SIGTTO

Society of International Gas Tanker & Terminal Operators Ltd

Reduction of Gas Carrier CO_2 Emissions

First Edition

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The purpose of this publication is to suggest several ways of reducing CO_2 emissions on vessels. While the information and advice given in this document (Reduction of Gas Carrier CO_2 emissions) has been developed using the best information currently available, it is intended purely as guidance to be used at the user's own risk. It is the responsibility of the owner and operator to identify and apply safe and efficient ways of reducing emissions on their vessels. No warranties or representations are given nor is any duty of care or responsibility accepted by The Society of International Gas Tanker and Terminal Operators (SIGTTO), the members or employees of SIGTTO, or by any person, firm, company or organisation who or which has been in any way concerned with the furnishing of information or data, for the accuracy of any information or guidance in the document or any omission from the document or for any consequence whatsoever resulting directly or indirectly from compliance with, adoption of, or reliance on guidance contained in the document even if caused by failure to exercise reasonable care.

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Introduction and Scope

1. Introduction and Scope

1.1 Introduction

This document is part of a series of documents supporting the shipping industry's environmental goals to reduce greenhouse gas (GHG) emissions. Carbon dioxide (CO_2) is a GHG, and it is vital that robust systems are in place to minimise the environmental impact of liquefied gas transportation.

Building on *Measurement and Reporting of CO_2 Emissions from Gas Carriers,*[1] which identifies sources of CO_2 emissions, measurement methodologies, and regulatory requirements to support reporting, this document recommends ways to reduce CO_2 emissions during the design, operation and maintenance phases of gas carriers.

Applicable only to liquefied natural gas carriers (LNGC), there is a direct relationship between methane and other emissions such as carbon dioxide (CO_2) and nitrogen oxides (NOx) that result from burning fossil fuels. These recommendations should be considered in addition to other factors affecting greenhouse gas (GHG) and other air pollution emissions.

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[1] SIGTTO – Measurement and Reporting of CO_2 Emissions from Gas Carriers.

1.2 Scope

All liquefied gas carrier types, designs and operations have the potential to reduce CO_2 emissions, and many of the considerations in this document are valid across trades. However, as the highest level of operational experience is available for large-scale ships, some of the guidance focuses on the technologies employed on them. These recommendations are not specific to storage or regasification units and liquefied gas bunker ships, but shipowners and operators might choose to follow those applicable to them.

The guidance only covers CO_2 emissions and does not consider other GHGs or air pollution emissions. For methane emissions, see *Reduction of LNG Carrier Methane Emissions*.[2] The guidance does not include CO_2 emissions when CO_2 is carried as cargo or from onboard CO_2 capture technologies.

The level of technical detail assumes that the reader is familiar with the operation of liquefied gas ships, so not all concepts are simplified or explained at an introductory level.

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[2] SIGTTO – Reduction of LNG Carrier Methane Emissions.

2

Overview of CO_2 Emission Reductions

2. Overview of CO_2 Emission Reductions

Gas carriers create CO_2 emissions by burning fossil fuels to generate energy for propulsion, power generation, or cargo management. This document groups these emissions into three main categories: emissions due to ship design and construction (Chapter 3), emissions during operations (Chapter 4), and emissions due to maintenance and inspection activities (Chapter 5). Figure 1 provides a summary of the structure of this document and refers to the main IMO metrics involved.

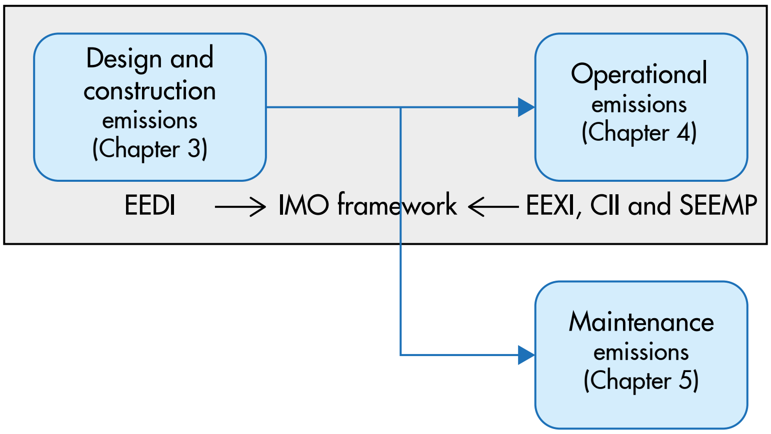

Figure 1: Emissions, document structure, and IMO regulation

The IMO regulation is driven by the Energy Efficiency Design Index (EEDI) or the Energy Efficiency Existing Ship Index (EEXI), which address the technical efficiency of the ship. The Carbon Intensity Indicator (CII) assesses the efficiency of its operations, and the *2024 Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP)*[3] provide the framework for the continuous improvement of the energy efficiency of ships.

Gas carriers that can be retrofitted can benefit from adapting to new technologies. Adoption of any of the recommendations should be without compromising safety. It is important to assess the implications of any change in the design of a ship or in the way the ships are operated and maintained.

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[3] IMO – MEPC.395(82) – 2024 Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP).

3

Emissions Due to Ship Design and Construction

3. Emissions Due to Ship Design and Construction

The design of a ship significantly influences its CO_2 emissions during its lifetime. This chapter provides recommendations to the shipowner, ship designer and shipyard to support them in selection of the technical solutions to be implemented.

3.1 Boil-Off Gas and Tank Pressure and Temperature Control

Gas carriers transport gases in liquid form because this is more efficient than transporting them in gas form. Liquefied gas transportation requires selection of an adequate cargo containment system (CCS) and methods of controlling tank pressure and temperature. Some of these methods of control generate CO_2 emissions.

3.1.1 Boil-off gas

Liquefied gases are carried in liquid form at a certain temperature and pressure. Equilibrium imbalance results in vaporisation of the cargo, which is caused either by heat ingress from the environment (Figure 2), by a drop in pressure, if the cargo is pressurised, or by a combination of both. These vapours are called boil-off gas (BOG).

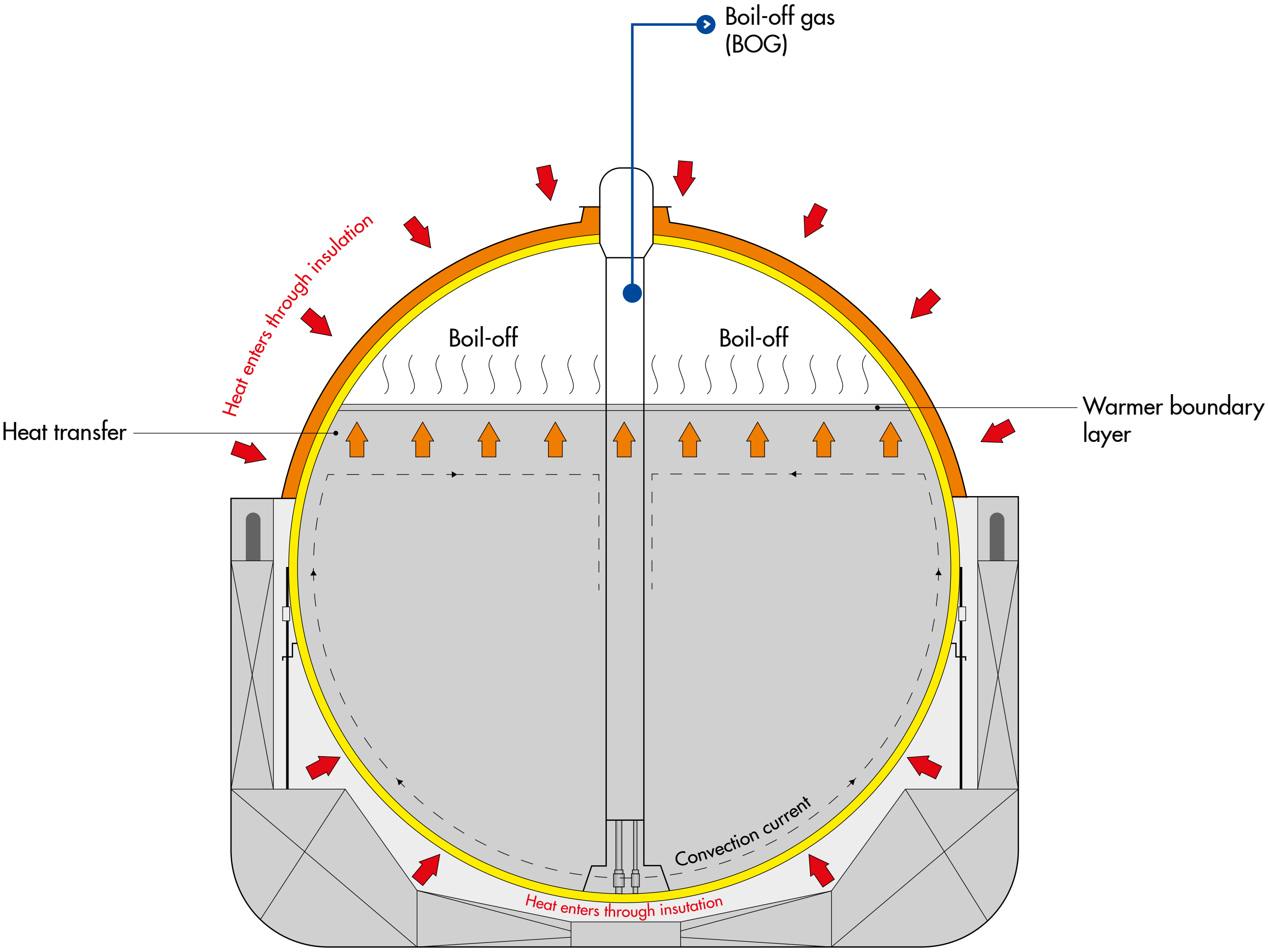
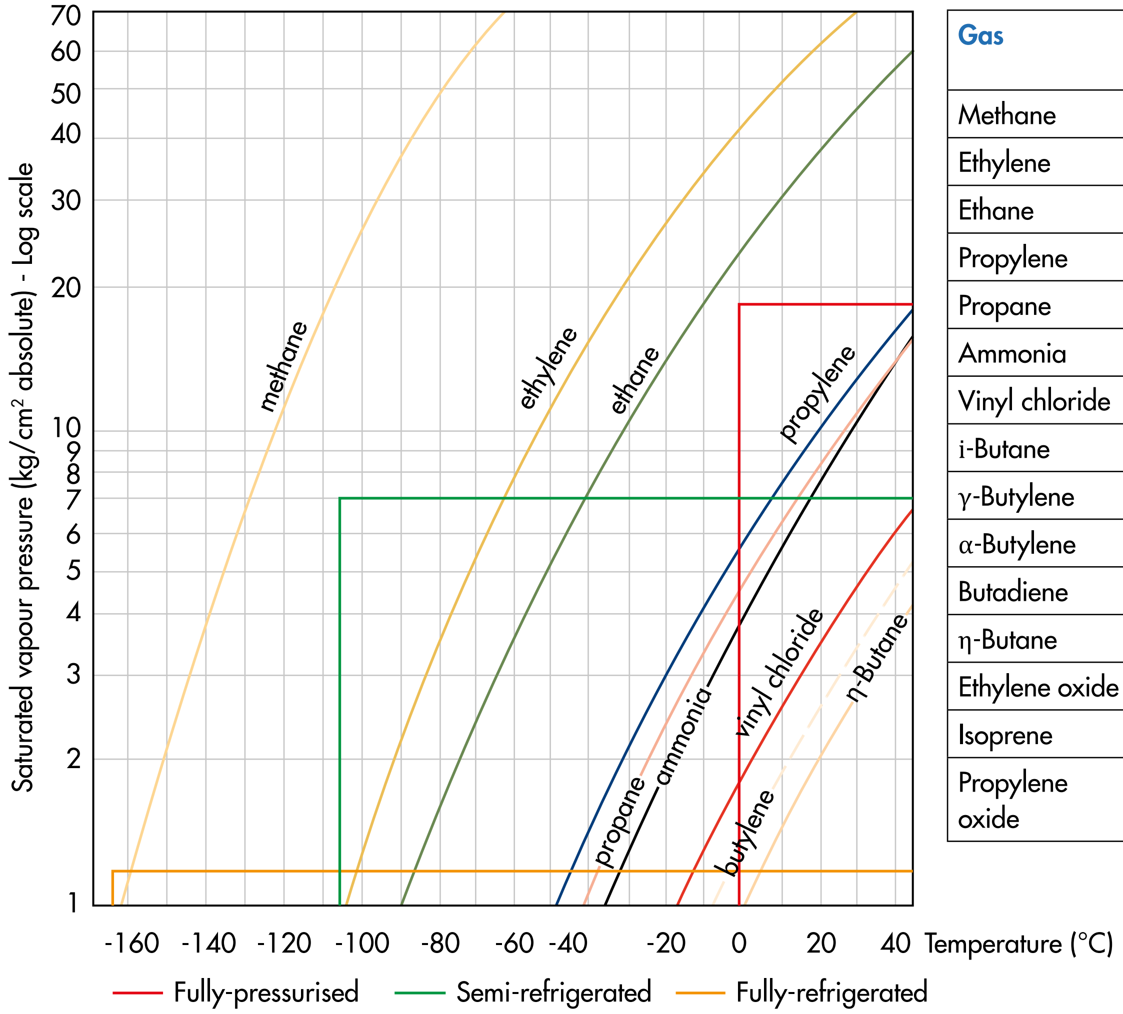


Figure 2: Heat ingress into the cargo tank

3.1.2 Cargo containment systems

There are various CCS technologies available, and selection is based on the cargo, shipowner's choice and type of trade. Figure 3 shows the saturated vapour pressure (SVP)[4] curves of the most common products and the three main CCS concepts: fully refrigerated, semi-refrigerated and fully pressurised. The types of CCSs, ie membrane, type A, B and C, and integral, are described in the IGC Code.[5]



Gas	Atmospheric Boiling Point (°C)
Methane	-162
Ethylene	-103.9
Ethane	-88.6
Propylene	-47.7
Propane	-42.3
Ammonia	-33.4
Vinyl chloride	-13.8
i-Butane	-11.7
γ-Butylene	-6.9
α-Butylene	-6.1
Butadiene	-5.0
η-Butane	-0.5
Ethylene oxide	10.7
Isoprene	34
Propylene oxide	34.2

Figure 3: Cargo containment systems for most common products

Fully refrigerated gas carriers use atmospheric tanks and require methods to control the pressure and temperature in the tanks. Some of these methods generate CO_2 emissions. Typical products that can be transported in this way include liquefied natural gas (LNG), ethylene, ethane, propane, butane and ammonia.

Semi-refrigerated, or semi-pressurised-fully-refrigerated, gas carriers have fitted tanks capable of carrying cargoes under pressure but, similar to the fully-refrigerated concept, they require methods to control the pressure and temperature of the tanks. Typical products transported in this way include ethylene, ethane, propane, butane, ammonia, propylene and vinyl chloride. Fully pressurised gas carriers do not require reliquefaction or liquid cooling plants, which eliminates CO_2 emissions from these sources.

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[4] SVP curves represent the pressure exerted by the vapour when in equilibrium with its condensed phases (solid or liquid) in relation to the temperature of the product.

[5] IMO – International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code).

Most CCS are fitted with insulation to minimise heat-flow into the cargo tanks and reduce BOG. Materials with low thermal conductivity are preferred because they generate less BOG.

3.1.3 Tank pressure and temperature control

The IGC Code prohibits venting of cargo for tank pressure and temperature control except in emergency scenarios and provides requirements for methods of control. Gas carriers use one or a combination of the following BOG control methods:

- Pressure accumulation
- reliquefaction of cargo vapours
- liquid cargo cooling
- thermal oxidation of vapours.

The pressure accumulation method allows pressure to build up within the system for a certain time period. This method does not generate any CO_2 emissions.

Some gas carriers have reliquefaction or liquid cooling systems that can either be fully rated or partially rated when compared to the BOG rate. These systems provide a means to manage tank pressure and temperature but they require intense use of energy which produce CO_2 emissions. The higher the BOG rate, the higher the amount of energy required. In general, the reliquefaction and liquid cargo cooling of LNG emit less CO_2 than thermal oxidation in the gas combustion unit (GCU).

Thermal oxidation[6] refers to use of cargo as fuel, use in a GCU or in a boiler. Cargo BOG as fuel is extensively used in LNGCs because it is an efficient way to control tank pressure and temperature and, at the same time, provide fuel to the propulsion and power generation systems.

The use of the GCU is usually the last option to prevent an emergency, such as venting due to a pressure relief valve release. Some LNGCs consider such systems to be emergency equipment and its use reduces the energy efficiency of the gas carrier.

3.1.4 Reliability, availability and maintainability

The overall capacity of the combined methods should include a suitable margin for the operating profiles of the ship, such as laden and ballast voyages, cargo condition and cargo management, different cargo grades, waiting time and type of trade. It should consider equipment that is unavailable because of a single failure or because it is under maintenance. The sizing of the GCU, the composition of products that it can safely burn, and the redundancy of equipment should be such that emergency venting is not required.

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[6] IGC Code paragraph 1.2.52 – *"Thermal oxidation method means a system where the boil-off vapours are utilized as fuel for shipboard use or as a waste heat system subject to the provisions of chapter 16 or a system not using the gas as fuel complying with this Code".*

3.2 Cargo Carrying Capacity and Hull

Cargo capacity is a determining factor of the hull size and shape, which in turn will affect a ship's resistance when moving through the water and its CO_2 emissions.

3.2.1 Cargo carrying capacity

Cargo carrying efficiency is usually defined as the volume of cargo (cubic metre) that a ship can safely transport over a distance (nautical miles) in relation to their emissions (CO_2 grams). Other metrics can be used depending on the type of cargo or regulatory context. The cargo carrying metric only represents the ship's emissions when sailing, it does not consider emissions when manoeuvring or during the ballast voyage. Multi-cargo gas carriers are subject to a combination of volume and density of the various cargoes, eg reduced filling limits for high density cargoes such as vinyl chloride monomer (VCM).

3.2.2 Ship speed

The design speed of an LNGC was traditionally defined by tank pressure and temperature control needs, while using cargo as fuel. New technologies allow LNGCs to operate efficiently at lower speeds. Determining the optimum design speed of LNGCs, and other types of gas carriers, involves a number of factors such as fleet size, volumes of cargo carried, supply chain efficiency, annual delivery programmes and other trading necessities. Optimum speed should not be confused with slow speed during operation. Slow speed may have short-term benefits for a ship, but it may lead to an overall fleet size increase and, ultimately, an increase in emissions for the same cargo transported.

3.2.3 Hull shape and resistance moving through the water

Traditional hull shape and bulbous bow or alternative bow engineering is based on assumptions made for a specific design speed for normal operations (see sections 3.3.1 and 3.3.2). Considerations can be made to lower the design speed while benefiting other ship parameters, such as increasing the cargo tank capacity. When designing the hull shape, bulbous bow, or alternative hull designs, representative weather conditions, trading profile, and voyage conditions should be considered.

Hull and propeller surface preparation determines the friction of the gas carrier moving through the water. Selection of the coating system should be discussed with the coating supplier taking into consideration the hull friction, operating profile of the ship, fouling risk and geographical area.

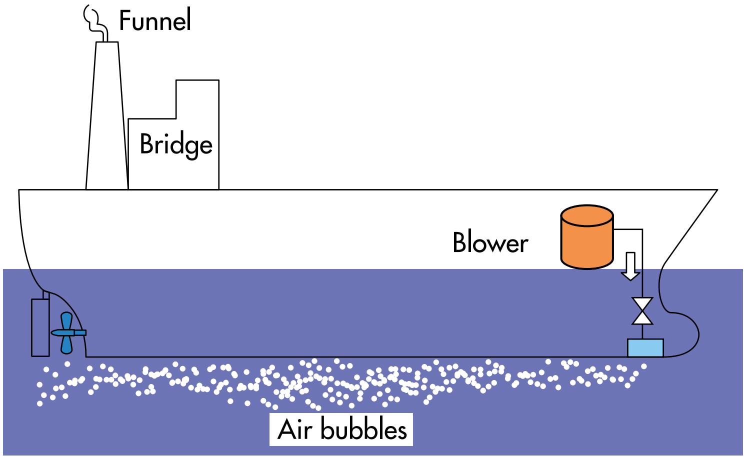

Figure 4: Simplified air lubrication system

Air lubrication systems (ALSs) reduce the resistance of the hull while sailing by expelling air through outlets located on the underside of the ship's hull. They reduce the CO_2 emissions due to fuel consumption when the gas carrier sails above a certain speed. This speed needs to be assessed, including the power required to operate the ALS. Figure 4 presents a simplified overview of the ALS.

3.2.4 Trim and ballast

For any given draught, there is a trim condition that gives minimum resistance to ship movement. Cargo and ballast plans should take into consideration the optimum trim that allows minimum hull resistance throughout upcoming voyages. Design or safety factors may influence operating at optimised trim conditions. All operational aspects such as under keel clearance, ballast water capacity, vessel stability etc., should be considered in the optimum trim assessment.

The power consumption of the ballast water treatment plant and the energy for pumping water in and out of the tanks should also be considered. Hulls with less ballast capacity and smaller equipment may require less energy for ballasting and deballasting, but ship stability should not be compromised.

3.2.5 Optimisation of cargo carrying capacity

It is common to design the CCS shape to maximise the volume of cargo in the hull. For instance a bi-lobe or tri-lobe shape instead of cylindrical tanks, dished ends instead of conical end Type C tanks, or the use of specific CCS types for certain cargoes or gas carrier size.

Another option is to optimise the engine room space. For example, gas carriers not using traditional fuel oils, that require conditioning before injection, do not need conditioning equipment that occupies space in the engine room. Modification of the engine room layout, by carefully assessing the position of the bulkheads to optimise cargo tank capacity and removal of storage tanks, can increase the cargo carrying capacity for the same principle dimensions of the hull.

3.2.6 Bunkers and heel strategy

Reducing the capacity of non-cargo spaces results in an increase in the cargo tank capacity by optimising the ship layout. This can be achieved through, for instance, reducing the capacity of bunkers and oil tanks while providing adequate capacity for the type of machinery and length of voyage.

Cooling down cargo tanks, especially LNG tanks because of their low temperature, is an energy-intensive process. In some operations it is more energy-efficient to keep the tanks cool by using heel. Fitting a Type C deck tank, or an integrated tank, assists in heel management. This tank might reduce or eliminate the need to gas up and cool down operations at the terminal, and the cargo can be used as fuel.

3.3 Propulsion, Power Generation and Other Systems

Cargo as fuel, if fitted, propulsion and power generation systems are an important part of the overall CO_2 emissions profile.

3.3.1 Propulsion and power generation

The propulsion system should be selected in combination with the power generation system and the selection of fuels (see section 3.4). Some configurations are more efficient, and result in lower emissions.

System design and equipment selection should consider:

- Relevant power load scenarios (operating profile and modes of operation)
- engine running efficiency range and
- reliability, availability and maintainability of the integrated system.

A configuration of multiple engines provides flexibility for scenarios when the loads vary. Power take-off generators installed in the propulsion shaft, or batteries, can allow the main engine to operate at more efficient loads and potentially stopping a power generation unit or units. Some operations, such as manoeuvring in certain ports, might require multiple engines running to prevent a hazard event in the scenario of a power generator trip. Power load scenarios typically consider systems for tank pressure and temperature control, but other relevant load scenarios may include larger power consumption such as cooling down of cargo or loading warm cargo.

3.3.2 Combustion engines

The CO_2 emission profile depends on the fuel used and the type of combustion engine, its design characteristics and the specific model. Engines should be selected to operate within the most efficient range, as defined by the manufacturer.

Reducing CO_2 emissions may result in increased emissions of other gases, such as nitrogen oxides (NOx).[7] These other emissions are not in scope for this document and are regulated by the IMO and some local or regional authorities.

Dual-fuel engines can burn fuel oil and gas. Methane has lower carbon content than oils, resulting in lower CO_2 emissions. However, consideration should be given to methane slip,[8] because it is as another GHG. For further reference see *Reduction of LNG Carrier Methane Emissions.*[9]

The installation of devices to measure the actual composition of gases, such as gas chromatographs, provides an accurate calculation of the methane number[10] and heating value. This allows reliable optimisation of engine performance. Digital performance tools enable online monitoring of engine running parameters, such as specific fuel consumption and cylinder pressures. These tools enable long-term storage of running data that may be used for analytics and performance improvement initiatives.

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[7] Including nitrous oxide (N_2O).

[8] Methane slip refers to gaseous methane, used as fuel, that has not combusted and is discharged into the atmosphere via the engine exhaust or crankcase ventilation.

[9] SIGTTO – Reduction of LNG Carrier Methane Emissions.

[10] Methane number is a measure of the resistance to knock of a gaseous fuel such as natural gas.

3.3.3 Propeller, rudder and bench tests

Specifically designed equipment can increase the efficiency of the propulsion system. Examples include design of the propeller for a specific hull shape, the design of propeller water inflow arrangements including potential use of fins and nozzles, or rudder blade design, such as a twist-flow rudder.

Physical testing and computational fluid dynamics modelling are beneficial for evaluating the effectiveness of these technologies. Examples include tank testing of propellers or bench testing of propulsion shafts, gearboxes or engines.

3.3.4 Efficiency of energy used

Evaluation of the energy consumers, and their power demand scenarios, may identify energy efficiency improvements. Similarly, evaluation of the power transformation and supply systems to energy consumer should be considered.

Traditional fuel oils require energy to maintain the temperature of the fuel oil above certain requirements, typically using steam from the economiser. If no traditional fuel oils are used (see Section 3.2.4), the energy recovered from the engine exhausts can be used in other applications, for instance, for electric power generation. Another example of improving of energy efficiency is the installation of thermal insulation in the accommodation and other spaces to optimise energy consumption for heating, ventilation, air-conditioning and refrigeration systems.

3.3.5 Innovative technologies

Development and use of new technologies can help to improve the energy efficiency of the ship and reduce emissions. The IMO provides guidance on the contribution to the EEDI or EEXI of some technologies, such as ALSs, wind-assisted propulsion systems (for lower speed vessels), waste heat recovery systems for generation of electricity and photovoltaic power generation systems.[11] Other technologies, such as energy storage systems (eg batteries and fuel cells when the technology matures), can be incorporated as well.

3.3.6 Ancillary equipment

High-efficiency motors and generators should be installed. Motors should be selected to operate within the optimum pump, compressor and propeller performance curves. Frequency inverters reduce the energy losses by adapting the speed of the compressor and pump to the flow demand of the system.

3.3.7 Inert gases

Inert gases are used to create a low oxygen atmosphere within tanks, and other enclosed spaces, to prevent fire and explosions. These gases are vented when access is required, for example for tank inspection. CO_2 is commonly used and is generated on board by burning fuel in the inert gas generator. Instead of generating CO_2, other gases, such as nitrogen, can be used.

The use of nitrogen, or any other inert gas, produced on board or from shore should be subject to an assessment of the carbon footprint. The emissions from burning fuels (CO_2) or producing other inert gases should be considered when selecting the inert gas at the design stage of the ship.

As an example, if there is a leakage of cargo in the insulation or barrier spaces, increased inert gas volumes will be required to maintain the atmosphere well below flammable limits.

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[11] IMO – MEPC.1/Circular 896 – 2021 Guidance on Treatment of Innovative Energy Efficiency Technologies for Calculation and Verification of the Attained EEDI and EEXI.

3.4 Selection of Fuels and Carbon Capture

Fuel selection determines the design of the fuel system of a gas carrier and the equipment installed, and is a major factor in the overall CO_2 emission profile.

3.4.1 Conventional and alternative fuels

The selection of fuels should consider well-to-wake GHG emissions. The IMO's *2024 Guidelines on Life Cycle GHG Intensity of Marine Fuels (2024 LCA Guidelines)*[12] provides a framework to calculate the CO_2 equivalent of fuels and energy carriers (eg electricity) using the global warming potential of CO_2, methane and nitrous oxide (N_2O) emissions across the fuel life cycle. Figure 5 illustrates the well-to-wake life cycle of fuels, including emissions during the well-to-tank and tank-to-wake phases.

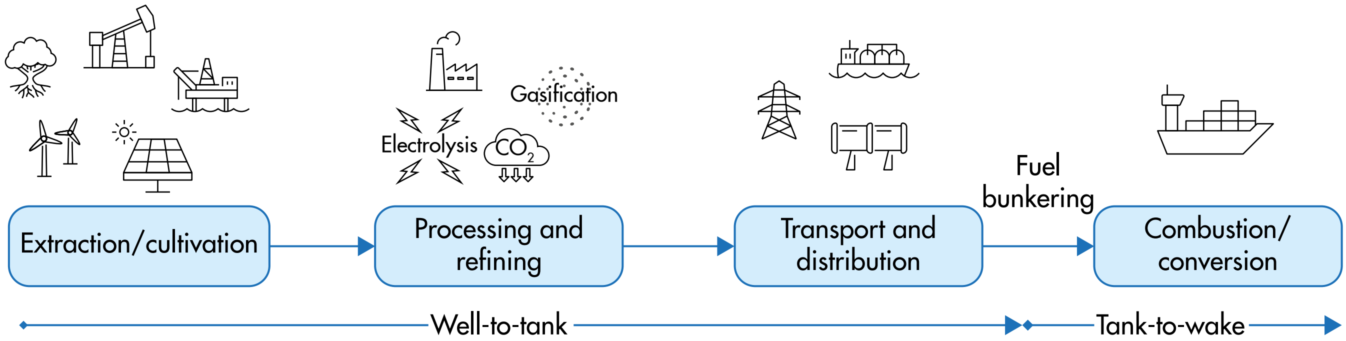

Figure 5: The IMO's generic well-to-wake illustration for the life cycle assessment of fuels

Gas carriers using alternative fuels should be designed for safe use of the specific product. In considering the use of alternative fuels, the shipowner should evaluate the intended operational profile, the technical and safety aspects, the availability of the fuel of choice and the emissions throughout the well-to-wake lifecycle. Existing gas carriers may benefit from similar considerations to improve the design.

The use of alternative fuels, or energy carriers is still evolving. Any alternative fuel should, as a minimum, provide an equivalent safety level compared to conventional fuels for liquids and as LNG for gases. Modular designs can provide the flexibility to adapt to the multiple fuel options that are being developed.

3.4.2 Onboard carbon capture

Consideration may be given to fitting onboard carbon capture technologies. For this approach to be effective, assurance is needed that the storage and sustainable disposal of CO_2 is carried out with minimal release into the atmosphere. This requires aspects such as:

- CO_2 onboard management
- safety aspects
- maintenance considerations
- discharge solutions
- training requirements.

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[12] IMO – MEPC.391(81) – 2024 Guidelines on Life Cycle GHG Intensity of Marine Fuels (2024 LCA Guidelines).

4

Operational Emissions

4. Operational Emissions

Even the most modern and efficient ships need to be operated efficiently to reduce their CO_2 emissions. This chapter provides recommendations to the shipowner and charterers to support their operations.

4.1 Management Framework

The stakeholders involved in the operation of gas carriers should work towards the common goal of reducing emissions.

4.1.1 Operations framework

Operating agreements between the parties involved should include environmental aspects and targets and control measures to reduce emissions. As an example, emission improvements can be gained by collaboration between charterers, schedulers, and shipowners. The shipowner's expertise should be taken into account to optimise the voyage and to help identifying measures to save energy and reduce emissions.

4.1.2 Regulatory framework

The EEXI, CII and SEEMP[13] provide the IMO regulatory framework. The attained CII is calculated by dividing a ship's annual CO_2 emissions by the transport work, which is the cargo capacity multiplied by the annual distance travelled.

$$\text{CII attained} = \frac{\text{Annual } CO_2 \text{ emissions}}{\textit{Cargo capacity} \times \textit{Annual distance}}$$

The CII rating is calculated by comparing this ratio against a required CII, which decreases annually. The rating reflects the operational energy efficiency of ships, using fuel consumption from the data collection system and the SEEMP as a management tool.

Because of the way the rating is structured, in some scenarios a good CII rating can generate more CO_2 emissions than promoting energy-efficient operations. Operators and charterers should be aware of these scenarios. Some examples are included below:

- A loaded ship waiting for discharge might emit less by waiting in location, eg anchorage, because of the method of control of the BOG (and vessel motion may be reduced, therefore BOG generation may be reduced). However, the CII has a better score when the ship is sailing because there is a distance travelled
- in some scenarios partially laden voyages might result in a better CII rating
- ballast voyages should be minimised because the ship is emitting CO_2 even though there is no cargo transported
- ship to ship cargo transfers may be done at anchor, where no distance is travelled, but there are emissions from the cargo operation
- LNG bunker ships deliver a special type of service that is different to the transport of cargo from exporters to the receiving terminal. They are generally smaller – in the order of 10,000 DWT (deadweight tonnage) – but the CII baseline levels out at 65,000 DWT. Voyages can be international based on the location of LNG ports but with much shorter distances compared to the LNG cargo trade. Most of the emissions come from management of the BOG and the fuel discharge. The result is that the LNG bunker ship rating has the worst score possible.

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[13] IMO – MEPC.346(78) – 2022 Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP).

The SEEMP provides a mechanism to improve the energy efficiency of the ship. Some ship operators implement additional environmental management systems according to ISO 14001[14] or ISO 50001,[15] which provides another framework for the improvement of environmental performance.

4.2 Passage Planning

Effective planning and execution of voyages reduces gas carrier emissions, as explained in the following sections.

4.2.1 Route selection

Defining the optimum route should consider:

- Route distance
- condition of the cargo at loading and discharge, BOG rate, and management methods
- additional distance travelled for bunkering or crew transfer
- ship to ship or bunkering locations
- weather conditions
- voyage speed and any power limitation
- selection of fuels and heel strategy
- trim and ballast conditions for ballast voyage
- location of inspections, maintenance or repair.

4.2.2 Weather routing

On specific routes, weather routing has a high potential for energy efficiency savings. Navigating through bad weather increases a ship's fuel consumption and the volume of BOG.

4.2.3 Arrival timing

Early communication between the charterer, terminal and ship operator should ensure timely arrival of the cargo. This should include berth availability, facilitation of optimum speed and route, BOG management, and the use of fuels.

The terminal's design philosophy and operational procedures should support this approach. Port authorities are encouraged to minimise delays to improve port turnaround time.

4.2.4 Voyage speed

Speed optimisation can save a significant amount of energy and emissions. Optimum speed means the speed at which the fuel used per cubic metre and nautical mile is at a minimum level. It does not mean minimum speed. Sailing at less than optimum speed consumes more fuel.

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[14] ISO 14001 – Environmental management systems – Requirements with guidance for use.

[15] ISO 50001 – Energy management systems.

It is common that, under many charter-parties, the speed of the ship is determined by the charterer and not the operator. The charter-party terms should encourage planning and operation at optimum speed.

Some existing ships achieve compliance with the EEXI by implementing power limitation which, mainly on some types of LNGC, should not affect the ship's optimum speed and the ability to manage the BOG efficiently. As part of the speed optimisation process, account should be taken of the need to co-ordinate arrival times with the availability of loading and unloading berths. The number of ships active on a particular trade route should also be considered when determining speed optimisation.

4.2.5 Use of fuels

Some gas carriers may have the capacity to use multiple fuels, such as heavy fuel oil, any other residual heavy oil, diesel oils, cargo as fuel, or alternative fuels. CO_2 emissions depend highly on the fuels used. In selecting the fuel, safety aspects, as well as environmental impact should be included in any considerations.

For ships that can use cargo as fuel, warm-up operation and use of heel should be planned to maximise efficient consumption of the gas.

When alongside a terminal, the provision of shoreside electricity, a process also known as cold ironing, can be used to reduce emissions and improve energy efficiency. This may be possible providing there are safety assessments in place that support the operation.

4.2.6 Cargo condition and conditioning

Terminals are typically more energy-efficient than ships at conditioning cargo. Charterers should provide cold cargo to the ship for energy efficiency purposes. Early agreement with the export and import terminal in terms of the cargo condition can help to reduce the energy involved in the overall cargo transport operation.

Warm cargo can be loaded under prior agreement with the receiving terminal so that onboard conditioning is avoided, although considerations need to be made for the cargo tank pressure capacity, and the expected conditions throughout the voyage.

4.2.7 Heel strategy

The heel strategy should consider the most energy efficient operation. Typically, sufficient heel is maintained in all cargo tanks to keep them cold because cooling cargo tanks down is an energy-intensive process.

When preparing for long ballast voyages, operators might heel out the cargo tanks completely or consolidate the heel in one tank and later use that heel to cool down other tanks. Other occasions for heeling out the cargo may include preparations for dry-docking or other maintenance requirements.

4.2.8 Trim and ballast

Voyages should be planned with the optimum trim for energy efficiency. Numerical analysis can improve fuel consumption if considering the weather conditions, trim and the energy for ballasting, deballasting and water treatment.

If partial loading is considered, trim software can be used in the assessment of the optimum trim and ballast conditions. Steering and autopilot settings may be optimised depending on the vessel condition.

4.3 Voyage and Cargo Discharge

The ship implements voyage orders through passage planning. However, voyage orders or passage plans can change as a result of, for example, unexpected bad weather, a change in discharge terminal, the need to wait for berth availability, or the choice of fuels. This section also applies to ballast and other voyages.

4.3.1 Waiting time

Arrival time and ability to discharge the cargo should be coordinated as part of normal operations. This is to prevent CO_2 emissions as part of the pressure and temperature control methods of the cargo tanks while waiting at anchor or drifting.

Steam turbine LNGCs are heavily affected by waiting times, when not using the BOG for propulsion, because they handle it by dumping steam to a seawater-cooled condenser. Similarly, other vessels with no reliquefaction or liquid cargo cooling systems may require the use of the GCU in this scenario. More modern LNGCs, and most gas carriers, manage the BOG by running a reliquefaction or liquid cooling system, but there are CO_2 emissions associated with these operations too.

4.3.2 Cargo management

Cargo management should be carried out according to the ship's operating manual and voyage orders. The reliquefaction or cargo cooling systems should operate in the most efficient way possible rather than being used at full power throughout some part of the voyage. Cargo composition, temperature and pressure play an important role in maximising the cargo delivery. Certain cargo compositions generate more BOG than others.

When there is a change to the voyage , an assessment should be made of the most energy-efficient way to manage ship emissions. This could include use of the GCU or boiler to avoid warming of the cargo, but this should be minimised.

4.3.3 Reporting of fuel consumption

Operational procedures and instructions should be followed with the aim to run systems and equipment in the most energy-efficient way. In addition to the measurement of CO_2 emissions[16] and Part II of the SEEMP, fuel oil and gas consumption could be measured and automatically reported to a data collection system. To facilitate this, appropriate and calibrated meters should be installed in every gas and fuel consumer, including the main engines, auxiliary engines, GCU, boilers and ancillary equipment.

4.3.4 Rudder control and autopilot

Modern rudder control systems can reduce resistance losses by better course control through less frequent and smaller corrections. Ways to minimise cross-track error in these systems should also be considered. For example, it may be better to optimise for course and make irregular but large course corrections rather than continuous small course corrections.

At certain stages of the voyage, the autopilot is deactivated, or very carefully adjusted, because it might not be an efficient way to control the course and rudder movements. Typical examples include approach to port and pilot stations, or in heavy weather.

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[16] SIGTTO – Measurement and Reporting of CO_2 Emissions from Gas Carriers.

5

Inspection and Maintenance

5. Inspection and Maintenance

This chapter provides guidance to shipowners and service providers. Effective planning and execution of inspection and maintenance activities reduces gas carrier emissions as explained in the following sections.

The maintenance philosophy should aim to minimise emissions through conducting maintenance activities on equipment on board at the optimum intervals. This can be done by ensuring that equipment is monitored for condition and energy performance. In some cases, by applying condition-based maintenance energy performance can be improved, while reducing unplanned maintenance.

5.1 Hull, Propeller and Rudder

A smoother hull is more efficient because it reduces resistance to the ship's movement. Figure 6 shows the power increase in relation to different anti-fouling strategies in equatorial conditions. While anti-fouling coatings remain the first option for preventing biofouling growth, there are studies that show the potential of biofouling management measures to support the performance of anti-fouling coatings to reduce fuel consumption.[17]

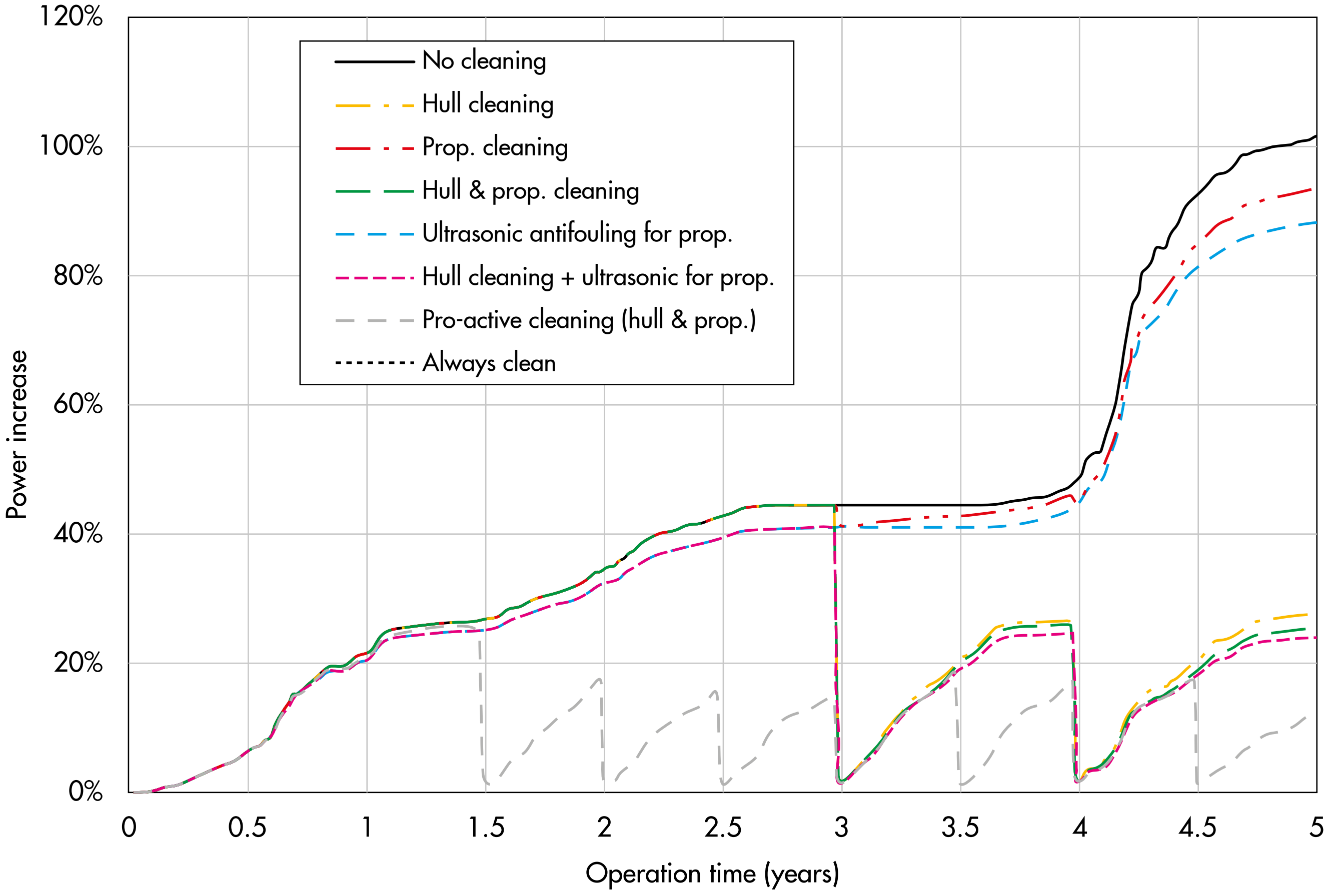

Figure 6: Comparison of different anti-fouling strategies in equatorial conditions

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[17] GEF-UNDP-IMO GloFouling Partnerships Project and GIA for Marine Biosafety, 2022, Analysing the Impact of Marine Biofouling on the Energy Efficiency of Ships and the GHG Abatement Potential of Biofouling Management Measures.

Real condition of the hull, propeller and rudder can be considered when planning the maintenance activities and frequency, including, for example, cleaning, painting and polishing in dry dock. In some cases, condition-based monitoring or inspections can be used to determine the optimum coating system or the application of new technologies to reduce marine growth.

5.2 Machinery and Energy Recovery

When planning maintenance activities and intervals, in addition to safety and reliability of equipment, CO_2 emissions and energy performance should be considered. A shipowner's maintenance system should incorporate the manufacturer's recommendations to retain equipment efficiency and emissions levels.

Energy recovery systems such as economisers, electrical systems, and motors, should be cleaned and maintained to operate in optimum condition. Operations should follow the manufacturer's recommendations to minimise heat loss and maintain efficiency.

Annexes

Annex 1 – Glossary of Terms and Abbreviations

ALS Air Lubrication System

BOG Boil-Off Gas

CCS Cargo Containment System, see IGC Code paragraph 1.2.8

CII Carbon Intensity Indicator

CO_2 Carbon Dioxide

DWT Deadweight Tonnage

EEDI Energy Efficiency Design Index

EEXI Energy Efficiency Existing Ship Index

GCU Gas Combustion Unit

GHG Greenhouse Gas

IMO International Maritime Organization

ISO International Organization for Standardization

LNG Liquefied Natural Gas

LNGC Liquefied Natural Gas Carrier

N_2O Nitrous Oxide

NOx Nitrogen Oxides

SEEMP Ship Energy Efficiency Management Plan

SVP Saturated Vapour Pressure

Annex 2 – Reference List

- SIGTTO – Measurement and Reporting of CO_2 Emissions from Gas Carriers
- IMO – MEPC.395(82) – 2024 Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP)
- IMO – International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code)
- SIGTTO – Reduction of LNG Carrier Methane Emissions
- IMO – MEPC.1/Circular 896 – 2021 Guidance on Treatment of Innovative Energy Efficiency Technologies for Calculation and Verification of the Attained EEDI and EEXI
- IMO – MEPC.391(81) – 2024 Guidelines on Life Cycle GHG Intensity of Marine Fuels (2024 LCA Guidelines)
- ISO 14001 – Environmental management systems – Requirements with guidance for use
- ISO 50001 – Energy management systems
- GEF-UNDP-IMO GloFouling Partnerships Project and GIA for Marine Biosafety, 2022 – Analysing the Impact of Marine Biofouling on the Energy Efficiency of Ships and the GHG Abatement Potential of Biofouling Management Measures (www.glofouling.imo.org/publications-menu)

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