DNV·GL

MARITIME

GLOBAL SULPHUR CAP 2020

Compliance options and implications for shipping – focus on scrubbers

EXTENDED AND UPDATED IN 2018

SAFER, SMARTER, GREENER

CONTENTS

INTRODUCTION

The global 0.50% sulphur cap will enter into force in 2020, and more than 70,000 ships will be affected by the regulation. Stricter limits on sulphur (SO_X) emissions are already in place in Emission Control Areas (ECAs) in Europe and the Americas, and new control areas are being established in ports and coastal areas in China. As a result, ship owners are weighing their options to ensure compliance.

For the 2020 deadline, there are in essence four choices available:

- Switching from high-sulphur fuel oil (HSFO) to marine gas oil (MGO) or distillates
- Using very-low-sulphur fuel oil or compliant fuel blends (0.50% sulphur)
- Retrofitting vessels to use alternative fuels such as LNG or other sulphur-free fuels
- Installing exhaust gas cleaning systems (scrubbers), which allows operation on regular HSFO

To assist in navigating these waters, this guidance paper aims to provide an update of the latest regulatory developments and enforcement measures, as well as technological and market developments for alternative compliance solutions.

This report is an update of the DNV GL Global Sulphur Cap brochure, published in October 2016, and includes an extended section on scrubbers. Other compliance options, e.g. LNG as fuel, are covered in other DNV GL publications, e.g., "Assessment of selected alternative fuels and technologies", published in June 2018.

SO_X REGULATIONS – A BRI

After an availability review of compliant low-sulphur fuel oil in 2020, the International Maritime Organization (IMO) has decided that the global fuel sulphur limit of 0.50% will enter into force in 2020. This requirement is in addition to the 0.10% sulphur limit in the North American, US Caribbean, North Sea and Baltic Emission Control Areas (SECA). Vessels that have exhaust gas cleaning systems installed will be allowed to continue using HSFO.

A significant recent amendment to the regulation is the agreement on a carriage ban for HSFO, except for ships equipped with scrubbers. While it will still be permitted to carry HSFO as a cargo, it will not be permitted to have HSFO in fuel tanks unless scrubbers are being used. This is intended to enable port state control (PSC) to detain ships carrying non-compliant fuel without having to determine if it has been used or not, and is expected to significantly discourage non-compliance when in international waters (see page 8 for more about compliance options).

The **European Union** Sulphur Directive stipulates a maximum of 0.10% sulphur content for ships in EU ports. In certain EU countries, the Water Framework Directive constrains the discharge of scrubber water. Belgium and Germany have prohibited the discharge of scrubber water in many areas, constraining the operation of open-loop scrubbers. Other EU countries may follow suit, with no common EU practice likely to be agreed.

Currently, Hong Kong has a 0.50% sulphur limit for vessels at berth. In late 2015, **China** published regulations for domestic SECA-like requirements in the sea areas outside Hong Kong/Guangzhou and Shanghai, and in the Bohai Sea. China took a stepwise approach, initially requiring a maximum 0.50% sulphur content in fuel burned in key ports in these areas, gradually expanding the coverage, and culminating in applying the requirements to fuel used in the sea areas from 2019 onward. China has recently announced that as of 1 January 2019, it is considering expanding the geographical coverage from the original three areas to a 12-nautical-mile zone covering the entire Chinese coast line. There is also the possibility that the requirement will be tightened from 0.50 to 0.10% pending a review shortly after 2019, and that a formal ECA application may be made to the IMO.

California's Air Resources Board (ARB) enforces a 0.10% sulphur limit within 24 nautical miles of the **California coast**. The regulation does not allow any other compliance options than low-sulphur marine gas or diesel oil (DMA or DMB). A temporary research exemption may be granted allowing the use of a scrubber. The application must be sent before entering California waters. After a formal review of the regulation, California legislators have decided to retain it as an addition to the ECA requirements. Both sets of regulations must be complied with when calling at port in California.

There is a general **global trend** of stricter local air pollution regulations coming into play. In addition to the areas discussed above, this is exemplified by emission regulations – both established and forthcoming – in places such as the Panama Canal, Taipei and local municipalities around the world.

EF SUMMARY

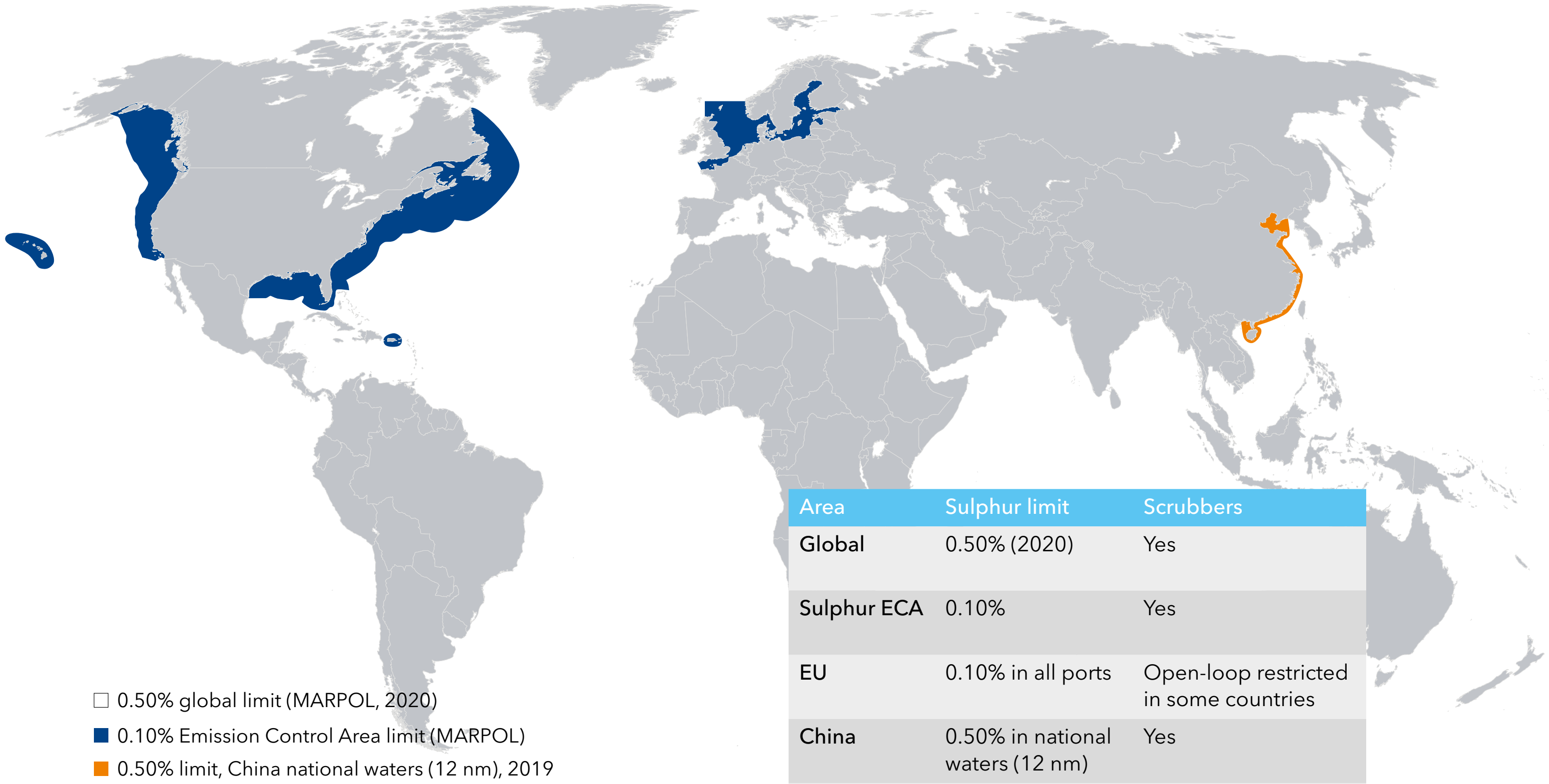

Figure 1: Regional and global sulphur regulations

Area	Sulphur limit	Scrubbers
Global	0.50% (2020)	Yes
Sulphur ECA	0.10%	Yes
EU	0.10% in all ports	Open-loop restricted in some countries
China	0.50% in national waters (12 nm)	Yes
California	0.10% within 24 nm	No, only through research exemption

ENFORCEMENT

The IMO is working on a number of guidelines and circulars intended both to ease the transition for ship operators and to encourage a uniform PSC practice around the world. These are expected to start being published towards the end of 2018 and throughout 2019.

One of the guidelines under development is a Ship Implementation Plan intended as a tool for ship operators to prepare for complying with the 0.50% sulphur limit in 2020. The plan is not mandatory and is not subject to endorsement by the flag state or a recognized organization (RO). However, PSC may take into account the preparatory actions described in the plan when verifying compliance. The guideline is expected to be finalized in November 2018. The plan addresses issues related to the use of compliant fuel oil and how to identify any safety risks associated with such fuels. The plan also includes appended guidance on impact on machinery systems and tank cleaning procedures.

In case compliant fuel is not available, non-compliant fuel can be used until the next port where compliant fuel can be procured. Ships are not required to deviate from their planned route. The IMO is developing a fuel oil non-availability report (FONAR) which will be required to be submitted to the flag state indicating the scheduled port visits and other relevant information.

Despite flag states having enforcement responsibilities in international waters, enforcement is expected to remain primarily a PSC matter. To discourage non-compliance in international waters, the IMO has therefore agreed a general carriage ban for HSFO, except for ships equipped with scrubbers. This enables PSC to detain ships carrying non-compliant fuel without having to prove that it has actually been used in domestic or international waters.

"Remote sensors" and "in-situ" SO_x emission monitoring are being tested as options for checking compliance with the regulation. So-called sniffers, installed in planes or fixed on bridges or harbour entries, can indicate whether compliant fuel is used while the exhaust plume of the ship is passing the sniffer. The intention is to identify ships which should be targeted for further inspection by PSC. It will not replace on-board fuel sampling, as PSC is legally obliged to rely only on physical fuel samples.

During an on-board inspection, PSC should look for evidence of compliance of the fuel oil delivered to or used on board the ship in Bunker Delivery Notes and the Oil Record Book, and for evidence of a written procedure and records of any fuel changeover.

The IMO is developing a requirement for a designated sampling point for in-use fuel. The purpose is to enable competent parties (e.g. PSC) to take representative samples of the fuel oil used on board. The requirement would apply to existing ships at the first International Air Pollution Prevention (IAPP) certificate renewal survey after entry into force (likely in 2021). Low-flashpoint fuel systems will be exempted from the requirement.

While penalties for this and other infractions are expected to vary significantly between port states, the HSFO carriage ban is expected to act as a significant deterrent against non-compliance. The costs (e.g. fines) of non-compliance have not been decided and are up to each PSC, but we can expect that ships would be required to offload non-compliant fuel. Nevertheless, enforcement is expected to remain uneven around the world, as PSC resources, historical enforcement focus, and capabilities vary significantly.

COMPLIANCE OPTIONS

The time to implementation is short, and operators need to choose their compliance strategy. There is no one-size-fits-all solution, and the best option very much depends on vessel type, size of vessel, operational patterns and which fuels are available in the short and long terms. For options requiring a retrofit, it is also important to consider the complexity of installation, possible off-hire and the remaining lifetime of the ship. Complicating factors when considering compliance options are regional and local regulations, which in some cases stipulate stricter requirements and in others prohibit certain compliance options.

Marine gas oil or distillates

Switching to distillate fuels will mean a significant increase in fuel cost and may also require upgrading to a fuel treatment plant due to the significantly lower viscosity of the fuel. Fuel tanks previously used for HSFO have to be carefully cleaned before bunkering MGO to avoid contamination and non-compliance problems.

The main concern with the use of MGO or distillates is associated with the availability in ports and the cost of these fuels. Many analysts estimate that in the first several months after implementation, the price differential between HSFO and distillates will be very high, thus substantially increasing the cost of fuel and making alternative compliance options financially attractive.

New compliant low-sulphur fuels

Low-sulphur-compliant fuel blends are expected to be available in the market through a variety of products. However, desulphurization plants are very costly and can take several years before they are operational. Therefore, most refineries will opt to refine higher grade fuels rather than invest in desulphurization systems. It is expected that new fuel blends to comply with the 0.50% sulphur cap will be introduced to cover the demand, at a cost reduced by 10 to 15% compared to straight distillate fuels. The first fuel samples will be presented towards the end of 2018. It is very likely that the new fuel blends will face compatibility problems, which will make fuel handling very important for safe operation. Other concerns regarding these fuels include long-term stability, the potential for catalyst fines, and their flashpoint.

Quality control when bunkering to ensure that on-spec fuel is received will be important. However, the existing fuel standard, ISO 8217, does not cover all safety aspects related to the new fuel blends. The corresponding ISO Working Group is working on identifying methodologies for testing long-term stability and compatibility between different fuel batches. Due to the processes involved in producing ISO standards, a new standard cannot be finalized before 2022. In response to the IMO request to provide consistency between the relevant ISO standards on marine fuel oils and the implementation of the 0.50% sulphur limit, the working group is planning to publish a Publicly Available Specification (PAS) in 2019, entitled "Considerations for fuel suppliers and users regarding marine fuel quality in view of the implementation of maximum 0.50% S in 2020". The PAS is intended to provide guidance for both fuel suppliers and ship owners, and ensure a smoother transition towards 2020.

DISTILLATE FUEL

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- Useable for most engine configurations

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- Higher fuel cost
- May create operational issues due to low viscosity of the fuel

NEW COMPLIANT FUELS

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- Useable for most engine configurations

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- Unknown fuel cost
- No track record as per September 2018
- Uncertain availability
- May create operational issues due to off-spec fuel or incompatibility (ref. ECA hybrid fuels)

HSFO with SO_x scrubber

HSFO will still be an option after 2020. However, to be in compliance, it will require the installation of exhaust gas cleaning technology commonly known as SO_x scrubbers. No changes will have to be made to the engines or fuel treatment plant, but the installation of a scrubber could be complex, especially for retrofits. There is a significant investment cost for the exhaust gas cleaning plant, and there will also be operational expenses related to increased power consumption and the possible need for chemical consumables and sludge handling.

One key question is whether scrubber manufacturers and other related equipment providers have the capacity to produce and install a sufficient number of systems on vessels before 2020. In the long run, if the price differential between high and low-sulphur fuels is high and maintenance proves to be manageable, scrubbers may become a widespread technology. Further details about SO_x scrubber technologies are provided in the following section.

LNG as fuel

LNG is expected to gain a more favourable position as an alternative for marine fuel for complying with the global sulphur cap. LNG as ship fuel is now a technically proven solution, and bunkering infrastructure is developing rapidly around the world. While conventional oil-based fuels will remain the main fuel option for most existing vessels in the near future, the commercial opportunities of LNG are interesting mainly for newbuildings, but in some cases also for conversion projects. Taking the leap to LNG should only be made on the basis of the best possible information and a thorough analysis.

Besides the commercial aspects, the main argument for choosing LNG as ship fuel and in the replacement of conventional oil-based fuels by LNG is the significant reduction in local air pollution – ranging from emissions of SO_x and NO_x to particulate matter (PM). The complete removal of SO_x and PM emissions and a reduction of NO_x emissions of up to 85% favours the use of LNG, especially in the ECAs. In addition, LNG can reduce greenhouse gas (GHG) emissions by 10 to 20%, depending on engine technology. As a fuelling option, LNG offers multiple advantages to human health and the environment. It also has a positive impact on the Energy Efficiency Design Index (EEDI) of the ship.

Today, gas engines cover a broad range of power outputs. Concepts include gas-only engines as well as dual-fuel four-stroke and two-stroke engines, and are thus suitable for all types of vessels.

Other alternative fuels

There is a variety of emerging fuels that could also be considered as compliance options for the global sulphur cap. The most predominant are methanol, different types of biofuels, and LPG. These are considered to have very little impact on the global market, but are alternatives that can be considered where supply is readily available. There are currently a few vessels operating with methanol as fuel, and at least two gas carriers have been ordered which use LPG as fuel. Apart from some of the biofuels, changing to these types of fuel will need engines, fuel tanks and fuel management systems to be adapted. For small vessels, with short cruising ranges, battery propulsion or fuel cells powered by hydrogen or methanol are a technically feasible solution, and also offer the benefit of zero-emission operations. Battery-powered ferries are already in operation, and hydrogen-powered ferries are planned to be built in the next two to three years in Norway, Scotland and California.

HSFO WITH SCRUBBER

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- Can use conventional HSFO
- Possible for retrofit
- Reduces particulate matter as well as SO_x
- Attractive business case for certain ship types

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- Initial investment (USD 2–10m)
- 3–5% fuel penalty
- Requires space for scrubber tower and supporting systems
- Requires chemicals (closed loop)
- Requires integration with ship's power management system
- Requires monitoring

LNG AS FUEL

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- Has good environmental performance
- Can reach NO_x Tier III requirements
- Positive impact on EEDI

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- High investment cost (USD 3–30m)
- Costly to retrofit
- Large regional variations in LNG price
- Methane slip in exhaust
- Requires space for tank
- Some engine types need additional systems to reach NO_x Tier III

SO_x SCRUBBER TECHNOLOGIES

Scrubbers have developed to become an established technology in maritime business since the introduction of SO_x-emission ECA zones in Europe and in North America in 2015.

Removing SO_x emissions from the exhaust gas to, or below, the emission limits stipulated in the MEPC.259(68) is considered a full equivalent as of Reg. 4 in MARPOL Annex VI to Sulphur compliant fuel (Reg. 14). Accepting that this piece of equipment will also add to the workload of the crew by requiring operating and maintenance efforts, it is a considerable alternative to compliant fuel. It is fair to say that decisions on scrubber installation are mainly driven by attractive payback times.

SCRUBBER SYSTEM DESIGN PRINCIPLES

Scrubbers neutralize the sulphur in the exhaust gases by an absorbent. Different absorbers can be used, and the technologies are typically categorized as "wet" or "dry" systems.

Wet systems using seawater as an absorber, also known as open-loop scrubbers, are by far the most predominant system in use. Most suppliers also offer closed-loop and hybrid systems using caustic soda or magnesium hydroxide as an absorbent.

Dry systems make use of agents in a dry form, such as limestone. Dry systems can consist of a fixed or a fluidized bed to make contact between the gaseous and the solid phases. Filters may need to be installed to remove airborne particles from the exhaust gas.

Wet absorber	Dry absorbers
■ Seawater	■ Limestone
■ Caustic soda	
■ Magnesium hydroxide	

MARPOL compliance and approval

Scrubbers must be in compliance with air emission and wash water discharge requirements. The IMO guidelines for exhaust gas cleaning systems, MEPC.259(68), offer two possibilities for approval of the systems:

- Scheme A offers the possibility to approve single systems, series of similar systems or a product range (similar designs with different capacities) and to show compliance via continuous monitoring of operational parameters and emission spot checks.
- For Scheme B, compliance is shown via continuous emission measurements and parameter checks.

Approvals following the Scheme A approach require extensive emissions tests on a full-scale installation during operation. Most of the systems installed up to now follow Scheme B, and they require continuous measurements of SO_2, CO_2 emissions and the wash water quality, as illustrated in Figure 2. Monitoring of the wash water quality includes continuous measurements of the pH, polyaromatic hydrocarbons (PAH) and turbidity.

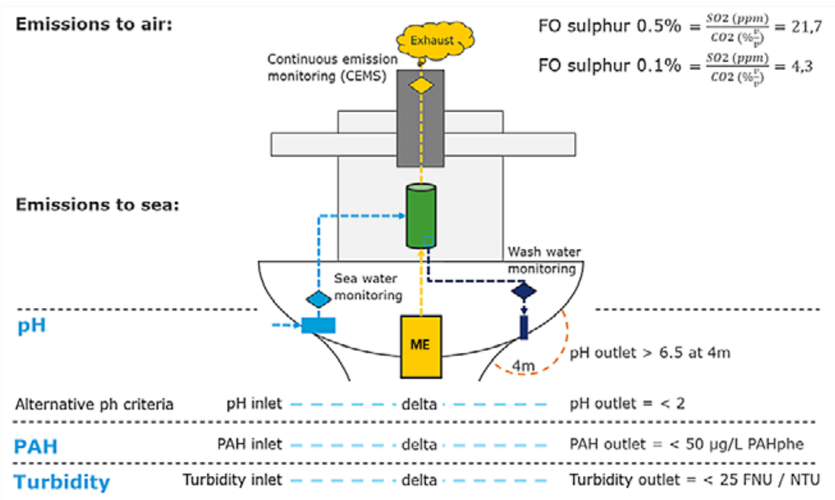

Figure 2: Monitoring requirements for ensuring compliance

EMISSIONS TO AIR

Compliance is demonstrated on the basis of the SO_2 (ppm)/ CO_2 (% v/v) ratio values.

EMISSIONS TO SEA

Wash water pH, polyaromatic hydrocarbons (PAH), turbidity and temperature must be continuously measured at the overboard discharge. Seawater PAH and turbidity must be continuously measured at the seawater inlet as well. In addition, wash water must be analysed for nitrates at commissioning and at each renewal survey.

Open-loop systems
Open-loop systems utilize the natural alkalinity of seawater to neutralize the sulphur in the exhaust gas. Open-loop systems can meet both 0.50 and 0.10% sulphur requirements and can be used in all areas with sufficient seawater alkalinity, except where there are restrictions on wash water discharge.

In an open-loop system, large volumes of seawater are pumped to the scrubber tower. The scrubber tower is designed to ensure sufficient retention time of the exhaust gas. Spray nozzles disperse the seawater in a pattern designed to maximize the neutralization of acidic gases. The wash water is drained from the bottom of the scrubber tower and exits the ship through discharge pipes. Some open-loop systems also include equipment for the treatment of wash water.

Closed-loop/hybrid systems
A closed-loop system provides flexibility for operation in areas with restrictions on wash water discharge or low-alkalinity seawater.

In a closed-loop system, process water is circulated from a process water tank through the tower and back to the tank. The process water is cooled in a heat exchanger to reduce evaporation of the process water. The ship's technical water is added to the process water to compensate for evaporation and drained wash water, while alkali is added to maintain the alkalinity. Some process water is drained and treated using centrifuges or chemicals.

Treated process water is transferred to a holding tank and discharged when permitted, and sludge is transferred to a sludge tank.

Some systems can operate both as open and closed-loop and are called hybrid scrubbers, offering increased flexibility for operation in all areas regardless of seawater alkalinity or rules constraining the use of open-loop scrubbers.

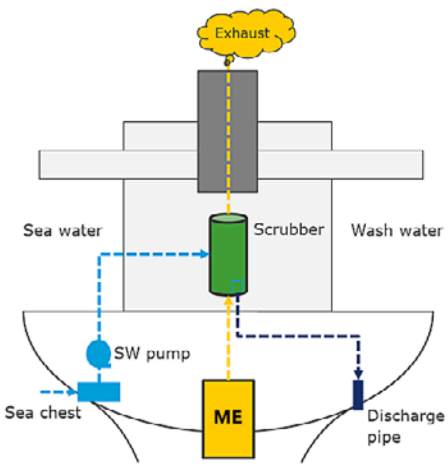

Figure 3: Open-loop scrubber

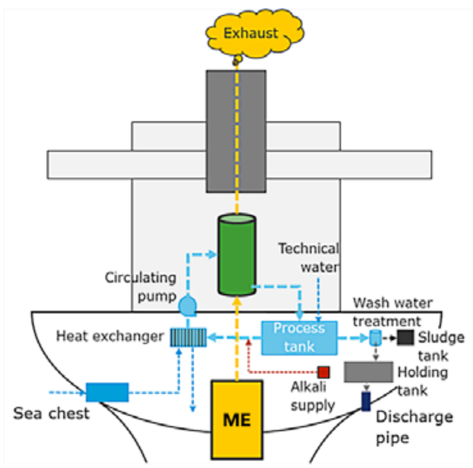

Figure 4: Closed-loop scrubber

OPEN-LOOP

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- Few components (lower cost)
- Utilizes seawater directly from the sea, no hazardous chemicals are required

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- Not allowed in some ports and areas
- Unsuitable in brackish and fresh waters
- US VGP pH compliance requires a "dilution" pump

CLOSED-LOOP/ HYBRID

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- Increased flexibility
- Can operate in all areas regardless of seawater alkalinity or temperature

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- Increased complexity (higher costs)
- Requires a constant supply of an alkaline medium (NaOH is hazardous and requires special handling)

In-line and multi-inlet types
In addition, one can choose between multi-inlet tower scrubbers, allowing for exhaust from more than one emission source, or a single-in-line tower scrubber that serves only one engine.

In-line tower
- Handles the exhaust flow from one engine
- Typically installed in the location of the silencer
- Can be operated in open or closed loop (as fitted)

Multi-inlet tower
- Handles the exhaust flow from several engines
- Typically installed in or next to the funnel
- Can be operated in open or closed loop (as fitted)

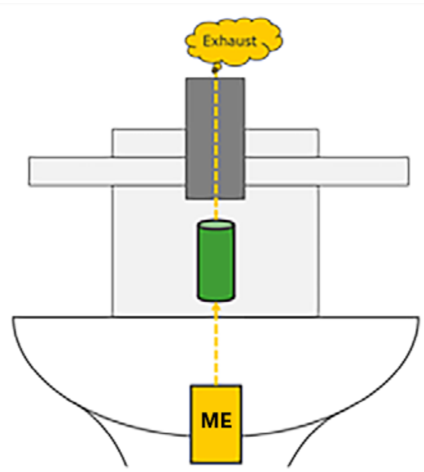

Figure 5: In-line tower scrubber system

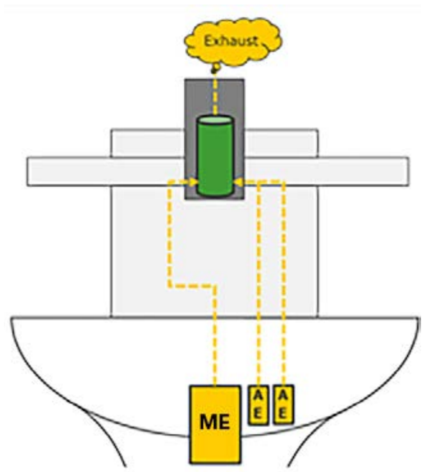

Figure 6: Multi-inlet tower scrubber system

IN-LINE TOWER

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- Small footprint if the tower can replace the silencer
- Lower centre of gravity, reducing impact on stability
- Lower energy consumption from lower pressure head
- Designed to sustain dry running (not allowed in some ports and areas)

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- Possibly more complicated tower installation
- Requires additional towers to cover more engines

MULTI-INLET TOWER

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- Can handle multiple exhaust streams with one tower
- Possibly easier installation
- Typically more cost-efficient solution for all engines

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- Possibly more complicated pipe routing
- Requires bypass solutions

TECHNICAL AND OPERATIONAL RISKS FOR OPEN-LOOP SCRUBBERS

Technical and operational risks
DNV GL has experience from more than 170 projects completed and has gained substantial insight on technical and operational risks for all types of scrubber systems. The main topics requiring particular attention for a successful installation and operation can be summarized as follows:

- Sensors and analysers, both for exhaust gas and wash water. Having reliable monitoring equipment is key since they are

SUB-SYSTEM	RISK/HAZARD	CAUSE	CONSEQUENCE
Seawater intake and supply	Loss of seawater supply due to clogging of sea chest	■ Marine growth in sea chest ■ Clogged sea chest from sand/debris	■ Shutdown of scrubber
	Reduced performance of seawater pump due to poor flow at inlet	■ Pipe bends in front of pump inlet	■ Reduced reliability of pump
	Loss of seawater supply due to failure of seawater pump(s)	■ Mechanical failure ■ Electrical failure	■ Shutdown of scrubber
	External leakage before scrubber tower	■ Burst/crack/break of seawater piping ■ Over-pressure ■ Closed valves ■ Corrosion/erosion	■ Flooding of engine room
Wash water discharge	Discharge water is not compliant with US VGP pH limit (no less than 6)	■ Design does not include solution for increasing wash water pH prior to discharge	■ Use of MGO/compliant fuel when in US water
	Corrosion of overboard discharge pipe	■ Poor coating or installation quality	■ Shutdown of scrubber ■ Repair of discharge pipe in-service
	Corrosion of valves in wash water discharge line	■ Corrosion due to low pH wash water ■ Improper material properties ■ Handling and installation	■ Downtime of scrubber
	External leakage after scrubber tower	■ Burst/crack/break of wash water piping ■ Over-pressure ■ Closed valves ■ Corrosion/erosion	■ Flooding of engine room
	Turbulence creating gas in wash water	■ Lack of degassing function in the drain line	■ Visible gas bubbles and possibly sheening ■ Possible non-compliance
Scrubber tower	Soot and scrubber water on deck	■ Soot accumulation during operation, blowout during quick change in engine load	
	Back-pressure in exhaust line exceeds limit	■ System design and capacity is under-dimensioned	■ Thermal overload on engines ■ Reduced output ■ Additional fuel consumption
	Flooding of scrubber tower	■ Clogged piping ■ Erroneous valve operation ■ Failure of high-level alarm	■ Flooding of engine room, worst case flooding of engine
	Cracks or deformation of scrubber tower	■ Corrosion ■ Incorrect welding ■ Incorrect installation ■ Mechanical stress between scrubber parts (tower and venturi)	■ Flooding of engine room

the basis to show compliance of the system. Measuring devices are usually systems already in use in land-based applications and need to be adapted for the use on board ships.

- Discharge water pipes and valves: wash water has a low pH and is highly corrosive. Therefore, components in contact with it must have sufficient corrosion-resistant properties. This includes shell side plating in areas of discharge water.

On the following pages we provide an overview of a selection of issues reflected by DNV GL's experience with open-loop scrubbers. Some additional risks have to be considered for closed-loop and hybrid scrubbers. These risks can be mitigated by careful system design and material selection.

SUB-SYSTEM	RISK/HAZARD	CAUSE	CONSEQUENCE
Scrubber tower	Clogging of scrubber tower demister	■ Insufficient cleaning of demister ■ Spray nozzles does not cover the whole area	■ Increased back-pressure ■ Soot on deck
	Corrosion/erosion of scrubber nozzles		■ Lower spraying efficiency ■ Damaged piping or pump due to increased pressure ■ Blocked/damaged valves downstream
	Insufficient scrubber efficiency	■ Tower design/size not suitable for exhaust flow and retention time ■ Droplet size and water volume not optimal	■ Non-compliant air emissions
	Exhaust gas flow through tower without seawater pumps running	■ Shutdown of seawater pump (false or actual alarm) ■ Exhaust valves in wrong position when starting engine ■ Air sailing function of exhaust valves not effective	■ Melting of plastic/low-heat-resistant components in tower
Exhaust piping	Leaking bellows at scrubber tower inlet and outlet	■ Thermal expansion / heat transfer of piping and related components at tower	■ Shutdown of scrubber
	Corrosion of exhaust pipe after scrubber	■ Acid environment ■ Material degradation due to corrosion	■ Wet exhaust line leak ■ Flow disturbances ■ Downtime of scrubber
	Internal leakage in exhaust gas bypass valves	■ Failure to fully close ■ Air seal fan failure	■ Internal leakage to bypass line ■ Exhaust flow through both scrubber and bypass ■ Non-compliance requiring changeover to MGO
	Burst explosion of exhaust line	■ Main valve and bypass valve both in closed position during start-up of main or auxiliary engine	■ Off-hire ■ Damaged exhaust pipe ■ Structural damage
Emissions monitoring	Low reliability of the Continuous Emission Monitoring System (CEMS)	■ Clogged sample line due to soot build-up ■ Clogged filter ■ Crystallization in sample line ■ Electrical failure ■ Failure of pump ■ Exhaust gas not sufficiently conditioned	■ Wrong or no reading ■ Non-compliance requiring changeover to MGO
Automation and control	Unreliable automation and control system	■ Internal undetected sensor failure ■ Undetected cable failure ■ Input failure of the controller	■ Wrong operation ■ Unintentional shutdown of system ■ Delayed emergency response
Hull and structure	Corrosion at hull in wash water discharge area	■ Low pH discharge water	■ Structural degradation

HOW WILL THE GLOBAL SULPHUR CAP AFFECT SHIPPING?

Beyond the expected environmental footprint, enforcement of the global sulphur cap will also have other implications on shipping, ranging from increased fuel costs and a different fuel mix to a change in the operational patterns of ships and the impact on asset values.

POTENTIAL IMPACT AND FUTURE TRENDS

Impact on GHG and other emissions
The compliance options available for the global sulphur cap will have an impact on the GHG and NO_x emissions of ships. Further regulation of GHG emissions, beyond the EEDI requirements, is on the IMO's agenda after the strategy was agreed recently in April 2018. Therefore, the compliance choices made today may affect compliance with future regulations on GHG reduction. In a similar manner, depending on the technology selected for the global sulphur cap, there may be an impact on choices available for compliance with NO_x Tier III standards.

Switching to MGO, distillates or blended fuels will maintain GHG and NO_x emissions at current levels, while using scrubbers with HSFO will result in a small increase in fuel consumption, of the order of 3 to 5%, and a corresponding increase of GHG emissions. Compliance with NO_x Tier III standards can be achieved by using Selective Catalytic Reactor (SCR) or Exhaust Gas Recirculation (EGR) systems, but in both cases the installation will be more complicated when combined with a scrubber.

At the same time, using LNG will result in a reduction of GHG emissions of 10 to 20%, depending on engine technology. Low-pressure gas engines have a certain amount of methane slip, therefore reducing the potential GHG benefits, but they offer compliance with NO_x Tier III levels. High-pressure systems eliminate methane emissions, but require the use of SCR or EGR for NO_x reduction to Tier III levels. Other alternative fuels, such as biofuels or hydrogen, can lead to even more drastic GHG emissions reduction, depending on how these fuels are produced. Depending on the fuels and combustion characteristics, NO_x reduction systems may be required.

Fuel prices and availability
Implementation of the global sulphur cap continues to generate countless discussions about future low-sulphur fuel availability as well as its possible

	SO_x EMISSIONS	GHG EMISSIONS	NO_x EMISSIONS
MGO, distillates, blended fuels	Reduced to below 0.50 or 0.10%	No change	No change; EGR or SCR required for NO_x Tier III
Scrubbers with HSFO	Reduced to below 0.50 or 0.10%	Small increase (3–5%)	No change; EGR or SCR required for NO_x Tier III; increased complexity due to combination with scrubber
LNG	Eliminated	10–20% reduction	20–80% reduction, depending on engine technology; high-pressure engines require SCR or EGR for Tier III compliance

price development. Predicting the future fuel price is indeed a challenging task, but it is widely expected that the transition to a higher-grade fuel will most likely result in substantially higher fuel costs for the industry.

The cost of different grades of fuel has traditionally closely correlated to the price of oil. However, such correlation should not be used for the future predictions. Increased blending will lift the demand for distillates, subsequently changing the historic correlation and most likely driving prices upwards. At the same time, lack of demand for HSFO can drive its price downwards. Thus, we may in the future observe a widening gap between two competing fuel solutions, with HSFO (combined with scrubber) setting the bottom price and MGO representing the upper level.

During the implementation of the SECA areas, most operators simply switched to MGO/MDO fuels. A similar trend of much higher magnitude is expected towards 2020, therefore increased MGO prices are inevitable in the short term. As the production of low-sulphur-blend hybrid fuels (0.50% sulphur) is gradually introduced, we may observe the prices of distillates eventually levelling off. However, if a substantial price differential between traditional HSFO and compliant fuels persists over time, the alternative solutions, such as scrubbers or using LNG as ship fuel, may prove to be the preferred solution.

Fuel availability in ports is another area of concern for ship owners and operators. In particular, the trends concerning the availability of 0.50% sulphur cannot currently (as of August 2018) be predicted, since many refineries are still developing these products. HSFO availability is also a concern for those installing scrubbers. While a lot of HSFO will be available as a by-product of refinery processes, it may not be available in many ports due to lack of demand. It is, however, expected that HSFO will be available in all major bunkering locations.

Fleet renewal and utilization
The expected increase in fuel costs leads many industry stakeholders to believe that a certain degree of speed reduction will be observed to reduce operating expenses. The focus on energy efficiency measures will also be intensified for the same reason. Fuel-efficient vessels will be more competitive, while vessels with scrubbers installed may have a significant competitive advantage. It is expected that, initially, vessels with scrubbers will be able to secure premium charter rates. However, if most vessels in a specific segment install scrubbers, daily rates will be lowered. Those vessels that do not have a scrubber yet may be forced to reduce their rates to unsustainable levels, eventually driving them out of the market. It is therefore very important for owners to monitor the competition in their segment to ensure that they are not left behind.

The substantial investments required to remain competitive under the global sulphur cap regime, combined with expenses related to ballast water treatment systems, may render older vessels unprofitable to maintain. This could lead to higher scrapping activity, and subsequently a renewal of the fleet with modern, more efficient vessels. This trend could also accelerate the introduction of alternative fuels, such as LNG.

Impact on insurance premiums and charter parties
Marine insurance will also be affected by the upcoming sulphur regulations. Insurance providers are concerned about the potential of engine damages, loss of propulsion and other ensuing problems that could be caused by the introduction of new fuel products that are still not well understood. Furthermore, there is potential for voyage disruption and delays due to lack of compliant or compatible fuel at a bunker port, or due to mechanical failures caused by poor bunker fuel quality. Marine cargo insurers are expected to revise their policies to cover such cases, where the cargo is not damaged but is significantly delayed due to issues related to the global sulphur cap. These new challenges may lead insurers to accept the risks by increasing their premiums, reflecting the uncertainties of the new reality.

Charter party clauses relating to bunkers will also need to be reviewed to avoid disputes. A notable example are prices of different fuels: when a charterer, who takes delivery of a vessel, is also buying bunkers on board and re-sells them to the owner upon re-delivery. During the transition to the sulphur cap, there can be a big difference in fuel prices, and this risk must be accounted for in the charter party. Other risks include, among others, the unavailability of compliant or compatible fuel and the performance varying due to fuel quality.

BUSINESS CASES

The year 2020 is rapidly approaching. Strategies and plans for how to comply with the global sulphur cap need to be addressed as soon as possible. So, what to do now?

To make a case for a management decision, a business case should be prepared for scrubbers, LNG or other compliance options. Such a business case will depend on a range of factors, including but not limited to:

- Fuel prices: expected, future price differential between compliant fuels, HSFO and LNG
- Availability of HSFO or compliant fuels in ports typically used for bunkering
- Investment cost for each option
- Fuel costs covered by owner or charterer (Will the vessel be able to secure higher charter rates if, for example, LNG or scrubbers are used?)
- Local regulations restricting scrubber operation (Is an open-loop or hybrid scrubber necessary?)
- Operational costs, including maintenance and repairs costs, and crew training costs

A cost comparison between open-loop and hybrid scrubbers, LNG and a range of compliant fuel alternatives are considered here for newbuildings with propulsion engine power ranging from 5 to 40 megawatts. The scenarios are general, and the conclusions will vary depending on the actual operating profile of each vessel and the assumptions made.

Business case assumptions

Below are a few general comments to assumptions to include in a "typical" business case where alternative compliance options are assessed:

- Cost comparisons are based on the price difference between compliant fuels and the alternative compliance options.
- A range of compliant fuel prices is considered, where the lower end represents a USD 40/tonne premium above the HSFO price, while the upper end represents a USD 365/tonne premium above the HSFO price. The baseline price differential used here is USD 200/tonne. It should be noted that the absolute price spread of the alternative fuels will vary with variations of HSFO prices.
- Running on HSFO with an open-loop or a hybrid scrubber is associated with an investment for scrubber installation and increased operating costs. Hybrid scrubbers have higher installation and operating costs compared to open-loop. Other assumptions made for scrubbers:
  - Scrubber systems will increase the vessel's fuel consumption by approximately 3 to 5%.
  - The downtime of the scrubber systems will introduce a cost for the running of compliant fuel.
  - The installation of scrubber systems will increase the maintenance cost (more for hybrid/closed-loop).
  - For hybrid and closed-loop systems, there will be an additional cost for alkali supply and sludge disposal.
- The LNG alternative has an investment cost for the fuel tanks, fuel management system and engine conversion, while the operating cost depends on the assumed LNG price. The LNG price here is set based on prices in Europe and North America, assuming prices ranging from USD 8 to 10/mmBTU.

Assessment of compliance options

To demonstrate the different variables for a business case, the examples below cover three main engine sizes:

OPERATIONAL PROFILE	5 MW	10 MW	40 MW
Main engine fuel consumption (tonnes/year)	2,800	5,700	22,800
Auxiliary engine fuel consumption (tonnes/year)	400	800	3,000

For the scrubber option, the following assumptions have been made:

SCRUBBER ASSUMPTIONS	VALUE
Seawater pump capacity (m^3/MWh)	50
Fuel consumption increase (%)	2
Scrubber downtime (days/year)	14
Alkali consumption (hybrid loop) (l/MWh)	19
Sludge production (kg/MWh)	5
Time outside of ECA (%)	75
Operation time in closed-loop (%)	15

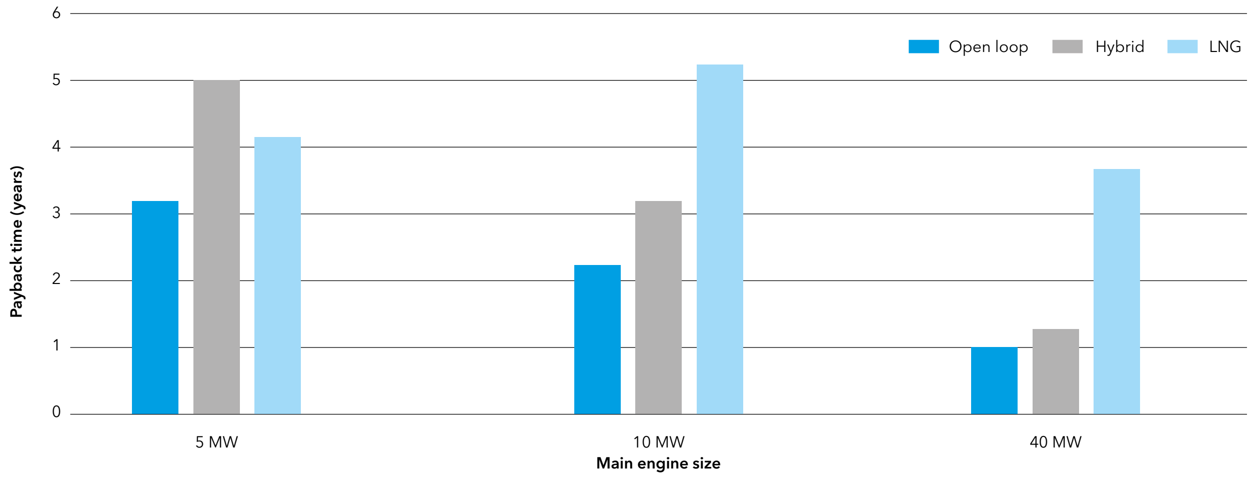
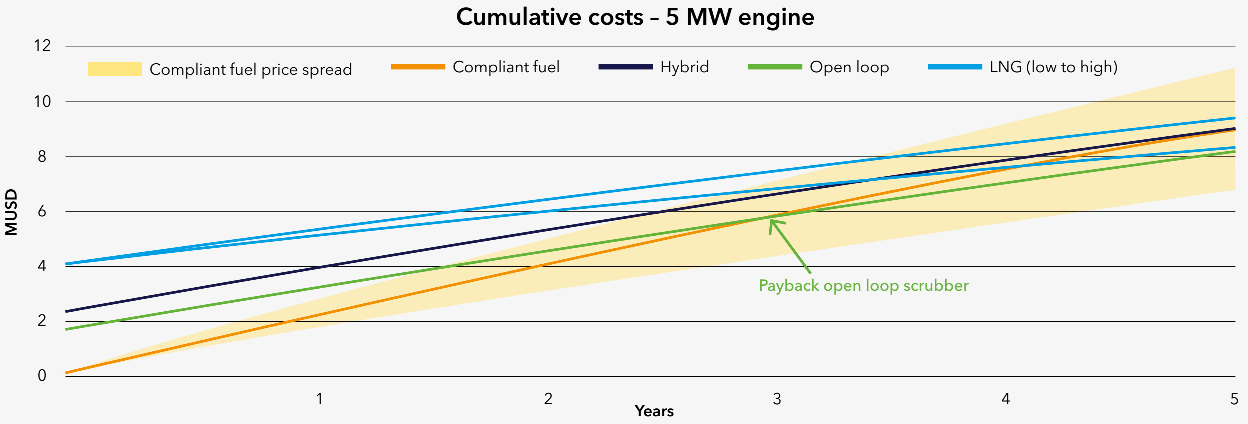


Figure 7: Payback time for open-loop and hybrid scrubbers, and LNG as a fuel, for vessels with three different main engine sizes. Price differential between HSFO and compliant fuels is assumed to be USD 200/tonne.

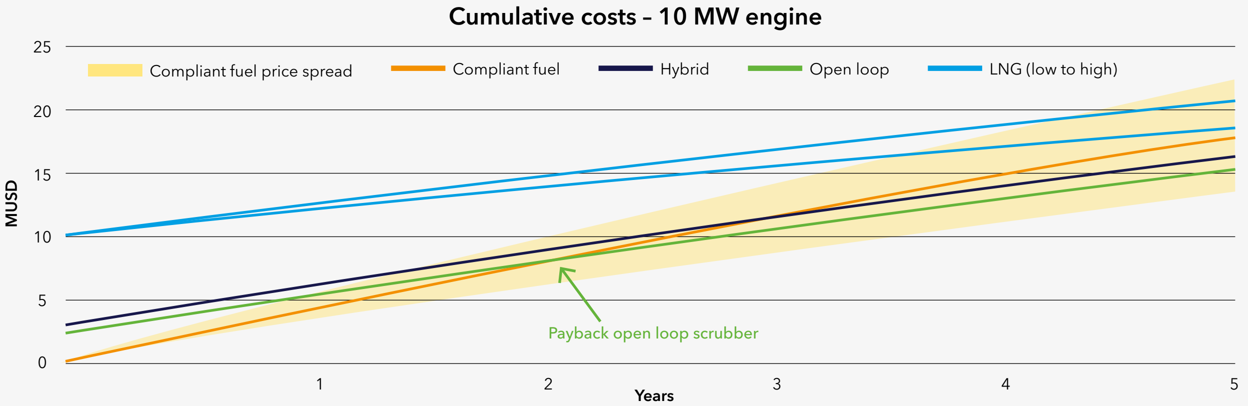
The results are summarized in terms of payback time in Figure 7, illustrating that scrubbers are clear winners for large vessels with high fuel consumption, while for smaller vessels LNG can be more attractive. However, there is much more than the payback time that should be considered when deciding on a compliance solution. Some reflections for different engine sizes and related vessel sizes are provided on page 20.



5 MW MAIN ENGINE POWER

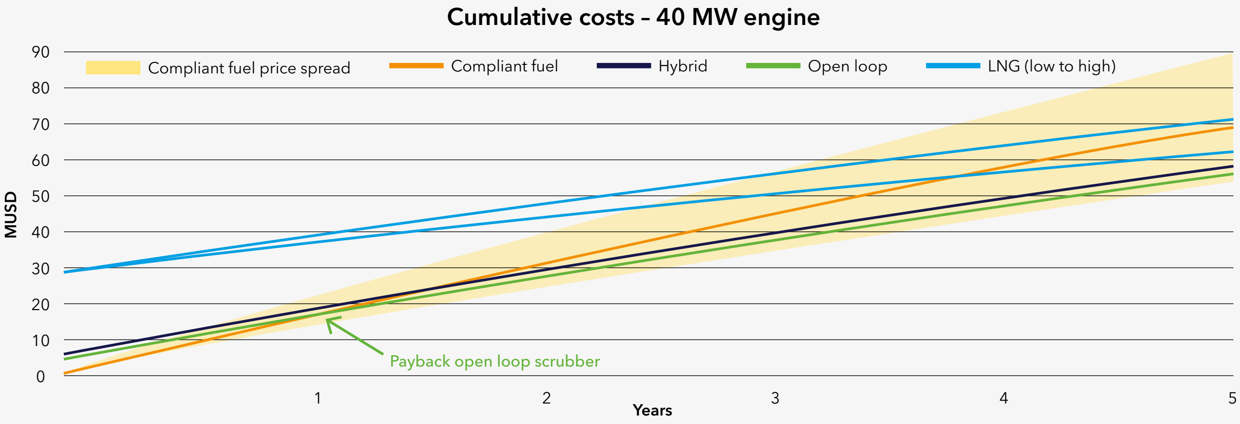
Typical vessel types in this category include handysize or lakesize tankers / bulk carriers, passenger and cruise vessels, and small container feeders. Due to their low fuel consumption, the payback time for a scrubber is relatively long. In the case assumed here, a payback time of three years for an open-loop scrubber and of five years for a hybrid scrubber were calculated. LNG as fuel has a payback time of four years. In the long term (ten to 15-year perspective), LNG can offer substantial savings for a vessel of this size, assuming that LNG supply can be secured at competitive prices.

Quite often, such vessels can operate for long periods of time in ECAs or areas with restrictions on scrubber wash water. In such a case, LNG can be a very attractive option, allowing for compliance with both SO_x and NO_x limits, while offering a 10 to 20% reduction in GHG emissions. In addition, the size of the scrubber and the space required for it could be an issue for smaller vessels.



10 MW MAIN ENGINE POWER

Typical vessels in this category include MR tankers, Panamax bulk carriers and container feeders. For these vessels, scrubbers have a payback time of two to three years, while LNG is estimated to be five years. Depending on the operational profile, exposure in ECAs, type of trade (liner or spot), different solutions can be considered. Bunkering infrastructure for LNG as fuel is under development worldwide, but for vessels with unpredictable port calls, this may not be an immediately applicable solution. In 2020, it is also expected that HSFO will not be readily available at all ports, which is a problem for vessels typically on tramp trade.



40 MW MAIN ENGINE POWER

Typical vessels in this category are container and cruise ships. For such a vessel, the payback time for both an open-loop and a hybrid scrubber is slightly more than a year, while the payback time for LNG as fuel is approximately four years. However, there can be important differences between container and passenger ships. On the one hand, the major part of the fuel consumption for container vessels takes place in transit, away from areas with potential restrictions in scrubber operation, therefore making open-loop scrubbers the best solution due to their relatively low cost and simple operation. On the other hand, cruise ships may be sailing in ECAs or close to coastal areas, often with restrictions in scrubber wash water discharge. In this case, investing in LNG could be a more suitable solution, considering a long-term perspective.

General considerations

In general, the payback time of compliance options for each vessel will depend not only on the engine size, but also on fuel tank capacity, since this is one of the most important cost elements for LNG as fuel. The actual operating profile of each vessel, including time spent in ECAs or areas with scrubber restrictions, will also affect this calculation.

The importance of fuel cost becomes very clear when looking at the cost distribution per main cost category in Figure 8. Uncertainty in the fuel prices can play an important role in the outcome of each decision. For large vessels with high fuel consumption, investing in a scrubber can be profitable even for low spreads of the HSFO-compliant fuel price. For smaller vessels, LNG can be more attractive, particularly when a long-term horizon is considered. Overall, the decision for the optimum solution will depend not only on payback time, but also on other factors such as GHG emissions, environmental profile, and long-term value creation potential.

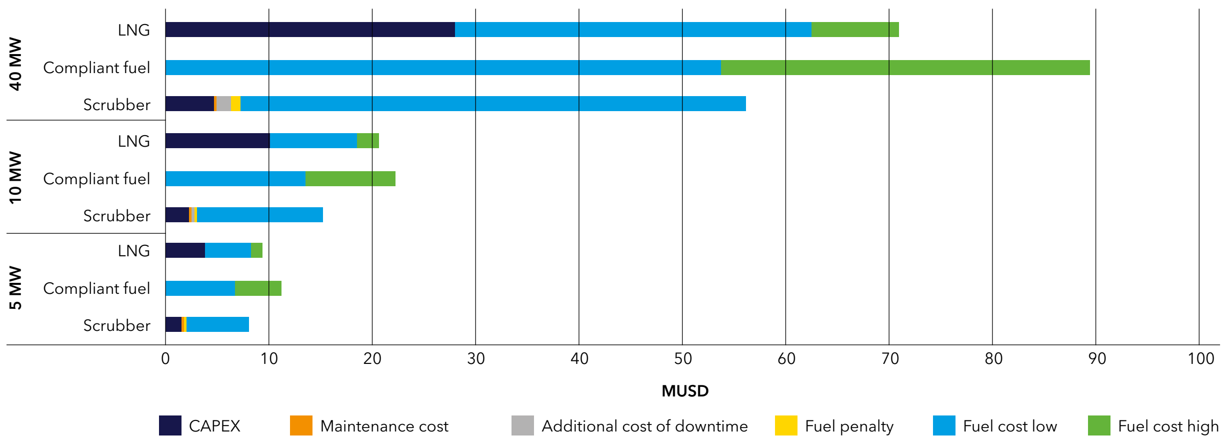


Figure 8: Accumulated costs over a period of five years at a 6% discount rate

MARKET TRENDS

With the global 0.50% sulphur limit approaching fast, owners are taking action to ensure they are prepared for 2020. This is reflected in the DNV GL statistics for scrubber orders. As of August 2018, more than 1,200 ships had either installed or ordered scrubbers to be installed by 2020, as illustrated in Figure 9. More than half of these orders were placed in the spring/summer of 2018. Many more ships are expected to order scrubbers in the following months, but the question is when these systems will be installed, with many manufacturers, yards and providers of sensors and emissions analysers already working close to full capacity. In any case, it is expected that fewer than 2,000 ships will have scrubbers installed by 2020, requiring the rest of the fleet to rely on compliant fuel. The industry – including banks, financial institutions, charterers and owners – seem to be willing to invest in a scrubber in return for the potential benefits from the expected savings in the fuel bill.

Until early 2018, most scrubbers had been installed or ordered for cruise and passenger vessels operating in ECAs. As many as 50% of these systems were closed-loop or hybrid designs, to ensure operation in restricted areas such as certain ports in North America. These trends were reversed in the last few months. As shown in Figure 10, bulk carriers, tankers and container ships are the three segments with the most scrubbers ordered. Open-loop systems are by far the most popular design now, due to their relative simplicity, particularly for retrofitting on existing vessels.

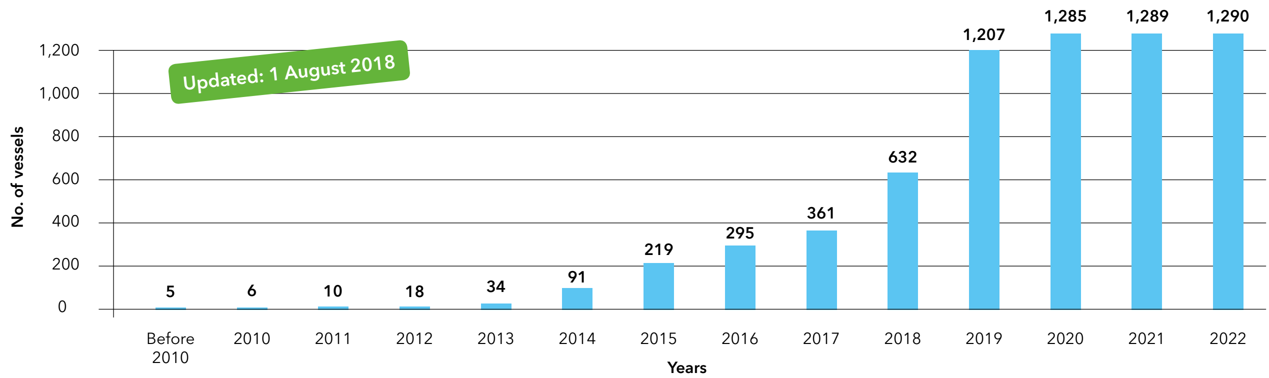


Figure 9: Cumulative number of vessels with scrubbers installed or ordered

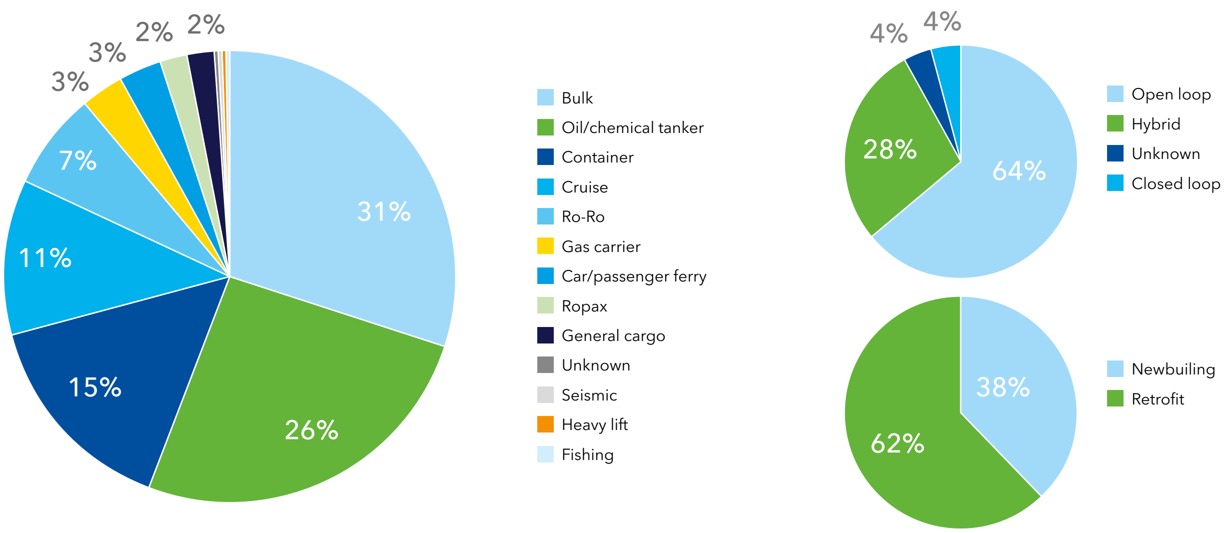
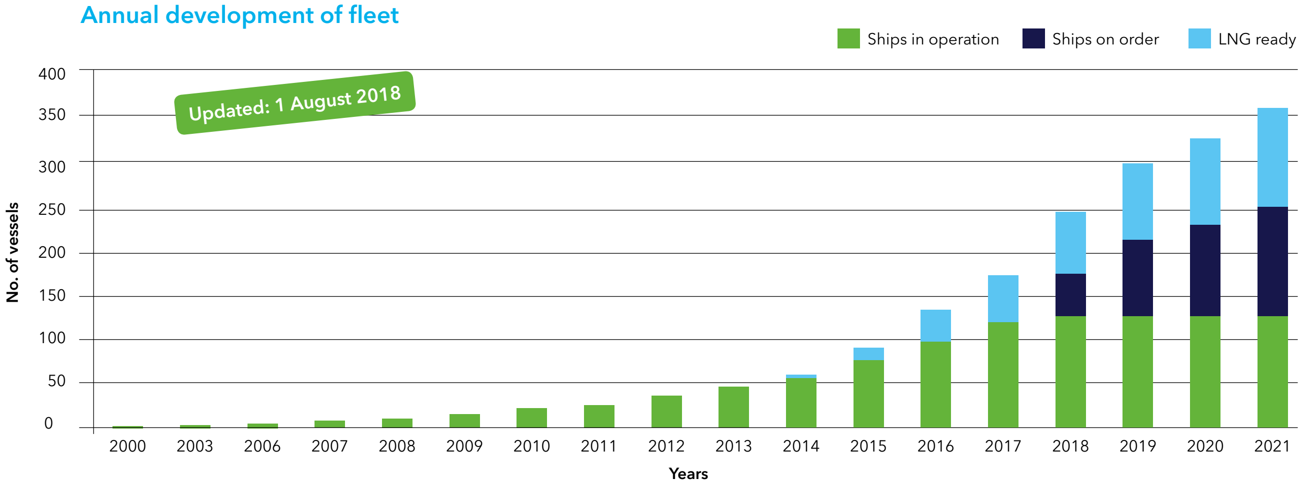


Figure 10: Share of various ship types in scrubber orders, share of scrubber system types, and newbuilding vs. retrofit projects

The number of ships using LNG as fuel is increasing as shown in Figure 11, and more and more infrastructure projects are planned or proposed along the main shipping lanes. In line with this dynamic development, DNV GL expects LNG to grow even more rapidly over the next five to ten years. Furthermore, LNG is commercially attractive and available worldwide in quantities able to meet the fuel demand of shipping in the coming decades. LNG as fuel is especially expected to increase for vessels frequently operating in the North American and northern European waters with existing or upcoming NO_x requirements. An increase in compliant-fuel prices relative to LNG will encourage operators to invest in LNG.

Alternative fuels, such as methanol and biofuels, are expected to only be able to serve a minor share of the market in the short term. They will be an alternative in some local areas, where the supply fits trading patterns for vessels. Looking farther into the future, hydrogen as fuel, with fuel cell technology combined with batteries, is an emerging alternative, particularly for small ships operating in fixed routes and with a secured energy supply.



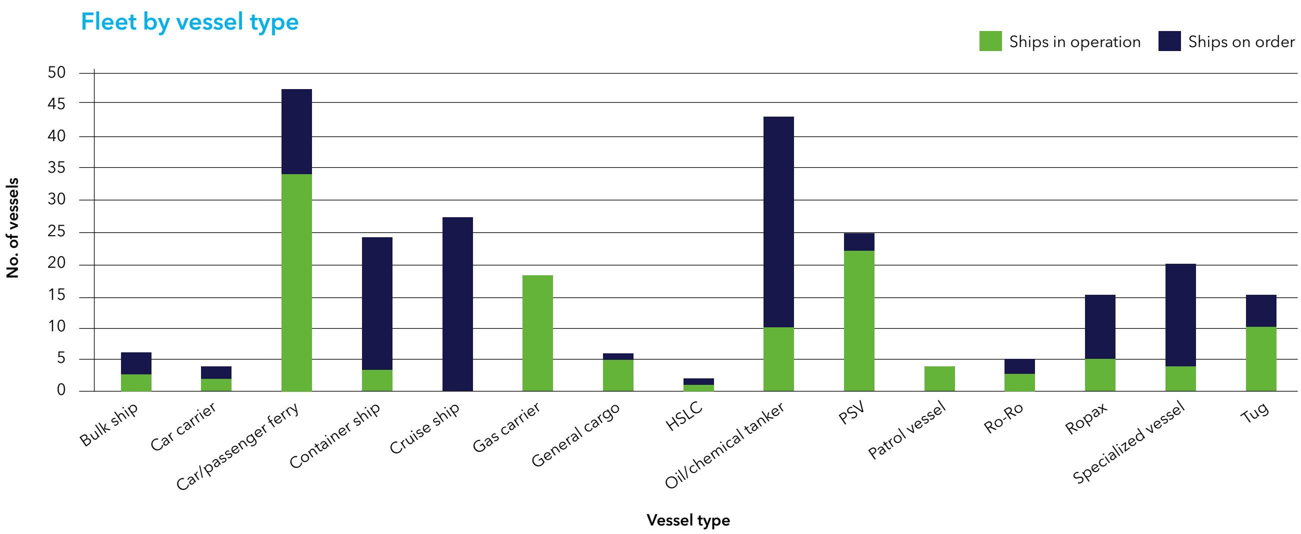


Figure 11: Cumulative number and type of LNG-powered vessels in operation, on order and ready to be retrofitted (LNG Ready)

DNV GL SUPPORT

With its long-standing maritime expertise in regulatory affairs, operational experience and technical innovation, DNV GL is prepared to support our customers to overcome the 2020 challenge.

CLASS SERVICES

Based on decades of experience, DNV GL has developed several class notations to support the switch to low-sulphur fuels, preparing ship owners for lower sulphur limits and more. The notations are briefly described below.

Emission Reduction notation
DNV GL recently introduced a new class notation for exhaust gas cleaning systems (EGCS). The notation, Emission Reduction (ER), will cover not only scrubbers for removing SO_X, but SCR and EGR systems for removing NO_X. The class notation sets out requirements for the design and arrangement of EGCS, SCR and EGR systems, including the piping systems conveying wash water and/or treatment fluids, the exhaust arrangements and components, control, monitoring and safety systems as well as manufacture, workmanship and testing.

Scrubber Ready notation
DNV GL has developed a class notation to help ship owners prepare their newbuildings for the installation of scrubbers. It ensures that the necessary preparations are in place for a smooth and cost-effective scrubber retrofit at a later stage. The Scrubber Ready notation is awarded to ships that have planned and partly prepared for the installation of a scrubber for the removal of SO_X at a later stage. The notation identifies the general type and category of scrubber systems that can be installed on the vessel. It also details the level of scrubber readiness, with the minimum scope attesting that the space available and future installation arrangement meet class and statutory requirements. For shipyards, working with the Scrubber Ready standard gives an easy framework within which to offer future-ready ship designs to the market.

Gas Fuelled notation
The Gas Fuelled notation's requirements cover all aspects of the gas-fuel installation, from the ship's gas-fuel bunkering connection all the way up to and including all gas consumers. The rules are applicable to installations where natural gas is used as fuel. Other gases are subject to special considerations.

The class notation is mandatory for any newbuilding being built with gas as fuel, either with gas-only or dual-fuel concepts.

Gas Ready notation
To be more flexible and competitive, a newbuilding can be prepared for future LNG conversions. Based on the experience from our LNG Ready service, as well as the more than 60 LNG-fuelled vessels in DNV GL class with the Gas Fuelled notation, we have developed the new Gas Ready notation. This notation ensures that a future LNG-fuelled version of the vessel complies with the relevant safety and operational requirements.

The basic level of the Gas Ready notation (with nominators D and MEc) verifies that the vessel complies with the relevant rules in terms of its overall design for future LNG fuel operations, and that the main engine can be converted or operate on gas fuel.

Low Flashpoint Liquid (LFL) Fuelled notation
Methanol is a low flashpoint liquid (LFL) fuel that is gaining interest in the market because it does not contain sulphur and is therefore suitable for meeting the existing 0.10% SO_X ECA requirements. Methanol has a flashpoint of about 12°C, and vessels are assigned the additional notation LFL Fuelled to demonstrate their compliance with the safety requirements set out in the industry-first rules published by DNV GL in June 2013.

DNV GL has been involved in newbuilding projects from the early design stage, working together with ship owners, engine makers and yards to ensure an equivalent level of safety to that of a conventional fuel oil system.

For more information, please contact your Key Account Manager or use our DATE (Direct Access to Technical Experts) service via "My Services" on our Veracity platform at **veracity.com**.

ADVISORY SERVICES

Maritime advisory is separated from class activities and supports customers with a variety of services to make the right technological and financial decisions for global sulphur cap compliance. Example of services include strategic advice for alternative fuels, scrubber technologies and the benchmarking of environmental performance, and risk assessment of all phases from decision to design, installation and commissioning. Additionally, our advisory experts have years-long experience in technology qualification, troubleshooting and root-cause investigations, both on a design level and for ships in operation.

Fuel strategy and decision support
The decision of the IMO to limit fuel sulphur content from 1 January 2020, the sulphur and NO_X in ECAs, and the recently adopted ambition to halve GHG emissions by 2050 mean the world's future fleet must rely on a broader range of fuels and adopt novel propulsion solutions and energy efficiency measures. The alternative fuel and ECA decision support service offers:

- the technical assessment of suitable SO_X and NO_X abatement technologies and alternative fuels, and
- the assessment of alternative fuel solutions as well as performance, operational experience, infrastructure, pricing and financial analysis.

Alternative Fuels Insight (AFI) platform
The AFI platform (**https://afi.dnvgl.com**) provides a 360-degree view on the uptake and infrastructure development of alternative fuels and technologies in shipping. The information is free and available to the public. AFI offers detailed insight in interactive map and statistics views, in addition to the information needed for improved decision-making regarding alternative fuels for vessels ordered today and in coming years.

Scrubber feasibility studies
DNV GL's Maritime advisory evaluates the technical feasibility and financial attractiveness of a scrubber solution. More advanced ship systems modelling and simulation tools, such as COSSMOS, can also be used to analyse the scrubber performance and its integration with other ship systems, if needed. The typical DNV GL approach for selecting a scrubber solution consists of business case assessment and technical feasibility review.

Scrubber water discharge assessment
The scrubber discharge water needs to comply with a maximum pH value 4 metres from the ship side, per IMO Resolution MEPC.259(68). To comply with this requirement, in some cases diffusers need to be installed to the discharge pipe outlet. We help scrubber manufacturers to conceptualize the design and test the effect of such diffusers. Computational Fluid Dynamics (CFD) is used to simulate the flow at the pipe outlet and estimate the impact on the pH value at the measuring point.

Control system software testing
Maritime advisory experts verify and test control system software using Hardware-in-the-Loop (HIL) technology. The result is a safer and more reliable automation systems and shorter commissioning times due to less software issues. By testing the control system with advanced simulators, the risk of the EGCS being out of compliance is reduced.

For more information on advisory services, please contact your Key Account Manager or local DNV GL office. You can also send an email to **environmentadvisory@dnvgl.com** or visit **https://www.dnvgl.com/maritime/advisory**.

INSPECTION SERVICES

Exhaust gas emission measurements
DNV GL's ENVILAB provides state-of-the-art exhaust gas emission measurements directly on site, whenever and wherever needed. Our exhaust gas emission measurements cover:

- Test-bed and on-board measurements according to the IMO MARPOL NO_x Technical Code 2008, RVIR Guideline 16 and 97/68 EG for diesel engines (off-road applications)
- Gaseous components, incl. NO_x, CO, CO_2, O_2, HCs, NMHC and SO_x
- Pollutant particle emissions such as particulate matter (PM), opacity or smoke number (FSN)

For exhaust gas measurements, please contact ENVILAB at **envilab@dnvgl.com**.

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DNV GL
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DNV GL is the world's leading classification society and a recognized advisor for the maritime industry. We enhance safety, quality, energy efficiency and environmental performance of the global shipping industry – across all vessel types and offshore structures. We invest heavily in research and development to find solutions, together with the industry, that address strategic, operational or regulatory challenges.

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