulation calls for the specific handling of condensate of exhaust gas depending on the fuel oil sulphur content, before it is discharged overboard as bleed-off water.

IMO marine engine regulations for NOx limits for ships at sea			
Date effective	Tier	Area	NOx limit, g/kWh, n < 130
2011	Tier II	Global	14.4 g/kWh
2016	Tier III	NOx Emission Control Areas	3.4 g/kWh
2021	Tier III	North Sea and Baltic Sea	3.4 g/kWh

IMO regulations for measurement of NOx content in bleed-off water			
Fuel type	Area	Measurement of bleed-off water	Date effective
Compliant fuel with sulphur content below 0.5%	NOx Emission Control Areas	Type-approved MEPC.107(49) oil content meter with measurements not to exceed 15 parts per million (ppm) oil in water or MEPC.259(68)-compliant meter that measures polycyclic aromatic hydrocarbons (PAH), turbidity and pH	June 2019
	North Sea and Baltic Sea		2021
Non-compliant fuel with sulphur content above 0.5%*	NOx Emission Control Areas	MEPC.259(68)-compliant meter that measure polycyclic aromatic hydrocarbons (PAHs), turbidity and pH	June 2019
	North Sea and Baltic Sea		2021

* Alternative solution: Transfer bleed-off water to an exhaust gas cleaning system (EGCS) for overboard discharge.

2. Selecting the right technology for NOx emission reduction

To comply with IMO Tier III requirements, shipowners can use NOx reduction technologies when using low- or high-sulphur fuels with high-efficiency, low-speed two-stroke diesel engines, which generally power the largest commercial vessels.

Shipowners can choose between exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) technology. The choice depends on various factors such as the ship type, fuel type, engine specified maximum continuous rating, capital and operating expenditures and other conditions. Shipowners may also choose to use alternative fuels such as liquefied natural gas (LNG).



Selective catalytic reduction technology

Selective catalytic reduction (SCR) is a post-combustion treatment method that uses a catalyst (ammonia as urea) to reduce the NO_x formed during the combustion process. The catalyst is sprayed over the exhaust gas and reacts with NO_x in the hot exhaust gas to form nitrogen and water. However, supplying and storing ammonia on board can present health and safety risks on board.

Exhaust gas recirculation technology

Exhaust gas recirculation is a method of modifying the inlet air to reduce NO_x emissions at the source. Recirculation of about 30% of the exhaust gas increases the heat capacity and lowers the oxygen content during combustion, which in turn reduces the flame peak temperature thereby minimizing NO_x formation.

To prevent engine damage from sulphur and soot when recirculating the exhaust gas, the gas is cooled in a scrubber using wash water. The wash water must be cleaned in a water treatment system to meet IMO requirements for overboard discharge. For overboard discharge, bleed-off water must have an oil content not exceeding 15 ppm as measured by an oil meter that is type-approved under resolution MEPC.107(49). Alternatively, bleed-off water can also be measured using sensors for PAH, pH and turbidity that are fully compliant with MEPC.259(68).

Unlike SCR equipment, which is installed after the engine, EGR equipment is integrated with the engine. This makes the EGR system compact and in installation and commissioning fast and reliable.

Alfa Laval PureNO_x LS:
More compact and cost-efficient for a
visible difference in bleed-off water.





Three ways to comply with IMO MARPOL Annex VI and NOx Technical Code

Engine type	Technology	Fuel type	Pros (+) and cons (-)
Two-stroke diesel engine	Exhaust gas recirculation system and PureNOx water treatment system	Low-sulphur fuel High-sulphur fuel Liquefied natural gas (LNG)	+ Low capital cost for engine sizes > 16 MW + Low consumables (NaOH) costs – Total cost of ownership based on ECA sailing time
	Selective catalytic reduction system		– Capital cost is a function of engine power. The greater the engine power the higher capital cost – Higher consumables costs than the EGR system due to the use of urea as a catalyst – Fluctuating urea price based on demand and availability – Health and safety risks associated with the presence of ammonia – Total cost of ownership based on ECA sailing time
	Switch to low-pressure LNG engine	N/A	– In compliance only if operated with LNG – High investment cost – Limited infrastructure – Fluctuating fuel price – Gas slip

Exhaust gas recirculation (EGR) system vs. selective catalytic reduction (SCR) system

Various factors	EGR system	SCR system
Factors that impact system effectiveness	<ul style="list-style-type: none"> • Engine exhaust gas temperature • Type and cost of consumables 	<ul style="list-style-type: none"> • Engine exhaust gas temperature • Fuel type, quality and sulphur content • Type and cost of consumables
Process type	Process-modified NOx emission control technique	Chemical NOx emission control technique
Capital cost	Low for engine sizes greater than 16 MW	The greater the engine power, the higher capital cost
Operating cost	Low due to the use of NaOH as the low-cost consumable material No catalyst No catalyst deposits to remove	High due to the large volumes of urea used Limited catalyst lifetime The catalyst must be treated with care because heavy metal deposits accumulate over time, clogging the system. Deposits must therefore be removed by SCR vendors or authorized contractors



3. Alfa Laval PureNOx

Alfa Laval PureNOx is a complete water treatment system for use with an EGR system. Based on proven centrifugal separation technology, PureNOx effectively cleans EGR wash water for reuse within the system as well as for discharge overboard according to IMO requirements.

A leading solution for Tier III NOx compliance, PureNOx has long been the choice for water treatment in EGR systems on ships. It is designed for continuous cleaning of EGR wash water in Tier II and Tier III engines. Two systems are available: Alfa Laval PureNOx LS for use with low-sulphur fuels and Alfa Laval PureNOx HS for use with fuels with high sulphur content.

Effective bleed-off water cleaning

Alfa Laval PureNOx LS (Low Sulphur) is a standard water treatment system for EGR two-stroke engines using low sulphur fuel. It fulfils with IMO resolution MEPC.307(73), containing the 2018 Guidelines for Exhaust Gas Recirculation Bleed-off Water for Tier II and Tier III requirements.

Based on experience from years of real-life operation, MAN Energy Solutions has determined that EGR process water cleaning is not necessary when low-sulphur fuel is used. This allows for a PureNOx LS setup that resembles a bilge water system, where the centrifugal separator cleans EGR bleed-off water down to levels of 15 ppm oil in water content and uses an oil monitor and a three-way valve to verify that the water is clean before safely discharging it overboard. What's more, its space-saving design is 50% more compact than the Alfa Laval PureNOx Prime, the previous PureNOx version.

Process water cleaning and synergy with SOx compliance

Alfa Laval can tailor an EGR water treatment system with proven PureNOx technology. In accordance with MAN Energy Solutions specifications, Alfa Laval PureNOx HS (High Sulphur) system will provide vital engine protection by also cleaning the EGR process water. An initial filter stage will remove the process water contaminants, while heavier particles will be separated from the bleed-off water prior to discharge through the SOx scrubber system.

For more information on Alfa Laval PureNOx HS, which is customized to meet your requirements, please contact your local Alfa Laval representative.

Alfa Laval PureNOx cleans the circulation water and the bleed-off water for overboard discharge on vessels using an EGR system and low-sulphur fuel.





4. Compact, cost-effective and compliant NOx emissions reduction

The Alfa Laval PureNOx LS pushes the boundaries of EGR water treatment technology – enabling shipowners around the world to comply with the strict NOx emissions regulations of the International Maritime Organization.

Proven at sea

With more than a decade of proven performance under actual operating conditions at sea, Alfa Laval PureNOx water treatment system has clocked tens of thousands of hours of sailing time since its prototype testing in 2010 through to the enhanced performance of Alfa Laval PureNOx Prime in 2016 and on to Tier III compliance for 2019 and beyond with Alfa Laval PureNOx LS and HS.

Complete, modular design

Easy to install and safe and easy to operate, the Alfa Laval PureNOx LS water treatment system is compact and versatile. Its small footprint. The module can be positioned anywhere in the engine room. This simplifies ship design and reduces installation time and costs. PureNOx LS generates minimal sludge for land disposal.

Peace of mind. No need to worry about compliance, high operating costs, or potential non-compliance fines. Alfa Laval PureNOx working with the MAN exhaust recirculation systems meets IMO requirements for NOx emissions reduction. Choosing PureNOx provides shipowners with total peace of mind.

Alfa Laval global service network

Get local expertise, supported by the global breadth and depth of Alfa Laval. We're here to help and are your first line of contact for assistance, parts and service, 24/7, every day of the year.

For more than 130 years, Alfa Laval has built a global presence with service centres and partners in nearly 100 countries and key marine harbours. Engineers who are PureNOx commissioning and service experts are available in Asia, Europe, North America and the US.

Most widely used EGR water treatment system

More shipowners use Alfa Laval PureNOx as their EGR water treatment system than any other water treatment system worldwide. Since announcing the availability of the Alfa Laval PureNOx LS, Alfa Laval expects an even higher order intake.

Reliable operation

Crew members are already familiar with well-known Alfa Laval high-speed separation technology. This makes operation and maintenance easy.

Low operating costs

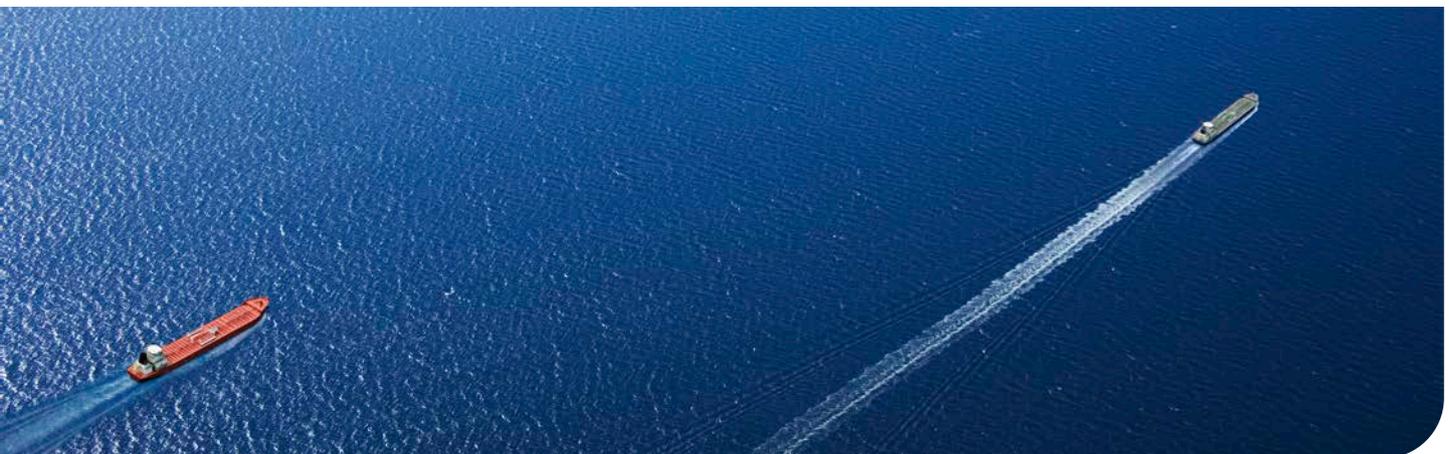
Operating costs are not dependent on the running hours of the separators. Disposal costs are low due to minimal sludge for land-based disposal.

Easy to maintain

Alfa Laval PureNOx is a straightforward, easy-to-maintain EGR water treatment system that consists of a single pump, a high-speed separator and a self-cleaning parts-per-million (PPM) sensor. Using filter technology requires more equipment and therefore requires more maintenance (see table below).

Safe system operation

No hazardous materials are used in or generated from the process. No operator training or special protective equipment is required.



5. Alfa Laval PureNOx water treatment system



The Alfa Laval PureNOx LS EGR water treatment module.

Alfa Laval PureNOx water treatment system on board ensures full compliance with IMO and VGP regulations for NOx emissions. It also provides you with peace of mind, allowing free movement of your vessel worldwide and easy access to our global service network.

For engines using low sulphur fuel, cleaning water in the recirculation loop is sent to the buffer tank. Any excess condensate water overflows from buffer tank to the exhaust gas recirculation drain tank. This overflow water is then pumped from the drain tank to the Alfa Laval PureNOx system for treatment. If treated water meets bleed-off requirements of 15 ppm oil in water content, it is discharged overboard. Any solids are sent to the sludge tank for disposal in port.

How it works

Combustion in a ship diesel engine mixes fuel with pressurized air with 21% oxygen content at high temperatures, forming carbon dioxide (CO₂), water (H₂O), sulphur dioxide (SO_x), and soot as fuel residues. SO_x emissions correlates to amount of sulphur in fuel. In addition, NO_x formation takes place, which is almost always independent of the fuel and depends on the peak flame temperature during combustion. In addition, condensate water, or bleed-off water, forms due to combustion, ambient air temperature and humidity levels.

By recirculating 35–40% of the exhaust gas, the increased CO₂ content in the gas dilutes the oxygen content. This reduces the peak flame temperature and thereby the formation of NO_x. However, this results in a slight increase in the amount of soot produced.

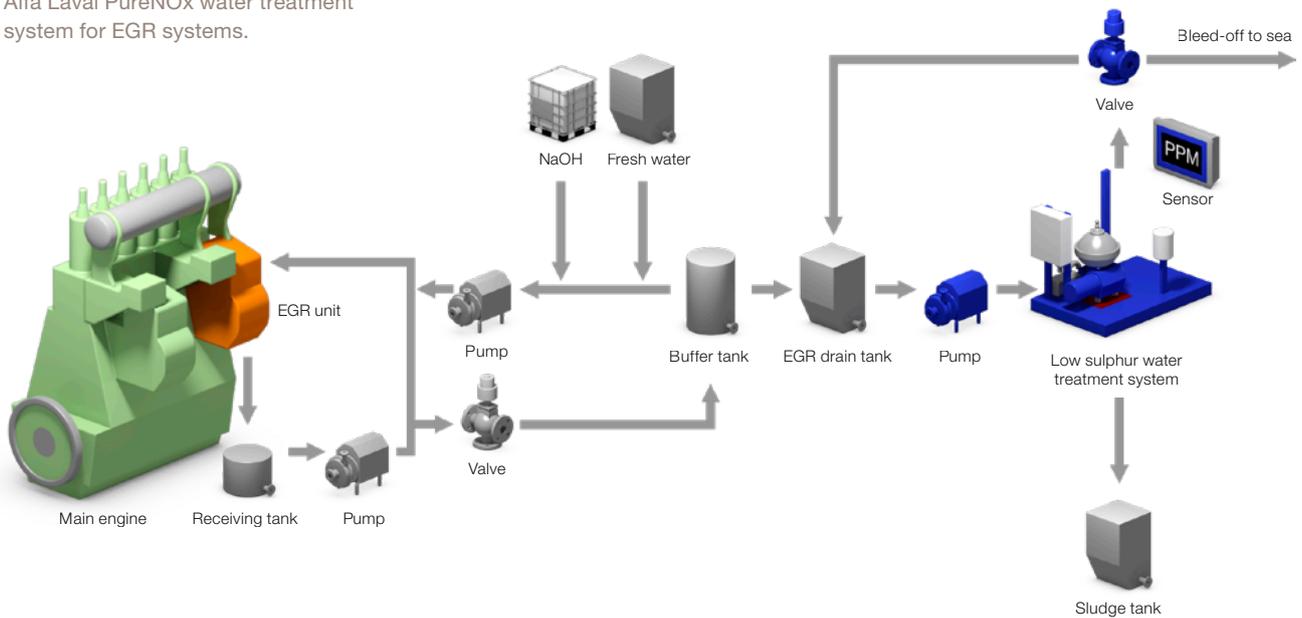
Since the exhaust contains higher levels of soot, the exhaust gas must be cleaned before it is recirculated by spraying the exhaust gas with water prior to the EGR process. A cooler condenses the evaporated water as well as the condensate formed during combustion; a mist catcher removes the droplets from the gas phase. The pressure of the cleaned exhaust gas is increased in a blower before it is introduced into the intake air.

The EGR bleed-off water is directed from a buffer tank to a drain tank by means of gravity. The pump transfers the dirty process water to the separator, which cleans it by means of centrifugation. After treatment in the separator, a PPM sensor measures the quality

of the bleed-off water to ensure it meets IMO requirements for overboard discharge. If required, it is possible to add sensors to enable operation in Vessel General Permit (VGP) areas.

Bleed-off water that meets IMO requirements is discharged overboard using a three-way valve. If the water does not meet IMO requirements, it is returned to the drain tank for further treatment; coagulant is added with a dosing pump to improve the process.

Schematic flow diagram:
Alfa Laval PureNOx water treatment system for EGR systems.



Alfa Laval PureNOx components

- Feed pump
- Coagulant pump
- Flow transmitter
- Centrifugal separator
- Oil content monitor
- Pressure control valve
- Flow switch
- Three-way valve
- Alfa Laval touch control panel
- GPS connection
- Set of tools
- Documentation

Optional equipment

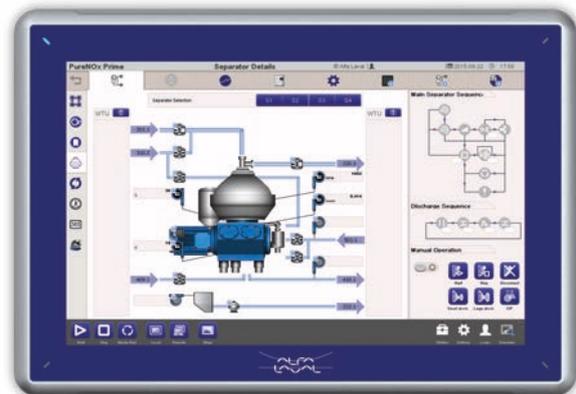
- pH sensor
- Turbidity sensor
- Polycyclic aromatic hydrocarbons (PAH) sensor
- Remote Alfa Laval touch control panel

Complete skidded module

The Alfa Laval PureNOx LS is a complete water treatment system mounted on a skid. The main components include the: feed pump, priming water solenoid, separator, control units, variable frequency drive pumps, dosing unit, sensing unit. In addition, these components comprise the treatment system:

1. Feed pump
2. Coagulant pump
3. Flow transmitter
4. Centrifugal separator
5. Oil content monitor
6. Pressure control valve
7. Flow switch
8. Three-way valve
9. GPS connection

Optional equipment, including sensors to measure pH value, turbidity, polycyclic aromatic hydrocarbon (PAH) content, and a remote Alfa Laval touch control panel are available.



The Alfa Laval PureNOx LS EGR water treatment system. It is designed using minimal piping, good sensor accessibility and all connections positioned on the same side.



6. Alfa Laval PureNOx: Emissions compliance and fuel savings

Don't worry about compliance. Enjoy total peace of mind with Alfa Laval PureNOx. Reliable and fully IMO-compliant, this EGR water treatment system effectively cleans EGR process water and saves fuel – no matter where your fleet sails. PureNOx has been proven at sea for nearly a decade.

Compliance today and tomorrow

Looking for new technology that pushes the boundaries of EGR water treatment technology? Look no further than the Alfa Laval PureNOx LS. – enabling shipowners around the world to comply with the International Maritime Organization's strict NOx emissions regulations. Emission Control Areas (ECAs), new global NOx requirements that take effect in 2019 and 2021, or NOx limits that already exist in Emission Control Areas (ECAs).

EcoEGR mode: Eco-friendly and fuel-efficient

An additional engine mode developed by MAN Energy Solutions, EcoEGR is designed for use with low sulphur fuels and ME-C engines with high-efficiency turbochargers. It optimizes specific fuel oil consumption without sacrificing NOx emissions reduction. In EcoEGR mode, the EGR system recirculates 10–15% of the exhaust gas in Tier II operation mode and 35–45% in Tier III mode. This requires continuous operation of both the EGR and the Alfa Laval PureNOx water treatment system. Fuel savings of between 2.5 and 5 g/kWh can be realized in EcoEGR Tier II mode.

Fast return on investment

Complying with NOx emissions requirements has never been easier, more convenient or more cost-effective. Besides its compact footprint and ease of operation, Alfa Laval PureNOx working together with MAN two-stroke diesel engines delivers measurable savings that continue to contribute to your bottom line. Payback on the initial investment in an Alfa Laval PureNOx is generally much faster than investing in competing technologies.



Exhaust gas recirculation is a method to significantly reduce the formation of NOx in marine diesel engines. By using this method, the Tier III requirements in NOx ECAs can be met.

– MAN Energy Solutions

Versatile operation

Inside and outside NOx Emission Control Areas and in Vessel General Permit areas, Alfa Laval PureNOx keeps on working, ensuring NOx emissions compliance at sea. Together with two-stroke diesel engines equipped with engine gas recirculation systems to ensure your ships comply with the NOx emissions regulations. Optimized for continuous operation, PureNOx supports the Eco EGR engine mode in Tier II.

Why Alfa Laval PureNOx?

- Proven, reliable and 50% more compact than previous system
- Easy to install, operate and maintain
- Low operating costs
- Safe operation
- No hazardous consumables
- Minimal sludge disposal
- Global service network
- Versatile for Tier II, Tier III and U.S. VGP requirements
- Ensures IMO and VGP regulatory compliance

Comparison of Alfa Laval PureNOx LS and PureNOx HS		
	PureNOx LS	PureNOx HS
Fuel type	<0.5 S	<3.5 S
Separator	NOPX 310	SWPX 810
Cooling water	No	Yes
Buffer tank incl.	No	Yes
Pre-filter	No	Yes
Mass flow meter	No	Yes
Standard flow meter	Yes	No
Overboard sensor type	Compliant with MEPC.(107)49 and MEPC.259(68)	No sensor required
Basic system operation	Cleaning bleed-off water on LS fuel	Cleaning bleed-off water to EGCS



7. OPEX savings

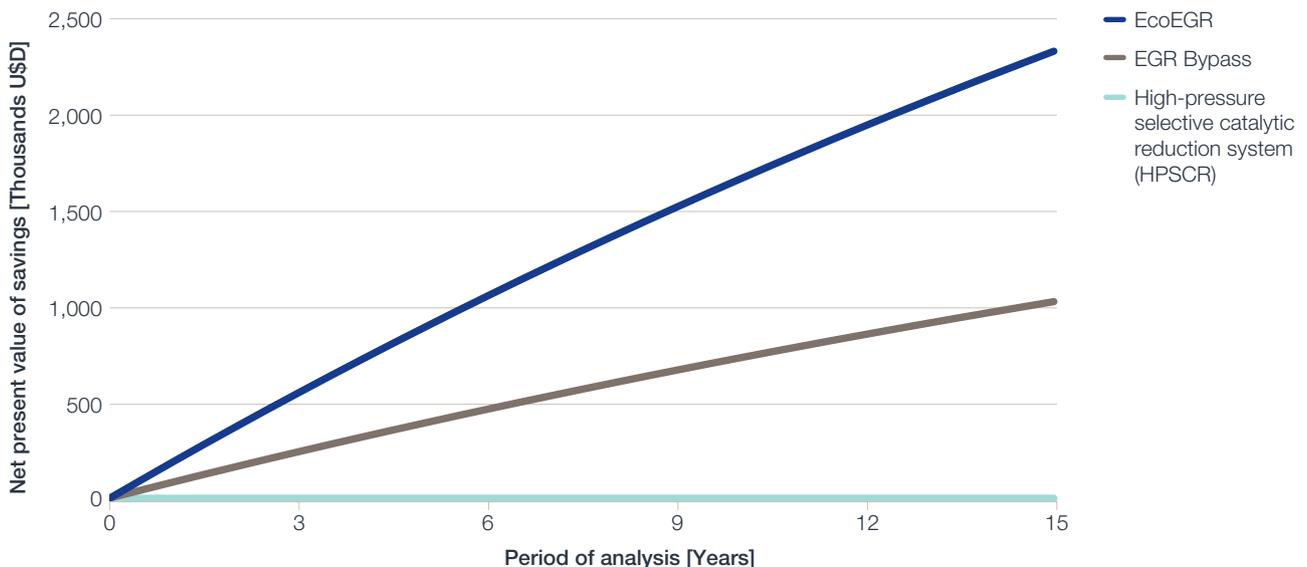
EGR vs SCR

Over a 15-year period, the Alfa Laval PureNOx module with exhaust gas recirculation technology delivers significant savings in operating expenditures compared to using selective catalytic reduction technology on board a typical LNG carrier.

These calculations take into account the operational cost, variable load profile, and Tier II and Tier III sailing time in NOx Emission Control Areas (NECAs). These are the main factors taken into consideration although other factors were also taken into consideration.

The relative net savings after 15 years amount to USD 2.3 million using Eco EGR, USD 1 million using EGR bypass mode, and no savings using HP SCR.

Ship type	LNG carrier
Ship capacity	174,000 m ³
Engine type	Two 5G70ME-C10.5-G
Power output	25 MW
Running time	7,680 hrs/year (6,912 international waters/768 NECAs)
Engine operation costs	Global gas and pilot oil, NECA gas and pilot oil, and lubrication oil
Other operation costs	Auxiliary electrical power, sludge handling, and NaOH and urea consumption



Source: MAN Energy Solutions.

This is Alfa Laval

Alfa Laval is active in the areas of Energy, Food, Water and Marine, offering its expertise, products and service to a wide range of industries in some 100 countries. The company is committed to optimizing processes and creating responsible growth. We drive progress, always going the extra mile to support customers in achieving their business goals and sustainability targets.

Alfa Laval's innovative technologies are dedicated to purifying, refining and recycling material. They contribute to enhanced energy efficiency, improved heat recovery, responsible use of natural resources, better water treatment, and reduced emissions. Thereby not only accelerating success for our customers, but also for people and our planet. Making the world better, every day. It's all about *Advancing better™*.

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How to contact Alfa Laval

Contact details for all countries are continually updated on our web site. Please visit www.alfalaval.com to access the information directly.