LNG boil-off gas at berth

LNG-fuelled containerships fit for mandatory Onshore Power Supply?

CE Delft

LNG boil-off gas at berth

LNG-fuelled containerships fit for mandatory Onshore Power Supply?

This publication was written by:
Stuart Ross, Dagmar Nelissen and Diederik Jaspers

Delft, CE Delft, November 2025

Publication number: 25.240546.208

Client: NABU

All public CE publications are available via www.cedelft.eu

More information about the study can be obtained from the project leader Dagmar Nelissen (CE Delft)

CE Delft – Committed to the Environment

CE Delft is helping build a sustainable world through its independent research and consultancy work. Our expertise is leading-edge in the fields of energy, transport and resources. We support government agencies, NGOs and industries in pursuit of structural change with our wealth of know-how on technologies, policies and economic issues. Since 1978 the skills and enthusiasm of CE Delft's staff have been focused on achieving this mission.

Content

Executive Summary

Context

An increasing number of ship types beyond LNG carriers now use Liquefied Natural Gas (LNG) for propulsion and/or other energy requirements on board. In order to reduce tank space requirements, natural gas has to be stored as a liquid on board ships. To become liquid, the gas has to be cooled down to around -162 °C and to prevent regasification, specific LNG tanks are used on board. Since evaporation of the liquefied gas within the onboard tanks cannot be fully avoided, boil-off gas (BOG) forms in the tanks.

Depending on the tank type and the ship's operational profile, BOG management is required to avoid tank overpressure and to comply with international regulations aimed at preventing emergency venting. A common management strategy is to use BOG energetically onboard. However, during a stay at berth - when energy demand is relatively low - the question arises whether the risk of inefficient use of the BOG or emergency venting of it increases, especially in cases where ships receive power from shore while at berth. Onshore Power Supply (OPS) is a key technology to reduce air and GHG emissions in ports.

Aim of the study

The study examines BOG formation in tanks of LNG-fuelled containerships when connected to OPS at berth and assesses the probability of unburned methane emissions or inefficient use of BOG. The focus is on containerships because they are among the ship types required to connect to OPS in major European ports starting in 2030. The analysis specifically considers Type B and membrane LNG tanks which are most commonly used by containerships today.

Main findings of the study

LNG-fuelled containerships equipped with Type B or membrane tanks generally have sufficient capacity to consume BOG during a conventional port stay using auxiliary engines. However, when connected to OPS, these engines must be switched off, limiting the ability to consume BOG onboard.

The containerships inventorised for this research do not (in general) have reliquefaction systems, sub-cooling systems, gas combustion units, nor an ability to accumulate large volumes of BOG in the tank. As a result, dual-fuel boilers are often the only onboard systems available to burn BOG and control tank pressure at berth during an OPS port call. Ship boilers generally operate independently of a ship's electrical grid and so cannot be powered by an OPS connection. Due to the possibility to use BOG in dual-fuel boilers at berth during an OPS port call, the study assesses the risk of emergency venting to be relatively low – although the installation of a gas-fired or dual-fuel boiler could not be confirmed for all inventorised ships.

The analysis also shows that the rate at which BOG would need to be consumed by the boiler typically exceeds the ship's actual steam demand, resulting in the BOG being combusted without use. This implies energy wastage and associated avoidable emissions should no additional BOG management measures be implemented.

Recommendations

The study first of all recommends the establishment of a common standard to quantify the boil-off rate from an LNG fuel tank. Various factors influence BOG generation, and there is no consistent industry-wide approach to defining which parameters or values should be included in such calculations. Moreover, a review is recommended between the current requirements of the IGF Code which require that onboard BOG management methods are capable of keeping a ship's LNG tank pressure below the set pressure of its relief valves for a period of 15 days - including idle periods when only power for domestic load is generated - with a fast-approaching new reality in which many ships will not generate electrical power for domestic load onboard at berth but be required to receive it from shore. The review could consider whether there are changes required to the IGF Code and its BOG management rules to maintain safety in this new context.

Concerning new LNG-fuelled containerships, the report notes an increasing share are being ordered with tanks that have a higher pressure tolerance. This feature in any case reduces the likelihood that tank pressure reaches unsafe levels or energy needs to be wasted during a ship's stay at berth with OPS. However further research is recommended on the exact relationship between the higher design pressure and the holding time of the tank to ensure this is sufficient also for long-stays at berth.

Meanwhile, for the existing containership fleet with Type B and membrane LNG tanks, retrofitting of tanks is likely to be extremely costly. Therefore, sharing operational experience on managing LNG tanks while connected to OPS is recommended as a first step to reduce the risk of BOG wastage or venting.

The use of OPS is strongly encouraged as an available technology to eliminate air emissions at berth however future research could consider the interplay between ship energy efficiency and OPS regulations with a view to achieving the greatest energy efficiency and lowest Well-to-Wake GHG intensity of the energy consumed. For existing containerships ordered before there was a clear prospect of widespread OPS obligations, special rules might be justified from an energy efficiency and emissions perspective if the ship has no other means of safely managing BOG besides wasting it. Under the current rules, this ship would economically weigh two options: either connecting to OPS and incurring costs for OPS and for wasting BOG or not connecting/connecting shorter to OPS and paying the according FuelEU penalty, thereby avoiding costs for OPS and for wasting BOG. Therefore special rules like, for example, a reduced penalty for a limited number of hours could be considered. Importantly, however, the negative effects of such special rules in the form of higher emissions, of potentially slowing down the uptake of cleaner technologies and improved BOG management systems, and of a distorted level-playing field between the ships eligible for such special rules and those not would also have to be considered.

List of abbreviations

Abbreviation	Description
BOG	Boil-off gas
BOR	Boil-off rate
CAPEX	Capital Expenditure
CARB	California Air Resources Board
CO_2	Carbon Dioxide
CH_4	Methane
EEA	European Economic Area
EU	European Union
GCU	Gas Combustion Unit
GHG	Greenhouse gas
GT	Gross Tonnage
HFO	Heavy Fuel Oil
IGF Code	International Code of Safety for Ships using Gases or other Low-flashpoint Fuels
IMO	International Maritime Organization
kW	Kilowatt
LHV	Lower heating value
MARPOL	International Convention for the Prevention of Pollution from Ships
MARVS	Maximum Allowable Relief Valve Setting (on an LNG tank)
MGO	Marine Gas Oil
MJ	Megajoule
MSC	Maritime Safety Committee (of the IMO)
NO_x	Nitrogen oxides
OPEX	Operational Expenditure
OPS	Onshore Power Supply
PTO	Power Take-off
SOLAS	International Convention for the Safety of Life at Sea
SO_x	Sulphur oxides
TEN-T	Trans-European Transport Network
TEU	Twenty-foot Equivalent Unit

1 Introduction

1.1 Background and research question

An increasing number of ships and ship types are able to use Liquefied Natural Gas (LNG) for propulsion and/or other energy requirements on board ships. LNG mainly consists of methane, a hydrocarbon considered to have a Global Warming Potential 28 times higher than CO_2 on a hundred year timescale and 84 times higher on a 20 year timescale (EC, 2025b).

In order to reduce the required storage space, the gas is stored as a liquid on board these ships, with the gas having to be cooled down to around -162 °C to become liquid. Evaporation of the liquefied gas within the onboard tank(s) cannot be fully avoided, leading to so-called boil-off gas (BOG) in the tanks.

Different types of tanks can be used to store LNG on board ships which are associated with different BOG rates. Also, different technical and operational BOG management approaches are available and permitted, including the energetic use of the BOG by the ship.

When the BOG is used as an energy source for onboard energy consumers in order to control the tank pressure and temperature, there are phases in a ship's operational profile when these energy consumers can use relatively little BOG, especially if ships use onshore power at berth. The energy requirement of the non-propulsion energy consumers is then relatively low, potentially requiring ships to take extra BOG management measures in order to fulfil regulatory requirements and to avoid venting. Given the (upcoming) requirements for ships to use OPS at berth, this study analyses whether the BOG formation represents a climate challenge in the form of venting. Given the high global warming potential of methane, venting to the atmosphere should be prevented.

1.2 Method

To conduct the study, the typical energy demand of containerships at berth is assessed, and the types of LNG tanks and onboard systems available for BOG consumption or other forms of pressure management are inventorised. Using multiple scenarios, the study estimates the amount of BOG generated during stays at berth, the corresponding energy content, and the potential for onboard utilisation thereof - with and without OPS use. These estimates help assess whether the generated BOG exceeds the ship's actual energy needs at berth, which could lead to energy wastage or, in the absence of appropriate BOG management, a build-up of tank pressure that could trigger emergency venting.

The study is mainly based on desk research, using research studies, regulations and guidelines, publicly available information from technology providers as well as data from Clarksons' World Fleet Register. In addition, to verify certain assumptions and conclusions, we reached out to a multitude of stakeholders, five of which were willing to provide us with feedback, some of which orally and some of which in writing. We highly appreciated this valuable feedback; any factual inaccuracies or misstatements are solely the responsibility of the authors.

1.3 Outline of the report

Chapter 2 provides an **introduction** to LNG as ship fuel, including boil-off gas as well as rules and regulations that apply for the use of LNG by ships that are relevant for the context of this study.

In Chapter 3 gives examples for **regulations** that require containerships to use OPS at berth together with an inventory of LNG-capable **containerships equipped with onboard OPS** connection points, also based on Clarksons' World Fleet Register.

In Chapter 4 an **inventory of LNG-capable containerships**, based on Clarksons' World Fleet Register is presented, focussing on containerships (to be) equipped with Type B and membrane tanks.

Chapter 5 discusses **containerships' energy demand at berth**.

Chapter 6, **the core of the report**, analyses the **BOG formation at berth**, differentiating OPS and non-OPS calls also considering the different BOG management options with the focus on those options that have been identified to be installed on LNG-capable containerships as part of Chapter 4.

Chapter 7 finally provides **conclusions** and **recommendations**.

2 LNG as ship fuel

2.1 The use of LNG as fuel in shipping

Liquefied Natural Gas (LNG) has been used as a fuel for shipping for decades however until recently it was predominantly used by LNG carriers, some of which use part of their cargo as fuel. The world's first purpose-built LNG carrier, the Methane Princess, entered into service in June 1964 (EIA, 2014). Only more recently has LNG started to be used as fuel for other types of ships. The first non-LNG carrier powered by LNG - the (2,268 GT[1]) ferry GLUTRA - came into service in 2000 in Norway and since 2010 the number of ships fuelled by LNG has grown consistently by between 20 and 40% per annum (SEA-LNG, 2025). Orders for large LNG fuelled ships first started to take off in the cruise and container segment and later in all other segments including tankers and bulk carriers (DNV, ongoing). In 2020 and 2021, orders from LNG fuelled tonnage represented a significant share of newbuilding gross tonnage for the first time (DNV, ongoing). However the use of LNG by ships still remains marginal compared to conventional fuel oils. Of the 213 million tonnes of fuel used by 28,834 ships subject to IMO fuel consumption reporting requirements in 2023[2], 12.9 million tonnes was LNG which is just over 6% (IMO, 2024a). By comparison, in 2019 - the first year of required fuel consumption reporting to IMO - the same amount of total fuel was reported of which 10.5 million tonnes was LNG which is just under 5%. Almost all of the LNG used by shipping to date is expected to have been fossil LNG. While bio and e-LNG alternatives are possible, their use in shipping today is limited with the prospects being rather longer-term: industry studies find for instance that the potential of bio-LNG could meet up to 3% of the total energy demand for shipping fuels in 2030 (SEA-LNG, 2022). Looking forward, future growth of LNG may be challenged by potentially climate neutral fuels like methanol and ammonia.

The growth in LNG in the last decade by ships other than LNG carriers is explained first of all by a need to lower the release of air emissions in accordance with international regulations. These regulations notably include global and regional sulphur limits[3] and the

---

[1] The ferry is 121 m long (Vessel Finder) but at 2,268 is not considered a particularly large vessel. For comparison, the average size of vessels calling at main EU ports is estimated at 8,058 gross tonnage per vessel (Eurostat, 2025). IMO fuel consumption reporting requirements for ships start at 5,000 GT.

[2] The requirements apply to ships of 5,000 GT and above which are subject to regulation 27 of MARPOL Annex VI. 2023 is the most recent year for which data is available. 12,890,011 tonnes of LNG were consumed by ships in scope of the requirements in 2023, a slight increase from other reporting years which started in 2019.

[3] SO_x emissions are virtually eliminated when LNG is used as a ship fuel (SGMF, 2023).

IMO NO_x Technical Code[4]. More recently, LNG has been seen as a way to reduce CO_2 emissions from shipping for which there is a growing body of international and regional regulations being developed. However concerns remain about methane emissions released throughout the fuel's lifecycle.

On 13 June 2025, in the global fleet, there were 1,401 ships in operation capable[5] of sailing on LNG (Clarksons Research, ongoing-a). While many of these are LNG carriers, 191 are containerships. A further 336 containerships capable of sailing on LNG were also on order at the same date.

2.2 Characteristics of LNG including boil-off gas

LNG is fossil natural gas that has been cooled sufficiently to condense into a liquid. At atmospheric pressure, this happens at a temperature of -162 °C (SGMF, 2023). The gas is liquified to reduce the space required to store it on board a ship: the volume of the liquefied natural gas is about 1/600th of the volume of the gas. Liquification makes it commercially feasible to transport large volumes of gas in a ship as cargo (in the case of an LNG carrier) and more practical for the gas stored onboard for use as fuel (for any other kind of ship). Notably, the energy density per unit volume of LNG is lower than conventional fuel oils so a greater volume of LNG is needed to achieve the same energy content when substituting conventional fuel oils with LNG: typically this is 1.8 times the volume (ABS, 2019). LNG must also be stored on board in such a way that warming of the liquid is prevented. In contrast to conventional marine fuels that do not significantly alter if left alone, LNG is a dynamic fuel which is actively trying to get back into a gaseous state (ABS, 2022).

Another different characteristics of LNG compared to conventional marine fuels is the 'flashpoint' of the fuel. Flashpoint is defined in the IMO SOLAS Regulations (Chapter II-2. Regulation 3.24) as "the temperature in degrees Celsius (…) at which a product will give off enough flammable vapour to be ignited (…)." In general, the lower the flashpoint the greater the risk of fire. While conventional fuels such as HFO (Heavy Fuel Oil) or MGO (Marine Gas Oil) have a flashpoint greater than 60 °C, the flashpoint of methane (the primary component of LNG) is -188 °C (ABS, 2019). Due to these differences, and to ensure the safety of the ship, crew and environment, specific regulations have been put in place for ships using gases or other low-flashpoint fuels (the IGF Code). This Code is discussed further in Section 2.4.

---

[4] While most oil fuelled engines need to be equipped with selective catalytic reduction (SCR) technology or exhaust gas recirculation (EGR) to reduce NO_x emissions to acceptable levels, most LNG-fuelled engines are NO_x-compliant without after-treatment (SGMF, 2023).

[5] This means containerships ships which, according to Clarksons World Fleet Register have a main engine fuel type as one of the following: IFO 380, LNG; LNG ULS IFO; LNG, VLS IFO or LNG, VLS MDO.

2.2.1 Boil-off gas

Boil-off gas is another unavoidable characteristic of LNG. When LNG is transported as cargo or used as fuel on board a ship, it is stored in specialised tanks which take account the very low storage temperature of LNG and the need to avoid heat ingress into the tank. Nevertheless, heat transfer to the LNG is unavoidable, due to the temperature difference inside and outside the tank (Wärtsilä, ongoing). As a result, some of the LNG begins to vaporise and collect as boil-off gas in the tank space above the liquid level (DNV, 2023).

The phenomenon of BOG can be compared to a pan of water with a lid on, which is warmed on a stove: as heat rises over time, part of the water boils off as steam and pressure increases inside the pan. As the steam is freed it creates more space inside the pan, reducing pressure. A similar principle applies to LNG in a fuel tank: if BOG is not removed, pressure builds-up and - if not managed - would eventually lead to the opening of pressure relief systems, in what is called ‘venting’, an event which can only be considered as an emergency (EMSA, 2018).

The emergency venting of BOG to the atmosphere is an important safety feature to avoid over-pressure in the LNG tank which could compromise the tank’s structural integrity, bringing risks to the crew, ship and environment. However, since BOG is primarily methane (CH_4), venting of the gas results in the release of a potent GHG. Methane is considered to have a Global Warming Potential 28 times higher than CO_2 on a hundred year timescale and 84 times higher on a 20 year timescale (EC, 2025b).

2.3 Determining factors on the amount of BOG generated

Boil-off gas can be divided into two components: static and dynamic (GTT, Ongoing). The first component depends on the ship design and the performance of the insulation system; the second includes all the other factors that are variable during the ship’s operations (GTT, Ongoing). The amount of LNG evaporating from a tank, generally termed the ‘boil-off rate’ or BOR, depends directly on these two components. There is - to our knowledge - no single universally accepted standard quantifying BOR which takes into account both of these components.

This section first discusses ‘static boil-off gas’ and how this is sometimes calculated, followed by ‘dynamic boil-off gas’ which depends on the actual operation of the ship and is not necessarily included in any formally calculated boil-off rate.

2.3.1 Static boil-off rate

Manufacturers of LNG tanks are known to perform a ‘boil-off rate (BOR) calculation’ which signifies the percentage of evaporated LNG per day, compared to the amount of LNG initially loaded (Korean Register, 2020).

While, based on consultation conducted for this research, there does not appear to be a single universally binding standard for this calculation, certain guidelines do exist[6]. According to these guidelines, the calculation involves determining the total heat flux that penetrates from outside to inside the LNG tank through the surface and corner areas of the tank, relying on detailed thermal analysis. The calculation also relies on defined environmental conditions (air temperature of 45 °C and seawater of 32 °C) and LNG characteristics (temperature at -163 °C, 98% tank filling ratio and latent heat of evaporation of 511 kJ/kg). Having calculated the total heat flux[7] the BOR is determined based on the following equation:

$$BOR = \frac{\sum Q_{leak}}{\rho_{LNG} \times v_{LNG} \times \lambda} \times 3600\, MJ \times 24\, hours \times 100\%$$

Where,

$\sum Q_{leak}$ = total heat flux that penetrates from outside to inside LNG tank

ρ_{LNG} = LNG density

V_{LNG} = Volume of LNG in cargo tanks

λ = Latent heat for vaporization

Based on interviews conducted for this research it is understood that the LNG density commonly applied for the calculation of the BOR is 450 kg/m^3 as given in (MSC.285(86), 2009). The key variable in static BOR calculation is therefore the total heat flux that penetrates into the LNG tank. Consequently the calculated BOR depends on the thermal characteristics of the LNG tank, particularly its ability to limit heat ingress through insulation. Interviews conducted for this research suggested that insulation thickness on LNG fuel tanks installed on containerships in operation varies between 300 and 400 mm which would be somewhat lower compared to modern large LNG carriers with the same types of tanks (400-530 mm).

Beyond tank insulation another important parameter in determining heat flux is the size of the LNG tank as it directly influences the surface-to-volume (S/V) ratio. Larger tanks have a lower S/V ratio, meaning that they experience proportionally less heat ingress per unit of LNG.

The static BOR calculation as presented above is understood to apply with respect to the total *capacity* of the tank (although this was not fully unanimous during interviews). In this respect a BOR of 0.15% on a tank of a maximum capacity 10,000 m^3 would result in 15 m^3 evaporated per day irrespective of the actual volume within the tank. A possible reason for this is that the calculation was first applied to LNG cargo tanks where the loaded volume

---

6 Information is available at the following pages from Korean Register and ABS: http://homedev.krs.co.kr/webzine/a/sub/sub.aspx?w_code=0201000000&no=3314&webzine_no=189 https://ww2.eagle.org/content/dam/eagle/rules-and-guides/current/design_and_analysis/309_gn_thermalanalysisofvessels/thermal-analysis-gn-sept19.pdf

7 For details on the calculation of heat ingress into LNG tanks see: http://homedev.krs.co.kr/webzine/a/sub/sub.aspx?w_code=0201000000&no=3314&webzine_no=189

(presumably full or very close to full) remains more constant until it is discharged (with the exception of course of BOG). In contrast, the actual volume of LNG in a fuel tank fluctuates more as fuel is consumed for propulsion and increases again as fuel is bunkered.

Since the static BOR calculation as presented above assumes very high air and seawater temperatures as well as the 98% level of fill in the tank, the calculation could on one hand be considered as the BOG generation rate of the tank at near 'worst-case' conditions. However on the other hand, the calculation importantly does not account for operational (dynamic) factors which can increase BOG generation inside an LNG tank.

2.3.2 Dynamic boil-off gas factors

It is understood that ship operational factors are not normally considered in the boil-off rate that may be calculated or guaranteed by tank manufacturers[8]. As a result the 'static' component of BOG which may be calculated based on the design of the tank may differ greatly from the 'dynamic' component that is experienced during actual operations.

This section discusses the main dynamic factors that influence BOG during a ship's operation. The factors are discussed in no particular order and their influence on the ship's total BOG generation rate likely varies from ship to ship.

1. **Sloshing of LNG liquid within the tank**. Sloshing is the movement of LNG within the tank due to waves or other vessel motions, creating kinetic energy resulting in heat and potentially evaporation of the LNG. Sloshing may be exacerbated when tanks are only partially filled and especially in tanks without bulkheads (partitions). Sloshing also causes friction on the inner wall of the tank creating an additional thermal effect (Korean Register, 2020) leading to a higher BOR. When a ship is at berth and not exposed to vessel motions, sloshing is expected to be a less relevant BOG factor than when the ship is at sea.

2. **Heat ingress**, due to the difference between the temperature in the LNG tanks and the temperature of the environment surrounding it (GTT, 2019). Environmental conditions are defined in the 'static' BOG component calculation but in practice environmental conditions vary widely. BOR increases with the temperature difference between the cold LNG inside the tank and the warmer environment outside.

3. **LNG 'aging'**: This refers to the different composition of LNG in a tank where the components with a lower boiling point evaporate first. The vast majority of LNG is methane however the composition can vary depending on the source of natural gas and the processing of the gas. MSC.285(86) assumes a typical composition

[8] A major manufacturer of LNG cargo and fuel tanks states: guaranteed BOR does not take into account cargo loaded, actual environmental conditions, tank and insulation cooling down, propulsion system and more generally the way the vessel is operated (GTT, 2019).

may be 94% methane, 4.7% ethane, 0.8% propane, 0.2% butane and 0.3% nitrogen (IMO, 2009). Aging implies that if LNG is bunkered with a higher nitrogen content (which has a boiling point of -196 °C at standard conditions) then the tank may have a slightly higher initial BOR. Other components, where present, have a higher boiling point such as -89 C for ethane and -42 C for propane.

4. **LNG bunkering and consumption**: Differences in operating pressures and temperature between a ship's LNG tank and that of the supplying terminal (or bunker barge) can influence BOG generation. BOG is generated when LNG enters a warmer tank of the receiving ship, referred to as flash gas (PRS, 2017). As ships frequently bunker fuel while at berth the influence of this dynamic BOR factor is likely to be highest during this operational phase. The generation of BOG may also be induced when LNG is taken from the fuel tank for (main engine) consumption on board, with a small share of the LNG then re-circulated back into the tank.

5. **Decreasing fuel tank level**: As the LNG level in the tank decreases due to fuel consumption, the boil-off rate relative to the remaining LNG volume tends to increase. This is because there is less remaining LNG to absorb incoming heat, making the liquid more susceptible to warming. However, the total amount of BOG produced may still decline, even as the rate per unit volume of the remaining LNG increases.

It can be concluded that there are various factors that influence the BOG rate from a ship LNG tank. While the BOG rate is sometimes presented as a fixed value - typically expressed as the percentage of LNG volume evaporated per day - it is in practice subject to significant variability and uncertainty. Given the lack of a universally accepted standard that integrates both static and dynamic influences, BOG rate must be understood as an indicative parameter, not a guaranteed figure. However, it should be noted that BOG formation occurs continuously: even under ideal static and dynamic conditions the BOG rate will never be 0. Illustrative of the uncertain nature of BOG generation, software exists to help crews and companies predict the rate of BOG and optimise its management[9].

2.3.3 Typical boil-off rates

Typical BOG rates for LNG in storage (and not specifically for LNG fuel tanks) due to heat ingress - even in tanks with very good vacuum insulation - are considered to be 0.1-0.5% per day (EMSA, 2018).

More specifically for LNG fuel tanks on containerships, a typical BOG rate is 0.3% of liquid per day as a conservative estimate, depending on tank temperature, filling level, etc. (DNV, 2023). A similar estimate is given in a case study on containerships which considered (for an LNG membrane tank) a typical BOG rate of 0.25 to 0.32% per day (MAN, 2018). These estimates for containerships are in line with figures heard during

[9] For example see https://www.danelec.com/performance/danelec-boil-off-gas / https://gtt.fr/lng-optim

interviews conducted for this research, although lower estimates of around 0.15% per day were also heard. These interviews also suggested that Type B and membrane tanks have comparable BOG rates, while the rate is moderately lower for Type C tanks. As discussed above it is also considered that smaller LNG tanks have a higher BOG rate than smaller ones. Studies focussed on LNG carriers for example cite a common BOG rate of around 0.1 to 0.15%/day for the tanks of large LNG carriers as the maximum value; however the tanks of smaller LNG carriers have a larger surface-to-volume ratio, resulting in a higher rate of 0.2 to 0.6%/day (Kim et al, 2019). Lower examples of BOG rates (for membrane LNG tanks) can be found in the range of 0.15% down to 0.07% (GTT, 2025c) however these values concern only the 'static' component of BOG. Furthermore, the tanks with 0.07 static BOG rate do not appear to be used by containerships[10].

For the analysis of BOG generation at berth for this study (Chapter 6) we use three scenarios of a 'high' BOG rate of 0.3%, 'medium' of 0.2% and 'low' of 0.07% for tanks of 18,000 m^3. For scenarios examining smaller tanks of 6,000 m^3 we apply slightly higher BOG rates. In study results (presented in Chapter 6) we consider the BOG rate to include both static and dynamic BOG components. We also apply the BOG rate with respect to the actual volume of LNG in the tank and not the tank's maximum capacity.

2.4 Rules and Regulations on LNG as a ship fuel

The regulatory framework for the use of LNG as a ship fuel is mainly set by the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code) (IMO, 2024b).

The IGF code is applicable to all SOLAS[11] ships (those sailing on international voyages, propelled by mechanical means and greater than 500 GT) using fuels with a flashpoint of 60 °C or less for which the building contract was placed on or after 1 January 2017[12].

The aim of the IGF Code is to minimize the risk to the ship, its crew and the environment, having regard to the nature of the low-flash point fuels involved (IMO, 2024b). As such, the Code sets requirements on - for instance - fire safety, explosion prevention, gas detection systems as well as operational requirements such as emergency drills and the availability of a fuel handling manual. The Code also requires that a risk assessment is conducted, to the satisfaction of the ship's flag administration, to ensure that the risks arising from the use of low-flashpoint fuels are sufficiently mitigated.

The most relevant requirements within the IGF Code for this study are found within chapter 6 of the Code concerning rules on fuel containment systems (fuel tanks).

---

[10] Based on references as of 31 March 2025, the tanks ordered for LNG as fuel units have a BOR of 0.085-0.15%. No orders of the tank type with a BOR of 0.07% are noted for LNG as fuel units (GTT, 2025b).

[11] International Convention for the Safety of Life at Sea.

[12] Exceptions exist only for government owned or operated ships used on non-commercial service as well as ships which carry gas a cargo (for which the IGC Code has been applicable since 1986).

These are within Part A-1 of the Code which covers ‘Specific Requirements for Ships using Natural Gas as Fuel’. These rules are discussed in more detail in the following sections.

2.4.1 LNG fuel tank types

Regulation 6.4.15 of the IGF Code defines four tank types[13] that could be used for the storage of LNG as fuel. Three of these tanks types (Types A, B and membrane) are low pressure and nominally referred to as ‘atmospheric tanks’ while Type C tanks are designed using pressure vessel codes (ABS, 2019).

A brief description of these tank types as well as their requirements and various advantages/disadvantages are given in Table 1.

[13] Other tank designs (novel concepts) are also possible if it can be demonstrated they maintain a level of safety similar to that achieved for known containment systems as designed using 6.4.15.

Table 1 - LNG tanks types as defined in IGF Code 6.4.15

<table>
<tr><th>Tank Type</th><th>Maximum pressure[14]</th><th>Potential advantages/disadvantages</th></tr>
<tr><td>Type A

A self-supported tank designed using classical ship-structural analysis procedures.

A complete secondary barrier is required.</td><td>0.7 barg</td><td rowspan="2">– Prismatic shaped tanks can be space efficient (more so than Type C tanks but less than membrane tanks).
– The complete secondary barrier for Type A tanks can increase construction time and there is limited design and construction experience in the maritime industry (DNV, 2023).
– Can be equipped with (perforated) swash bulkheads which can minimise sloshing of the fuel (DNV, 2023). Sloshing can damage the tanks as well as promote BOG generation.
– Compared with membrane tanks, Type A & B tanks transfer sloshing loads to the ship structure only partially (DNV, 2023).
– Likely to require BOG management solution due to pressure limitation (DNV, 2023).</td></tr>
<tr><td>Type B

Similar to Type A but designed with more rigorous analysis on stress and fatigue as well as crack propagation characteristics.

A partial secondary barrier is required.</td><td>0.7 barg</td></tr>
<tr><td>Type C

Designed based on pressure vessel criteria, permitting high levels of pressure accumulation within the tank.

A secondary barrier is not required.</td><td>10 barg, however for the large foam insulated type installed on containerships the max. is in practice around 4.5 barg.</td><td>– High capacity to retain BOG for extended periods. Internal pressure may be increased to several times atmospheric pressure (SGMF, 2023).
– However, the higher the design pressure, the thicker the shell of the pressure vessel needs to be, and the higher the tank weight and cost (DNV, 2023).
– Type C tanks are inherently cylindrical, which can limit space efficiency however this can be mitigated by bilobe and trilobe designs to better fit in rectangular spaces and vertical installation in some configurations.
– Unlikely to require extensive additional methods to manage BOG in periods of low ship energy demand.</td></tr>
</table>

[14] Design vapour pressure is the maximum gauge pressure, at the top of the tank, to be used in the design of the tank. These pressure limits are provided in 6.4.15 of the IGF Code and expressed in MPa however these have been translated to barg which is unit most commonly used in other literature. Note that higher tank pressure limits are possible in consultation with ship flag administrations of for voyages of restricted duration.

Tank Type	Maximum pressure[14]	Potential advantages/disadvantages
Membrane This tank relies on the structural support of the ship's hull. They are primarily made of corrugated steel membrane, positioned on top of prefabricated insulation panels, including a complete secondary membrane made of composite material (GTT, 2025c). A complete secondary barrier is required.	Normally not exceeding 0.25 barg. However where hull strength is accounted for, pressure may be increased to 0.7 barg.	– Membrane tanks can be made into any shape so can be used space efficiently within a hull (SGMF, 2023). – However since there is no inner structure such as bulkheads, fuel moves freely within the tank (thus sloshing). Depending on the actual fill level, loading condition and dynamic motion, severe sloshing impact loads may be generated (DNV, 2023). – Sloshing may be reduced by enlarging the lower sloped tank walls but this impacts space utilisation (DNV, 2023). – Likely to require BOG management solution due to pressure limitation (DNV, 2023).

It is expected that the selection of a containership's LNG tank is a decision of financial importance and technical complexity, requiring detailed analysis. For containerships of around 20,000 TEU, the costs of the LNG tank system are estimated to be USD 10-15 million; this accounts for 55-65% of the estimated additional CAPEX for LNG compared with a conventionally fuelled ship (DNV, 2023). Furthermore, the IGF code also requires that an evaluation is made (as part of a wider risk assessment) concerning the type of tank to be installed and whether its use implies additional safety measures need to be integrated into the overall vessel design (IGF Code Regulation 6.4.1.1).

2.4.2 LNG fuel tank pressure control systems (BOG management methods)

There are significant differences in the pressure LNG fuel tanks are designed to handle, as indicated in Table 1. Whereas large Type C tanks may be designed to handle pressure up to around 4.5 barg, membrane tanks and Type B tanks - presently the most commonly installed type of tank on LNG-fuelled containerships - have a maximum design pressure of 0.7 barg. This design pressure can only be exceeded when an equivalent level of safety is demonstrated and subject to approval of the ship's flag state.

The relatively low maximum design pressure of LNG fuel tanks (besides Type C tanks) is important because the IGF Code requires that tank internal pressure should not exceed 90% of the maximum pressure setting, termed the Maximum Allowable Relief Valve Setting (MARVS).

IGF Code Regulation 6.9.1.1 requires that an LNG tank's pressure and temperature shall be maintained at all times within their design range by means acceptable to the Administration[15], e.g. by one of the following methods:

1. Reliquefaction of vapours.
2. Thermal oxidation of vapours.
3. Pressure accumulation.
4. Liquefied gas fuel cooling.

The above methods are described in more detail in the Table 2, together with potential limitations of these methods for containerships.

[15] "With the exception of liquefied gas fuel tanks designed to withstand the full gauge vapour pressure of the fuel under conditions of the upper ambient design temperature" (this typically would be Type C tanks).

Table 2 - Methods to control tank pressure and temperature, as stated in IGF Code Regulation 6.9.1

Pressure control system	**Description/explanation**	**Considerations**
Reliquefaction systems	These are systems to cool down BOG vapour to reconvert it to liquid. The IGF Code considers such systems could be arranged in different ways[16]: – a direct system where evaporated fuel is compressed, condensed and returned to the fuel tanks; – an indirect system where fuel or evaporated fuel is cooled or condensed by refrigerant without being compressed; – a combined system where evaporated fuel is compressed and condensed in a fuel/refrigerant heat exchanger and returned to the fuel tanks.	Reliquefaction systems may involve high capital costs (to install the system) and operational costs (since energy is required to run the system) (DNV, 2023).
Thermal oxidation systems	The IGF Code regulation 6.9.4 considers thermal oxidation can be done in two ways: 1. Consumption of the vapours by onboard consumers (engines, boilers). 2. Consumption of the vapours in dedicated gas combustion unit (GCU). It shall be demonstrated that the capacity of the oxidation system is sufficient to consume the required quantity of vapours. In this regard, periods of slow steaming and/or no consumption from propulsion or other services of the ship need to be considered.	Concerning Method 1 (consumption of the BOG by ship engines or boilers): – Using the BOG energy can be a flexible and cost-effective way of meeting ship energy demand (DNV, 2023). – Attention needs to be given to which onboard consumers are most suitable for consuming the BOG. For certain consumers, BOG may have to be conditioned to be used as fuel (DNV, 2023). – For some consumers like high-pressure (diesel cycle) main engines, BOG would first need to pass through high-pressure gas compressors, increasing complexity (DNV, 2023). Concerning Method 2 (consumption of the BOG in a GCU): – This is usually not considered a good option as the efficiency of converting heat to power is comparatively low and dumping the heat from the CGU would waste the energy contained in the BOG (DNV, 2023).

[16] If the reliquefaction system produces a waste stream containing methane during pressure control operations within the design conditions, these waste gases shall, as far as reasonably practicable, be disposed of without venting to atmosphere (IGF ode Regulation 6.9.3).

Pressure control system	Description/explanation	Considerations
Pressure accumulation	Allowing the BOG to increase the pressure in the tank.	This is only suitable for Type C tanks. Another option could be to transfer the BOG to a dedicated extra tank however this involves high technical effort and cost (DNV, 2023).
Liquefied gas fuel cooling	Concerns cooling of the tank to keep the LNG in liquid state.	Installing a sub-cooler involves both additional CAPEX and OPEX but will increase operational flexibility. This is an option whenever other measures are not feasible or less cost-effective. In cases where a ship has high pressure (diesel cycle) main engines and does not have auxiliaries able to run on gas then such systems might be needed (DNV, 2023).

As indicated in Table 2, managing BOG through reliquefaction systems or sub-cooling entails high capital and operational costs. Management via pressure accumulation is also only feasible for ships equipped with Type C tanks. On the other hand, consumption of BOG in auxiliary engines to generate electricity which is in any case needed, brings flexibility and costs benefits. These reasons make the consumption of BOG in auxiliary engines the most favourable option for containerships (DNV, 2023). The prominence of this method by containerships today was also highlighted in interviews and reinforced in the inventory conducted for this study (discussed in full detail Chapter 4). Indeed, the majority of LNG-fuelled containerships in operation today are equipped with Type B or membrane tanks, both of which have low pressure tolerance and thus limited ability to manage BOG through pressure accumulation. The inventory further revealed that these ships generally lack reliquefaction systems and dedicated gas combustion units. While the presence of sub-cooling systems could not be verified, they are associated with additional costs (as shown in Table 2), and no literature could be found suggesting that sub-cooling is commonly used in practice on containerships. As a result, thermal oxidation - specifically, the use of BOG by onboard consumers - is in this study assumed to be the primary method for managing BOG on containerships with Type B or membrane tanks. This is also reflected in the analysis of Chapter 6 which examines how BOG generated during a stay at berth without OPS can be used onboard the ship to cover at least part of the ship's energy demand. However, when a vessel is connected to OPS, auxiliary engines do not operate which restricts the ship's ability to consume BOG onboard. This presents a limitation to the method of consuming BOG onboard which is also examined in Chapter 6 for port calls when OPS is mandatory.

Looking ahead, the increasing enforcement of OPS requirements and growing operational experience with LNG-fuelled containerships using OPS may lead to a wider adoption of other BOG management methods by containerships, or a combination of different methods. Importantly, it is expected that widespread use of OPS by LNG containerships is yet to occur: all LNG-capable containerships have been built or retrofitted since 2020 - many even more recently - and most have dual-fuel capability, allowing them to operate on conventional fuels without using LNG. Additionally, while some regional regulations mandate OPS use in specific ports, some of these requirements do not take effect until 2030 while others include exemptions for LNG-fuelled ships. Even in regions where OPS use is required for LNG vessels, these ships are not always deployed on routes that call at such ports. For instance, one shipping company interviewed for this study indicated that none of its LNG-capable ships had yet connected to OPS. As such, operational experience of using OPS with LNG fuels as well as more certainty on the legal framework which is now in place for OPS may lead to different BOG management methods being used in the future. Evidence of such a change in approach is already present in data for LNG capable containerships on order, which is discussed in Chapter 4.

Importantly, the chosen method of controlling tank pressure and temperature should be capable of maintaining tank pressure below the set pressure of the tank pressure relief valves for a period of 15 days. This applies also when the ship is in idle condition, i.e. if only power for domestic load is generated (IGF Code Regulation 6.9.1.1). Venting of fuel vapour (BOG) for control of the tank pressure is not acceptable except in emergency situations (IGF Code Regulation 6.9.1.2).

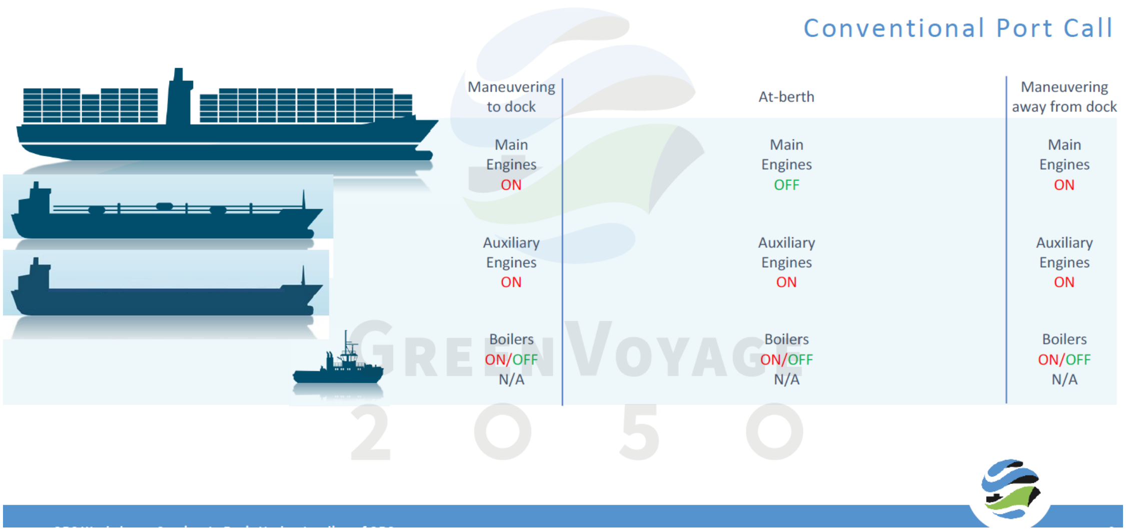
3 Containerships and Onshore Power Supply

3.1 Regulatory requirements to use OPS

Internationally, there are a number of regulations which require large containerships to use Onshore Power Supply (OPS) - or equivalent emission reduction technologies - while at berth.

In essence OPS is a technology that enables a ship to receive electricity from the shore while at berth instead of generating its own electricity by means of onboard (generally fossil fuel powered) generators. This electricity from shore is then used to cover the ship's power demand at berth. The basic concept of OPS is illustrated in the following figures. Figure 1 shows a conventional port call while Figure 2 shows a port call where OPS is used.

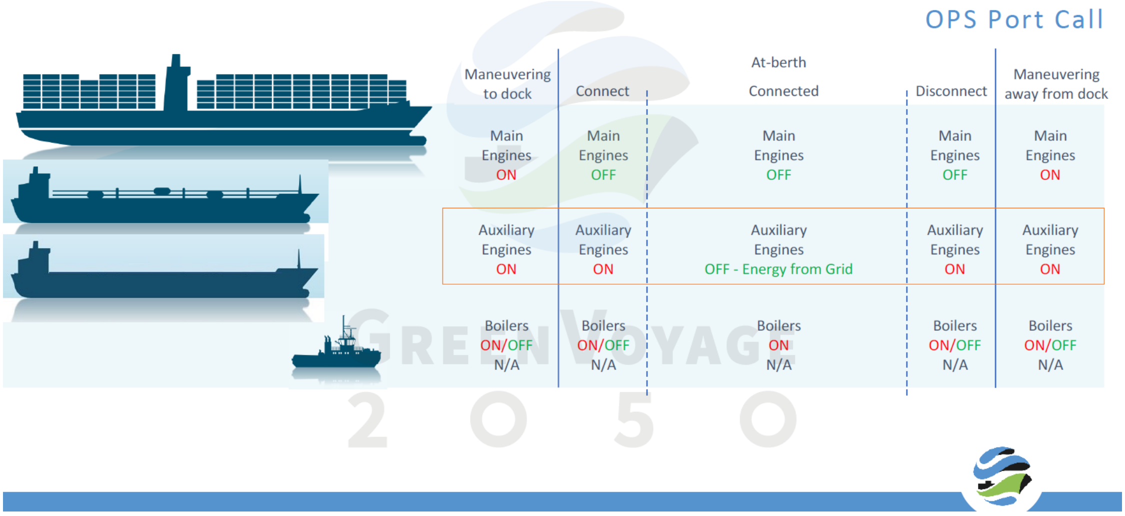
Figure 1 - Illustration of ship onboard consumers used during a conventional port call



Source: (IMO-Norway GreenVoyage2050 Project, 2023).

Content

Figure 2 - Illustration of ship onboard consumers used during a port call when Onshore Power Supply (OPS) is used



Source: (IMO-Norway GreenVoyage2050 Project, 2023).

Whereas under a conventional port call a ship generates power via its auxiliary engines which in turn feeds the ship's electrical switchboard, in an OPS port call the electricity comes from shore so the ship's auxiliary engines are switched off. This is important for containerships running on LNG because it means that BOG which may ordinarily have been expended in auxiliary engines has to be managed in another way, otherwise its accumulation will increase pressure in the LNG tank. Still, during both a conventional and OPS port call, ship boilers continue to run via their conventional power source. This is because ship boilers generally operate independently of a ship's electrical grid - the energy production and distribution has no electrical distribution phase (EMSA, 2022a). That being said, there are examples of electric steam boilers for ships on the market (ICCT, 2023) but this is not the norm on most ships today[17]. During an OPS port call there is also lag-time between the ship's arrival at berth and the actual completion of the shore-connection (generally up to 2 hours) during which time the ship will have to run auxiliary engines for required power[18].

Two prominent examples of regulations requiring containerships to connect to OPS are discussed hereafter.

---

[17] Certain marine boilers can also be configured as electric hybrids (Alfa Laval, 2025b). These boilers must however be delivered as hybrid-ready from the start as retrofitting is not an option (Alfa Laval, 2025b).

[18] In California, ships using shore power are allowed to run their auxiliary engines for up to three hours while at berth to connect/disconnect from shore power (CARB, 2020).

3.1.1 FuelEU Maritime Regulation

FuelEU Maritime (EU, 2023) has been applicable to certain ships calling EEA (European Economic Area) ports to reduce climate but also air pollution and sets two main requirements:

1. An annual GHG intensity limit for all ships subject to the Regulation (since 1 January 2025).
2. An obligation for certain ships ≥ 5,000 GT to use OPS or another 'zero emission technology' at berth (from 1 January 2030).

In particular, the second requirement is relevant to this study because it applies to containerships[19]. The obligation for containerships to connect to OPS starts on 1 January 2030 according to the schedule presented in Table 3. Note that containerships may also connect to OPS (where available) earlier than 2030 as a means to reduce the ship's overall GHG intensity but this is on a voluntary basis.

Table 3 - Types of ports where containerships must connect to OPS or use a ZET in accordance with the FuelEU Maritime Regulation and related timeline

Timeline	Type of port
From 1 January 2030	TEN-T core and comprehensive ports which, as an annual average between 2027-2029 received more than: – 100 port calls from seagoing containerships above 5,000 GT; – 40 port calls from seagoing ro-ro passenger ships and high-speed passenger craft above 5,000 GT; – 25 port calls from seagoing passenger ships above 5,000 GT. A list of identified TEN-T comprehensive ports can be found in in Annex II of the Union Guidelines for the TEN-T network.
From 1 January 2030 – 31 December 2034	In ports that are not covered by the above provisions but which a Member State has, after consulting all relevant stakeholders, nonetheless decided to apply the requirement to that port or parts of it (i.e. certain terminals).
From 1 January 2035	Any other port under the jurisdiction of an EU Member State where the quay is equipped with OPS.

Source: Authors, based on Article 6 of the FuelEU Maritime Regulation.

Importantly, ships operating gas or oil-fired boilers, for either hot water, vapour services or other purposes, at berth, will not have to switch them off (EC, 2025a). This means LNG containerships could potentially consume BOG in such boilers on board. But all electrical power demand from this ship should come from the shore and not from the ship's onboard generations.

[19] Defined as: ships designed exclusively for the carriage of containers in holds and on deck. Ships which do not exclusively carry containers such as general cargo, Ro-Ro, or Ro-Con are not subject to the requirement. Passenger ships are also in scope of the requirement.

The FuelEU Regulation does permit a number of exemptions to the requirement for use of OPS, such as berth stays under 2 hours and for safety reasons. It also allows the use of so-called zero-emissions technologies instead of OPS. However the use of LNG does not make a ship eligible for any exemption under FuelEU and nor is LNG considered a zero-emissions technology.

3.1.2 California Air Resources Board (CARB) Regulations

In the US state of California an ‘At-Berth Regulation’ was first approved in 2007 which set emission or power reduction requirements for various ships at berth to reduce air emissions. It first targeted containerships, passenger ships, and refrigerated-cargo ships at six California ports (including the major container ports of Los Angeles and Long Beach) with compliance requirements that began in 2014. Connecting to shore power was one of the ways in which ships could reduce their at berth emissions in line with the Regulation, although other compliance options were possible. It has been widely seen as one of the main drivers of OPS development in the shipping industry.

More recently, a revised, ‘2020 At-Berth Regulation’ has been in place for a wider range of ship types with compliance to that regime having started for containerships in 2023. Under the Regulation shore power is considered the ‘gold standard’ in reducing emissions from ocean-going vessels in California (CARB, 2024). That being said, other compliance options - including the use of certain alternative fuels - are possible pending confirmation of their eligibility as a ‘CARB Approved Emission Control System’ (CAECS). The use of LNG does not provide automatic compliance to the Regulation. However if an operator can provide testing data showing the vessel’s emissions meet or exceed the standards provided by the Regulation, then LNG (in certain engines) could potentially be approved as a CAECS (CARB, 2024).

Like the FuelEU Maritime Regulation, ship boilers are not in scope of the requirement so may continue to operate as normal (CARB, 2024). The exception is tanker vessels where ship boilers are in scope if used to operate steam driven pumps (CARB, 2024).

3.1.3 Other international drivers/regulations on OPS

In addition to the above examples, there are other regulations which may require or encourage containerships to connect to OPS in the future.

In 2012, the Ministry of Transport of China set a technical code (JTS155-12) stating that OPS should be included in the design and construction of new container, bulk, cruise, and RO-Pax terminals (EMSA, 2022b). In the same country, the Marine Environmental Protection Law also considers (article 88) that ‘when reaching a port, a vessel with good conditions for the use of shore power, other than one that uses clean energy, shall use shore power in accordance with the relevant provisions issued by the state’ (Japan P&I Club, 2024). However it is understood from interviews conducted during this research that ships using LNG may be exempted from this OPS requirement in China, at least in certain ports, on the grounds that LNG is considered cleaner energy than conventional ship fuel.

The IMO has also developed interim guidelines on the safe operation of OPS for ships in port (MSC.1/Circ.1675, 2023), although there's presently no obligation via any existing IMO regulation for ships to actually connect to OPS.

3.2 Availability of onboard OPS connection points on inventorised ships

The establishment of regulations encouraging containerships to use OPS - even if only in certain regions of the world - appears to have had an impact on the uptake of ships of this type with the onboard infrastructure to connect to OPS at berth.

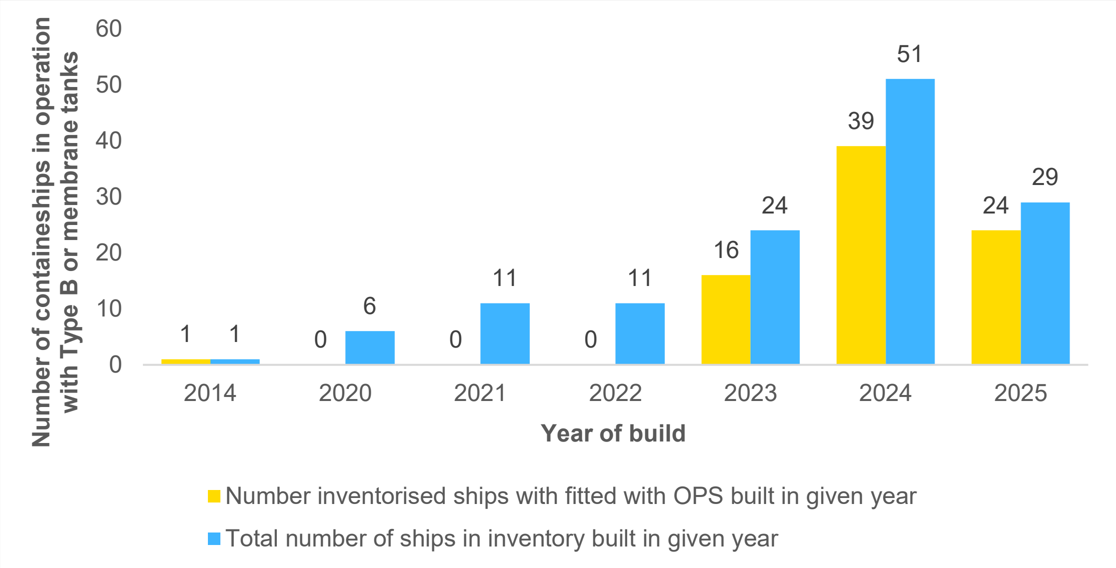
Of the 6,919 containerships in operation in the global fleet of 5,000 GT or greater on 14 July 2025, 1,169 already have the necessary onboard infrastructure installed according to (Clarksons Research, ongoing-b)[20]. This is 17% of containerships of this size.
By comparison, of the global fleet of 68,904 ships of any kind of 5,000 GT or greater only 3,238 have the necessary onboard infrastructure for OPS (5%) (Clarksons Research, ongoing-b).

As well as the regulatory framework encouraging containerships to use OPS, it is also considered that compared to other ship types, the design of containerships might facilitate the installation or onboard conversion for the necessary ship-side infrastructure for OPS connections. Taking advantage of modularization, containerships can expend one 40 ft container slot to install a modular OPS unit, containing all necessary control systems, circuit breakers, cable reel, and - whenever necessary - transformers and frequency converters (EMSA, 2022b).

The inventory carried out for this study found that 80 of the 133 inventorised ships in operation with Type B and membrane LNG tanks have an OPS connection point fitted onboard (see Figure 3).

[20] Note: Data is available only for High-Voltage Shore Connection Points (HSVC) and whether they are 'fitted' onboard the ship. Note that low voltage shore connections also exist but these are not given as a parameters in Clarkson's World Fleet Register. High voltage shore connections are considered most relevant for seagoing containerships (Annex II of the AFIR on technical specification for seagoing ships references an international standard for high-voltage shore connections).

Figure 3 - Inventorised fleet of containerships with LNG membrane and Type B fuel tanks - available data on fitted OPS connection by year of build



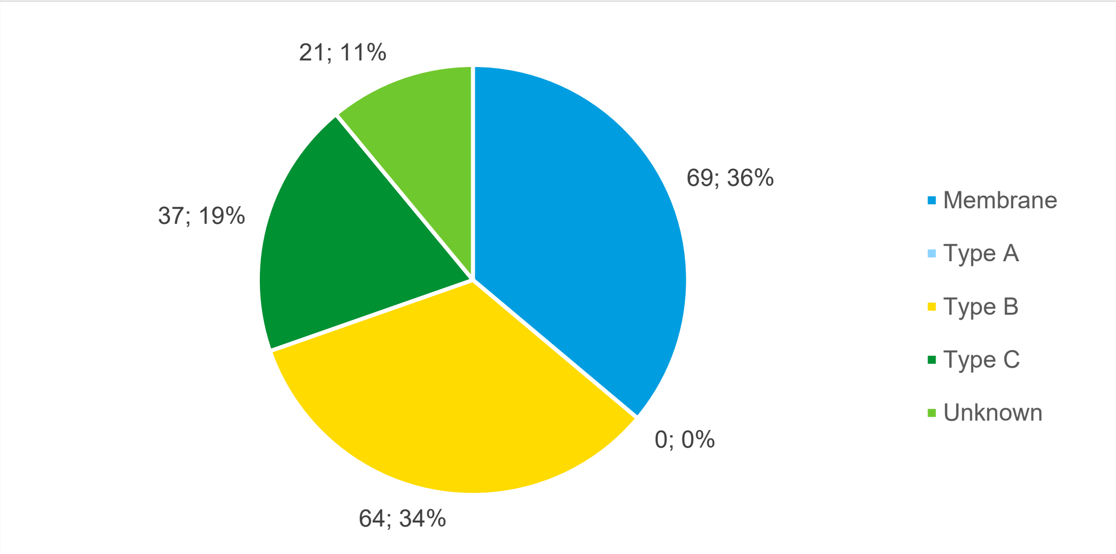
Source: Authors, based on (Clarksons Research, ongoing-a).

Figure 9 also shows that a much higher share of the inventorised ships built since 2023 have OPS connection points fitted (76%) compared to those built in 2022 or earlier (3.5%). This indicates that more recently built ships may have been designed with more attention to OPS given the increase in regulations which address the technology for containerships, such as the FuelEU Maritime Regulation for which the proposal was launched in July 2021 and the regulation adopted during 2023. For LNG capable container ships on order with membrane and Type B tanks, 60% are expected to be built with onboard OPS connection points installed as of 13 June 2025 (Clarksons Research, ongoing-b). The main results of the inventory are discussed in Chapter 4.

4 Inventory of LNG-capable containerships

In June 2025 there were 191 containerships in operation capable[21] of sailing on LNG. Of these ships, 69 had membrane fuel tanks installed as shown in Figure 4. A further 64 of these ships had Type B tanks, 37 had Type C tanks and 21 had LNG fuel tanks of unknown type. There are no recorded cases of containerships in operation with Type A tanks (Clarksons Research, ongoing-a).

Figure 4 - LNG capable containerships in operation by LNG fuel tank type, as of June 13 2025



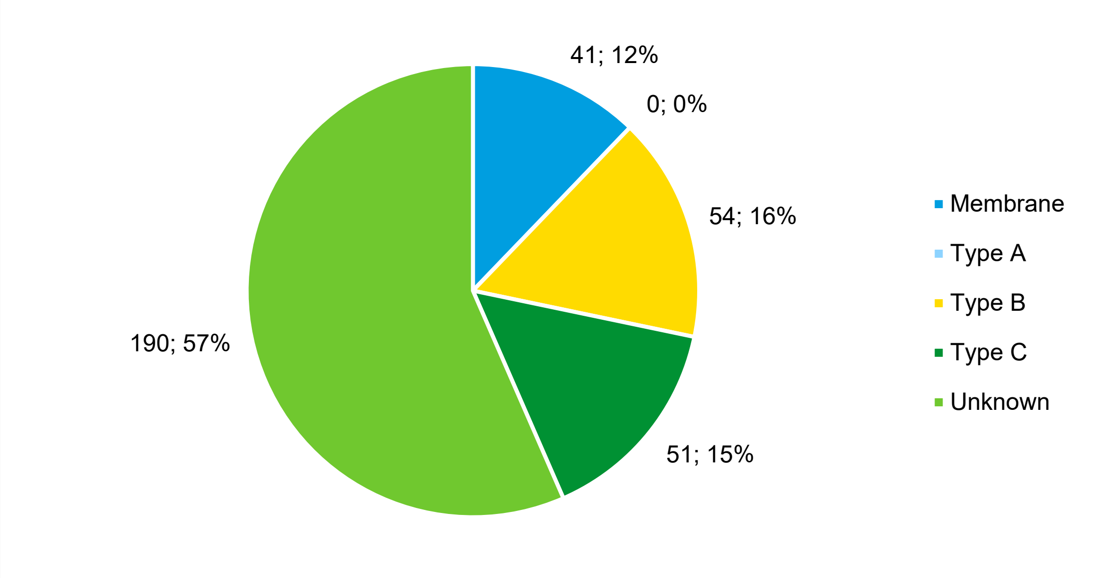
Source: Authors, based on (Clarksons Research, ongoing-a).

On the same date (13 June 2025) there were also 336 containerships on order that will be capable of sailing on LNG. Of these ships, 41 were expected to have membrane tanks and 54 of them Type B tanks as shown in Figure 5. A further 51 of them were expected to have Type C tanks. For 190 of the containerships on order the LNG fuel tank type to be installed was unknown. None are expected to have Type A tanks. (Clarksons Research, ongoing-b).

[21] This means containerships ships which, according to Clarksons World Fleet Register, have a main engine fuel type as one of the following: IFO 380, LNG; LNG ULS IFO; LNG, VLS IFO or LNG, VLS MDO.

Content

Figure 5 - LNG capable containerships on order by LNG fuel tank type, as of June 13 2025



Source: Authors, based on (Clarksons Research, ongoing-a).

It can be concluded that membrane and Type B tanks are the most common LNG tanks for containerships in operation today. These tanks are comparable in the sense that they are both tanks which are not designed to handle large pressure accumulation. It is therefore likely that ships with both these tanks employ similar methods to manage the BOG to avoid over-pressure in the tank. The dominant method for these ships is understood to be thermal oxidation (Section 4.2.1 discusses the large number auxiliary engines which are typically installed). However, concerning new-build containerships it is clear that Type C tanks will be more prominent, representing 34% of the ships for which the type of tank to be installed is known as of 13 June 2025. These tanks are, in contrast to membrane and Type B tanks considered to be generally less space efficient which may come at a cost of cargo carrying capacity. On the other hand, Type C tanks are designed to be able to safely accumulate pressure and thus also BOG. This means the method of pressure accumulation as presented in Table 2 may also be used by the ship to manage BOG, or at least present a longer holding time for the ship before BOG has to be managed via consumption (thermal oxidation). Based on interviews conducted as part of this research, a reason for a shift towards Type C tanks is partially due to a desire to have more options to manage BOG. However other reasons are that certain designs of Type C tanks (bilobe or trilobe shapes) enable higher space efficiency and increasing experience among shipyards and suppliers to deliver Type C tanks and related onboard systems.

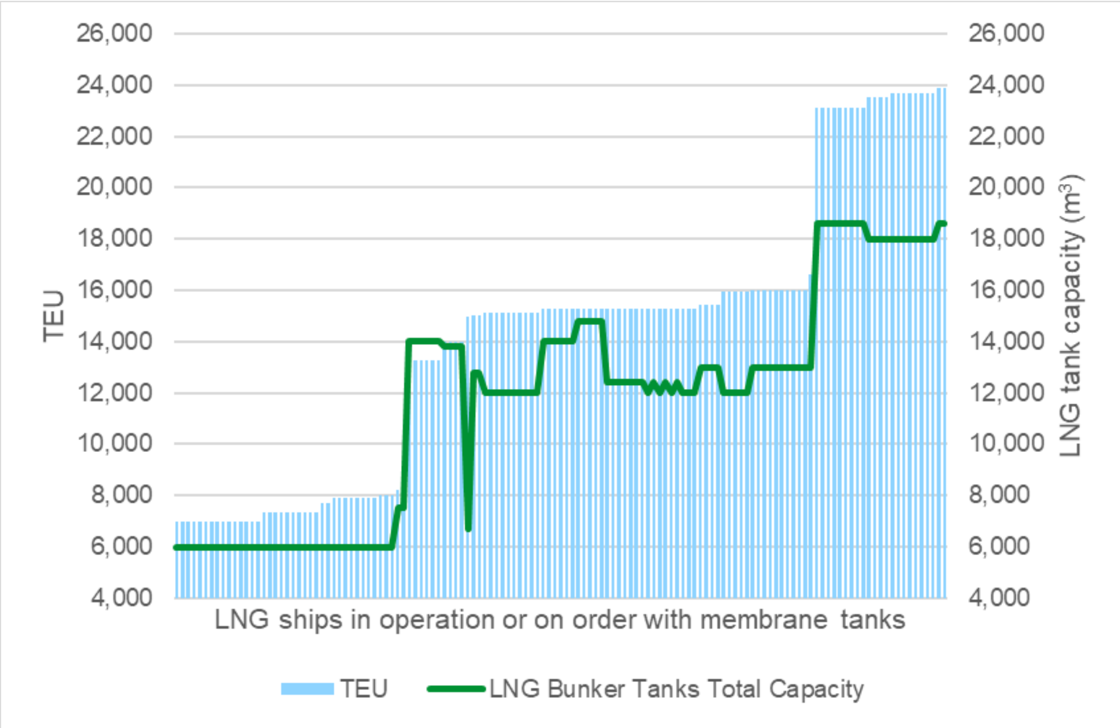
A detailed inventory of LNG capable containerships with membrane and Type B tanks was taken as of 13 June 2025. The inventory focussed on these tank types because they are presently the most common and are both low-pressure tanks which, unlike Type C tanks, do not have the ability to accumulate large amounts of BOG for long periods.
The challenge to manage BOG at berth is therefore considered to be higher for

membrane and Type B tanks. In the following section, the main features of this fleet are discussed. Most focus is however placed on the fleet in operation for which more technical data is available than the fleet on order.

4.1 TEU and LNG tank size of LNG containerships

Figure 6 shows there is a wide range in the size of containerships in operation and on order with Type B and membrane LNG tanks. Measured in TEU[22], there are ships of up to 24,000 TEU with these tanks, which are among the largest containerships in the world. However, there are also significantly smaller ships with these tanks (around 7,500 TEU) as well as many ships in the middle of this TEU range. The average TEU capacity of the inventorised fleet in operation is 14,276 TEU. By means of comparison, the term 'megaship' is usually used to describe containerships of 18,000 TEU or more (TOC Logistics, 2017) so the average sized ship in the inventory is still a very large ship.

Figure 6 - TEU and LNG tank size of containerships with Type B and membrane LNG tanks - in operation and on order



Source: Authors, based on (Clarksons Research, ongoing-a).

[22] TEU describes how many 'Twenty-foot Equivalent Unit' containers the ship can carry.

Figure 6 also presents the size of a ship's LNG tank, measured in cubic metres of storage capacity LNG, in relation to its TEU carrying capacity[23]. The LNG storage capacity in Figure 6 is the ship's total storage capacity for LNG fuel: for all of the ships inventorised, one single LNG membrane tank is/will be installed to store the LNG fuel, in contrast to the storage of conventional fuels which typically takes place in multiple tanks[24].

As may be expected, Figure 6 shows that larger ships have in general also larger LNG fuel tanks. For example, the largest ships in the range of 24,000 TEU also have the largest LNG storage tanks (up to 18,600 m^3) while the smallest ships in the range from 7,000-8,024 TEU all have LNG fuel tanks of 6,000 m^3. However, as represented in Figure 6, there is a bit more variety in the size of the ship's LNG tank for ships in the middle of the TEU range: for example there are several ships of 13,264 TEU with LNG tanks of 14,000 m^3 while another ship of 14,993 TEU has an LNG tank of only 6,700 m^3. The latter differences potentially relate to the geographic trade of the ship, which may dictate how frequently the ship can bunker LNG, as well as differences between companies and shipyards with regard to the chosen design and operating strategy for the ship. In one case a contributing reason for a relatively small LNG tank volume compared to the ship's TEU size is likely because the ship was not originally designed to operate on LNG but was retrofitted during its operational life.

4.2 BOG management systems on containerships

4.2.1 Dual fuel auxiliary engines

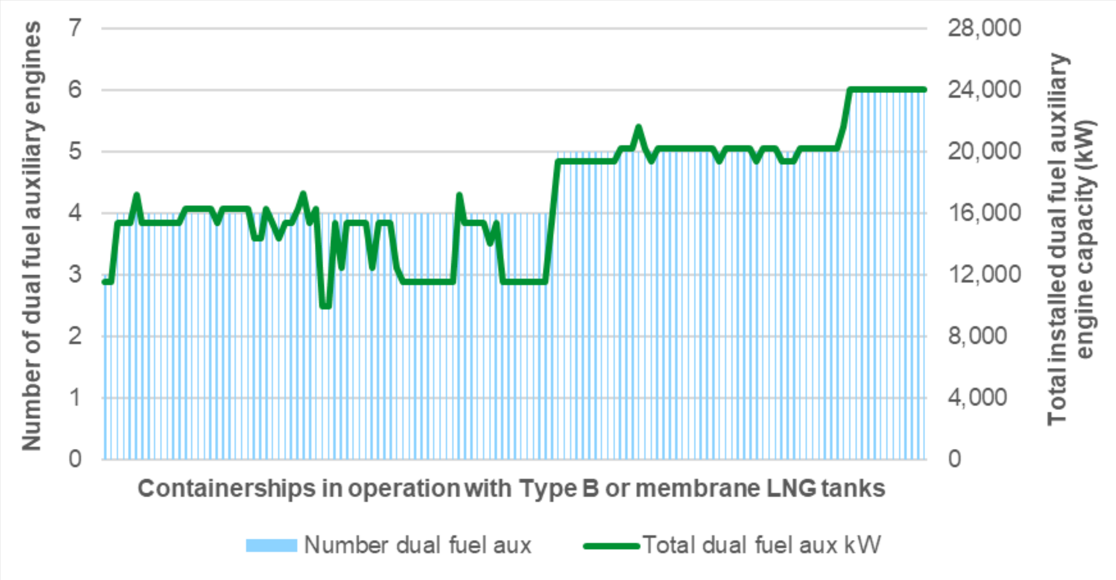
Besides the main engine, the inventorised containerships usually have 4 or 5 dual fuel auxiliary engines installed, as presented in Figure 7. Dual fuel means the auxiliary engines are designed to operate on gaseous as well as liquid fuel (such as diesel). These engines can thus consume BOG as fuel. The inventorised containerships all have at least 3 dual fuel auxiliary engines and in some cases up to 6.

---

[23] For four ships, the LNG tank capacity was not available but was assumed to be the same as ships of the same TEU and GT as ships in the same company (most likely sister ships).

[24] In some ships with Type C LNG tanks, the fuel is also stored in more than 1 LNG tank.

Figure 7 - Number of total mechanical power of dual fuel auxiliary engines installed on containerships in operation with LNG membrane tanks



Source: Authors, based on (Clarksons Research, ongoing-a).

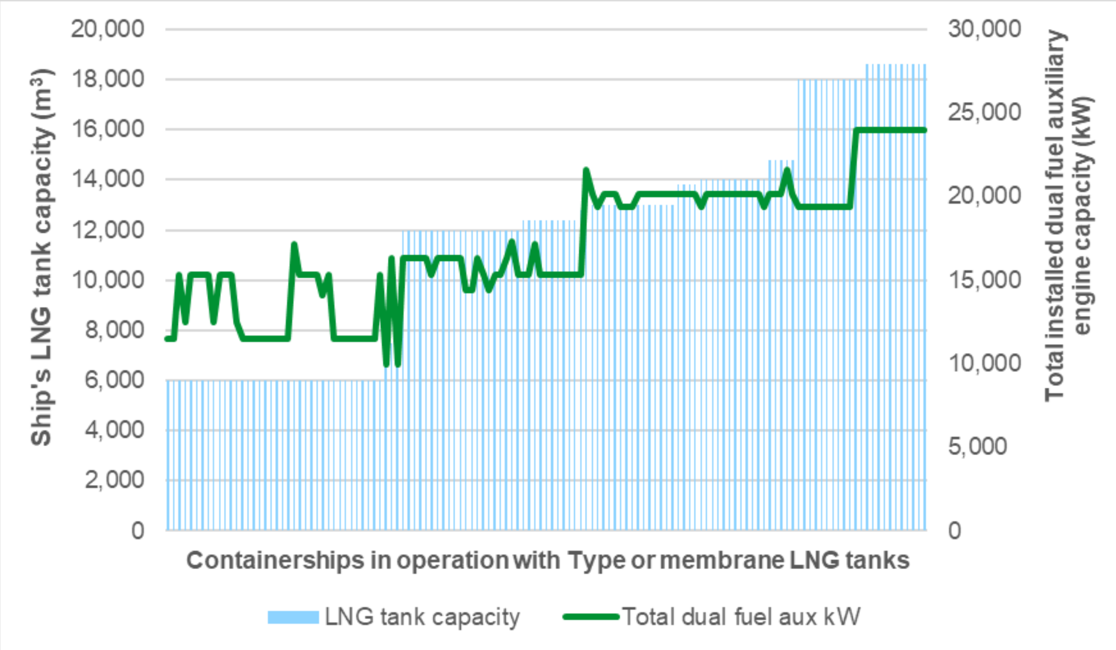
On an individual level, the installed dual fuel auxiliary engines have a mechanical power of 2,880 kW up to maximum of 4,500 kW. The average power per dual fuel engine across the inventorised fleet is 3,800 kW. Slightly over half of the inventorised fleet have dual fuel engines of the same series from the same manufacturer. The fuel consumption of these engines is around 184 g/kWh in diesel mode and 7,270 kJ/kWh in gas mode at 100% load (HEC, 2025). The fuel consumption in gas mode would correspond to 148 gram BOG per kWh assuming the BOG is 100% methane[25].

The total mechanical output power of each ship's dual fuel auxiliary engines is also plotted in Figure 7 (see green line). This is the total mechanical power that can be produced by the ship's installed dual fuel auxiliary engines, which is then converted into electrical power (ekW) via the ship's onboard generators, subject to generator and alternator efficiency. The largest total mechanical power of the dual fuel engines for the inventorised ships is 24,000 kW and the smallest 9,975 kW. The average is 17,238 kW. The high power of installed dual fuel auxiliary engines is an indication that the ship's strategy to manage BOG is to consume it in these engines.

[25] 7,270 kJ/kWh divided by 49.1 MJ/kg (the Lower Heating Value of methane) = 148.1 g/kWh.

The inventory also shows that ships with larger LNG fuel tanks in general also have larger total installed dual fuel auxiliary engine capacity (see Figure 8). For example, the series of ships with the largest LNG fuel tanks of 18,600 m^3 also have the largest total installed dual fuel auxiliary engine capacity of 24,000 kW. However that trend is not always true: for instance there are ships with large LNG tanks of 18,000 m^3 with a total installed dual fuel auxiliary engine capacity of 'only' 19,380 kW. Conversely, there are ships with relatively small LNG tanks of 6,000 m^3 and a total installed dual fuel auxiliary engine capacity over 15,000 kW.

Figure 8 - LNG tank size of inventorised ships and installed dual fuel auxiliary engine mechanical power



Source: Authors, based on (Clarksons Research, ongoing-a).

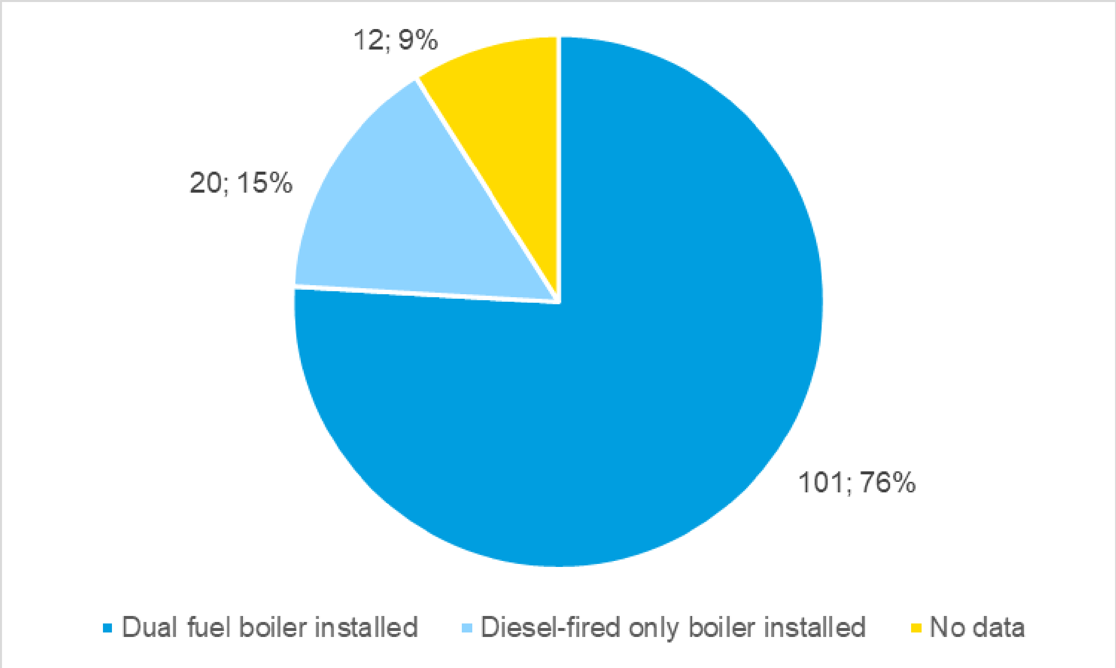
4.2.2 Dual fuel boilers

Figure 9 shows that the vast majority of LNG containerships in operation with membrane and Type B tanks have a boiler installed which is capable of running on gas or on diesel and gas. Out of the 133 containerships in operation with membrane or Type B fuel tanks, 101 have a dual fuel boiler installed and only 20 have a boiler that is listed to be diesel fired only. There are also 12 containerships for which no data about any installed boiler is available[26]. Figure 9 shows only the containerships with Type B and membrane LNG tanks in operation due to insufficient data availability about the boilers for the ships on order.

[26] It is expected that all ships will have a boiler so the explanation is most likely that data simply was not available when the database was compiled rather than an actual absence of a boiler onboard the ship.

Content

Figure 9 - Number of LNG capable containerships with LNG membrane and Type B in operation with dual fuel boilers



Source: Authors, based on (Clarksons Research, ongoing-a).

The capacity of ship boilers is generally measured in their output of steam in kg or ton per hour. However details on the specific capacity of boilers installed is not available for most of the inventorised ships. What is more commonly available is the model range that is installed on the ship, without the specific capacity of the installed dual fuel boiler.
The available information is listed below as an indication:

- 33 ships have a dual fuel boiler from a model range with capacities of 1.2-6.5 ton/hr steam;
- 6 ships have a dual fuel boiler installed with a specific capacity of 12 ton/hr steam;
- 18 ships have a dual fuel boiler from a model range with capacities of 12.5-55 ton/hr steam.

The consumption of BOG in ship boilers in discussed in more detail in Section 5.2.2.

4.3 BOG management systems not installed on inventorised fleet

While the inventory revealed that neither of the following systems are commonly installed on LNG capable containerships, a brief description of reliquefaction and dedicated gas combustion systems is nonetheless given here together with the extent of information that was found in the inventory or other literature. This is because these systems are noted in the IGF Code as possible methods to control tank pressure and temperature within the tank design range (see Table 2) and so these methods could potentially be used by containerships if the necessary equipment were installed (where technically and operationally viable). Note that Table 2 also includes the method of liquefied gas fuel cooling (e.g. sub-cooler systems) however no data could be found on this method on the database consulted for the inventory, nor evidence of their use by containerships in other literature.

4.3.1 Gas Combustion Units

A Gas Combustion Unit (GCU) is a specialised unit that can be installed on ships with the express function of burning BOG.

At present, GCUs appear to be most frequently installed on LNG carriers and less frequently installed on other gas-capable ships such as containerships. Indeed, the total amount of BOG generated on gas carriers is likely to be far higher than on containerships simply due to the size of the LNG cargo tanks: the largest LNG carriers can carry upwards of 266,000 m^3 LNG (Nakilat, 2025) compared to the largest LNG fuel tank inventorised for this research (18,600 m^3).

No cases of GCUs being installed onboard containerships were recorded in the database used to compile this inventory. That being said some container shipping companies do make reference to gas combustion units in annual reports in the context of advanced technologies to reduce methane leakage for LNG-fuelled vessels (CMA CGM, 2024).

4.3.2 Reliquefaction systems

Reliquefaction is the process of returning evaporated BOG back into a liquid state and returning it to the LNG tank. This takes place in a dedicated onboard reliquefaction system outside the LNG tank.

Reliquefaction systems are quite common on LNG gas carriers. Of the 830 LNG carriers in the world fleet on 10 June 2025, 363 (44%) are thought to have some form of reliquefaction system onboard[27] (Clarksons Research, ongoing-a). However according to Clarksons research there are no LNG capable containerships with reliquefaction systems installed (Clarksons Research, ongoing-a)[28]. Potential reasons why containerships do not have reliquefaction systems are high CAPEX as well as high OPEX due to the increased energy demand (DNV, 2023). Dedicated reliquefaction systems may also take up too much space to be viable for containerships. One the other hand, recondensing systems (similar to reliquefaction but on a smaller scale) are known to be available in the market for LNG containerships (discussed in Section 6.4.4).

[27] This counts full and partial reliquefaction systems, based on the data available.
[28] As of 28 July.

5 Energy demand of containerships at berth

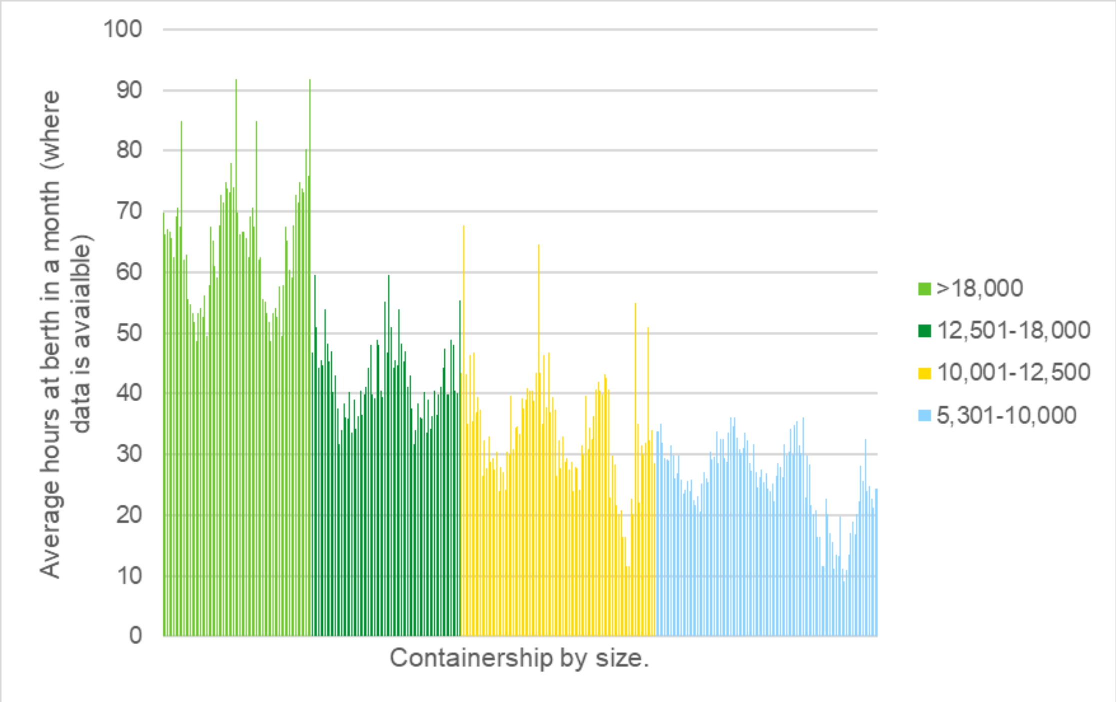
The energy demand of a containership at berth depends on the time the ship remains at berth as well as the systems the ship uses during that time. This chapter first discusses time at berth by containerships and then energy demand, which is split into electrical and thermal energy demand.

5.1 Time at berth

Detailed international data on the time that ships spend in port is generally presented in terms of the port call as a whole and not specifically the time the ship spends at berth. UNCTAD for example presents bi-annual data on the median time ships spend in port limits per port call, showing for 2023 0.99 days (23.8 hours) for all ships of 1,000 GT of greater (UNCTAD, 2024). The same data source also shows large varieties per ship type: for example dry bulk carriers spent a median time of 2.13 days (51 hours) in port while containerships spent a median time of 0.71 days (17 hours) in port. However this data covers the time ships spend within port boundaries overall (UNCTAD, 2025), some of which may have been spent manoeuvring, waiting at anchorage or other activities. The data is also aggregated for all ships greater than 1,000 GT while the ships that have been inventorised for this study are on average 14,276 TEU.

Detailed international data on the time spent by containership's at berth is, on the other hand, less widely available. The duration of a containership's stay at berth naturally depends on the amount of cargo to be loaded/unloaded from the ship (itself a function of the ship's size) and the efficiency of the terminal to carry out this process. Both of these factors are expected to vary from port to port and region to region. Figure 10 presents data from the Port of Rotterdam which does provide more granular data for the time containerships spend at berth within the port.

Figure 10 - Monthly average time spent at berth, January 2022-December 2024 for deepsea and feeder containerships at the Port of Rotterdam



Source: Authors, based on (Port of Rotterdam, 2025).

Note: Months without available data have been excluded.

As could be expected, Figure 10 shows that larger containerships in general spend more time at berth than smaller containerships (presumably due to more cargo being loaded/unloaded). The longest monthly average for time spent at berth is 91.9 hours while the lowest monthly average is 10.9 hours. The overall monthly average time spent at berth for all the containership sizes presented in Figure 10 is 39.5 hours however for the largest two ship categories the average is 53.7 hours. It is recalled that the majority (70%) of ships inventorised for this study are greater than 12,501 TEU (Section 4.1).

Figure 10 also shows a difference in time spent at berth by season: for most of the size categories the peaks are at the start, end and middle of the year while ships on average spend less time at berth in the months in-between. Again, differences in time at berth due to seasonality are likely to depend on the region of the port.

5.2 Containership energy demand at berth

When a ship is at berth, it no longer needs energy for propulsion. However, even without propulsion, ships may require a significant amount of energy at berth as several of the ship’s systems still need to operate. This includes ventilation, heating, cooling, pumps, control systems and - for some ships - cargo handling systems (GloMEEP, 2020).
For containerships, significant amounts of energy may also be needed at berth for

refrigerated containers but energy for cargo handling systems can probably be excluded. For fully cellular containerships (which is the ship type inventorised) loading/unloading of cargo takes place via specialised cranes at the quayside. Indeed, none of the LNG capable containerships of any tank type are ‘geared’ (Clarksons Research, ongoing-a) so there are no onboard cranes for loading/unloading containers. Where these are installed for other ship types the use of these cranes would significantly add to the ship’s energy demand at berth.

Most of the energy needed by ships at berth is electrical power, which is generated during most port calls via onboard generators connected to the auxiliary engines. However a certain share is thermal power deriving from diesel or gas fired boilers. Studies examining the share of energy consumption by ships in port (not necessarily at berth) suggest 70.5% of the energy consumption derives from auxiliary engine use and 29.5% from using the boiler (Aijou et al, 2019). That being said, the share of energy from ship boilers for dual fuel ships is likely lower than conventional fuelled ships which may have a higher demand for steam to keep viscous fuels like HFO in a liquid state.

5.2.1 Electrical energy demand

In terms of electrical power demand of containerships at berth, estimates can be found in literature such as presented in Table 4.

Table 4 - Electrical power demand of containerships per size

Gross tonnage	Average power demand (MW)	Peak power demand (MW)
< 10,000	1.5	2
< 50,000	2	5
> 50,000	4	6

Source: (EMSA, 2022a).

As shown in Table 4, the power demand of a containership is not stable: there are peaks depending on the systems the ship has to run onboard at a given time (for instance to temporarily run pumps or mooring winches) but still the average power demand from ships can be high. In the case of a containership greater than 50,000 GT an average power demand of 4 MW is considered. However it should be noted that all of the inventorised ships are significantly larger than 50,000 GT: the smallest is 81,770 GT and the largest is 224,995 GT. In terms of a maximum electrical energy demand of containerships, 7.5 MVA is foreseen in the international norm IEC/IEE 80005-1 for high-voltage shore connections (Bernacchi, 2019).

Other estimates on the energy demand of containerships were gathered during this research as presented in Table 5. The table distinguishes between baseline energy demand without reefers and energy demand from reefers, depending on the number installed. The total energy demand is given in column 5.

Table 5 - Containership energy demand indications gathered via interviews. Table assumes reefer demand of 3.6 kW per TEU of loaded and active reefers

Containership size (TEU)	Baseline energy demand (excluding reefers) (kW)	Example TEU of active reefers	Energy demand from reefers (kW)	Total energy demand (kW)
3,000-8,000 TEU	1,000	200	720	1,720
3,000-8,000 TEU	1,000	600	2,160	3,160
3,000-8,000 TEU	1,000	1,000	3,600	4,600
> 8,000 TEU	1,200-2,500	600	2,160	3,360-4,660
> 8,000 TEU	1,200-2,500	1,000	3,600	4,800-6,100
> 8,000 TEU	1,200-2,500	1,400	5,040	6,240-7,540

Notes: Almost all of the inventorised fleet are greater than 8,000 TEU. The number of reefers installed will be highly variable.

Table 5 shows that the number of active reefer containers onboard a containerships can have a significant impact on the ship's total energy demand. This is discussed in more detail later in this section.

The following (non-exhaustive) list provides an overview of ship systems which are likely to require electrical power during the time a containership is at berth. A more detailed description of energy demand from refrigerated containers and ventilation is given hereafter as these systems are expected to represent the highest energy demand at berth for most containerships:

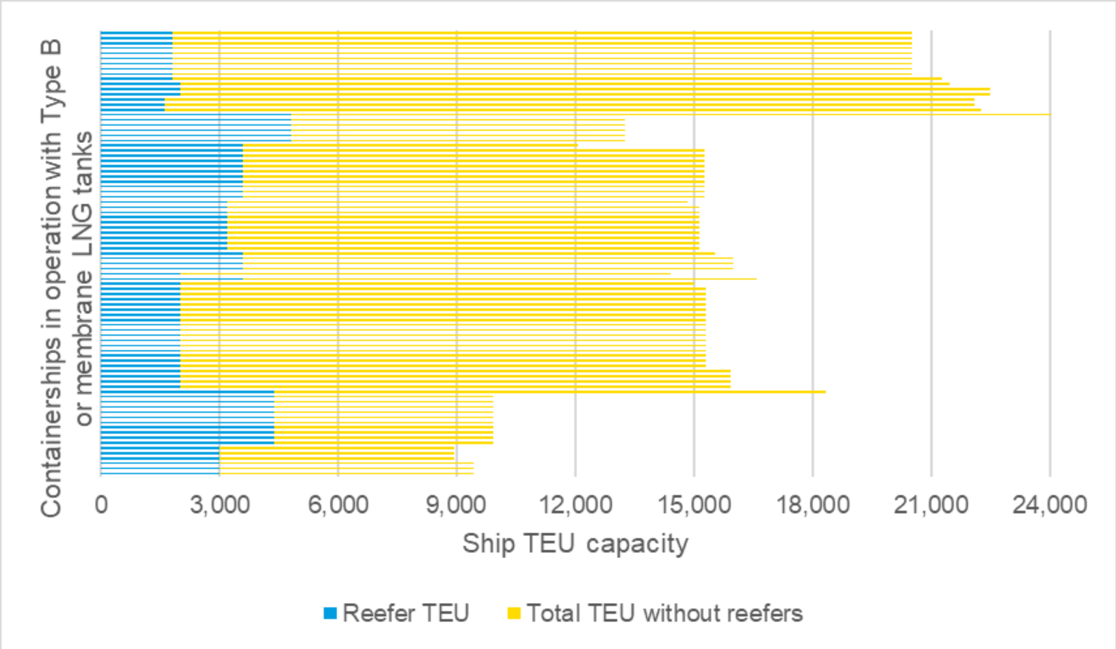
- refrigerated containers;
- ventilation;
- ship service systems: e.g. mooring systems, pumps and machinery;
- accommodation services including lighting;
- deck machinery;
- communication systems/bridge equipment;
- emergency and safety systems.

Refrigerated (reefer) containers

The term 'reefer' refers to refrigerated containers which are equipped with a refrigeration unit that is connected to the power supply on board the ship (Kuehne+Nagel, 2025). The baseload energy demand of a containership at berth is strongly dictated by the number of refrigerated containers (EMSA, 2022b).

Therefore, the inventory for containerships with Type B and membrane LNG tanks also gathered data on the reefer capacity of these ships in TEU compared to the ship's total TEU capacity (see Figure 11).

Figure 11 - Reefer TEU capacity compared to total TEU capacity of containerships with membrane and Type B LNG fuel tanks. Ships without available data on reefer capacity are excluded (44 ships)



Source: Authors, based on (Clarksons Research, ongoing-a).

Note: The figure also not present the reefer capacity for ships on order due to insufficient data availability.

Figure 11 indicates that on average around 20% of the inventorised ship's total TEU capacity could be used by a reefer container. Of these ships, the lowest share of reefer containers is 13% and the highest 36%. While in practice the number of loaded and actively temperature-controlled reefer containers is likely to be highly variable and influenced by the type of trade and route of the ship, the number will have an important bearing on the ship's electrical power demand at berth. A very broad average for the power demand of a single refrigerated container is considered to be 3.6 kW per TEU (20 foot container) while a 40 foot container is around 7 kW (GDV, ongoing). Certain containers may also require a higher degree of cooling (and thus more energy) than 3.6 kW while others may need less cooling. During interviews for this study, estimates for the energy demand per reefer unit reached up to 7 kW per unit (although this is more likely to be a 40 foot reefer container which is 2 TEU). It is estimated that 40 ft 'High Cube' reefer containers account for over 90% of the volume moved in reefer containers globally (Maersk, 2025).

It can be concluded that the amount of reefer containers onboard significantly increases the amount of energy required by a containership and could exceed demand for all other ship systems at berth.

Mechanical ventilation
Mechanical ventilation is needed in various areas of a ship including the engine room and accommodation areas but also cargo holds comprising refrigerated cargoes and certain containers with cargo subject to cooling requirements of the IMDG Code (dangerous goods). Some studies suggest ventilation for a ship's engine room alone can represent between 3.5 and 5.5% of the overall power installed on the ship (Pérez et al, 2016). For LNG and other low-flashpoint fuels the required power for ventilation is potentially even higher than conventional fuelled ships. For example, the IGF Code requires that emergency shut-down protected machinery spaces should have ventilation with a capacity of at least 30 air changes per hour (Regulation 13.5.2) (IMO, 2024b).

It can be concluded that there are multiple onboard systems requiring electrical power while a containership is at berth. In some cases and for the largest ships, the total power required by the ship could reasonably exceed the estimates given in Table 4 and Table 5. The potential for higher energy demand from containerships at berth is also reflected in some regulations. To give an example: the FuelEU Maritime Regulation requires a ship's FuelEU monitoring plan to list the ship's established total electrical power demand at berth in kW. This value can be retrieved from the ship's electrical load balance study or, alternatively, can be considered as 25% of the total of the maximum continuous ratings of the main engine(s) of the ship as specified on the Engine International Air Pollution Prevention certificate, or the nameplate of the engine (OJEU, 2024). By means of example using the option to determine power as 25% of the total MCR of main engines: the largest inventorised ships have a main engine with an output of 63,840 kW so 25% of this would be 15,960 kW. This is a very significant energy demand at berth and more than double the estimates given in Table 4 and Table 5. It is also significantly higher than the max power known for any berth in Europe or Norway today, with one exception for a cruise ship berth of 20,000 kW (EAFO, 2025)

5.2.2 Thermal energy demand

On top of electrical energy, containerships at berth also require thermal energy in the form of steam produced by a boiler. This steam is used for purposes such as:

- hot water generation;
- accommodation heating;
- tank heating (for non-LNG fuel tanks);
- tank cleaning;
- certain air conditioning systems.

Based on interviews conducted for this study, the estimated steam demand for LNG-capable containerships at berth ranges from approximately 1,000 to 4,000 kg of steam per hour. Logically, the amount of steam needed would be higher in winter conditions and lower in summer. On some ships the amount of steam required could also be higher than this estimate - for instance, there are certain types of ballast water treatment systems which rely on heat to neutralise marine organisms present in the water (in contrast to filtration, chemicals or UV processes). The extent to which such ballast systems (or other steam-demanding systems) are installed on containerships is unknown.

6 Boil-off gas formation and consumption at berth

6.1 Potential BOG formation at berth

The amount of BOG that a ship generates at berth depends on three main factors:

- the BOG generation rate comprising both static and dynamic components;
- the volume of LNG in the ship's tank during the time at berth;
- the length of time the ship remains at berth.

However, each of these three factors are variable. Section 2.3 presented BOG generation rates in the region of 0.07-0.32% depending on the technical characteristics of the tank and the operational factors at play. Section 4.1 also showed a wide variety in the capacity of LNG fuel tanks installed on the inventorised fleet (from 6.000 m^3 to 18,600 m^3) and the actual volume of LNG in the tank when a ship arrives at berth is also variable. Furthermore, the time a containership spends at berth also fluctuates as presented in Section 5.1 which showed a range of 11-92 hours for the size of containerships inventorised.

Due to these variable factors, in this analysis we assume different scenarios to estimate - in an approximate way - the potential amount of BOG generated within a Type B or membrane LNG tank when a containership is at berth. The scenarios cover the extremes of both very high and very low BOG formation as well as a scenario in-between.

The three scenarios are presented in Table 6 and all assume that the ship arrives at the berth with no accumulated BOG, although in practice this may not always be possible as explained in Section 6.4.2. We also assume that the BOG is all methane however in practice the specific composition could also contain small shares of other gases as covered in Section 2.2.1. For each of the scenarios a 18,000 m^3 tank is assumed as well as a 6,000 m^3 tank. These are approximately the largest and smallest tanks presently installed on LNG containerships with Type B and membrane tanks as per the inventory carried out in Chapter 4. For each of the three scenarios a slightly higher BOG generation rate is assumed for the 6,000 m^3 tank. This because smaller tanks have a worse surface to volume ratio than larger tanks so may be subject to greater heat ingress per volume of LNG stored.

Table 6 - Scenarios – BOG generation at berth

Parameter	Scenario 1 (18,000 m^3 tank – High BOG)	Scenario 1 (6,000 m^3 tank – High BOG)	Scenario 2 (18,000 m^3 tank - Medium BOG)	Scenario 2 (6,000 m^3 tank - Medium BOG)	Scenario 3 (18,000 m^3 tank – Low BOG)	Scenario 3 (6,000 m^3 tank – Low BOG)
BOG rate (per day)	0.30%	0.32%	0.20%	0.22%	0.07%	0.09%
Time at berth (hours)	75	75	40	40	15	15
Time at berth (days)	3,125	3,125	1,667	1,667	0,625	0,625
Tank fill level at arrival	90%	90%	50%	50%	40%	40%

To estimate the amount of BOG generated during a ship's time at berth in the above scenarios, the following methodology was applied:

1. **BOG Generation**: The daily BOG rate is applied to the actual volume of LNG in the tank and then divided by 24 hours to determine the hourly volume of LNG evaporated. This liquid volume flow is then converted into mass using the standard LNG density in liquid state (450 kg/m^3, as per IMO MSC.285(86)). This results in the total BOG generated in kilograms per hour (see column 3 of Table 8).
   Example: 0.20% x 9,000 m^3 is 18 m^3/day or 0.75 m^3/hr evaporated LNG. This equates to ~ 338 kg/hr.

2. **Chemical Energy Content**: The total BOG mass during the stay at berth (in kg) is multiplied by the Lower Heating Value (LHV) of methane - 49.1 MJ/kg, as used under the FuelEU Regulation - to estimate the chemical energy in MJ (this is represented in column 4 of Table 8 for the total time the ship is at berth).
   Example: 13,520 kg BOG generated during a port call x 49.1 = 663,832 MJ

3. **Electricity generation potential:** To put the chemical energy from the BOG into perspective we assume it is used in a dual fuel auxiliary engine to produce electricity. The chemical energy in MJ per hour is converted to kWh by multiplying by 0.2778 (1 kWh = 3.6 MJ), and an engine efficiency of 45% was assumed[29]. (see column 5).

[29] It is generally considered that gas generators are less efficient than diesel generators. EMSA guidance on OPS assumes a diesel generator has a thermal efficiency of 50% (EMSA, 2022b).

Example: 663,832 MJ/40 hours = 16,596 MJ/hr.
16,596 MJ/hr x 0.2778 = 4,610 kWh/hr
4,610 x 0.45 = 2,075 kW.

4. **BOG consumption potential from auxiliary engine**: Finally, column 6 presents the BOG consumption rate in grams per kilowatt-hour (g/kWh), calculated by dividing the hourly mass of BOG (column 3) by the useable electrical output (column 5).
Example: 338 kg/hr / 2075 kW = 0.163 kg/kWh
The resulting value of around 163 g/kWh is consistent with literature on dual fuel auxiliary engines on gas mode[30].

The results of each scenario are presented in Table 7 where column 3 presents the amount of BOG generated in kg/hr.

Table 7 - LNG tank BOG generation in kg per hour in various scenarios (column 3) with resulting chemical energy and potential electricity generation from onboard auxiliary engines

Scenario	**LNG tank size (m^3)**	**BOG generation (kg/hr).** See Step 1 above	**Chemical energy content from BOG during port call (MJ)** See Step 2 above	**Electricity generation potential (kW)** See Step 3 above	**BOG consumption potential from auxiliary engine(s) (g/kWh)** See Step 4 above
Scenario 1.1 (large tank – High BOG)	18,000	911	3,354,758	5,592	163
Scenario 1.2 (small tank – High BOG)	6,000	324	1,193,130	1,989	163
Scenario 2.1 (large tank - Medium BOG)	18,000	338	663,832	2,075	163
Scenario 2.2 (small tank - Medium BOG)	6,000	124	243,536	761	163
Scenario 3.1 (large tank – Low BOG)	18,000	95	69,968	583	163
Scenario 3.2 (small tank – Low BOG)	6,000	41	30,197	252	163

Table 7 shows BOG generation ranges from 41 kg/hour in Scenario 3 to 911 kg/hour in Scenario 1. For Scenario 2 ('medium BOG') the BOG generated per hour is 338 kg/hr for the large 18,000 m^3 tank and 124 kg/hr for the 6,000 m^3 tank.

[30] IMO guidelines providing EEDI calculation examples give a fuel consumption of 160 g/kWh for an auxiliary engine using LNG (MEPC 73/19/Add.1 – see appendix 4). Meanwhile, Hyundai provides a fuel consumption of 7,270 kJ/kWh in gas mode at 100% load for the HiMSEN Dual Fuel Engine H35DF series of engines which is a frequently installed auxiliary engine among the inventorised fleet (HEC, 2025): https://www.hyundai-ec.com/en/sub/product/H35DF.html MAN cites a consumption of 7,440 kJ/kWh at 85% MCR on gas mode for its dual fuel L35/44DF model (MAN, 2022).

The following section builds on the results of Table 7 by assessing BOG management under two berth scenarios:

1. A stay at berth without OPS where the BOG is directed to auxiliary engines, being the default strategy for most LNG containerships today (Section 6.2).
2. A stay at berth with OPS where BOG is directed to the remaining onboard consumers that stay operational while the ship is connected to OPS at berth (Section 6.3).

Both of these scenarios are linked to Section 5.2, which discussed containership energy demand at berth, in order to assess whether BOG can be fully utilised or must be wasted or, in emergencies, vented.

The analysis focuses on these two methods because they are currently the most likely BOG management methods used by containerships with Type B and membrane tanks, based on the systems these ships have installed. As established in Chapter 4, no or little evidence was found of installed systems on the inventorised ships that would enable alternative BOG handling methods at berth in the form of reliquefaction, sub-cooling, or thermal oxidation via dedicated gas combustion units. Pressure accumulation is also not considered a full solution to manage BOG during prolonged port stays, given the low pressure tolerance of the Type B and membrane tanks in the inventorised fleet. That said, Section 6.4 briefly (and non-exhaustively) discusses the potential use of alternative methods as well as other operational practices that might support BOG management while connected to OPS. Although these methods and practices are unlikely to offer complete solutions for the current fleet, they may become more relevant as technologies evolve and operational experience with LNG-fuelled ships using OPS increases.

6.2 BOG management without OPS where the BOG is directed to auxiliary engines

The electricity generation potential of BOG when used in a dual fuel auxiliary engine is presented in column 5 of Table 7, which assumes a 45% efficiency of such engines. The results in the table show that in the highest BOG scenario, up to 5,592 kW (5.6 MW) could be generated while in the lowest scenario 252 kW (0.25 MW) would be generated. In the medium scenario between 761-2,075 kW (0.7-2.1 MW) would be generated. By comparison, Section 5.2.1 discussed the electrical power demand of large containerships, such as those inventorised, to be in the range of 2.5-7 MW depending heavily on the amount of reefer containers onboard. If we assume large containerships have a baseload energy without reefers of 2.5 MW then all of the generated electricity from each scenario would be productively used onboard. This approach not only prevents pressure build-up in the LNG tank but also provides electricity which is in any case required for onboard systems. The exception is the high scenario with a large 18,000 m^3 tank where, if all BOG would be directed to auxiliary engines then the electricity generation potential could exceed the ship's electrical demand if a baseload of 2.5 MW is still assumed. However the smallest inventorised ship with a tank of that size is 23,112 TEU so is very likely to have a much higher baseload electrical energy demand and have at least some reefer containers onboard, vastly increasing the ship's electrical energy demand.

In addition to the auxiliary engines, BOG can also be directed to a boiler for steam generation or gas combustion if needed. According to interviews, ships are typically equipped with a free-flow line to such systems, ensuring safe handling of BOG in the event of an engine shutdown. The role of these alternative systems is further discussed in Section 6.3, which addresses port calls with mandatory OPS. The present section goes into more detail on the energetic use of BOG in auxiliary engines during a regular port call without OPS.

6.2.1 Auxiliary engines

As outlined in Section 4.2.1, LNG-fuelled containerships equipped with membrane and Type B tanks have at least three auxiliary engines capable of operating on gas (with diesel used as a pilot fuel) and in some cases up to 6.

The same section also noted that the average mechanical output per auxiliary engine is 3,800 kW, and that over half of the inventorised fleet uses engines from the same manufacturer and engine series. According to the engine manufacturer, the specific fuel consumption of these dual-fuel auxiliary engines in gas mode is 7,270 kJ/kWh at 100% load (HEC, 2025). This corresponds to approximately 148 grams of BOG per kWh, assuming the BOG consists entirely of methane[31]. Using this engine data as an illustration, it is possible to estimate how much BOG can be consumed when operating these engines at berth, and how much electrical power is produced in doing so. These values are presented in Table 8.

Table 8 - BOG consumption and power output for auxiliary engines at 100% load

Number of auxiliary engines in use	Total power output (kW)	BOG consumption rate (g/kWh)	Total BOG consumed per hour (kg)
1	3,800	148	562.4
2	7,600	148	1,124.8
3	11,400	148	1,687.2
4	15,200	148	2,249.6

Note: Specific BOG consumption will vary by engine type. The value of 148 g/kWh is merely used as an illustrative guide (and closely aligned with the fuel consumption listed in Table 7). Auxiliary engines in gas mode will also consume a small amount of pilot fuel which is not considered in the table. In practice the generator output in kW may also be less due to further losses in the alternator device.

[31] 7,270 kJ/kWh divided by 49.1 MJ/kg (the Lower Heating Value of methane) = 148.1 g/kWh.

Table 8 shows, for instance, that operating one such engine at full load would consume 562 kg of BOG per hour and generate 3,800 kW of electrical output. Although auxiliary engines may not routinely run at full load at berth, the data in the table provides a basis for comparing BOG generation (as outlined for the various scenarios in Table 7) with BOG consumption (by the engine). Both of these are illustrated in Table 9.

Table 9 - Comparison of BOG generation from Table 7 with BOG consumption in auxiliary engine in Table 8

Scenario (large tanks)	Generated mass BOG (kg/h)	No. of 3,800 kW engines auxiliary engines needed to run to consume the BOG
Scenario 1.1	911	2 engines at close to 100% load
Scenario 1.2	324	1 engine at around 55% load
Scenario 2.1	338	1 engine at around 60% load
Scenario 2.2	124	1 engine at around 20% load
Scenario 3.1	95	1 engine at very low load
Scenario 3.2	41	1 engine at very low load

In Table 9 it can be seen that the total BOG generated from the 18,000 m^3 tank in Scenario 1 (911 kg/hr) could be fully consumed by operating two auxiliary engines near full load. In Scenario 3, with just 41-95 kg/hour of BOG generated, operating a single auxiliary engine at a low load would be sufficient to use up the BOG.

6.3 BOG management with OPS where BOG is directed to the remaining onboard consumers

During port calls where OPS is used, a ship's auxiliary engines are shut down, removing the primary means of consuming BOG. In these cases, the BOG must be redirected to dual-fuel boilers or, where available, gas combustion units (GCUs). However, since GCUs are not commonly installed on the inventorised fleet, this section focuses first on the consumption of BOG via marine boilers. As indicated in Section 4.2.2, at least 76% of LNG capable ships with Type B or membrane tanks have a dual fuel boiler installed meaning the boiler can operate on BOG gas.

6.3.1 Boilers

As discussed in Section 4.3, the steam demand on LNG-fuelled ships is estimated to range between 1,000 and 4,000 kg/hr, depending on the ship's size, operational season, and the number of onboard systems requiring steam.

To assess how this steam demand translates into BOG consumption, data from the technical datasheet of a dual-fuel marine auxiliary boiler - installed on some ships in the inventorised fleet - is used (MHI, 2022). In alignment to this source, gas consumption as presented is considered to be 100% methane with a Lower Heating Value of 50 MJ/kg[32]. For example, to produce 5,000 kg/hr of steam, the boiler consumes 322 kg/hr of BOG.

Table 10 shows the boiler's gas (BOG) consumption for steam generation between 5,000-8,000 kg/hr as directly provided in technical datasheets, while Table 11 extrapolates this relationship to the lower steam demands expected on LNG-fuelled containerships.

Table 10 - Methane gas consumption marine dual fuel auxiliary boiler

Evaporation (kg steam per hour)	5,000	6,000	7,000	8,000
Gas consumption (BOG) kg/hr	322	387	451	516

Source: based on information available online technical data sheets for Dual Firing Auxiliary Boilers from Mitsubishi Heavy Industries (MHI, 2022).

Table 11 - Methane gas consumption marine dual fuel auxiliary boiler

Evaporation (kg steam per hour)	1,000	2,000	3,000	4,000
Gas consumption (BOG) kg/hr	64	129	193	258

Source: Authors, extrapolated based on online technical data sheets from Mitsubishi Heavy Industries (MHI, 2022).

Table 11 shows that a ship with a steam demand of 1,000 kg/hr would consume around 64 kg of BOG per hour, while the upper bound of 4,000 kg/hr steam would consume approximately 258 kg of BOG per hour. These figures are useful in relation to the BOG generation rates presented in Table 7.

- In Scenario 3.1 and 3.2 (low BOG) a low steam demand would be sufficient to consume all BOG produced.
- In Scenario 2.2 (medium BOG in a small tank), a steam demand of around 2,000 kg/hr would be needed to consume all BOG produced while in Scenario 2.1. steam demand would need to exceed estimates and be around 5,000 kg/hr steam. The same is true for Scenario 1.2.
- In Scenario 1.1 (high BOG) BOG reaches 911 kg/hr which, if directed to a boiler to generate steam results in a huge surplus well beyond the estimated steam needs of a containership.

It is also important to note that steam demand is seasonal, and in many cases, directing all BOG to the boiler may result in overproduction of steam relative to the ship's needs, likely ending in energy wastage. It is however important to consider that technologies are commercially available which are aimed at converting waste heat into electrical power – notably making use of the Organic Rankine Cycle Technology. The energy efficiency of these systems has not been examined in this report.

---

32 This is marginally higher than the 49.1 MJ/kg that is used in results presented in Table 7.

6.3.2 Gas Combustion

In situations where the amount of BOG generated exceeds a ship's thermal energy demand, another option available is to combust the excess BOG without actually producing steam or using the energy. This is typically achieved through a Gas Combustion Unit, a specialised system designed specifically to burn BOG. However, some dual-fuel boilers are also designed to safely combust BOG, effectively performing the same function as a GCU (MHI, 2022).

Gas Combustion in boilers

The rate at which BOG can be combusted in a boiler without producing steam is not explicitly stated in available technical documentation. Nevertheless, the inventory reviewed in this study includes several cases of installed boilers with steam production capacities far beyond the natural steam demand of this type of ship as gathered via interviews (1,000-4,000 kg/hr steam). This suggests the boiler may be intended to act as a GCU where required, as a back-up solution to manage BOG. As indicated in Section 4.2.2, ships for which boiler data is available have a dual fuel boiler from a model range with capacities of 1.2-55 ton/hr steam. Extrapolating the BOG consumption of lower capacity boilers from Table 10 and Table 11 this would be a range of around 77-3,548 kg/hr BOG. Taking the average capacity of the model ranges available as presented in Section 4.2.2 the assumed rate of BOG consumption would be:

- 33 ships have a dual fuel boiler of 3,850 kg/hr steam which would consume approximately 248 kg/hr BOG;
- 6 ships have a dual fuel boiler installed with a specific capacity of 12,000 kg/hr steam which would consume approximately 774 kg/hr BOG;
- 18 ships have a dual fuel boiler of 33,750 kg/hr steam which would consume approximately 2,177 kg/hr BOG.

In practice, the combustion rate of BOG in a boiler without creating steam is expected to be higher than if steam is actually generated in the boiler but this has not been confirmed. That notwithstanding, the numbers above shows that ships with large capacity boilers should not face any challenge to combust BOG even in high BOG scenarios. However in cases where ships have both a low capacity boiler – or no gas capable boiler at all - and are subject to a scenario where large amounts of BOG are generated (such as up to 911 kg/hr BOG in Scenario 1) then there is a potential challenge to manage the BOG. A boiler of insufficient gas combustion capacity may not be the most likely scenario since ships with larger LNG tanks (hence more BOG per hour) are likely to have the largest capacity boilers but a challenge to manage BOG in this way cannot be ruled out. Indeed, a case was presented during interviews for this study of a ship in operation with a BOG generation rate of 400-650 kg/h while the boiler has a capacity of ~400 kg/h. This ship could potentially face a challenge to manage tank pressure by the use of the boiler in cases of high BOG generation unless 1) more kg/hr BOG can be combusted in the burner part of a boiler when used without generating steam, 2) the capacity of the boiler can be increased as a retrofit. A more serious challenge is present for ships which do not have a gas capable boiler installed at all: the inventory found 20 ships where only a diesel fired boiler was installed and 12 where no information on any boiler was installed.

Gas Combustion in Gas Combustion Unit
Another option for BOG combustion is in a dedicated GCU, although these are not commonly installed on the inventorised fleet. Commercially available GCU's are designed to handle large volumes of BOG - between 1,000 and 4,500 kg/hour (Alfa Laval, 2025a). In cases where two combustion chambers are installed, total capacity can reach up to 9,000 kg/hour, both of these far exceeding the BOG generation rates found in Table 7 even for the largest containerships. Examples of lower capacity GCUs in the range of 25-1,000 kg/hr BOG can also be found in technical brochures (Volcano, 2025). During interviews conducted for this research, the general sentiment was that GCUs are an 'easy' way of managing BOG including during OPS port calls although concern was raised about the inefficient use of energy.

Importantly, the combustion of BOG in either a GCU or a dual-fuel boiler operating without steam generation is not expected to result in the release of methane. Several manufacturers explicitly cite zero methane slip in their GCU product specifications[33], and the same is presumed to apply to properly operated marine boilers configured for gas combustion.

6.4 Additional BOG management practices and potential methods used by inventorised fleet

Section 6.1 demonstrated that during a regular port call without OPS, BOG can be directed to dual-fuel auxiliary engines to generate electricity, thereby covering at least part of the ship's electrical energy demand without a significant risk of energy waste. Section 6.2 subsequently examined the use of BOG in onboard boilers during OPS port calls, noting that while BOG can, in some cases, be used meet the ship's natural steam demand, in other instances it may be combusted without effectively utilising its energy content.

The following section explores additional methods and operational practices that containerships might employ to manage tank pressure and minimise BOG energy losses. These could be used independently or in combination with the approaches discussed in Sections 6.2 and 6.3. It should be noted, however, that the practices outlined below are not expected to offer immediate or complete solutions for managing BOG at berth during

[33] See for example: https://www.shipserv.com/ShipServ/pages/profiles/66244/documents/SAACKE_Flyer_GCUevo_A4_EN.pdf

OPS port calls for the inventorised fleet, nor do they represent an exhaustive list of available options.

6.4.1 Pressure accumulation in tanks

It must be stressed that the generation of BOG in an LNG tank does not need to result in *immediate* management in the form of consumption: all tanks do have a certain holding time to accumulate pressure before pressure relief valves are triggered. As such, in some cases, it might be feasible for ships to manage BOG during an OPS call via a combination of pressure accumulation and (minimal) consumption e.g. in the boilers. However, for Type B and membrane tanks the possibilities for pressure accumulation are very limited. For both tanks, the IGF Code sets a maximum design vapour pressure of 0.7 barg which can only be increased with approval from the ship's Flag Administration. In fact for membrane tanks the maximum pressure is normally 0.25 barg but the IGF Code permits it to be increased to 0.7 barg if the hull scantlings are increased accordingly and consideration is given, where appropriate, to the strength of the supporting thermal insulation.

Estimates gathered during the course of this research for the holding time of Type B and membrane tanks, without BOG consumption, were in the range of 6-10 hours. This is very limited bearing in mind that large containerships are considered to spend on average 40 hours at berth and almost never less than 10 (see Table 7). A slightly longer holding time could however provide some flexibility to ships during an OPS call by slightly reducing the amount of BOG that needs to be expended and reduce the likelihood of energy wastage.

In general it can be said that, unless the maximum permitted pressure of the tank is increased, higher holding times can be achieved only in cases when the tank is subject to a lower overall BOG rate and when the tank has a low level of fill, which would provide a larger space for vapour to collect in the tank so the pressure builds more slowly.

Potentially higher pressure Type B and membrane tanks

Some examples of higher-pressure tolerant Type B and membrane LNG tanks with a demonstrated level of safety have been accepted by some flag administrations.
This includes a membrane LNG tank of 4,500 m^3 which was approved for use on a cruise ship at a design pressure of 2 barg by the class and flag administration (GTT, 2021).
More recently, approval in principle has also been announced for larger LNG volume membrane tanks design rated for 1 barg pressure which are described as offering ship-owners the following benefits (GTT, 2025a):

- extended time before the tank reaches its maximum pressure;
- warmer-temperature bunkering;
- OPS compliance without compromising tank integrity.

Content

It has not been possible to accurately verify the full extent to which the increased pressure tolerance improves tank holding time.

Type C tanks
The design pressure of Type C LNG fuel tanks is considered to be in the range of 4-10 bar so can accommodate more BOG vapour than a Type A, Type B or membrane tank (DNV, 2023). As a result, tank holding times without requiring active pressure control are extended up to three weeks (DNV, 2023) This is a major advantage of Type C tanks when the possibilities to consume BOG are limited, such as during an OPS port call. However a manufacturer of Type C tanks consulted for this research, considers that also for these tanks it is essential to have an accurate calculation of the BOG rate which considers as many factors and scenarios as possible in order to guarantee that pressure build up alone will be enough to handle the BOG for port operations.

For the existing container fleet in operation, Type C tanks are less common than Type B and membrane tank totalling 37 on 13 June 2025 – most of which are relatively small containerships under 4,000 TEU[34]. However for cruise ships with LNG tanks, Type C is the dominant choice. Of the existing fleet of 25 LNG capable cruise ships on 5 June 2025, 24 had Type C tanks and 1 had membrane tanks (Clarksons Research, ongoing-b). For containerships on order, Type C tanks are notably more prominent as has been discussed in Chapter 4 (see Figure 5).

6.4.2 Arrival at berth with as low tank pressure as possible - potential BOG consumption in main engines on entry to port

BOG consumption in main engines is not widely discussed in this report because these engines are in principle switched off when a ship is at berth. However consumption via main engines is potentially relevant to enable ships to arrive at berth with as little or no accumulated BOG in the LNG fuel tank as possible. This would provide for 1) a slightly longer holding time before the BOG starts to accumulate to unsafe levels, and 2) slightly less consumption of BOG is required during the stay at berth than if the ship arrives with BOG already accumulated. The latter potentially allows the BOG to be used for useful energy and avoid inefficient or wasted use of the BOG energy. BOG consumption via main engines (as well as the other consumers discussed above) could be possible during a ship's sea-passage or approach to the port/berth. As such, BOG consumption in main engines is briefly discussed below. It has not been examined for how many of the inventorised ships main engine BOG consumption is possible.

[34] However not all containerships in operation with tank C tanks are small: there are 3 ships of CMA CGM in the range of 8,000 TEU and 5 of MSC in the range of 11,500-15,600 TEU.

LNG engines come in high-pressure (diesel-cycle) and low-pressure (Otto cycle) designs. For low-pressure main engines, gas is injected into the engine at a pressure of 5-15 bar whereas on high-pressure engines gas is injected at a pressure of 350 bar (DNV, 2023). In order for high-pressure engines to consume BOG, high pressure gas compressors would be required which increase complexity, size, weight and costs (DNV, 2023). This leaves low-pressure main engines as the more feasible type of LNG main engine to consume BOG. However shipping companies also have to find a balance in their choice of main engine for lowing the ship's overall emission profile and possibilities to consume BOG onboard: in general it is high pressure engines which are considered to have the lowest methane slip which lowers the ship's overall emission profile. To give an example, default values used for the FuelEU Maritime Regulation assume 3.1% of the mass of LNG used in a (low-pressure) Otto dual fuel medium speed engine is not combusted and results in 'slipped' emissions whereas for a (higher pressure) diesel cycle dual fuel slow speed the assumption is 0.2%. On the other hand, these high-pressure diesel cycle engines come with the disadvantage in that they are not easily compatible to consume BOG. A similar dilemma is presented via energy efficiency technologies such as Power Take-off (PTO), where electricity might be generated from the main engine in a more efficient way than via the auxiliary engines. The use of PTO potentially increases the ship's overall energy efficiency, which is important for regulations such as the CII, but potentially leaves the ship with less options to productively consume the BOG since electricity has already been generated by PTO from the main engine.

Even when a ship can consume BOG in its main engines, doing so may not always support the ship to arrive with low accumulated BOG in the LNG tank. This could for instance be the case if a ship is underway for a long time towards ports in long estuaries (e.g. Antwerp or Hamburg). During this time the ship may be sailing at slow speed and generate BOG in the tanks at a faster rate than it needs to be consumed. Ships may also have to wait outside ports at anchorage for extended periods to wait for their berth during which time the main engine is probably not running but on warm stand-by.

6.4.3 Reliquefaction systems

Section 4.3.2 noted that (full) reliquefaction systems are not known to be installed on containerships with membrane or Type B LNG tanks, probably due to capital and operational costs as well as a lack of available space.

Indeed the operation of reliquefaction systems can require a significant amount of energy. For LNG carriers at berth, power requirements are considered to be highly driven by reliquefaction units (EMSA, 2022a). To give an indication of the energy demand of a reliquefaction system, technical data sheets consulted from one available system give a range of 0.64-1.08 kW per kg of LNG reliquefied (Wärtsilä, 2025). This would mean that a ship that evaporates 15 m^3 of LNG during a port call would potentially reliquefy 6,750 kg of LNG (assuming a density of liquid LNG of 450 kg/m^3). In terms of energy demand this could be 4,320-7,290 kW for the reliquefaction process alone.

It can be concluded that reliquefaction systems are not known to be installed on containerships. While, based on the literature, there do not appear to be technical limitations for these to be installed on containerships - doing so could be energy, space and cost intensive. Should the ship also be required to connect to OPS, the reliquefaction system would also increase the total amount of electricity required from shore.

6.4.4 Recondensing systems

Although dedicated reliquefaction systems do not appear to be installed on containerships, similar technologies are installed on some containerships - with one example being Recycool™ which is described by the maker as a recondenser system (GTT, 2025d). According to the online description[35], the system operates when a ship's (high-pressure) main engines are running on gas. During this time Recycool™ functions by cooling generated BOG by recovering cold energy from the fuel gas that is sent to high-pressure engines; the condensates are then returned to the tank in liquid form (GTT, 2025d). Such systems thus offer a new method for managing BOG beyond consumption of it. This technology is understood to be installed on at least 10 containerships in operation and a further 10 newbuilds announced in September 2024 (GTT, 2025d).

This particular solution may however not offer a direct solution to managing BOG at berth since the system requires the main engines to be running.

[35] See the following link for more detailed explanation: https://gtt.fr/recycooltm-cutting-edge-recondenser-system

7 Conclusions and recommendations

Conclusions

This research finds that during port calls without OPS, containerships with Type B and membrane LNG tanks have ample means to consume BOG in auxiliary engines for generating electricity and that this is the default method used by these ships today.
In scenarios where BOG generation is high, the generated electricity can potentially cover all of the ship's electrical energy demand at berth depending on the number of active reefer containers onboard and electrical systems running. Even in scenarios assuming very high BOG production, it is found that onboard BOG consumption capacity in the form of auxiliary engines exceeds the rate of BOG production. For example, in the highest case examined, operating just 2 auxiliary engines at close to full load or 3 at a lower load - out of a possible six on some ships - is sufficient to consume all the BOG generated, producing around 6 MW of electrical power. This electrical output still remains within the expected demand range of the largest containerships at berth when reefer containers are considered. Should BOG consumption via the auxiliary engines temporarily exceed actual electricity demand, excess gas can be diverted to dual-fuel boilers to meet the ship's thermal energy demand. Overall, this confirms that during a port call without OPS, onboard BOG consumption for energy use is sufficient to maintain tank pressure within safe limits, avoiding the need for venting or gas combustion.

During a port call where a containership uses OPS on the other hand, opportunities to consume BOG via onboard consumers are more limited. This is because auxiliary engines are switched off while the ship is connected to OPS. Since the ships inventorised for this research do not (in general) have reliquefaction systems, sub-cooling systems, Gas Combustion Units, nor an ability accumulate large volumes of BOG such as in a Type C tank, this leaves dual-fuel boilers as the remaining onboard system for managing BOG energetically to avoid that tank pressure accumulates to unsafe levels. However, the analysis shows that - except in low BOG generation scenarios or medium scenarios with small tanks - the rate at which BOG would need to be consumed by the boiler typically exceeds the ship's actual steam demand. This is especially true during seasons with lower thermal energy requirements, and considering that LNG-capable ships generally have a low heat demand due to the absence of a need to heat large quantities of viscous fuel. This mismatch potentially leads to wasted heat. There are however some technologies to recapture heat and generate electricity, though the efficiency of these systems has not been assessed in this study. Importantly, a lack of useful consumption of BOG during an OPS port call does not mean ships have to resort to venting BOG. This is permitted only in emergency situations and high awareness of the environmental and climate consequences of this occurring were highlighted by all organisations consulted for this research. Where ships cannot usefully use BOG, options exist to safely combust the gas to avoid overpressure in the LNG tank. This can be done in boilers without generating steam or, where fitted, Gas Combustion Units (GCU). However both of these options result in wasted energy unless the heat from BOG consumption can be recovered.

The results of this study are therefore that the risk of venting methane gas to the atmosphere is in general low. However questions are raised regarding the considerable likelihood that BOG is simply combusted during stays at berth where OPS is mandatory, leading to energy inefficiency or in the worst case energy wastage. Concerningly, for 20 of the inventorised ships (15%) the presence of a gas-capable boiler to consume or eventually combust BOG as a form of pressure dissipation could not be confirmed and for a further 12 ships (9%) no data was available on any installed boiler. These concerns are eased if the absence of these boilers is explained simply as a lack of available data or certainty that the ship - on the basis of its trading route - will not call any ports where OPS is required. Alternatively, the ships may be equipped with other BOG management systems that could not be identified during the inventory. However if none of these explanations apply it is unclear how the ship would control its tank pressure during a long stay at berth where OPS is mandatory. The risk of emergency venting is thus never zero. Indeed, even when boilers with sufficient gas combustion capacity are available there is no guarantee they are fully operational. Looking ahead, the risk of energy wastage is expected to decrease as more containerships with Type C tanks enter the fleet. As of 13 June 2025 and for the containerships on order for which the type of LNG tank is known, 34% will be built with a Type C tank (Clarksons Research, ongoing-a). These tanks can accommodate higher pressure build-up and therefore reduce the immediate need for thermal oxidation of BOG at berth during an OPS port call.

At the same time it should be acknowledged that practical experience of LNG-fuelled containerships actually connecting to OPS at berth may still be at an early stage. In the case of one interviewed shipping company, none of the company's LNG fuelled ships were yet to connect to OPS. This experience could lead to new strategies, technologies, or operational practice to manage BOG during OPS calls in a way that avoids tank overpressure and reduces potential wastage of BOG energy. The issue of BOG management notably also extends to other ship types than only containerships. In 2023 a submission to the IMO from trade associations representing multiple segments of the industry pointed to safety issues associated with incorporating OPS arrangements on ships using boil-off gases as fuel as an issue remaining to be addressed (MEPC 80/7/6, 2023).

Recommendations

1. **Lack of universal standard on tank boil-off rate:** This study found no universally accepted standard quantifying the boil-off rate from an LNG fuel tank. Even when this is calculated there are uncertainties with regard to which parts of 'static' and 'dynamic' BOG influences are included in the calculation which is normally made by tank manufacturers (see Section 2.3). There are also uncertainties regarding the density of LNG in liquid and gas form that should be used in these calculations. This is considered a limitation to compare the expected boil-off rate from different tanks and accurately quantify the amount of BOG that may be generated. It is possible, but not confirmed, that boil-off rate calculations which have been developed for LNG cargo tanks are potentially less appropriate for LNG fuel tanks where the volume fluctuates more as fuel is consumed for propulsion and increases again as fuel is bunkered.

2. **Sharing of operational experience of using OPS with LNG fuel tanks:** Widespread use of OPS by (container) ships with LNG tanks in use is still to take place. Sharing of experience and operational practices - including across industry segments - could support best-practice in connecting to OPS while managing BOG, improving energy efficiency and further lowering the risk of venting in emergencies. The sharing of experience could also extend to terminal operators as well as LNG storage and tanker industry, port authorities, regulators and others. Consideration could also be given to the potential energetic use of BOG from ships by other port users.

3. **Consider the consistency of the IGF Code and widespread OPS regulations:** Presently, the IGF Code requires that the method used by an LNG fuelled ship to control tank pressure and temperature should be capable of maintaining tank pressure below the set pressure of the tank pressure relief valves for a period of 15 days including idle periods when only power for domestic load is generated. However, given that an increasing number of regulations now require a significant part of that domestic load to be provided by OPS, it could be examined if changes are required to the IGF Code, such as the 15-day rule, tank pressure limits or additional safety requirements

4. **LNG tank types:** On the one hand, it could be considered that tanks with an ability to accumulate more pressure are an obvious solution to enable ships to sail on LNG and simultaneously connect to OPS. This research has noted both an increase in containerships ordered with Type C tanks as well as flag approvals for Type B and membrane tanks with higher pressure. More research is recommended to first of all assess the impact of higher design pressure tanks on the holding time of a tank before BOG needs to be consumed at berth in an OPS call as this remains an uncertainty. However it is also clear that changing or

upgrading a ship's LNG tank type is not a practical solution that can easily be made for ships in operation or already under construction. An LNG ship and its onboard systems may be designed around the LNG tank so retrofits are expected to involve high costs and technical complexity.

5. **Energy efficiency**: It can be considered that BOG combusted at berth simply for the purpose of reducing tank pressure is not in line with energy efficiency standards and regulations in the shipping industry. All of the containerships inventorised for this study are subject to MARPOL Annex VI Regulation 26 concerning the Ship Energy Efficiency Management Plan (SEEMP). This includes the SEEMP III which is supposed to function as a plan to ensure the ship is on track to meet energy efficiency targets (termed a Carbon Intensity Indictor). While the combustion of BOG at berth will in most cases be small compared to the ship's fuel use for propulsion, it could represent a more significant share of fuel expended in cases where many of the ship's port calls require an OPS connection. As such, combusting BOG without generating energy to be used on board the ship is not only energy inefficient but could potentially also result in a lower energy efficiency rating for the ship (although future changes to the CII metric are possible). The use of OPS is strongly encouraged as an available technology to lower GHG and air emissions at berth however future research could consider the interplay between ship energy efficiency and OPS regulations with a view to achieving the greatest energy efficiency and lowest Well-to-Wake GHG intensity of the energy consumed. Special rules might be justified from an energy efficiency and emissions perspective if the ship has no other means of safely managing BOG besides wasting it. Under the current rules, this ship would economically weigh two options: either connecting to OPS and incurring costs for OPS and for wasting BOG or not connecting/connecting shorter to OPS and paying the according FuelEU penalty, thereby avoiding costs for OPS and for wasting BOG. Therefore special rules like, for example, a reduced penalty for a limited number of hours could be considered as an interim solution for the existing fleet of containerships. Another option could be to revise the rules to extend the limited flexibility in the lag-time which is currently permitted in regulations before ships are required to actually connect to OPS (this is presently between 2-3 hours and is intended to ensure enough time to safely connect the ship and shore infrastructure). An increase in this lag-time could better ensure energetic use of BOG and lower the pressure in the LNG tank before a switch to OPS needs to be made. Importantly, however, the negative effects of any such special and revised rules in the form of higher emissions, of potentially slowing down the uptake of cleaner technologies and improved BOG management systems, and of a distorted level-playing field between the ships eligible for such special rules and those not would also have to be considered.

6. **Reporting obligations for vented methane**: The IGF Code clearly prohibits the venting of BOG to the atmosphere except in emergency situations. However research for this study, including interviews with companies in the sector, found no formal obligations requiring ships to report instances where BOG has had to be vented. Reporting obligations may be required on the basis of ship class, flag or company rules but they are not reflected in the IGF Code. Further research or consideration could be made towards whether it makes sense, from an environmental perspective, to introduce mandatory reporting requirements in cases where BOG is vented in emergency situations. Reporting obligations in case of venting may also have a safety perspective (as it is a flammable gas) as the presence of the gas potentially poses a challenge to other industry or activity in the local area. Potential safety implications of (emergency) venting have not been examined in this research.

7. **Boil-off gas is not exclusive to LNG**. Other alternative fuels for shipping such as ammonia (DNV, 2023) and hydrogen (Saif et al, 2022) also generate BOG although the boiling point of ammonia at -33 °C (EMSA, 2024) is significantly higher than LNG (methane), potentially presenting less of a boil-off challenge. However potential solutions to boil-off in OPS port calls should also consider these fuels and the quantities of boil-off that may be expected.

Literature

ABS. (2019). *ABS Advisory of Gas and Other Low Flashpoint Fuels*.

ABS. (2022). *Sustainability Whitepaper - LNG as a marine fuel*.

Aijou et al. (2019). *Study on container ship energy consumption*.

Alfa Laval. (2025a). *Gas Combustion Unit product leaflet*. Alfa Laval. https://www.alfalaval.com/globalassets/documents/industries/marine-and-transportation/marine/alfa-laval-gas-combustion-unit-2.0_product-leaflet_en.pdf

Alfa Laval. (2025b). *Marine boiler solutions for LNG as fuel*.

Bernacchi. (2019). *Connecting low power consumption vessels to shore-to-ship power facilities*.

CARB. (2020). *At Berth Frequently Asked Questions*. California Air Resources Board (CARB). https://ww2.arb.ca.gov/sites/default/files/2021-11/TTD21-272%20At%20Berth%20FAQs.pdf

CARB. (2024, September 26 2024). *At Berth Frequently Asked Questions*. California Air Resources Board (CARB). https://ww2.arb.ca.gov/our-work/programs/ocean-going-vessels-berth-regulation/frequently-asked-questions-faq

Clarksons Research. (ongoing-a). *Clarksons Research Portal*. https://www.clarksons.net/n/#/portal

Clarksons Research. (ongoing-b). *World Fleet Register*. https://www.clarksons.net/wfr/

CMA CGM. (2024). *2024 CSR Report*.

DNV. (2023). *Alternative Fuels for Containerships: LNG, Methanol and Ammonia*.

DNV. (ongoing). *LNG as marine fuel technologies: Engines types*. https://www.dnvgl.com/maritime/lng/engines-for-gas-fuelled-ships.html

EAFO. (2025). *European Alternative Fuels Observatory, Maritime Ports and Infrastructure (accessed 18 July 2025)*.

EC. (2025a). *Decarbonising maritime transport – FuelEU Maritime*.

EC. (2025b). *DG Energy - Methane emissions*.

EIA. (2014). *June marks 50th anniversary of the first commercial liquefied natural gas tanker*. U.S. Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=16771

EMSA. (2018). *Guidance on LNG Bunkering to Port Authorities and Administrations*.

EMSA. (2022a). *Shore-Side Electricity Guidance to Port Authorities and Administrations - Part 2*.

EMSA. (2022b). *Shore-Side Electricity, Guidance to Port Authorities and Administrations, Part 1 – Equipment and Technology*. EMSA.

EMSA. (2024). *Safety of Ammonia for Use in Ships*.

EU. (2023). *Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC*. European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1805

Eurostat. (2025). *Maritime vessels statistics*. European Commission. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Maritime_vessels_statistics

GloMEEP. (2020). *About GloMEEP*. https://glomeep.imo.org/

GTT. (2019). *GTT Inside Volume 14, February 2019*.

GTT. (2021). *Approval in Principle (AiP) from DNV for membrane tanks with a design*

vapour pressure of up to 2 barg. GTT. https://gtt.fr/sites/default/files/GTT%20Inside%20N%C2%B022-June%202021_1.pdf

GTT. (2025a). *GTT secures DNV Approval in Principle for 1 barg membrane tanks on LNG-powered vessels*. GTT. https://gtt.fr/news/gtt-secures-dnv-approval-principle-1-barg-membrane-tanks-lng-powered-vessels

GTT. (2025b). LNG as fuel units. In: GTT.

GTT. (2025c). *Mark III systems*.

GTT. (2025d). *Recycool™, a cutting-edge recondenser system*. GTT. https://gtt.fr/recycooltm-cutting-edge-recondenser-system

GTT. (Ongoing). *LNG Optim*. https://gtt.fr/lng-optim

HEC. (2025). *HiMSEN Dual Fuel Engine H35DF*.

ICCT. (2023). *Shore power needs and CO2 emissions reductions of ships in European Union ports: Meeting the ambitions of the FuelEU Maritime and AFIR*.

IMO-Norway GreenVoyage2050 Project. (2023). *2023 Onshore Power Supply Workshop*.

IMO. (2009). *Resolution MSC.285(86) - Interim Guidelines on Safety for Natural Gas-fuelled engine installations in ships*.

IMO. (2024a). *Energy Efficiency of ships. Report of fuel oil consumption data submitted to the IMO Ship Fuel Oil Consumption Database in GISIS (Reporting year: 2023)*.

IMO. (2024b). *International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels*.

Japan P&I Club. (2024, 18 June 2024). *Japan P&I News: China —Requirements for the Use of Shore Power in Chinese Ports*. Japan P&I Club. https://www.piclub.or.jp/wp-content/uploads/2024/06/No.1279_China%EF%BC%8DRequirements-for-the-Use-of-Shore-Power-in-Chinese-Ports.pdf

Kim et al. (2019). *Case Study on Boil-Off Gas (BOG) Minimization for LNG Bunkering Vessel Using Energy Storage System (ESS)*.

Korean Register. (2020). *Guidelines for Calculating Boil-off Rate (BOR)*. Korean Register (KR). http://homedev.krs.co.kr/webzine/a/sub/sub.aspx?w_code=0201000000&no=3314&webzine_no=189

Kuehne+Nagel. (2025). *What is a reefer container? Facts and dimensions*. https://home.kuehne-nagel.com/en/-/knowledge/what-is-a-reefer-container

Maersk. (2025). *Keeping it cool: An overview of reefer containers*.

MAN. (2018). *11,000 teu container vessel*.

MAN. (2022). *MAN L35/44DF*. MAN Energy Solutions. https://www.man-es.com/docs/default-source/document-sync/man-l35-44df43e5738b66d943f7819681882f4e9dac.pdf?sfvrsn=a43c30d0_3

MEPC 80/7/6. (2023). *MEPC 80/7/6 The role of Onshore Power Supply (OPS) in the future maritime energy mix*.

MHI. (2022). *Mitsubishi Dual Firing Auxiliary Boiler MC, MJC*.

MSC.1/Circ.1675. (2023). *Interim guidelines on safe operation of onshore power supply (OPS) service in port for ships engaged on international voyages*.

MSC.285(86). (2009). *Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships*.

Nakilat. (2025). Incredible facts you should know about Nakilat. In.

OJEU. (2024). *Commission Implementing Regulation (EU) 2024/2031 of 26 July 2024 on the template for monitoring plans pursuant to Regulation (EU) 2023/1805 of the European Parliament and of the Council on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC*.

Pérez et al. (2016). *Energetic optimization of the ventilation system in modern ships*.

Port of Rotterdam. (2025). *Port Performance*.

PRS. (2017). *Bunkering Guidelines for LNG as marine fuel*.

Saif et al. (2022). *Modelling of Liquid Hydrogen Boil-Off*.

SEA-LNG. (2022). *The role of bio-LNG in the decarbonisation of shipping*.

SEA-LNG. (2025). *Global fleet*. SEA-LNG. https://sea-lng.org/why-lng/global-fleet/

SGMF. (2023). *LNG as a marine fuel: an introduction - Version 5*.

TOC Logistics. (2017). *Megaships means mega changes to the shipping industry*.

UNCTAD. (2024). *Port call and performance statistics: time spent in ports, vessel age and size, annual (analytical)*.

UNCTAD. (2025). *Description - Port call and performance statistics: number of port calls, semi-annual*.

Volcano. (2025). *Brochure - Gas Combustion Unit for LNG Fueled Vessel*. Volcano. https://www.volcano.co.jp/english/products/marine/pdf/MECS-G.pdf

Wärtsilä. (2025). *Compact Reliq™ BOG Reliquefaction Unit*.

Wärtsilä. (ongoing). *Wärtsilä: Encyclopedia of Marine and Energy Technology: Ship resistance*. https://www.wartsila.com/encyclopedia/term/ship-resistance