Feebate mechanism

Parameterization for rewarding zero or near-zero GHG emission fuels

CE Delft

Committed to the Environment

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Content

Summary

One of the ambitions of the 2023 IMO Strategy is the uptake of zero or near-zero (ZNZ) technologies, fuels and/or energy sources to represent at least 5%, striving for 10% of the energy used by international shipping by 2030. To meet this target, some of the proposed measures in the potential basket of mid-term measures work with a feebate mechanism: a combination of ‘fee’ and ‘rebate’, with the additional costs incurred by parties using ZNZ fuels being offset by the revenues of a fee/levy/contribution. However, ZNZ fuels are not precisely defined yet and it is also still unclear how compensation as part of the feebate mechanism should be determined, depending on the design of the mechanism and the fuel used. In this context, this study has analysed possible parameters of a feebate mechanism.

Identifying ZNZ fuels

In a first step, a literature review has been carried out to identify ZNZ fuels, defining ZNZ fuels by means of a maximum Well-to-Wake (WtW) GHG intensity. Three alternative WtW GHG intensity thresholds (10/15/20 g CO_2-eq. per MJ) have been assumed to this end. The literature review shows that whether or not a fuel type qualifies as a ZNZ fuel highly depends on the inputs and production pathway. As a consequence, if you identify ZNZ fuels by means of a maximum WtW GHG intensity threshold, fuel types as such can in most cases not be unambiguously considered to be a ZNZ fuel or non-ZNZ fuel. For most fuel types, however, inputs and production pathways are in principle available that would allow a fuel type to qualify as a ZNZ fuel and the specific conditions under which a fuel type could meet the assumed WtW GHG intensity thresholds can be identified. To give an example, the use of electricity from the grid could, if the share of renewable electricity in the mix is relatively low, lead to e-fuels not qualifying as ZNZ fuels. In contrast, if 100% renewable electricity was used, many e-fuels can be expected to meet the lowest assumed threshold of 10 g CO_2-eq./MJ. Regarding specific inputs and production pathways, it can be concluded that blue fuels and biofuels based on energy crops cannot be expected to qualify as ZNZ fuels even if the least stringent of the three threshold values was applied. Also, if the most stringent of the three threshold values was applied, the probability is low that biodiesel (FAME, HVO) and bio-oil would qualify as ZNZ fuels. For e-LNG this depends on the engine and the according methane slip.

Availability of potential ZNZ fuels

In a second step, the 2030 availability of potential ZNZ fuels has been estimated by means of a literature review, considering both advanced biofuels and e-fuels. For the purpose of this analysis, it was assumed that advanced biofuel and e-fuels will both qualify as ZNZ fuel, without being able to differentiate projects based on the actual WtW GHG intensity of the produced fuels. Based on the literature review, we estimated for 2030 a maximum global supply of 13.5 EJ, an expected global supply of 4.2 EJ and a minimum supply of 1 EJ of potential ZNZ fuels. For the estimation of the minimum supply, only those projects with a final investment decision have been considered. Given the expected supply of potential ZNZ fuels of 4.2 EJ, the availability of ZNZ fuels does not seem to pose a barrier to meeting IMO’s ZNZ fuel target. However, it must be kept in mind that in other sectors there might also be demand for ZNZ fuels and not all advanced biofuels and e-fuels might qualify as ZNZ fuels, depending on the specific WtW GHG intensity threshold applied.

In a third step, the potential 2030 demand for ZNZ fuels, focusing on the availability of ships that can potentially use ZNZ fuels, and the energy demand of these ships has been analysed. Based on an analysis of the current fleet and orderbooks, it can be concluded that, if the ships which are currently in the fleet and on order and that are able to use alternative fuels, would all use the alternative fuel to cover 100% of their energy consumption by means of the according ZNZ fuel type, then not only the 5% (base) but also the 10% (strive) IMO ZNZ fuel/technology target can be expected to be met. If, however, relatively little biomethane and e-methane were available, the strive target can probably only be met if also ships that are only 'ready' to use alternative fuels (other than methane) were actually converted to allow for the actual use of these fuels. The actual demand for the ZNZ fuels of course still requires closing the price gap between ZNZ and fossil bunker fuels.

Additional fuel costs and fee required

In a last step, the potential parameters for a feebate mechanism have been further analysed. To this end, a literature review has been conducted to determine cost price ranges for the different potential ZNZ fuels and a low and a high cost price scenario has been differentiated. For these two scenarios, the additional fleet ZNZ fuel costs compared to VLFSO have been determined, assuming that the IMO 2030 ZNZ targets are just met, resulting in additional fuel costs of between approximately 12 and 23 billion USD for the 5% target and between approximately 24 and 46 billion USD for the 10% target. It is difficult to match the cost price findings from the literature with specific GHG intensities of the fuels. Assuming that the 10 gCO_2-eq./MJ threshold applies to the high price scenario and the 20 gCO_2-eq./MJ threshold to the low price scenario, we have derived the 2030 levy/fee/contribution per tonne of GHG that would be required to compensate for the additional fuel costs of the ZNZ fuels as presented above: If the 5% ZNZ target was just met, a levy/fee/contribution in the range of approximately USD 15 to 25 per tonne of GHG emissions, while if the 10% ZNZ target was just met, a range of approximately USD 30 to 50 per tonne of GHG emissions was required. This is assuming that a levy/fee/contribution has to be paid for all GHG emissions, independent of the fuel that is used.

List of abbreviations

Table 1 - List of abbreviations

Abbreviation	Description
AD	Anaerobic digestion
CCS	Carbon capture and storage
CO_2	Carbon dioxide
CO_2-eq.	Carbon dioxide equivalents
CST	Centistokes
EJ	Exajoule
ETS	Emissions Trading System
EU	European Union
FAME	Fatty acid methyl ester
FID	Final investment decision
FT	Fischer-Tropsch
FT-BTL	Fischer-Tropsch Biomass-to-liquids
g	Gram
GHG	Greenhouse gas
GJ	Gigajoule
HFO	Heavy fuel oil
HVO	Hydrotreated vegetable oil
IMO	International Maritime Organization
LCA	Life cycle assessment
LH_2	Liquefied hydrogen
LCOF	Levelized cost of fuel production
LCOE	Levelized cost of electricity
LNG	Liquefied Natural Gas
MEPC	Marine Environment Protection Committee
MGO	Marine gas oil
MJ	Megajoule
OCCS	Onboard carbon capture and storage
POME	Palm oil mill effluent
RED	Renewable Energy Directive
TtW	Tank-to-Wake
UCO	Used cooking oil
USD	United States dollar
VLSFO	Very Low Sulphur Fuel Oil
WtT	Well-to-Tank
WtW	Well-to-Wake
ZNZ fuel	Zero or near-zero greenhouse gas emission fuel

1 Introduction

1.1 Political context

In order to meet the ambitions of the 2023 IMO strategy on reduction of greenhouse gas emissions from ships, the IMO has implemented short-term measures and is currently working on the development and implementation of mid-term measures.

Some proposed measures in the potential basket of mid-term measures work with a feebate mechanism, a combination of ‘fee’ and ‘rebate’, with the additional costs incurred by parties using zero or near-zero greenhouse gas emission (ZNZ) fuels being offset by the revenues of a fee/levy/contribution.

One of the ambitions of the 2023 IMO Strategy is the uptake of ZNZ technologies, fuels and/or energy sources to represent at least 5%, striving for 10% of the energy used by international shipping by 2030. However, ZNZ fuels are not precisely defined yet. It is also not clear yet, how compensation, as part of the feebate mechanism, should be determined, depending on the design of the mechanism and the fuel used. The Dutch Ministry of Infrastructure and Water Management asked CE Delft to study and analyse possible parameters of such a feebate mechanism.

1.2 Objective and scope of the study

The aim of this study is to investigate and analyse possible parameters of the feebate mechanism. For this purpose, the following three tasks have been carried out:

1. The identification of ZNZ fuels.
2. An analysis of the costs, supply and demand of the ZNZ fuels identified in Task 1.
3. An analysis of the ZNZ fuels identified in Task 1 and their costs in the context of the 2030 goal of the 2023 IMO GHG strategy and the feebate mechanism.

1.3 Outline of the report

In the following, in Chapter 2, we will first identify ZNZ fuels taking into account three criteria: maximum greenhouse gas intensity, sustainability and availability in 2030. Subsequently, in Chapter 3, the future cost price, future supply of and future demand are analysed for the ZNZ fuels identified in Chapter 2, not taking into account any feebate mechanism. Chapter 4 further analyses the ZNZ fuels and their costs in the context of the 2023 IMO GHG Strategy (5-10% coverage of 2030 energy use of international shipping by ZNZ fuels) and the feebate mechanism. Finally, conclusions are provided in Chapter 5.

2 Identification of ZNZ fuels and availability of in 2030

This chapter identifies zero or near-zero greenhouse gas emission marine (ZNZ) fuels, considering three criteria: the maximum greenhouse gas intensity of the fuels, sustainability and availability of the fuels in 2030. Section 2.1 focuses on the greenhouse gas (GHG) intensity and categorises the fuels based on three alternative threshold values. Section 2.2 discusses sustainability criteria. Section 2.3 provides insight into the 2030 production capacity of the ZNZ fuels as identified in Section 2.1, as well as their potential availability.

2.1 Greenhouse gas intensity and ZNZ fuels

To identify ZNZ fuels, we consider three alternative threshold values for the maximum Well-to-Wake (WtW) greenhouse gas intensity:

1. A maximum of 20 g CO_{2e} per MJ of fuel.
2. A maximum of 15 g CO_{2e} per MJ of fuel.
3. A maximum of 10 g CO_{2e} per MJ of fuel.

The Marine Environment Protection Committee (MEPC) has adopted the 2024 Guidelines on Life Cycle GHG Intensity of Marine Fuels (ca.gov, 2024). Currently, these guidelines contain only a small number of initial default GHG intensity values and the guidelines are under ‘continuous technical review’ to, among other things, further develop Well-to-Tank (WtT), Tank-to-Wake (TtW) and WtW default emission factors for the different fuel production pathways. The aim of this study is not to formally establish default values for the LCA Guidelines.

The MEPC also published an interim guidance note in 2023 (MEPC.1/Circ.905) that states that, as long as the comprehensive method for the calculation of the GHG intensity of the marine fuels based on the LCA Guidelines has not been established yet, for marine biofuels that have been certified under a recognised international certification scheme to meet the sustainability criteria under that scheme and also have been certified to provide a WtW GHG emission reduction of at least 65% (i.e. achieve a WtW GHG intensity of at least 33 g CO_2-eq./MJ compared to the WtW reference value of 94 CO_2-eq./MJ of fossil MGO), the GHG intensity value included in the Proof of Sustainability of the marine biofuel can be used for the Data Collection System (DCS) and the Carbon Intensity Indicator (CII). Biofuels that are not certified as sustainable or that have a WtW GHG intensity above 33 g CO_2-eq./MJ are treated as the equivalent fossil fuel type (MEPC, 2023).

2.1.1 Literature study

We have conducted a literature review to collect WTW GHG intensity values for non-fossil marine fuels. The following scope was used with regard to the GHG intensity:

- the global warming potential over 100 years (GWP_{100}) is applied;
- as far as possible, not only CO_2 but also CH_4 (methane) and N_2O (nitrogen dioxide) emissions are considered;
- methane slip and volatile emissions are taken into account;

- post-combustion emission capture or onboard after treatment systems, like OCCS are not considered;
- the use of pilot fuel is not attributed to the use of the main fuel, and thus the emissions from burning pilot fuel are not taken into account.

The result of the literature review is presented in Table 2.

Table 2 - Overview of WtW GHG emission intensities of potential ZNZ fuels based on a literature review

#	Type of potential ZNZ fuel	Resource	Production pathway	WtW GHG emission factor (g CO_2-eq./MJ)	Assumptions and remarks	Source
1	Biodiesel (FAME)	Used cooking oil (UCO)	Transesterification	8.3-17		Min.: (Prussi et al., 2020) Max.: (Lloyd's Register, 2024)
		Animal fats, tallow oil		14-15		Min: (Prussi et al., 2020) Max: (EU, 2023)
		Advanced (non-food residues)		20.8	Electricity grid mix used. IMO initial default emission factor.	(ca.gov, 2024)
2	Biodiesel (HVO)	Energy crops		34-116		(DNV & Ricardo, 2023)
		Advanced (non-food residues)		3-21		(DNV & Ricardo, 2023)
		UCO, tallow oil, POME		11-16		(Prussi et al., 2020)
3	Biodiesel	Farmed wood	Gasification plus Fischer-Tropsch synthesis	14-18		(Prussi et al., 2020)
		Black liquor		10		(EU, 2023)
		Agricultural and forestry residues		-12 to 6		Min.: (Watanabe et al., 2022) Max.: (Carvalho et al., 2023)
		Waste wood		10-16		Min.: (Prussi et al., 2020) Max.: (EU, 2023)
4	Bio-oil	UCO, animal fats	Hydrotreated	12-16	Typical value (RED III)	(EU, 2023)
		Agricultural and forestry residues	Hydrotreated pyrolysis	13-15		(Carvalho et al., 2023)
		Food crops, residues	Fast pyrolysis	10-100	Drop-in biofuel	(Watanabe et al., 2022)
		Agricultural and forestry residues	Hydrothermal liquefaction	5-55		(Watanabe et al., 2022)

#	Type of potential ZNZ fuel	Resource	Production pathway	WtW GHG emission factor (g CO_2-eq./MJ)	Assumptions and remarks	Source
5	Liquefied biomethane (bio-LNG)	Wet manure		-99 to -6	Adapted from typical values from RED III (liquefaction instead of compression assumed). Negative because of avoided methane emissions from manure storage. Value strongly depends on assumption on storage of digestate and burning of off-gas.	(EU, 2023)
		Maize-manure mixture		-2 to 19	Adapted from typical values from RED III (liquefaction instead of compression assumed).	(EU, 2023)
		Maize whole plant		31		(Prussi et al., 2020)
		Intermediate crops		25		(Prussi et al., 2020)
		Organic municipal waste		14		(Prussi et al., 2020)
		Sewage sludge		26		(Prussi et al., 2020)
		Agricultural and forestry residues	Gasification	-10 to 15		(Watanabe et al., 2022)
6	Biomethanol	Agricultural and forestry residues		-15 to 5		(Watanabe et al., 2022)
		Forestry residues and waste wood		10-15		Min.: (Studio Gear Up, 2022) Max.: (EU, 2023)
		Manure	Anaerobic digestion (AD)	-103 to -55	Lower value: pig manure. Higher value: cow manure.	(Studio Gear Up, 2022)

#	Type of potential ZNZ fuel	Resource	Production pathway	WtW GHG emission factor (g CO_2-eq./MJ)	Assumptions and remarks	Source
		Farmed wood		15-25	Higher value: short rotation coppice poplar.	Min.: (Prussi et al., 2020) Max.: (Studio Gear Up, 2022)
		Maize	AD	20-38		(Studio Gear Up, 2022)
		Organic waste	AD	8		(Studio Gear Up, 2022)
		Black liquor	Gasification	10		(EU, 2023), (Studio Gear Up, 2022)
7	e-hydrogen	Grid mix	Electrolysis plus liquefaction	0-46		(DNV & Ricardo, 2023)
		Renewable electricity		0.7-3.6		Min.: (Studio Gear Up, 2022) Max.: (Prussi et al., 2020)
8	e-ammonia	Renewable electricity	Electrolysis + Haber-Bosch synthesis	0-55	The high value of the range is also based on renewable electricity. Values from literature vary widely (Sphera, 2024).	(DNV & Ricardo, 2023), (Sphera, 2024)
9	Liquefied e-methane (e-LNG)			4-16	Value depends on engine technology and operation, esp. methane slip.	(Maersk Mc-Kinney Møller Center for Zero Carbon Shipping, 2022)
10	e-methanol	Grid mix		102-153	Lower value: EU grid mix of 275 g CO_2-eq/kWh. Upper value: US grid mix.	(Studio Gear Up, 2022)
		Renewable electricity		1.8-10		Min.: (Prussi et al., 2020) Max.: (Studio Gear Up, 2022)
11	e-diesel	Renewable electricity		0.8-0.9	The only found range for e-diesel appears too low compared to values for e-hydrogen and e-methanol.	(Prussi et al., 2020)

Note: All biomass feedstocks other than crops and farmed wood are biomass residues and their availability is therefore limited by production and consumption volumes in the economy. The potential of crops is restricted by land availability, production for food and feed, and sustainability criteria.

The overview of WtW GHG intensity values of sustainable marine fuels in Table 2 shows that the GHG intensities strongly depend on the biomass feedstocks used, on the production pathways (technologies) and on the renewable share of the electricity used, especially in the case of e-fuels. For biomass residues, which encompass most of the feedstock types, the WtW GHG intensity value is also influenced by the method of allocating the upstream GHG emissions to the different main products and residue streams. Generally, a very low share of the upstream emissions is allocated to the residue streams, which explains the low GHG intensity values of biomass residues compared to energy crops.

The origin of the CO_2 has an insignificant contribution to the GHG intensity of e-fuels. For example, Prussi et al. (2020) show that for the production of e-diesel, the use of fossil CO_2 from flue gases, biogenic CO_2 from biogas upgrading or CO_2 from direct air capture (DAC) has a negligible effect on the GHG intensity of this fuel. There are two reasons for this. First of all, the use of fossil CO_2 captured from flue gasses can be considered a delayed CO_2 emission which can be considered net climate neutral (Studio Gear Up, 2022). Secondly, studies assume that renewable electricity and residual heat are used in the CO_2 capture process.

The large ranges for specific fuels is for an important part caused by the consideration of different feedstock types, production pathways and renewable electricity shares within that range. Another explanatory factor may be that many biofuel and e-fuel technologies are still under development, as shown by technology readiness levels as reported in the literature (ABS et al., 2023b; Concawe, 2024). As the exact production processes are still uncertain, so is their environmental performance.

With regard to e-fuels, some literature sources do not clearly distinguish between e-fuels produced by means of renewable electricity versus electricity from the grid (‘grid mix’). Moreover, for both electricity sources large ranges are reported. For renewable electricity, different values can probably be explained by different assumed wind and solar mixes, different production locations (countries), inclusion or exclusion of emissions related to the manufacturing of wind turbines and solar panels[1], and different assumptions regarding the energy required for the e-fuel synthesis steps. For grid electricity, the grid mix (renewable electricity share) at the production location has a large influence on the GHG intensity (an average EU value is 70 g/MJ (Studio Gear Up, 2022), but the GHG intensity reduces to zero as the renewable share increases). As underlying assumptions are often not given, it is not possible to explain differences between values from literature in further detail, nor inconsistencies such as the e-diesel GHG intensity range (which appears too low) and the e-ammonia range which has a very wide range considering that renewable electricity is used.

The literature overview in Table 2 does not include ‘blue fuels’, i.e. fossil-based fuels of which the CO_2 emissions are captured[2] and stored long-term in empty gas fields, aquifers or salt caverns. This is because these fuels were found to have values higher than the highest WtW GHG emissions threshold of 20 g CO_2-eq./MJ as applied in this study (see Table 3). Only blue ammonia might qualify as ZNZ fuel in 2030, at least if the threshold was above 10 g CO_2-eq./MJ. The release of methane in the production stage of the fossil fuels and the

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[1] According to the IMO LCA guidelines, the GHG emissions related to the manufacturing of production installations such as wind turbines are not included in the WtW GHG intensity of fuels.

[2] CO_2 could either be captured onboard (post-combustion) or in the fuel production plant (to produce a fuel that does not contain fossil carbon). Literature studies on blue fuels usually consider the latter, which is possible on a larger scale and avoids the need for temporary onboard CO_2 storage.

share of non-captured CO_2 in the carbon capture stage are important contributors to the Well-to-Wake GHG emissions of blue fuels.

Table 3 - WtW GHG emission factors of blue fuels

Fuel	GHG intensity (g CO_2-eq./MJ)	Assumptions	Source
Blue hydrogen	28-46		(DNV & Ricardo, 2023)
Blue ammonia	28-55		(DNV & Ricardo, 2023)
	11-109		(Sphera, 2024)
Blue methanol	33-38	Made from municipal solid waste with a 75% biogenic content	

Furthermore, the literature overview does not include biofuels combined with CCS and biohydrogen or bio-ammonia. Biofuels combined with CCS can in most cases lead to net negative Well-to-Wake GHG emissions (Watanabe et al., 2022), but this requires carbon capture at the biofuel production facility and long-term geological storage of the CO_2.

2.1.2 Categorisation of ZNZ fuels

Based on the literature overview of WtW GHG intensity values of ZNZ fuels from Table 2, we have made a classification of ZNZ fuels on the basis of the three GHG intensity thresholds as applied in this study. This classification is presented in Table 4.

Table 4 - Classification of ZNZ fuels on the basis of three alternative WtW GHG intensity thresholds

#	Type of ZNZ fuel	Fuel subcategories above highest threshold	ZNZ fuels within the three alternative thresholds for the maximum GHG intensity (fuel subcategories in column(s) to the right of a threshold value also fall under this threshold)		
		> 20 g CO_2-eq./MJ	≤ 20 g CO_2-eq./MJ	≤ 15 g CO_2-eq./MJ	≤ 10 g CO_2-eq./MJ
1	Biodiesel (FAME)	Food crops	Advanced feedstocks (non-food residues)	Used cooking oil (UCO), animal fats	*Rare*
2	Biodiesel (HVO)				*Rare*
3	Biodiesel (Fischer-Tropsch)		Farmed wood	Waste wood	Agricultural and forestry residues
4	Bio-oil	Food crops, hydrothermal liquefaction		hydrotreating, pyrolysis	*Rare*
5	Liquefied biomethane (bio-LNG)	Food crops, intermediate crops, sewage sludge	Maize-manure mix	Organic waste, gasification of agr. and forestry residues	Wet manure
6	Biomethanol	Food crops	Farmed wood (partially)	Woody residues	Manure, organic waste, black liquor (gasification)
7	e-hydrogen	Grid mix	Grid mix	Grid mix	Renewable electricity
8	e-ammonia	Renewable electricity	Renewable electricity (values in literature vary widely)		
9	e-methane (e-LNG)				*Partially, depending on*

#	Type of ZNZ fuel	Fuel subcategories above highest threshold	ZNZ fuels within the three alternative thresholds for the maximum GHG intensity (fuel subcategories in column(s) to the right of a threshold value also fall under this threshold)		
		> 20 g CO_2-eq./MJ	≤ 20 g CO_2-eq./MJ	≤ 15 g CO_2-eq./MJ	≤ 10 g CO_2-eq./MJ
			🟩	🟩	*engine and methane slip.*
10	e-methanol	Grid mix	🟩	🟩	Renewable electricity
11	e-diesel		🟩	🟩	Renewable electricity

Note: If a large part of the GHG intensity range of a certain ZNZ fuel falls under a specific GHG intensity threshold, the corresponding cell is coloured green. Blue fuels do not meet the thresholds and are therefore not included.

Due to the various factors that influence the WtW GHG intensity of a fuel and the uncertainty associated with the production of innovative fuel production pathways, it is not possible to assign a generally valid, unique WtW GHG intensity factor to a fuel type category. As a consequence, fuel type categories cannot be unambiguously identified as being either ZNZ or non-ZNZ fuel.

As Table 4 illustrates, the WtW GHG intensity ranges often cross two or more thresholds. However, as the large ranges are the result of different feedstocks, renewable electricity shares and production pathways having different GHG intensity values, we have indicated in the cells of Table 4 specific conditions under which marine fuels can meet the assumed WtW GHG intensity thresholds. We observe that no strict GHG intensity categorisation of ZNZ fuels can be made based on feedstock, renewable electricity share or production technology.

Biofuels made from food crops usually have a WtW GHG intensity above the highest threshold of 20 g CO_2-eq./MJ, which means that these would not qualify as ZNZ fuels if one of the three thresholds as applied in this study were selected to define ZNZ fuels. The use of biomass residues as a feedstock usually results in GHG intensity values below one or more thresholds, with the exception of bio-LNG produced through anaerobic digestion of sewage sludge. This is because of the co-production of methane, which is a far more potent greenhouse gas than CO_2. The production of bio-LNG from wet manure may have a negative GHG intensity as large as -90 g CO_2-eq./MJ (as indicated in the RED III), because a large part of the methane emitted during manure storage are avoided. This more than compensates for methane slip when bio-LNG is used as a marine fuel.

The use of electricity from the grid (‘grid mix’) for the production of e-fuels could also mean that these fuels are not ZNZ fuels, in case a large part of the electricity production mix is produced from fossil fuels (without CCS). However, if 100% renewable electricity is used, many e-fuels can meet the lowest threshold of 10 g CO_2-eq./MJ. E-ammonia forms an exception: both DNV and Ricardo (2023) and Sphera (2024) give a large GHG intensity range for e-ammonia that is produced using renewable electricity, which prevents a general positioning of this fuel under a specific threshold.

2.2 Sustainability criteria

The use of ZNZ fuels should not only lead to a relatively high reduction of the WtW GHG emissions, but ZNS fuels should also fulfil certain sustainability criteria to avoid any trade-offs.

As stated before, MEPC has adopted the 2024 guidelines on the life cycle GHG intensity of marine fuels (2024 LCA Guidelines) (MEPC, 2024). These guidelines specify the following ten sustainability themes/aspects related to marine fuels/energy carriers used for ship propulsion and power generation onboard:
1. Greenhouse gases.
2. Carbon source.
3. Source of electricity/energy.
4. Carbon stock – direct land use change (DLUC)[3].
5. Carbon stock – indirect land use change (ILUC)[4].
6. Water.
7. Air.
8. Soil.
9. Waste and chemicals.
10. Conservation.

For some of these themes/aspects, a quantitative metric/indicator has been established while for others qualitative criteria. However, no threshold values/minimum requirements have been established yet which is why it is difficult at this stage to discard certain fuels/fuel production pathways as ZNZ fuels.

2.3 Production capacity and availability of ZNZ fuels for maritime shipping

Based on a literature review we have estimated the possible development of global production capacity of ZNZ fuels towards 2030, shown in Table 5.

For the purpose of this study, only the development of advanced biofuels, i.e. biofuels made from biomass residues and non-food crops (without competition with food/feed production), are of interest. This is because biofuels made from food crops have a GHG intensity surpassing the highest GHG intensity threshold considered in this study (see above).

As it is expected that global biofuel production will continue to be dominated by biofuels made from food crops (OECD-FAO, 2021), only a fraction of global biofuel projects are relevant for this study.

In addition, only the share of the expected global e-fuels production capacity that will produce e-fuels with a GHG intensity below WtW GHG intensity thresholds is relevant for this study. Although it is not possible to differentiate between production capacity based on GHG intensity value in this literature review, we note that the average GHG intensity of grid electricity of a small number of countries is already low enough to be able to produce

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[3] When land is transformed into agricultural land in order to grow crops for the production of the biofuels.

[4] When food crops are used for the production of biofuels and consequently land is turned into agricultural land to keep up the food crop production.

e-fuels that meet one or more of the GHG intensity thresholds using grid electricity[5]. This number will increase as renewable electricity shares of countries grow over time.

Table 5 - Estimation of global production capacity of potential ZNZ fuels in 2030

Fuel type	**Production capacity in 2030 (EJ/year)**			**Data source**	**Remarks**
	Min.	**Expected**	**Max.**		
Advanced biofuels	0.7	1.4	2.3	Min.: (DNV & Ricardo, 2023) Exp.: (S&P Global, 2022) Max.: (DNV & Ricardo, 2023)	Max.: announced projects plus potential additional projects that could be realised up to 2030. Exp.: minimum global sales potential, based on current and planned biofuel blending shares.
Biomethanol	*(0.01)*	*(0.05)*	*0.09*	*(DNV & Ricardo, 2023)*	
E-fuels	0.3	(2.8)	11.2	(DNV & Ricardo, 2023)	Max.: announced projects, plus potential additional projects that could be realised up to 2030. Exp.: assuming that 50% of announced capacity from DNV & Ricardo (2023) is realised.
E-hydrogen	*0.2*	*(1.5)*	*2.9*	*Min.: (IEA, 2024)* *Max.: (DNV & Ricardo, 2023)*	*E-hydrogen overlaps with e-ammonia, as the latter is made from the first. As a result, estimations for these two e-fuels cannot be simply added up.*
E-ammonia	*(0.1)*	*2.6*	*(5)*	*(DNV, 2024b)*	
E-methanol	*(0.01)*	*(0.05)*	*0.10*	*(DNV & Ricardo, 2023)*	
Total	**1.0**	**4.2**	**13.5**		**Sum of advanced biofuels and e-fuels**

Note: 'Min.' = projects with FID; 'Expected' = expected development; 'Max.' = potential (announced projects). 'Advanced' = made from biomass residues and non-food crops. Values between brackets are estimated from CE Delft for this study.

If all announced projects for the production of advanced biofuels and e-fuels will be realised, the global production capacity in 2030 would amount to 13.5 EJ. However, it is not likely that all announced projects are realised, because many of them are currently in an early stage of development (e.g., a feasibility study is being conducted). At minimum, the projects that have made a final investment decision (FID) can be expected to be present in 2030, but the total production capacity of these projects would probably be much lower than the expected total capacity. We have estimated an expected production capacity realisation for advanced biofuels and e-fuels of 4.2 EJ by 2030 (see Table 5). To put this expected 4.2 EJ of potential ZNZ fuel production capacity into perspective, the global fuel energy demand of maritime shipping has been estimated to amount to about 11 EJ in 2021 (DNV & Ricardo, 2023) and to between 9.1 and 10.6 EJ in 2030 (DNV, 2024a).

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[5] For example, the average GHG intensity of electricity produced in France in 2023 was 56 g CO_{2e}/kWh, or 15.6 g/MJ, which might enable the production of e-fuels below the GHG intensity threshold of 20 g CO_{2e}/MJ. Source: www.ourworldindata.org/grapher/carbon-intensity-electricity, accessed in January 2025.

Given the outcome of the literature review as presented above, the availability of ZNZ fuels does not seem to pose a barrier to meeting IMO's ZNZ fuel target[6]. However, it must be kept in mind that in other sectors there might also be demand for ZNZ fuels and that not all advanced biofuels and e-fuels might qualify as ZNZ fuels, depending on the specific WtW GHG intensity threshold applied.

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[6] The 5 to 10% ZNZ fuel target would then translate into 0.46 to 1.1 EJ that would have to be covered by means of ZNZ fuels.

3 Future cost of and potential demand for ZNZ fuels

This chapter estimates the future cost price of and the demand for ZNZ maritime bunker fuels as identified in Chapter 2, not taking into account any feebate mechanism. The future cost price of the ZNZ fuels is discussed in Section 3.1 and the future demand in Section 3.2, focusing on the availability of ships that can potentially use ZNZ fuels and their energy demand.

3.1 Future cost price of ZNZ fuels

The costs of ZNZ marine fuels play an important role in determining the required rebate as part of the feebate mechanism. The main factors that affect marine fuel prices are shortly described below:

- **Production costs:** Fuels must be produced from certain raw materials. Both the raw materials themselves and the fuel production process involve costs. The costs of the fuel production depends on the type of process and can be divided into capital costs and operational costs. Production costs normally decrease as the scale of the production increases. In the context of ZNZ fuels, biomass feedstock costs and costs for renewable electricity costs can play an important role. In the last decade, on average, the levelised cost of electricity has been decreasing, except for hydropower and geothermal power (IRENA, 2024).
- **Transportation, liquefaction and distribution costs:** Raw materials must be transported to the production facility. After the production process, the fuel must be liquefied in certain cases in order to be transported. The produced (and sometimes liquefied) fuel must be distributed to several bunker sites. Transport, liquefaction and distribution incur costs.
- **Differences in various regions:** Depending on the origin of the raw materials, the location of the production facility, the production process and scale of the production facility, the above mentioned production, transportation and distribution costs may vary between regions.
- **Demand in other sectors:** Demand in other sectors can also effect the marine fuel price. The costs price for marine fuels can increase in case the demand for the raw materials increases.
- **Environmental and fiscal policies** can have an impact on the final price of marine fuels. A good example is the impact of the EU Emissions Trading System (EU ETS). The EU ETS is an EU policy measure that requires ships of 5,000 GT and above to purchase and surrender EU ETS emissions allowances for each tonne of reported CO_2 emissions in the scope of the EU ETS system. In the case of this specific policy measure, the costs involved depend on the type of fuel and associated emissions.
- **War, natural disasters and unrest:** This last aspect is difficult to predict. A war can rattle the global economy and affects fuel prices. The current war between Ukraine and Russia is a good example. A natural disaster or war can, in addition, also disrupt or break supply lines, refineries or storage tanks (Mansfield Service Partner, 2024).

As a result of above mentioned factors, the cost price for a type of fuel is not uniform, but may vary by region, by day and by production process (Ship&Bunker, 2024) (Francielle Carvalho et al., 2021).

Table 6 provides a range of expected ZNZ marine fuel cost prices for 2030, based on a literature review. These studies do not always distinguish fuel prices in terms of different resources and production pathways (as mentioned in Section 2.1) and in terms of different regions where the fuel is produced. The scope of the costs considered is also not always clear, however, none of the sources includes the additional capital costs that may accrue if a ship wanted to use the fuels onboard ships.

Table 6 - A range of expected ZNZ marine fuel cost prices in 2030, based on various literature studies

		Expected fuel cost price (USD/GJ) in 2030				
#	**Type of ZNZ marine fuel**	**DNV (2024a)***	**CE Delft and Ecorys (2021)****	**Reports published by EMSA*****	**Francielle Carvalho et al. (2021)**	**Francielle Carvalho et al. (2023) *******
1	Biodiesel (FAME)	Not available	3-62	15-23		
2	Biodiesel (HVO)	Not available	27-57	16-28	Europe: 30-58	
3	Biodiesel (Fischer-Tropsch)	Not available	15-196	10-36	**FT-BTL-centralised:** Europe: 30-58; South Africa: 23-25; USA: 25-31	Brazil: 23-28; USA: 29
					FT-BTL-decentralised: Europe: above 60 USA: around 60	
4	Bio-oil	Not available	24-42		Europe: 30-58; USA: 25-31	Brazil: 27-28 USA: 30-31
5	Liquefied biomethane/ bio-LNG	26.5	12-35	10-27		
6	Biomethanol	30.8	9-35	22-49		
7	E-hydrogen (Green LH_2)	50.8	Not available	58-65****		
8	E-ammonia	46.5	Not available	From Australia: 50-58; Chile: 45-53; Morocco: 40-48; Spain: 41-48		
9	E-methane (e-LNG)	58.0	Not available	27-37		
10	E-methanol	61.2	Not available	33-42		
11	E-diesel	Not available	Not available	37-47		

* DNV provides expected marine bunkering costs for 2030 in the Comprehensive Impact Assessment of the basket of candidate mid-term GHG reduction measures (DNV, 2024a). DNV states that, in principle, the fuel price is a function of the costs of raw material, production and distribution of the fuel and the relationship between supply and demand[7] in the market. The proportion of costs related to these various aspects is not mentioned. The average fuel bunkering costs are based on an extensive literature study.

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[7] In case the total demand for low emission fuels exceeds the supply for bio- and blue fuel feedstocks DNV adjust the fuel prices of all the fuel types made from those feedstocks to the equivalent, in terms of energy and emissions, cost of e-fuel of the same type. As an example, DNV increases the fuel price for bio-LNG to the bunkering costs of e-LNG, and the fuel price of blue ammonia will converge with the fuel bunkering cost of e-ammonia.

** CE Delft and Ecorys (2021) provides a range of expected future production costs per fuel type. This does not include distribution costs. Prices are given in €/GJ in this literature source. We have converted the prices to USD/GJ with a conversion rate of € 1.00 is 1.07 USD (exchange rate on 07/11/2024).

*** The costs are based on several studies published by EMSA: ABS et al. (2022), ABS et al. (2023b), ABS et al. (2023a), and ABS and CE Delft (2024). The costs are estimated and projected for the year 2030. The costs include fuel production costs, shipping to EU, conversion at destination (where required) and storage in port

**** In this study, it is assumed that hydrogen is transported as ammonia since this was found to be cheaper than distribution of hydrogen.

***** The fuel cost estimates include feedstock costs, levelized costs of fuel production (LCOF) and transportation costs.

As a comparison, Table 7 gives the average marine fossil fuel bunker costs in October 2024 (S&P Global, 2024). From Table 6 and Table 7 it can be concluded that the expected ZNZ marine fuel prices for 2030 are significantly higher than the current average fossil fuel oil and gas oil prices.

Table 7 - Monthly average fossil marine bunker fuel costs, October 2024

Fuel type	Fuel cost range (USD/GJ)*
Bunker Fuel Oil 380 CST - 3.5% sulphur	11.8-15.2
Marine Fuel and Gas Oil - 0.5% sulphur	13.2-14.8
Low Sulphur Marine Gas Oil - 0.1% sulphur	14.7-16.4

* EU ETS costs are not included (non-inclusive). Range of fuel costs based on S&P Global (2024).

3.2 Future demand for ZNZ fuels

The potential demand for ZNZ fuels in 2030 is analysed focusing on the availability of ships that can potentially use ZNZ fuels and their energy demand. The analysis is based on Clarksons World Fleet Register (Clarksons Research, ongoing) and the Fourth IMO GHG Study (CE Delft et al., 2020).

Clarksons World Fleet Register is a database which provides insight into both the current global fleet and the orderbook. The database provides various information for the individual ships from 100 GT on, amongst which information on the ships' main engine fuel type.

Currently[8], there are around 111,600 existing ships recorded in the Clarksons World Fleet Register and around 6,545 ships are on order (Clarksons Research Portal, 2024). Table 8 lists the number of existing ships that currently can be propelled by LNG or another alternative fuel type, while Table 9 lists the according number of ships in the orderbook.

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[8] September 25, 2024.

Table 8 - Existing ships that currently can run on LNG or another alternative fuel type*

Type fuel	# ships	Percentage relative to the total number of existing ships operating on alternative fuels (%)	Percentage relative to the total fleet (%)
LNG (incl. CNG)	1,215	72%	1%
Batteries propulsion	249	15%	<1%
LPG	132	8%	<1%
Methanol	43	3%	<1%
Ethane	25	2%	<1%
Hydrogen	14	<1%	<1%
Nuclear	10	<1%	<1%
Ammonia	3	<1%	<1%
Total	**1,691**	**100.0%**	**1.5%**

Source: CE Delft analysis based on Clarksons Research Portal (2024).

* ‘Batteries & diesel’ and pure biofuel have been discarded.

Prior to 2002, there were only a few ships capable of running on alternative fuels. This share has been increasing since 2002, however, despite this increase, the overall share of the fleet that currently can operate on alternative fuels is still minimal, at only 1.5%. Of the ships currently capable of running on alternative fuels, most are suitable for LNG (72%), followed by battery propulsion (15%) and LPG (8%). Alternative fuels such as ammonia and hydrogen are used by a few ships only.

Table 9 - Ships on order that could be operated on LNG or other alternative fuels once they are in operation*

Type fuel	# ships	Percentage relative to the total # ships on order operating on alternative fuels (%)	Percentage relative to the total # ships on order (%)
LNG (incl. CNG)	1,015	59%	16%
Methanol	279	16%	4%
Batteries propulsion	175	10%	3%
LPG	131	8%	2%
Ethane	63	4%	<1%
Hydrogen	33	2%	<1%
Ammonia	31	2%	<1%
Nuclear	7	<1%	<1%
Total	**1,734**	**100.0%**	**26%**

Source: CE Delft analysis based on Clarksons Research Portal (2024).

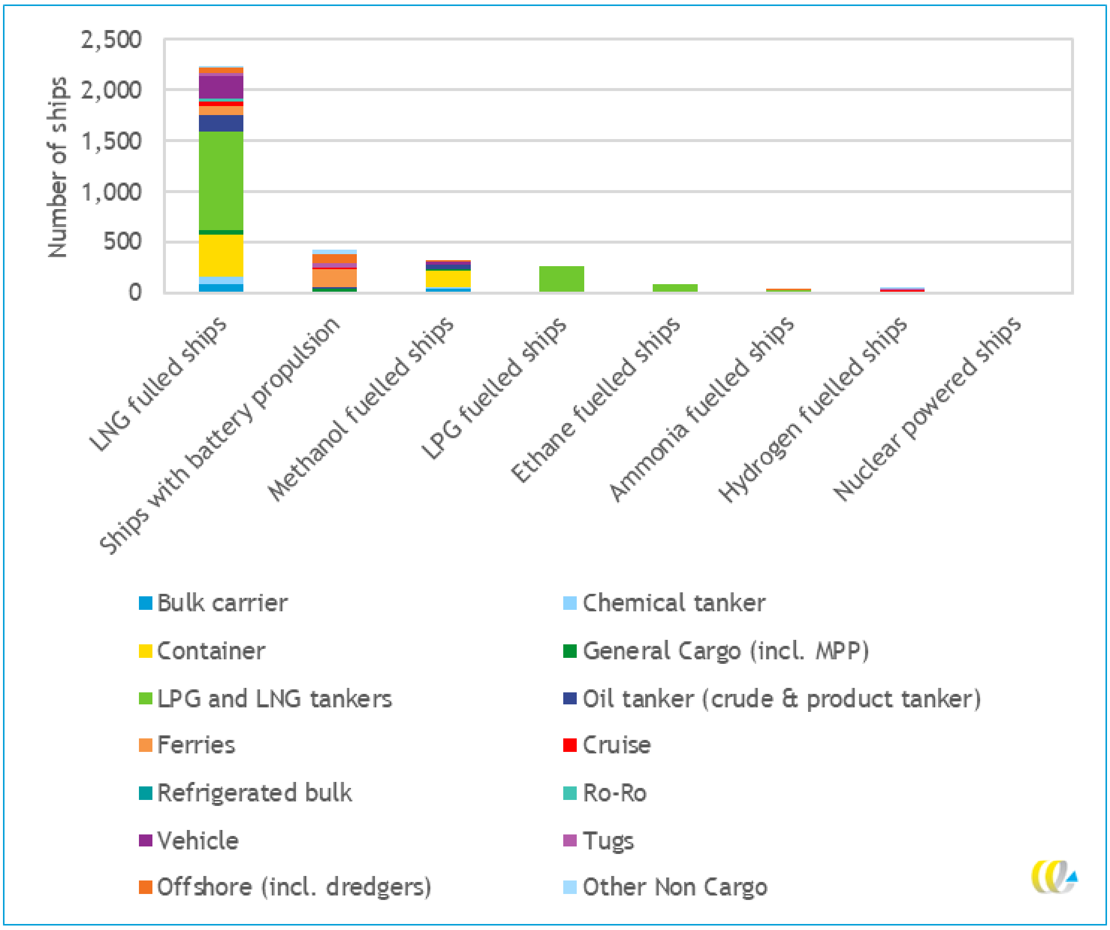
* ‘Batteries & diesel’ and pure biofuel have been discarded.

The orderbook shows that the number of ships being built in the coming years and which are capable of running on alternative fuels is increasing significantly. Nearly 26% of the ships currently in the orderbooks will be suitable for alternative fuels.

LNG-fuelled ships still have the largest share in the ships on order and capable to run on an alternative fuel type. However, based on the orderbook, it is expected that the demand for other alternative fuels such as methanol, LPG, and ethane will be increasing. Based on the orderbook, the demand for methanol-fuelled ships will, after LNG-fuelled ships, increase most in the coming years.

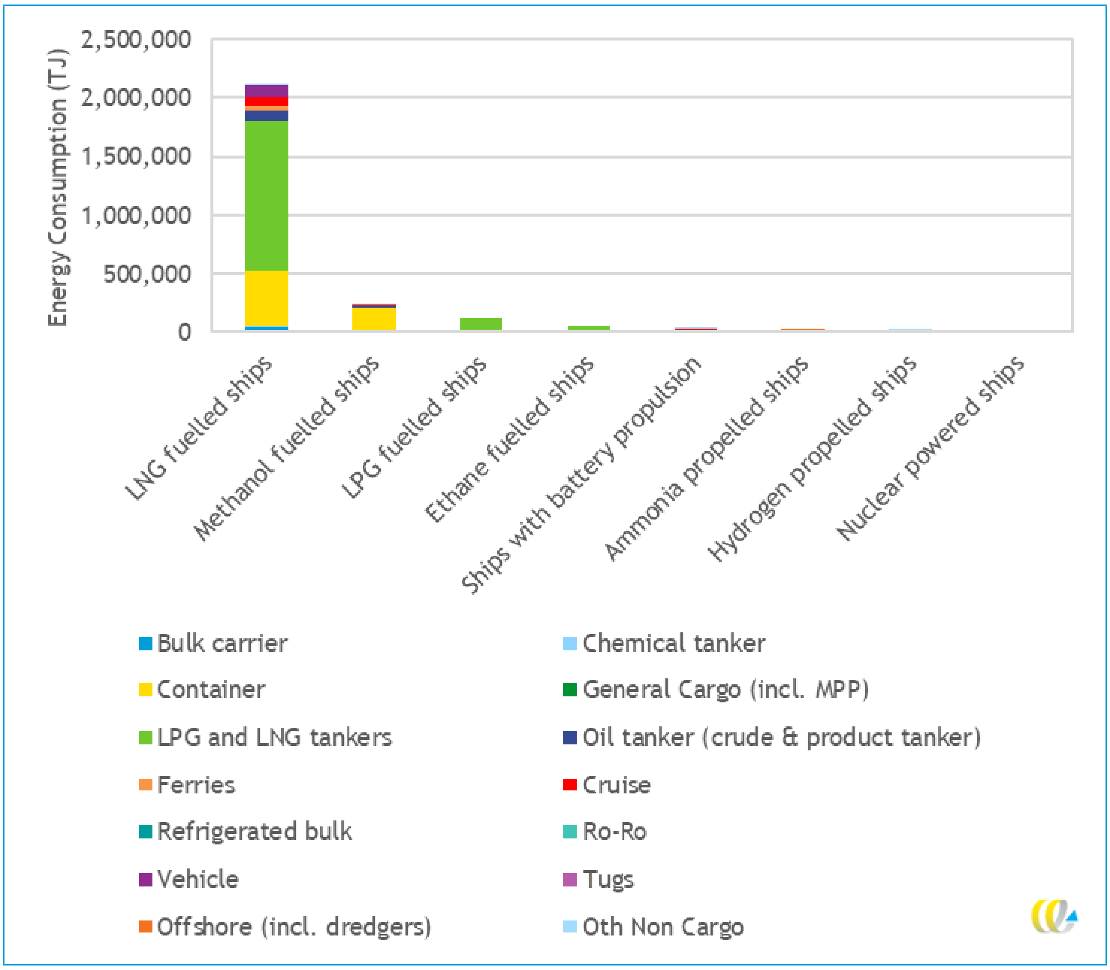
Taking the current fleet and the orderbook together, the following figure provides an overview of the number of ships per alternative fuel type, also differentiating the according ship types.

Figure 1 - Ships in the fleet and on order that can be operated on LNG or other alternative fuels



Assuming that these ships' average annual energy consumption is in line with the average 2018 energy consumption as determined for the according ship type/size categories in the Fourth IMO GHG Study, the annual energy demand of the ships that can be operated on LNG or other alternative fuels can be determined. Figure 2 presents this energy demand, differentiated by main fuel and ship type. In total, this energy consumption amounts to 2.56 EJ. The energy consumption of LNG fuelled ships thereby dominates (82%). If excluded, the total energy consumption amounted to 0.46 EJ.

Figure 2 - Estimated energy demand (TJ) of ships in the fleet and on order that can be operated on LNG or other alternative fuels



Comparing Figure 2 with Figure 1, shows that battery propulsion is only relevant for relatively small ships with relatively low energy consumption.

Since there is still a high degree of regulatory uncertainty and since alternative fuels are, at least as green fuels, hardly available at this stage, more and more ships are ordered that are ‘ready’ to be fuelled by a certain alternative fuel type, i.e. the ship can be relatively easily be retrofitted to be operated on a certain alternative fuel type once required/ available.

In total, there are 1,548 ‘ready’-ships in the fleet and on order. Figure 3 provides an overview of the distribution of the number of these ships over the fuel and ship types. Note thereby that there are some ships that are ‘ready’ to be operated on two or even three types of alternative fuels[9].

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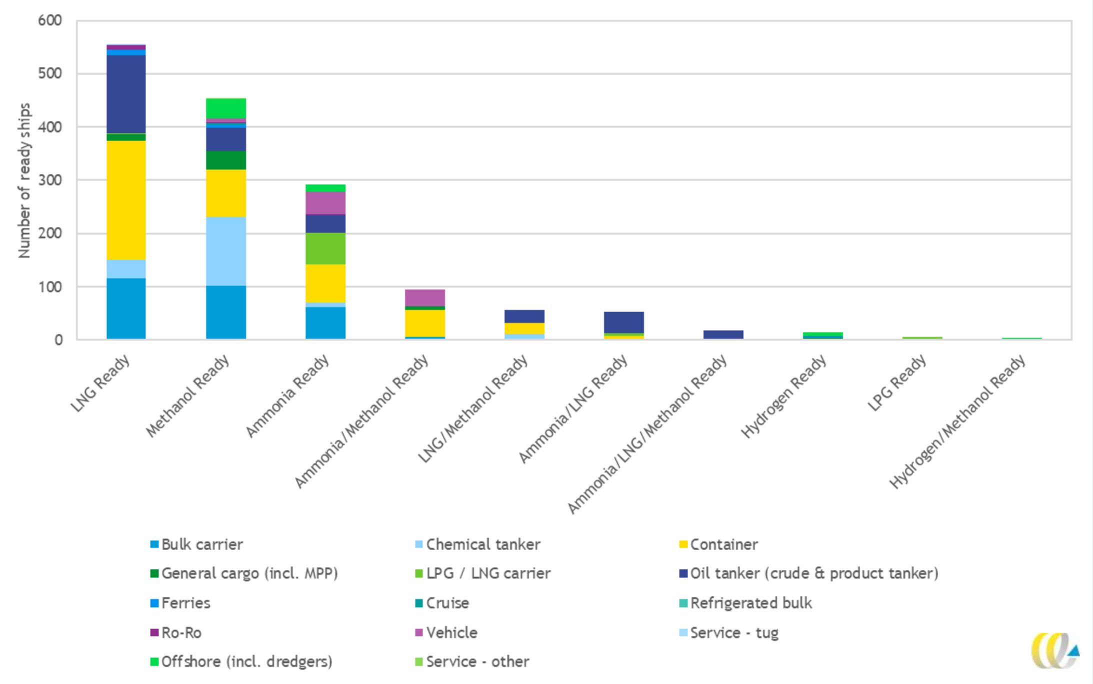
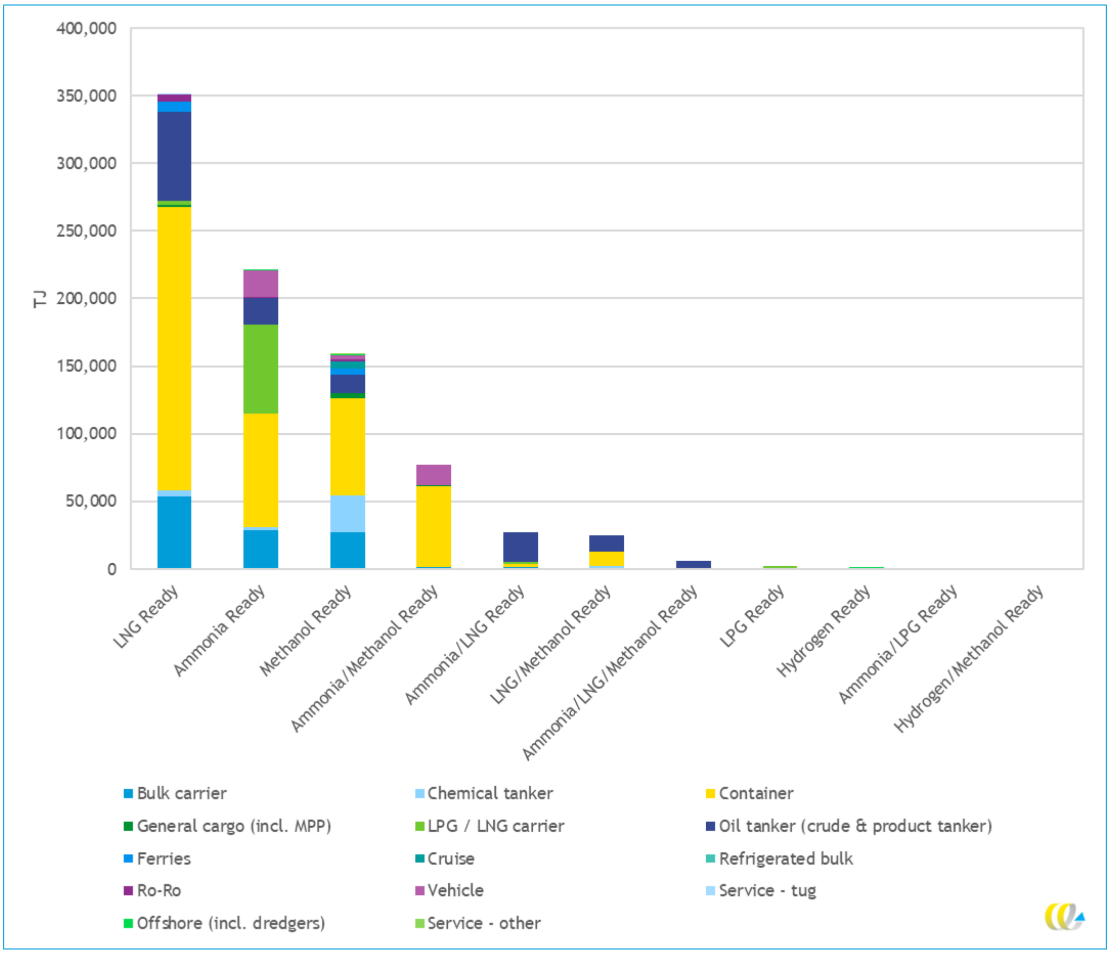
[9] This is why you have to be careful to avoid double counting if you count the number of ships that can be propelled with alternative fuel types.

Figure 3 - Ships in fleet and on order that are 'ready' to be operated on LNG or (an)other alternative fuel type(s)



Assuming again that these ships' average annual energy consumption is in line with the average 2018 energy consumption as determined for the according ship type/size categories in the Fourth IMO GHG Study, the annual energy demand of the 'ready- ships that can be estimated. In total it amounts to 0.87 EJ and excluding LNG ready ships to 0.52 EJ. Figure 4 provides a breakdown of this energy demand differentiating the different fuel and ship types.

Figure 4 – Estimated energy demand (TJ) of ships in fleet and on order that are ‘ready’ to be fuelled by LNG or (an)other alternative fuel type(s)



The global energy demand of maritime shipping has been estimated to amount to between 9.1 and 10.6 EJ in 2030 (DNV, 2024a). Meeting IMO’s 2030 ZNZ fuel/technology target, would therefore require that between 0.46 and 1.1 EJ of the sector’s energy demand was covered by means of ZNZ fuel/technologies. Based on the analysis above, it can be concluded that, if the ships which are currently in the fleet and on order and that are able to use alternative fuels would all use the alternative fuel to cover 100% of their energy consumption by means of the according ZNZ fuel type, then not only the 5% (base) but also 10% (strive) target can be expected to be met. If relatively little biomethane and e-methane were available, the strive target can probably only be met if also ships that are only ‘ready’ to use alternative fuels (other than methane) were actually converted to allow for the actual use of these fuels.

However, most of the ships in the orderbook will be built between 2024 and 2028. After 2028, the number of ships in the current orderbooks decreases significantly, which means that they are not ordered yet. In view of both global and European policies to reduce the GHG emissions, we expect that the number of ships suitable for alternative fuels will only increase further.

The actual demand for the ZNZ fuels of course still requires closing the price gap between ZNZ and fossil bunker fuels.

4 Additional costs and contribution

This chapter further analyses the ZNZ marine fuels and their costs in the context of the 2030 ZNZ targets of the 2023 IMO GHG Strategy and the feebate mechanism, considering the additional costs for ZNZ fuels if the IMO ZNZ targets were met (Section 4.1) as well as the related feebate contributions (Section 4.2).

4.1 Additional costs for the use of ZNZ marine fuels

If the revenue of the feebate was used to cover the additional fuel costs for the use of ZNZ fuels, the contribution that would have to be paid as part of the feebate mechanism naturally depends on the fleet additional costs for the use of the fuels.

We estimated these additional costs for the 2030 fleet, focusing on the difference between the price of conventional bunker fuels and the cost price of the potential ZNZ marine fuels. Potential other operational costs and capital costs that might accrue if ships were ZNZ-fuelled have not been considered.

IMO's ambition is that the uptake of ZNZ GHG emission technologies, fuels and/or energy sources represent at least 5% striving for 10% of the energy used by international shipping by 2030. Therefore, both 5 and 10% uptake of ZNZ marine fuels in 2030 were considered.

For the 2030 energy consumption of the global fleet, we assumed a lower limit of 9.1 EJ and an upper limit of 10.6 EJ (DNV, 2024a).

Regarding the ZNZ marine fuel mix, we made the simplifying assumption that three fuel types (methanol, methane and ammonia) are used and that these fuels are used in equal proportions. Regarding the remaining, non-ZNZ marine fuel mix, we assumed that only VLSFO is used.

Section 3.1 provided an overview of expected 2030 cost prices of the potential ZNZ fuels. Unfortunately, the studies providing data on the cost price of the ZNZ fuels do not provide exact information about the WtW-GHG intensity of the underlying fuel production pathways. We therefore worked with different scenarios. Two cost price scenarios were differentiated: One high price scenario were only e-fuels and only the upper end of the cost price ranges are considered and one low price scenario where, next to e-ammonia, biomethane and bio methanol are considered, taking a relatively low e-ammonia cost price and taking relatively high biofuel prices into account, for the biofuels to be able to meet the ZNZ thresholds.

Table 10 provides an overview of the assumed ZNZ fuel mix as well as the price scenarios.

Table 10 - Simplified assumed 2030 ZNZ marine fuel mix and assumed cost price range

ZNZ marine fuel type	Share (in %)	Upper level fuel cost price (USD/GJ)	Lower level fuel cost price (USD/GJ)
Methanol	33.3	61.2	50
Methane	33.3	58.0	35
Ammonia	33.3	58.0	40
Total/Average	**100%**	**59.1**	**41.7**

Details about the assumptions regarding fossil fuel can be found in Table 11.

Table 11 - Details about the assumptions regarding fossil fuel

Aspect	Value	Unit	Details
Conventional fossil fuel price	15.46	USD/GJ	Based on the average Low sulphur marine gas oil, 0.1% sulphur, see Table 7.
GHG intensity of the selected fossil fuel	95.48	gram CO$_2$-eq./MJ	Based on VLSFO in the table in Annex 2 of IMO LCA guideline.

Given the assumptions as described above, the following additional fuel costs for the use of ZNZ marine fuels accrue, assuming that the IMO 2030 ZNZ targets are just met:

Table 12 - Estimation of the fleet additional fuel costs for the use of potential ZNZ marine fuels instead of VLSFO (billion USD)

Targets of the 2023 IMO GHG Strategy	Additional costs in 2030, assuming the lower level of ZNZ marine fuel cost prices and the lower limit of the fleet energy consumption	Additional costs in 2030, assuming the higher level of ZNZ marine fuel cost prices and the higher limit of the fleet energy consumption
5% uptake of ZNZ marine fuels in 2030	11.9 billion USD	23.1 billion USD
10 % uptake of ZNZ marine fuels in 2030	23.9 billion USD	46.2 billion USD

The estimation of the addition fuel costs as presented in Table 12 can be considered a slight overestimation, since the GHG contribution has not been accounted for[10] and since the 2030 non-ZNZ fuel reference can be expected to be more expensive than the assumed VLSFO.

4.2 Contribution

If the feebate was used to cover the additional fuel costs associated with the use of ZNZ fuels, the contribution that would have to be paid as part of the feebate depends on various factors.

For the purpose of this study we have assumed the following in this regard:
- The contribution is assumed to be paid per tonne of GHG emissions and would have to be paid for all the GHG emissions of the sector, independent of the fuel type that is used.
- We assume that the 2030 ZNZ targets are just met and that the funds are only allocated to those users that collectively contribute to meeting IMO's 2030 ZNZ target and that these users are fully compensated for their additional operational fuel costs.
- The simplifying assumption is made that all ships not using ZNZ fuels, contributing to the 2030 IMO ZNZ target, use VLSFO. This means that the calculated required contribution per tonne GHG could be slightly underestimated, since the additional costs might have to be distributed over less total 2030 fleet GHG emissions. On the other hand, as already explained in Section 4.1, the estimated contribution can therefore also be expected to be an overestimation since the fleet additional fuel costs for the use of

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[10] Also considering the GHG fee/contribution/levy results in lower additional costs, for example 11.4 billion USD instead of the 11.9 billion USD as specified in Table 12.

ZNZ fuels can be expected to be lower if the actual 2030 non-ZNZ fuel mix had been considered.

- Since the literature does not allow a clear match of the expected ZNZ fuel cost prices and the WtW GHG emissions of the underlying fuel production pathways, we determined the contribution for the different threshold values without allocating a WtW-GHG intensity of a fuel price cost scenario (see Table 13). However, it can be expected that the strictest threshold (10 g CO_2-eq. per MJ) better matches high ZNZ fuel price scenario, while the lowest threshold (20 g CO_2-eq. per MJ) better matches the low ZNZ fuel price scenario.

Table 13 shows the calculated contributions in terms of USD per ton of GHG emissions for the different ZNZ fuel price/energy consumption scenarios and the 5 and 10% IMO ZNZ fuel target.

Table 13 - Contribution (USD/t GHG) required to cover the additional costs for meeting the 2030 IMO ZNZ target, depending on the WtW GHG intensity of the fuels

Contribution (USD/t GHG)	Scenario: Lower level of ZNZ marine fuel cost prices and lower limit of the fleet energy consumption			Scenario: Higher level of ZNZ marine fuel cost prices and higher limit of the fleet energy consumption		
ZNZ fuel WtW GHG intensity (g CO_2-eq. per MJ)	10	15	20	10	15	20
5% uptake of ZNZ marine fuels in 2030	14.4	14.3	14.3	23.9	23.8	23.8
10 % uptake of ZNZ marine fuels in 2030	30.1	30	29.8	50.2	49.9	49.6

Assuming that the 10 gCO_2-eq./MJ threshold applies to the higher end of the fuel cost ranges and the 20 g CO_2-eq./MJ threshold to the lower end, it can be concluded that a contribution of between approximately 15 and 25 USD/t GHG emissions is sufficient to meet the 5% 2030 IMO ZNZ target and that a contribution between approximately 30 and 50 USD/t GHG emissions is sufficient to meet the 10% 2030 IMO ZNZ target, depending on the fleet energy consumption and the ZNZ fuel price levels. This, however, requires the revenues of the feebate to only be allocated to the use of ZNZ fuels required to just meet the IMO targets.

The contribution per tonne of GHG will be higher, the more the non-ZNZ using ships consume fuels other than the (assumed) VLSFO, thus reducing the total GHG emissions. To give an impression: If the average GHG intensity of the non-ZNZ consuming part of the fleet was 90 g CO_2-eq./MJ instead of the above assumed 95.48 g CO_2-eq./MJ, then, without considering a different price gap between the conventional and the ZNZ fuels, a contribution of 32-52 USD/t GHG would be required to be able to meet the 10% 2030 IMO ZNZ target, assuming that the fleet additional fuel costs are kept constant.

On the other hand, the contribution per tonne of GHG as presented in Table 13 can expected to be slightly lower given that, as explained in Section 4.1, the additional fuel costs for the ZNZ fuels have been slightly overestimated.

5 Conclusions

Zero or near-zero greenhouse gas emission (ZNZ) fuels could be defined by means of the Well-to-Wake GHG intensity of the fuels. In this study, three alternative GHG intensities threshold values have been analysed: 10, 15, and 20 g CO_2-eq/MJ.

Based on the analysis mentioned before, four main conclusions can be drawn:

1. Whether or not a fuel type qualifies as a ZNZ fuel highly depends on the inputs and production pathway. As a consequence, if ZNZ fuels are identified by means of a maximum WtW GHG intensity threshold, fuel types as such can in most cases not unambiguously be considered to be either ZNZ fuel or non-ZNZ fuel. For most fuel types, however, inputs and production pathways are in principle available that would allow a fuel type to qualify as a ZNZ fuel and the specific conditions under which a fuel type could meet the assumed WtW GHG intensity thresholds can be identified. Regarding specific inputs and production pathways, it can be concluded that blue fuels and biofuels based on energy crops cannot be expected to qualify as ZNZ fuels even if the least stringent of the three threshold values was applied. Also, if the most stringent of the three threshold values was applied, the probability is low that biodiesel (FAME, HVO) and bio-oil would qualify as ZNZ fuels. For e-LNG this depends on the engine and the resulting methane slip.
2. The availability of ZNZ fuels does not seem to pose a barrier to meeting IMO's ZNZ fuel/technologies target. It is, however, not clear at this stage, whether competition from other sectors might limit the availability of the fuels for the shipping sector and what the availability of the fuels would be, depending on the three alternative GHG intensity thresholds as analysed in this study.
3. An analysis of the current fleet and orderbook shows that, if all ships that can be propelled by means of an alternative fuel type (i.e. other than VLSFO, MDO or MGO) would cover a 100% of their energy consumption by means of a ZNZ fuel type, the 2030 IMO ZNZ strive target could be met. This however requires sufficient supply of ZNZ bio- or e-methane.
4. A literature review has been conducted to determine cost price ranges for the different potential ZNZ fuels and two cost price scenarios have been differentiated: A high price scenario, considering the upper end of the cost price range of e-fuels and a low price scenario, considering a relatively low e-ammonia cost price and relatively high biofuel prices. For these two scenarios, the additional fleet ZNZ fuel costs compared to VLFSO have been determined, assuming that the IMO 2030 ZNZ targets are just met, resulting in additional fuel costs of between approximately 12 and 23 billion USD for the 5% target and between approximately 24 and 46 billion USD for the 10% target. This is assuming a ZNZ fuel mix with an even distribution over methane, methanol and ammonia and a non-ZNZ fuel mix of 100% VLSFO. The estimation can be considered a slight overestimation, since the GHG contribution has not been accounted for and since the 2030 non-ZNZ fuel reference can be expected to be more expensive than the assumed VLSFO.

   It is difficult to match the cost price findings from the literature with specific GHG intensities of the fuels. Assuming that the 10 g CO_2-eq./MJ threshold applies to the high price scenario and the 20 g CO_2-eq./MJ threshold to the low price scenario, we have derived the 2030 levy/fee/contribution per tonne of GHG that would be required to compensate for the additional fuel costs of the ZNZ fuels as presented above: If the 5% ZNZ target was just met, a levy/fee/contribution in the range of approximately USD 15 to 25 per tonne of GHG emissions, while if the 10% ZNZ target was just met, a range of approximately USD 30 to 50 per tonne of GHG emissions was required. This is assuming that a levy/fee/contribution has to be paid for all GHG emissions, independent of the fuel that is used.

The estimated required GHG levy/fee/contribution can be considered a slight underestimation, since the additional fuel costs might have to be distributed over less total GHG emissions if the actual 2030 non-ZNZ fuel mix was considered. On the other hand, it can also be considered a slight overestimation, since the additional costs have been slightly overestimated by not considering the actual 2030 non-ZNZ fuel mix and the GHG levy/fee/contribution.

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