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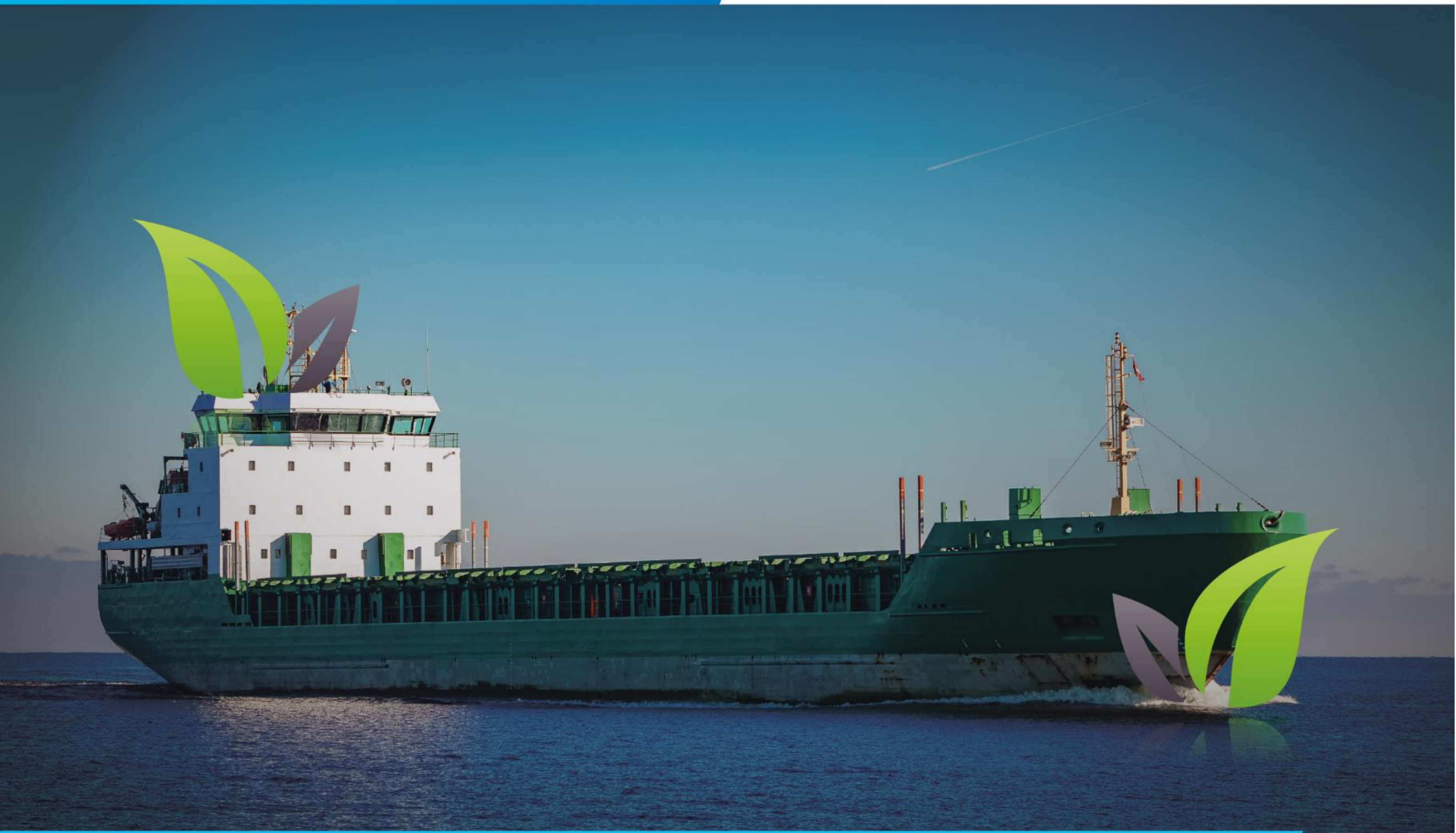

# UPDATE ON POTENTIAL OF BIOFUELS IN SHIPPING

BY ABS, CE DELFT & ARCSILEA

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# Executive Summary

The maritime industry faces a number of substantive challenges, mostly driven by increasingly stricter air emissions and climate legislation. Among the broad spectrum of technology and fuel-solution pathways available for ship designers, builders, owners and operators, biofuels potentially offer medium and long-term marine fuel alternatives that can enter the market relatively quickly. They also offer the potential, if sustainability criteria are met, to reduce carbon output compared to traditional carbon-based fossil fuels.

While the current use of biofuels in marine-engine applications is very limited, (the IMO 2020 Data Collection System (DCS) indicated that 99.91% of marine fuel use was of carbon-based conventional fuels) there is significant potential for biofuels to capture a larger share of the total maritime fuel consumption and support the EU and IMO's GHG-reduction ambitions for the maritime industry. Recent regulatory developments in the EU covering GHG emissions and the lifecycle aspect of fuels provide a basket of measures in line with the climate goals that could accelerate their adoption.

The 'drop-in' characteristics of biofuels, that is the possibility to replace conventional petroleum-refined hydrocarbons without substantial modifications (and in some cases, without any modification) to engines, fuel tanks, pumps or supply systems, may offer an immediate, attractive and cost-effective solution for the existing fleet.

This report provides an update on a previous study developed by EMSA on biofuels, examining the full range of biofuels, both liquid and gaseous, from the perspective of current production capacity, storage-and-distribution infrastructure and power-generation technologies. It also features techno-economic analyses and includes risk-based case studies to evaluate their potential for the maritime sector.

Also, the study clearly identifies the key advantages in the use of biofuels in shipping and the remaining challenges, technology and regulatory gaps restricting immediate application.

**Availability**

In the EU, biomass streams come mainly from agriculture and forestry. Today, the production of biofuel is primarily based on biomass from crops. However, this source is of limited potential, due to sustainability concerns of using food-based crops as fuel; biomass from waste, such as forestry residues, lignocellulosic crops, agricultural residues and manure are seen as more sustainable options. However, converting those types of biomass streams into biofuels requires more advanced processes.

The projections for the availability of sustainable biomass volumes vary considerably. Projections for 2030 forecast between 6.3 to 8.0 exajoules (EJ) of available biomass volume in the EU and increasing to 6.7-14.7 EJ by 2050[1] (for comparison purposes, the international maritime transport sector represented about 12.0 EJ in 2021[2]). But there is great uncertainty in forecasts, as there are technical and economic barriers as well as sustainability requirements to consider when evaluating future availability.

Globally, the projected availability varies from 83-134 EJ in 2030 to 131-207 EJ in 2050[3], although other references project global sustainable biomass availability at just 30-50 EJ in 2050[4], depending on the different criteria to define what is sustainable. So, it follows that sustainability criteria will play an important role, which can significantly limit the amount of available biomass.

It is also generally accepted that competition for biomass from other industrial sectors will significantly reduce the amount available for shipping. As an example, projections in the EU show that the share of biomass demand in the power generation segment may increase from 34% in 2015 to 46% in 2050, i.e., potentially reaching a total demand for 4.5 EJ[5] in the EU alone.

[1] European Commissions Impact Assessment for the 2030 Climate Target Plan (EC, 2020)
[2] IEA World Energy Balances, 2020 (IEA WEB, 2020)
[3] Bio-Scope study (CE Delft & RH DHV, 2020)
[4] Energy Transition Commission (Energy Transitions Commission, 2021)
[5] European Commissions Impact Assessment for the 2030 Climate Target Plan (EC, 2020)

Should the sustainable biofuel market reach its full potential, other aspects such as the risk of fraud (e.g., using non-sustainable sources of biomass and declaring the resulting fuel as sustainable) could impact availability with severe consequences for global biodiversity. Therefore, measures should be in place to limit the various risks and in particular the possibility of fraud.

**Sustainability**

Setting sustainability requirements is complicated by the trade-offs between climate mitigation and biodiversity conservation; finding the right balance will have an impact on the amount of biomass that can be used to produce biofuels. Some biofuels can significantly reduce full lifecycle GHG emissions (or the well-to-wake [WTW], equivalent in shipping) due to the biogenic nature of their carbon. Advanced biofuels from woody biomass can reduce GHG emissions by more than 90% and, when used in combination with carbon capture storage and sequestration technologies, more than 100% in reductions are possible compared to traditional marine fuel oils. In contrast, biofuels from food and feed crops have a lower potential to reduce emissions and in fact they can even increase emissions in what are known as Indirect Land Use Change (ILUC) cases, such as when pasture or agricultural land previously earmarked for food and feed is diverted to produce biofuels

Current discussions on sustainable biofuels tend to favour woody biomass and other waste and residues, but there are many unresolved issues, on which scientists and policymakers do not agree.

Biofuels are normally sulphur free and therefore do not emit Sulphur Oxides (SOx). Resulting Nitrogen Oxides (NOx) emissions are generally slightly higher or at the same level when using biofuels compared to those produced when using distillate fuels. That said, using bio-methanol can result in reduced NOx emissions (both in Otto and Diesel engine cycles). Using biomethane, on the other hand, can contribute to a reduction of NOx emissions mainly if combusted in Otto-cycle diesel engines. In Diesel-cycle engines, the use of biomethane may result in a 20-30% NOx emission reduction compared to using distillate fuels. However, for this to be achieved, a re-calibration of the engine towards low NOx modes would be required with the caveat that that would result in higher Specific Fuel Oil Consumption (SFOC) if no aftertreatment is used.

The related reduction in particulate matter (PM) emissions is modest for the diesel-like biofuels; again, it is in the bio-methanol and biomethane derivatives where the big reduction in those emissions is observed.

In terms of reducing pre-combustion emissions (known as well-to-tank [WTT]), pathways where bio-methanol, dimethyl ether (DME), and Fisher Tropsch (FT) diesel are produced from lignocellulosic biomass offer the greatest potential for GHG reductions.

**Suitability and cost evaluation**

More than eleven biofuels have been assessed for this report, most of which have until today seen very limited use as fuels for shipping.

Low flashpoint fuels, such as LNG and methanol, have been used for many years and, since bio-methanol and bio-LNG generally have the same specifications as methanol and LNG, they can directly replace them without adding complications to the ships' operations.

The diesel-like fuels, such as hydrotreated vegetable oil (HVO) and fatty acid methyl esters (FAME) have been tested primarily in blends (up to B100) with conventional fuels. Their share of the biofuel market is rapidly increasing, as is the knowledge among engine-makers and operators about their impact on engine operations and tank- and fuel-supply systems.

In the near future, similar reliability and maintenance costs as traditional diesel engines can be reasonably expected, but more experience is required especially on monitoring combustion chamber components.

The remaining diesel-like fuels, such as FT diesel and pyrolysis oils, are still in their early stages of development. Results available from in-service tests with these fuels are limited, but expectations are that they will be produced in ways that will increase their lower calorific values (LCV), which lies currently in average about 9% lower than that of MDO. If their LCV increases, these biodiesels may directly compete and eventually replace MDO in marine engines without having an impact on the bunkering frequency of the ships and therefore improving their total cost of ownership (TCO) performance.

TCO models were developed in this report for three vessel groups: containerships, bulk carriers and tankers. For the cost analysis, very low sulphur fuel oil (VLSFO) was used as a proxy of comparison for the biofuels selected in the study.

The biofuels were chosen for their ability to be directly used in existing engine systems with very minor or no modification, resulting in negligible capital expenditures (CAPEX). This allowed cost competitiveness to be assessed directly by simply comparing the fuel costs.

On that matter, bio-methanol and biomethane can be considered as a direct replacement of their respective fossil-fuel equivalents and therefore, there are no CAPEX costs related to adaptation of engine, fuel gas supply systems and tanks.

Using VLSFO as reference, the study finds that in 2030, assuming increased bunkering to compensate for differences in LCV values between fuels and also considering carbon pricing, the TCO is projected to be almost twice as high (around 92-94% higher) for vessels fuelled with bio-methanol and biomethane. . By 2050, the price gap between VLSFO and both biomethane and bio-methanol is expected to decrease, with the price gap between VLSFO and biomethane being higher. Considering carbon pricing, the TCO for vessels fuelled with bio-methanol may by 2050 even be lower than for vessels fuelled with VLSFO. For oil-based biofuels, the analysis shows that by 2030 FT-diesel and HVO may be comparable to VLSFO in terms of TCO, with the TCO even being lower than for VLSFO vessels by 2050 if carbon pricing is considered. Considering carbon pricing, for FAME, the TCO analysis estimates an additional cost of 40% in 2030 and lower TCO compared to VLSFO by 2050, at a level comparable to bio-methanol.

However, as previously stated, there is substantial uncertainty regarding the availability of biomass in 2030 as well as in 2050. A scarce availability of course will have a significant impact on the prices of those fuels. With most forecasts anticipating shortages of biomass in the future, biofuel prices can be expected to continue raising.

**Ranking the biofuels**

Based on the points discussed previously, the different biofuels were ranked in relation to their potential, based on an equal weighting for the following criteria: sustainability, availability, technology readiness level (TRL) for production, suitability and projected cost. This exercise produced the rankings seen below, where the most promising are listed on top:

1. Bio-methanol, FT diesel, biomethane from digestion of waste and residues and DME arrive very close together at the top three in the ranking

2. FAME from fat, oil or grease feedstocks (FOGs), biomethane from gasification arrive close together at the two mid ranking positions

3. FAME from vegetable oils, HVO from FOGs and from vegetable oils arrive in the lower three ranking positions

**Regulations**

From the regulatory standpoint, the drop-in nature of biofuels facilitates their adoption. Many of the existing regulatory frameworks for other fuels are transferrable to the case of biofuels, although yet open to interpretation in aspects related to SOLAS or MARPOL and ISO requirements. However, ongoing revisions of existing standards and regulations for using biofuels also favour their adoption.

Nonetheless, more regulatory adaptations and initiatives can contribute to a faster adoption, including:

- Updates of ISO standards to address a wider range of potential biofuels
- Further develop the IGF Code to include fuels with flashpoints between 52˚ and 60˚C
- Potential further updates of IMO MARPOL Annex VI Regulation 14 with additional reductions of sulphur limits, thus favouring biofuels that inherently have very low-sulphur contents

- Investigating ways to, subject to sustainability criteria, potentially use biofuel carbon factors in MARPOL Annex VI carbon intensity regulations.
- Further develop Unified Interpretations, Unified Requirements and Recommendations by classification societies via IACS
- Further develop the NOx Technical Code to provide more clarity on its application to biofuels
- Encourage discussions and further work in terms of the application of SOLAS II-1/regulation 3-1, to support a harmonized application and usage of biofuels under the ISM Code and provide a solid support for classification societies requirements called out by SOLAS.

**Risk & Safety**

Three HAZID analysis were conducted on three different ship designs using biodiesel fuels such as HVO, FT diesel and FAME, and equipped with both 4-stroke and 2-stroke marine engine systems. This was complemented with a HAZID on an LPG carrier using DME and equipped with a dual-fuel engine system designed to use LPG. The fuel-supply system was adapted to use DME and examine the potential of blending DME with LPG using different blend ratios. Neither biomethane nor bio-methanol were considered for the HAZID part of the study as they are considered to be drop-in fuels for which the same risk implications as their fossil equivalents apply.

The main outcome of the three HAZID analysis is that there are no unresolvable or unmitigable risks to prevent the uptake of biodiesels, such as HVO (and FT Diesel), FAME and DME mixtures as fuels for marine applications.

Also, the analysis revealed that the fuels investigated adapt relatively easily to marine applications. They also showed that their applicability and associated risks depend strongly on the properties of the specific fuels, which are in turn dependent on the production processes and feedstock used to produce them. Depending on the feedstock and process use, the resulting biofuel may present a higher toxicity level or impact the overall reliability of the equipment.

There, the usage of biofuels may also require more frequent surveys, cleaning, and perhaps additional maintenance than conventional fuel oils and potentially improved and more frequent crew training requirements. As experience with the use of biofuels grows, the frequency of these additional surveys and procedures can be expected to reduce to similar levels as those of conventional fuel oils.

**Concluding Remarks**

Despite existing barriers as identified in the study, the uptake of biofuels is expected to increase, as it is the only readily available option at the industry to start its decarbonisation. Biofuels benefit from their drop-in nature, the fact that many of the existing maritime regulations can be transferred from their fossil equivalents and that the risks associated with using biofuels are similar to those of conventional fuels. Although not seen as a major barrier, it would be beneficial to increase knowledge sharing and update current regulations to explicitly and homogenously account for biofuels. This can provide more clarity and reduce the administrative burden and concerns of flag States, class societies, shipowners and operators when considering biofuels.

While the demand grows, the availability of fully sustainable biofuels needs to grow and this alone will be challenging, due to the uncertainty in turn on the availability of sustainable biomass. Currently, with most of the biofuel production coming from crops, there are concerns around issues such as ILUC, food production impact and others. Switching to other sources of biomass (such as algae or waste and residues) is necessary to ensure the uptake of potentially more or fully sustainable biofuels. However, the introduction of international lifecycle guidelines and sustainability criteria is paramount to ensure that the biofuels with the highest potential to decarbonise the industry receive proper consideration and investment. As all industries will compete for the same scarce sources of sustainable biomass, common cross-industry sustainability criteria would be desirable to facilitate concentration of efforts and resources towards similar biomass sourcing and biofuel production pathways for all industries.

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# 1. Introduction

## 1.1 Background

The European Green Deal and the 2030 Climate Target Plan aim to have reduced greenhouse gas (GHG) emissions by at least 55% by 2030, relative to 1990, and achieve climate neutrality in 2050. All sectors should contribute to this target, including maritime transport.

At a global level, the initial International Maritime Organization (IMO) Strategy on Reduction of GHG Emissions from Ships aims, among other goals, to have reduced the global GHGs from shipping by at least 50% in 2050, compared to 2008, and recognises that 'the global introduction of alternative fuels and/or energy sources for international shipping' is necessary to achieve these strategic targets.

Achieving these targets will require a transition from the fossil fuels on which the shipping sector currently relies to renewable and low-carbon fuels (RLFs), as well as improvements in the energy efficiency of ships. The two are mutually reinforcing: RLFs are currently 2-10 times more expensive than fossil fuels, so their increased use will make more energy efficiency improvements cost-effective. At the same time, RLFs depend on scarce inputs such as arable land, renewable electricity or fresh water, and the demand for those inputs will be reduced if ships become more energy efficient.

One of the RLF categories is biofuels, i.e., fuels that are made from biological sources. EMSA published an overview of biofuels in 2012; in the decade since, the production processes have evolved, and numerous new biofuels have been used on ships. This report presents an overview of the current biofuels in use and the prospective fuels that could be used in maritime shipping.

## 1.2 Scope and Objectives

The aim of this study is to provide an overview of the state of play on the use of biofuels in the shipping sector, to review standards and regulations and to analyse safety implications associated with their use.

While the study does not intend to provide direct input to legislative or regulatory initiatives, it provides background information for the European Union (EU) initiatives aimed at reducing GHG emissions from maritime transport, such as the pending inclusion of shipping in the EU emissions trading scheme (ETS) or Fuel EU Maritime. It can be used to guide European programmes on research and innovation funding, as well as legislation on fuel infrastructure; for example, the revision of the Alternative Fuels Infrastructure Regulation. It is also intended to be a background document to contribute to IMO discussions, e.g., on renewable fuel policies, life cycle analyses (LCA) and WTW emission methodologies, the safety aspects of new fuels, and/or any amendments to safety standards.

## 1.3 Definitions

### 1.3.1 Drop-in fuels

(IEA, 2019) The IEA defines drop-in biofuels as "liquid bio-hydrocarbons that are functionally equivalent to petroleum fuels and are fully compatible with existing petroleum infrastructure". In this definition, 'infrastructure' relates both to petroleum distribution and refining, and to the applicable fuel specifications, i.e., for using these fuels in engines (IEA, 2019).

This report focuses on the use of biofuels by ships, including liquid and gaseous biofuels, and blends of petroleum and bio-derived hydrocarbons. The definition of drop-in fuels used in this report is: "Fuels that can be used as an alternative to conventional petroleum-refined hydrocarbon fuels without substantial modifications to the engine, fuel tanks, fuel pumps and the overall fuel-supply system."

A fuel can be considered a drop-in fuel for a certain engine type, but not necessarily across all engine types, and not across all engine designs and fuel-supply systems. This complex suitability mainly applies to liquid biofuels intended to replace conventional residual or distillate fuels. However, this is not the case with liquefied biomethane, for example, which is considered a drop-in fuel for LNG-fuelled ships. Similarly, bio-methanol is considered a drop in fuel for ships designed to operate on petroleum or fossil-derived methanol.

Liquid biofuels can be considered as drop-in fuels, whether as a 100% biofuel (B100), or when blended with conventional petroleum-refined hydrocarbon fuels up to a certain share. For example, FAME is an example of a biofuel that can be blended in various ratios.

The International Council on Combustion Engines (CIMAC) provides guidelines for using blends containing up to 7% v/v of FAME, which do not require technical modifications to the ship, the engine or fuel-supply systems. The 7% limit is also included in the ISO 8217:2017 standard for marine fuels. Recently, fuel suppliers have marketed fuels containing 10%, 20% or 30% FAME (B10, B20 and B30, respectively), which fall outside the current scope of ISO 8217, without reports of issues. This indicates that the share limits in blends up to which biofuels can be considered drop-in may change over time when new blends are tested.

One of the main features which make biofuels attractive is this defined drop-in characteristic which, depending on availability, can help to decarbonise the bulk of the shipping fleet that currently runs on conventional light fuel oil or marine diesel/gas oils, their low-sulphur equivalents or heavy fuel oil. The decarbonisation outcome is a result of the life cycle balance (from production to final usage) of the bio-sourced to replace the fossil-fuel, i.e., to what extent the carbon savings from production of biofuels compensates for the emissions resulting from burning the fuel onboard as opposed to a full fossil-based fuel usage. This provides an advantage over RLFs solutions that would require an engine retrofit, fuel-handling precautions, and additional safety systems such as LNG, methanol or ammonia.

Several fuels included in this report cannot be classified as 'drop-in' due to the lack of industry experience with these fuels and, consequently, the lack of available information and service experience. Some fuels are considered 'drop-in up to a limited blend percentage and require confirmation by engine designers regarding their applicability.

### 1.3.2 Fuel oil

According to MARPOL Annex VI, Regulation 2, 'fuel oil' means any fuel delivered to and intended for combustion purposes for propulsion or operation onboard a ship, including gas, distillates and residual fuels. This report adopts a narrower definition of fuel oil, namely all petroleum-derived fuels which are liquid at ambient temperatures and atmospheric pressure. Examples are HFO, Intermediate Fuel Oil (IFO), VLSFO, Ultra Low Sulphur Fuel Oil (ULSFO), Marine Gas Oil (MGO), Marine Diesel Oil (MDO) and other distillates.

### 1.3.3 Distillates

Distillates are a subset of fuel oils containing exclusively distilled fractions and no residual oil, commonly known as MGO. Examples include those classified as a DMA fuel, which is clear and brighter in appearance; others are DMB and DMC marine diesel oil grades which are not required to be clear and bright. DMA and DMB marine fuel can also contain a small proportion of heavy fuel oil, so they are not 100% pure distillates and thus not "real" marine gasoils. DMZ is a distillate fuel that must not contain residual fuel constituents; it has a higher aromatics content and a slightly increased viscosity, at 40°C, compared with the other distillate fuels.

### 1.3.4 Residuals

The remaining residue in the fractional distillation, which does not pass into the gas phase, is referred to as residual fuel or heavy fuel oil. The sulphur content of this HFO can be reduced by further processes, if required. In accordance with ISO 8217, residual fuels are divided into six fuel types depending on their viscosity (kinematic viscosity) – RMA, RMB, RMD, RME, RMG and RMK.

In practice, a blend or a mixture of distillate fuels and residual fuels are mostly used, i.e., the IFOs. IFO 380 and IFO 180 (RMG) are the fuels most commonly used in shipping.

## 1.4 Acronym List

Refer to Appendix K

# 2. Use of biofuels in the shipping sector: an update

Biofuels are produced from renewable feedstocks and contain very low or no sulphur. They have the potential to reduce the lifecycle GHG emissions from the marine sector and, at the same time, meet the industry requirements for sulphur emissions. In the absence of sulphur, biofuels emit very low levels of particulate matter during their combustion. Due to their environmental benefits, sustainable biofuels are considered to be marine fuels that could decarbonise the shipping industry.

The most efficient way to introduce biofuels in shipping is either through drop-in biofuels that can wholly replace fuel oils; these biofuels may also be blended with compatible fossil-based marine fuels in quantities verified by equipment suppliers and engine designers.

This chapter analyses the state of play on the use of biofuels in the shipping sector, both current and for the foreseeable future. Section 2.1 presents the different fuels and their current and future feedstocks and production pathways. Section 2.2 analyses the sustainability of biofuels for maritime ships and Section 2.3 discusses their availability in Europe and globally. The fuels' suitability for use in existing ships is analysed in Section 2.4, together with potential modifications to engines and fuel systems that would be needed to adapt them to use biofuels. Section 0 presents an analysis of the cost impact of replacing conventional fuels by biofuels and the conclusions drawn from the investigation are reported in Section 2.6.

## 2.1 Biofuel Types, Feedstock and Production Pathways

### 2.1.1 Introduction

Biofuels are derived from biological renewable resources such as plant-based sugars, vegetable oils, algae, terpenes and waste from animal fats. The feedstock and production processes that are available determine the properties of the biofuels and their applicability as fuels for shipping.

The main biofuels relevant to maritime shipping can be classified into four groups: biodiesels, bio-alcohols, bio-crudes and gaseous biofuels, as depicted in Figure 1 (below). Biodiesels and bio-alcohols can serve as drop-in fuels for distillate marine fuels; biocrudes are suitable as drop-ins that can replace conventional fuel oils (HFO)and VLSFO and ULSFO. Gaseous biofuels (such as liquefied biomethane [LBM]) can be used as drop-in fuel that can replace fossil-derived liquefied natural gas (LNG).

For each biofuel, up to two main production pathways (i.e., specific series of consecutive production processes) have been identified.

In the next Subsection 2.1.2, the technical options for producing and using biofuels as marine fuels are summarised, starting with a description of the production pathways per biofuel category.

For each production pathway, a short technical description of the production process is provided, and the main feedstock groups are identified. There are six feedstock groups: oil crops; sugar and starch crops; lignocellulosic crops; fats, oils and greases (FOG), lignocellulosic and agricultural residues; and algae. The suitability of these biofuels is briefly examined for marine engines. More detailed information on suitability is presented in Section 2.4.

In Subsection 2.1.3, the 'readiness' of the technical options is examined more closely, followed (in 0) by an overview of production developments. To gain a better understanding of what the industry, researchers and policy makers are working on, pilot projects and research and development (R&D) activities are discussed in 2.1.5.

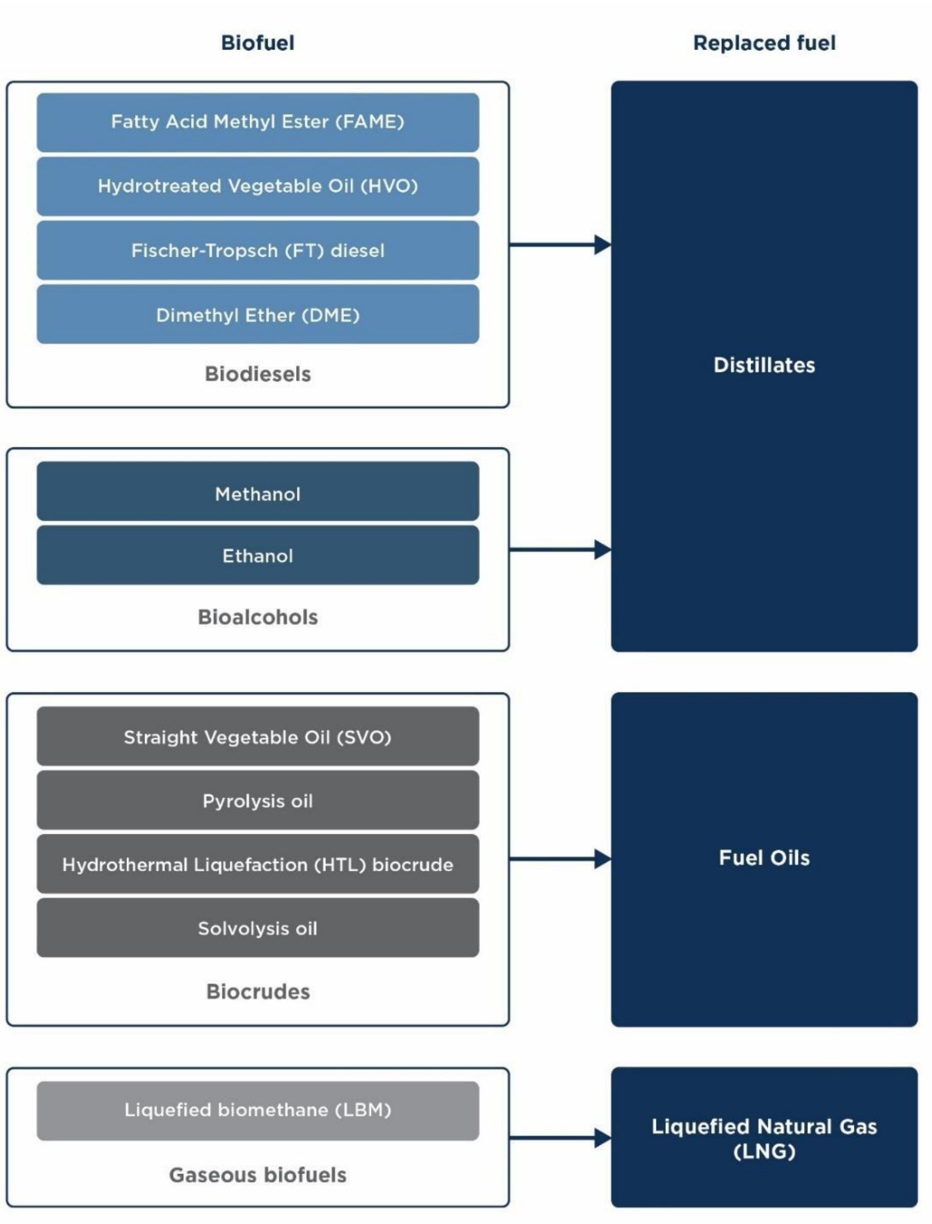


Figure 1. Overview of biofuels, production pathways and biomass-feedstock groups

Biofuels are often categorised between conventional and advanced biofuels. Conventional biofuels are crop-based and often referred to as 'first-generation' biofuels. On the other hand, advanced biofuels are produced from non-food biomass feedstocks and referred to as 'second-generation' biofuels. Therefore, the term 'advanced biofuels' refers to their feedstock rather than production pathway. Both, first- and second-generation biofuels are addressed in the subsequent sections, where applicable.

### 2.1.2 Technical options

#### 2.1.2.1 Biodiesels

Biodiesels can be produced from a range of feedstocks (i.e., crop, waste residuals, non-food biomass, etc.) with several production pathways which determine the biodiesel's GHG-reduction potential. The different production pathways of biodiesels that typically could be used as drop-in fuels to replace commonly used distillates, such as marine gasoil, are presented in Figure 2.

This section describes FAME, HVO, FT Diesel and DME, respectively.

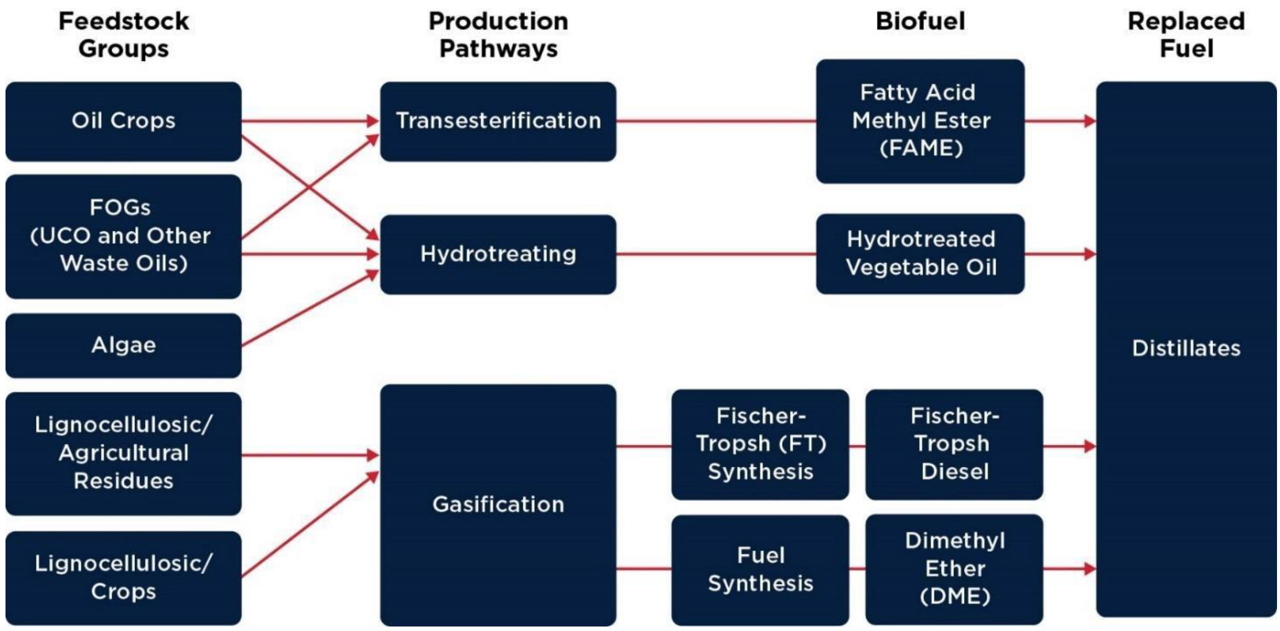

Figure 2. Production Pathways for Biodiesels

***Fatty acid methyl ester (FAME)***

Fatty acid methyl ester is the most common type of biodiesel (mainly used in the road-transport sector). It is produced from bio-oil (triglycerides) and methanol or ethanol, using a transesterification (chemical-conversion) process, as indicated in Figure 2. Glycerol and water are by-products of this process (IEA Bioenergy, 2017; Ecofys, 2012).

The biomass feedstocks most commonly used to produce FAME in Europe are rapeseed oil, palm oil and used cooking oil. Other feedstocks include soybean (common in the U.S. and South America), corn and coconut (common in the Pacific Islands). Animal-based greases and fats, such as tallow and poultry litter, also are used (IEA Bioenergy, 2017). Algae, a widely available potential feedstock, can be used to produce FAME through a transesterification process, but the lipids would need to be removed from the algal biomass beforehand (IEA Bioenergy, 2017).

For diesel engines, FAME is a more suitable fuel than plant oils (see the section on straight vegetable oil [SVO] below). It can be used as a replacement fuel for marine diesel oil and MGO in diesel engines, but this may require engine modifications and approval from the engine manufacturer.

FAME can be considered a drop-in biofuel which can replace up to a certain percentage of a fossil fuel oils. FAME has been used in blends of up to 30% with fossil fuel oil, requiring little or no engine modifications (IEA Bioenergy, 2017).

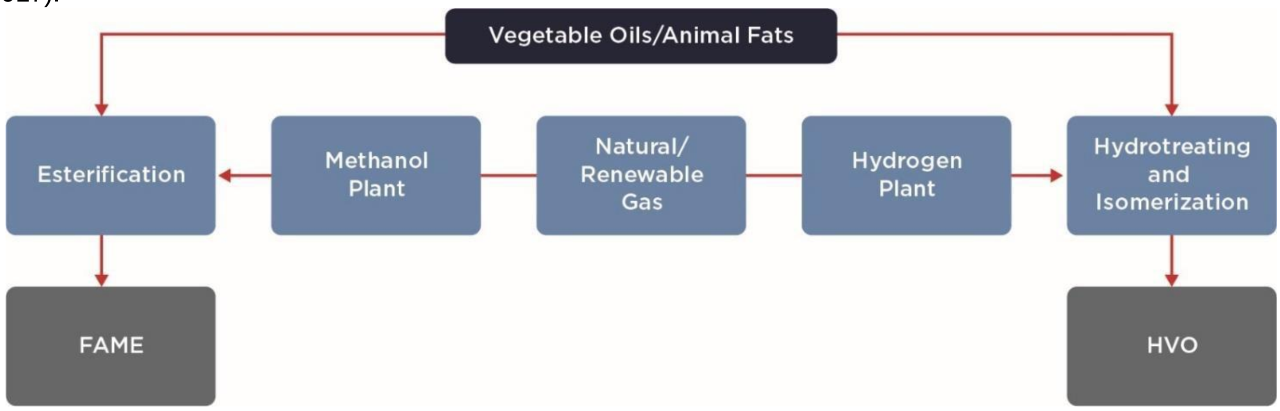

Figure 3. Schematic of inputs and outputs of esterification and hydrotreating processes for biofuel production, adapted from (NESTE 2020)

***Hydrotreated vegetable oil (HVO)***

HVO, also known as renewable diesel or hydrotreated esters and fatty acids, is a biodiesel. To produce HVO, feedstocks undergo a process of hydrotreatment and refining, usually in the presence of a catalyst as shown in Figure 3 where it is compared to FAME production. In the two-stage hydrotreatment process, hydrogen is first deoxygenated and the double bonds in the hydrogen molecules are saturated to form alkanes. In the second stage, the alkanes are isomerised and cracked.

HVO can be produced from vegetable oils, or FOGs, such as those used for cooking oil and animal fats, or from the algal lipids extracted from algae.

Due to hydrotreatment during production, a process similar to fossil-refinery practices, the fuel oils are more similar to petroleum diesel than to FAME. This results in higher quality of fuel that is typically produced meeting diesel fuel standards such as EN 590 and ASTM D975.

Pure HVO is considered a drop-in fuel, and can replace fossil diesel oil in most of the available marine engines (ICCT, 2020).

***Fischer-Tropsch (FT) diesel***

FT diesel is produced by using gasification in combination with Fischer-Tropsch synthesis.

In the gasification process (see Figure 4, below), the biomass produces a synthesis gas (syngas), which is mainly a combination of hydrogen and carbon monoxide. The process takes place at a high temperature (around 900°C) and pressure, and with a low proportion of oxygen and/or steam-to-gas. It decomposes the biomass into its basic components (CO, $H_2$ and $CO_2$). The gas is then cleaned to remove sod and tar (IEA Bioenergy, 2017). In the FT-synthesis process, the syngas reacts over a catalyst and forms carbon chains (CC) of various lengths.

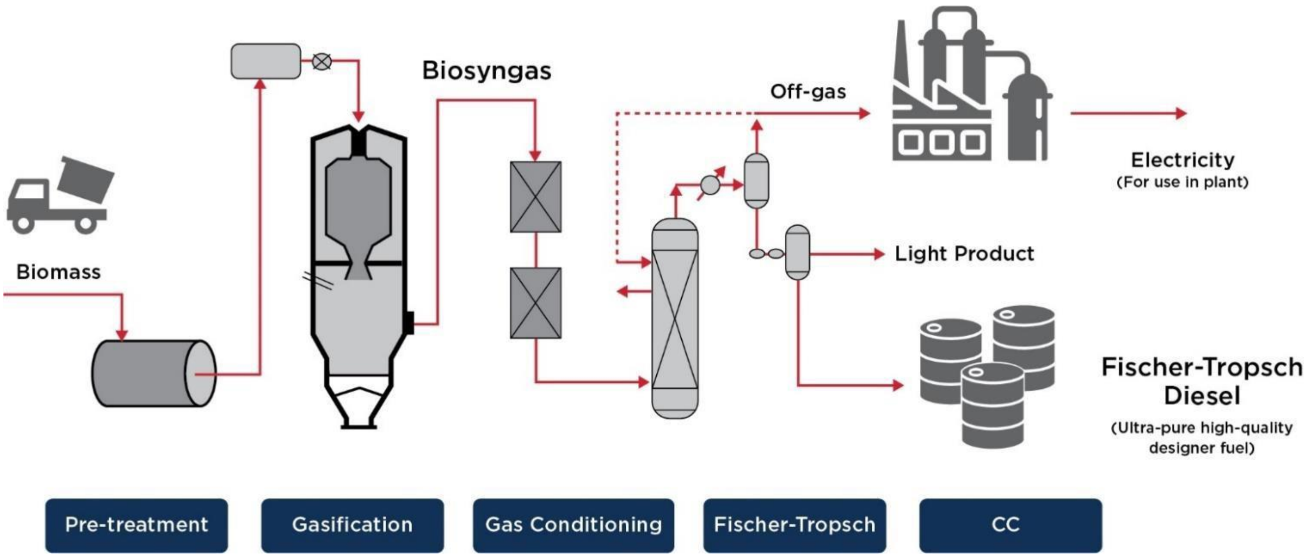


Figure 4. Schematic overview of the syngas/FT-diesel production processes, adapted from (Zwart & van Ree, 2008)

Various biomass feedstocks can be used, including agricultural residues and lignocellulosic (woody) biomass. The latter can be used after gasification, which breaks down the molecules in the woody materials. Types of lignocellulosic biomass include forestry residues, quick-growing woody crops such as miscanthus and willow, and agricultural residues such as corn stover and wheat straw.

FT diesel is a drop-in fuel that can be used ‘neat’ (i.e., it can fully replace fossil diesel), or can be blended with fossil diesel up to a high percentage without engine modifications (ICCT, 2020).

### *Dimethyl ether (DME)*

DME can be produced by the gasification of biomass, followed by catalytic-fuel synthesis (see Figure 5, below). During the gasification process, biomass is broken down into syngas, which can be used to produce DME directly, or the gas can be first converted to methanol as an intermediate product, followed by methanol dehydration (Ecofys, 2012; IEA Bioenergy, 2017).

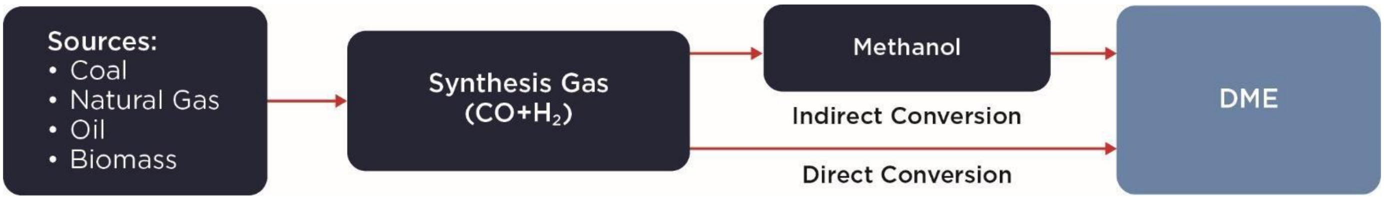


Figure 5. Dimethyl ether production, adapted from (Azizi, et al., 2014).

Thanks to gasification technology, virtually all types of biomass feedstock can be used; lignocellulosic biomass via thermal gasification and wet biomass feedstocks via super critical water gasification (see the description on liquefied biomethane (LBM) in 2.1.2.4).

DME can be used as part of a blend with MGO or MDO after limited engine modifications, although the percentage blend is understood to be rather low and is thus self-limiting in terms of $CO_2$ reduction when considered as a drop-in fuel. However, DME may be used with LPG where it can be considered a drop-in fuel, though blending percentages above 30% still need to be verified and additional storage tanks and fuel-supply systems will be needed. To use DME as a 'neat' fuel requires dedicated engines (ICCT, 2020).

### 2.1.2.2 Bio-alcohols

Bio-alcohols are another group of liquid biofuels that can be produced from a range of feedstocks and production pathways, these are depicted in Figure 6 below. The most relevant bio-alcohols to the marine sector are bio-methanol and bioethanol, both of which can be used to replace distillates. It is acknowledged that methanol or bio-methanol produced from natural gas or biomass, respectively, requires marine engines that are specifically designed or converted to operate on methanol, as well as the relevant fuel-storage tanks and fuel-supply systems.

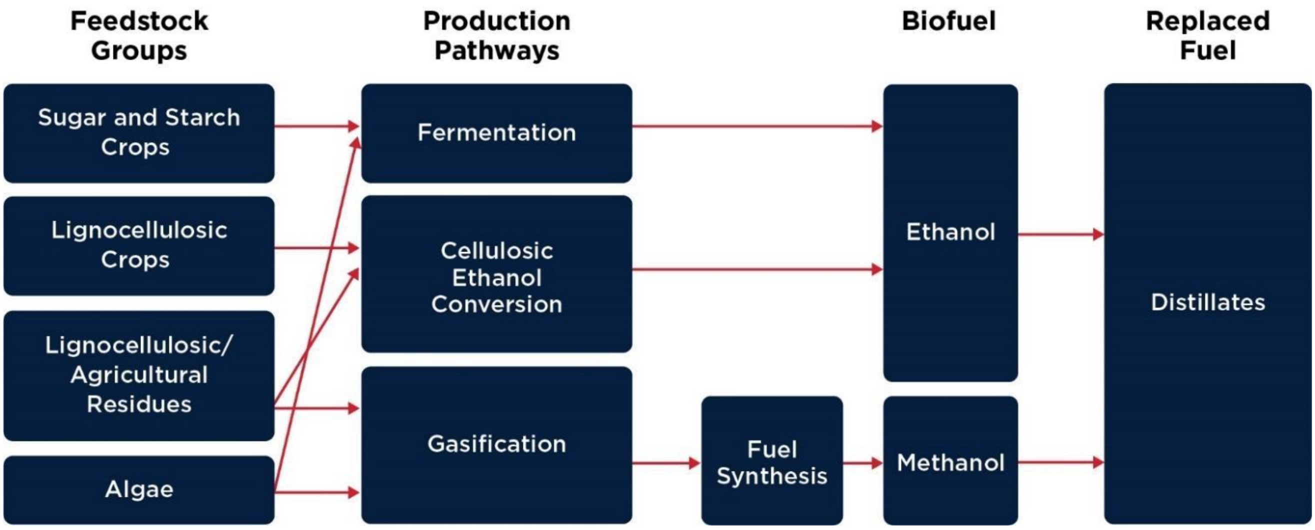


Figure 6. Bio-alcohols Production pathways

### *Bioethanol*

Bioethanol is produced by fermenting sugar and starch crops (glucose-based feedstocks) such as wheat, sugar cane and maize or algae. This type of bioethanol is often referred to as "first-generation" bioethanol. First-generation refers to biofuels from food crops, but also to the conversion pathway. The term "conventional bioethanol" is used as well. As the different meanings of these definitions are often used, it is recommended to mention both the fuel and the feedstock.

The three main steps used to produce bioethanol through cellulosic ethanol conversion of lignocellulosic biomass are pre-treatment, hydrolysis and fermentation. Pre-treatment extracts the carbohydrates from the biomass.

Hydrolysis of cellulose and hemi-cellulose produces sugars, which are then fermented. There are different types of hydrolysis (including enzymatic hydrolysis, the use of acids and treatment with hot water or steam) each with their own advantages and disadvantages.

In the hydrolysis process, lignin is a residual product that can be used in gasification or solvolysis to produce another biofuel, such as solvolysis oil (Ecofys, 2012; IEA Bioenergy, 2017). For more information on solvolysis oil see the description under 'biocrudes' in 2.1.2.3.

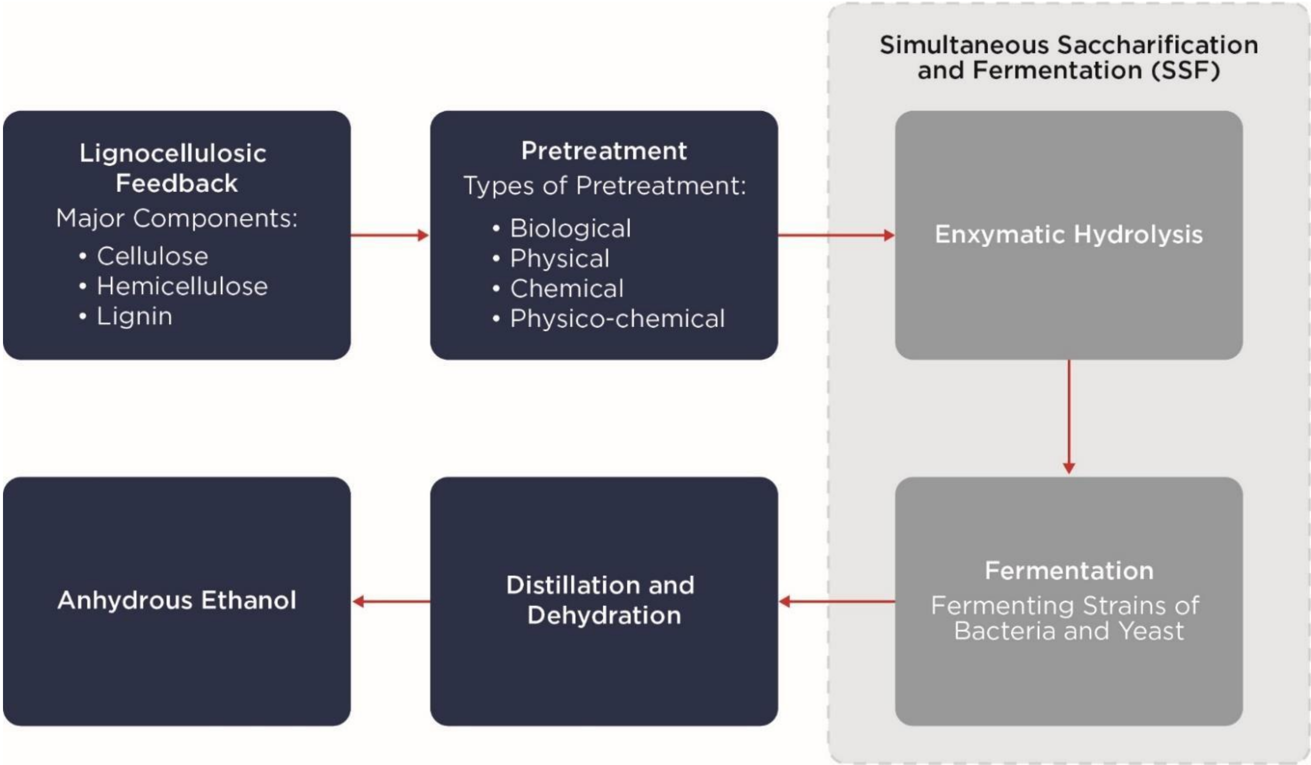


Figure 7. Main steps in bioethanol production, adapted from (Robak & Balcerek, 2018)

Bioethanol also can be produced from lignocellulosic and algal biomass, using innovative production technologies (Devarapalli & Atiyeh, 2015) Bioethanol from lignocellulosic and algal biomass is often referred to as "second generation" or "advanced" bioethanol, as these new production pathways that came after the pathways for bioethanol from sugars and starches. In EU policy "advanced" refers to the feedstocks, but sometimes it also refers to the more advanced conversion technology.

Bio-ethanol could be used as a drop-in fuel for maritime shipping, but as with bio-methanol (in the following section), it will require that the engine, the fuel-containment and fuel-supply systems are designed to operate on ethanol. Although 2-stroke and 4-stroke marine engines operating on methanol are currently in service, there is insufficient information available about the use of ethanol on marine engines. Engine designers are already considering the development of such engines and it is very likely that these will become available in the near future. A 2-stroke engine designer has already communicated that is likely that their methanol dual-fuel engine, which is currently in service, will also be able to operate on ethanol with just a few changes to its control system.

***Bio-methanol***

Bio-methanol is produced through the gasification of biomass and a synthesis of the resulting syngas to methanol (Ecofys, 2012). In the synthesis step, syngas is pressurised and converted to methanol in the presence of a metal catalyst, followed by the removal of water and impurities. The methanol conversion is done at high pressure and low temperatures (50-100 bar and 220-275°C, in the catalyst of copper and zinc oxides on alumina) (IEA Bioenergy, 2017).

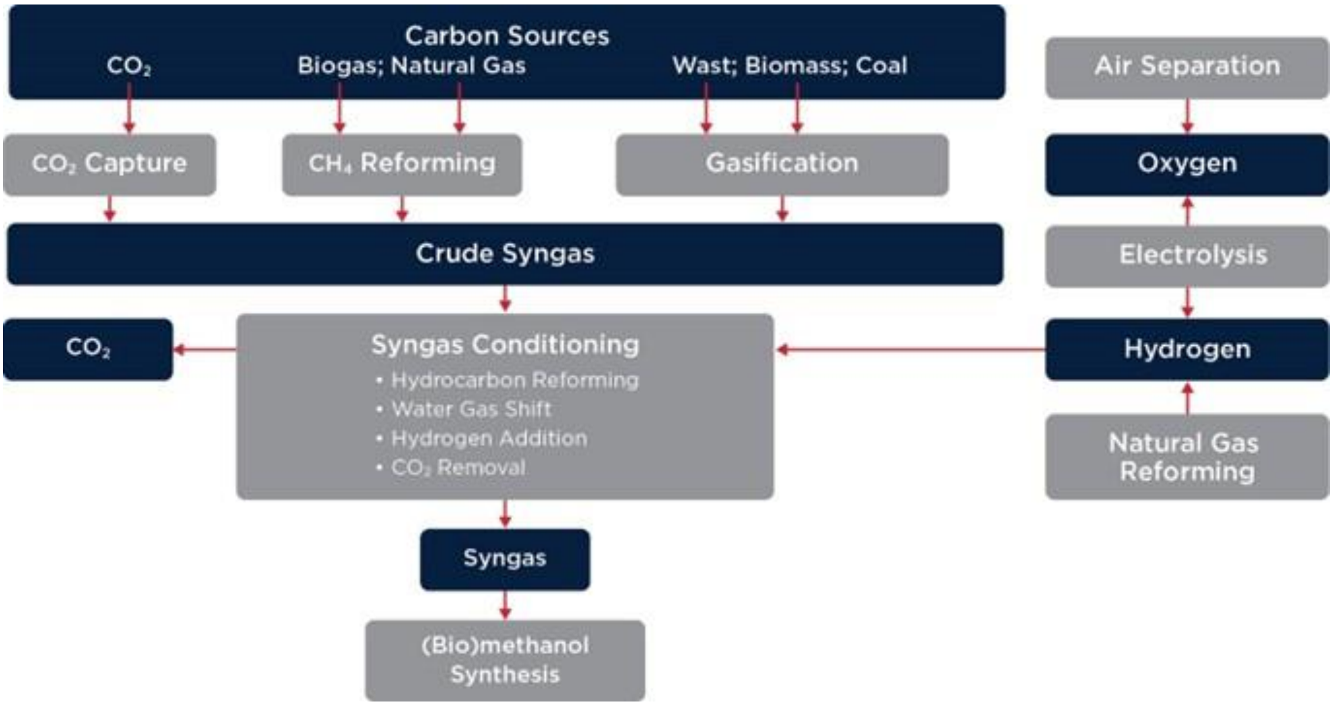


Figure 8. The major production processes of methanol from carbon sources, adapted from (IEA-ETSAP and IRENA, 2013).

Lignocellulosic biomass can be used as a feedstock in combination with thermal gasification, wet biomass in combination with supercritical water gasification (see the description on LBM in 2.1.2.4).

A limited amount of bio-methanol can be blended with marine diesel for use in marine engines (Paulauskiene, et al., 2019). It also could be used at higher percentages in adapted or multi-fuel engines, or as a 100% methanol fuel in direct-methanol fuel cells.

Large bore 2-stroke or 4-stroke engines using methanol and equipped with separate injection systems for fuel oil and methanol, i.e., dual-fuel (DF) engines, can typically burn methanol containing a percentage of water. Methanol mixes easily with water and this is a known technique for reducing NOx emissions in internal combustion engines, whether as direct injected water, humidification of intake air or by emulsifying or mixing it with the fuel. It is possible to burn a fuel solution using more than 50% water in some of these engine designs.

However, using a water in methanol solution will result in a fuel penalty during combustion, as it costs energy to heat up the water. Furthermore, the energy used to supply or produce the fresh water onboard - by freshwater generators, for example - needs to be considered.

Some engine designs using a mix of up to 50% water with 50% methanol can reduce NOx emissions to IMO Tier III levels; these engines are already in operation in chemical carriers burning methanol as a fuel (Prevljak, 2021) (MAN ES, 2022) (Mayer, 2019).

#### 2.1.2.3 Biocrudes

Biocrudes are unrefined liquids of biological origin. They include straight vegetable oil as well as pyrolysed, thermolysed and solvolysed biomass. Figure 9 presents an overview of their production pathways and identifies the biocrudes that are discussed in this section.

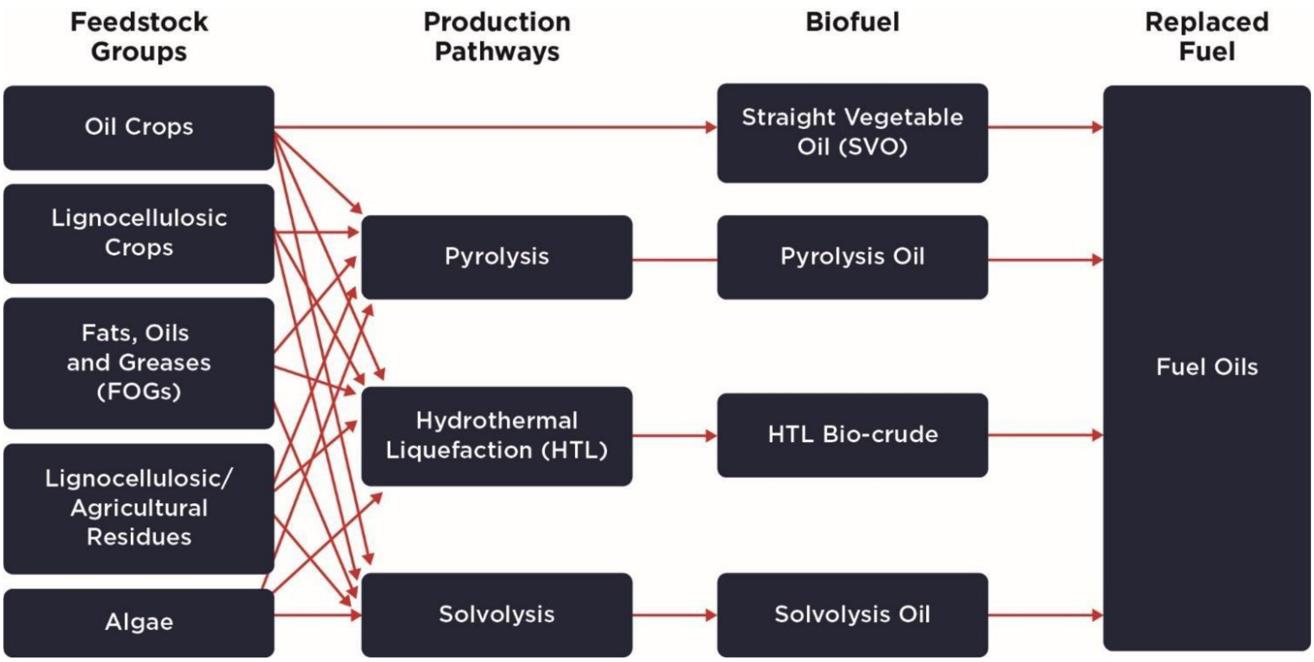


Figure 9. Biocrudes production pathways

***Straight vegetable oil (SVO)***

SVO is a biocrude, solely produced by extracting oil from biomass. The process (see Figure 10, below) does not require any intermediate production steps. It can be used directly in marine diesel engines and as a feedstock for biodiesel production.

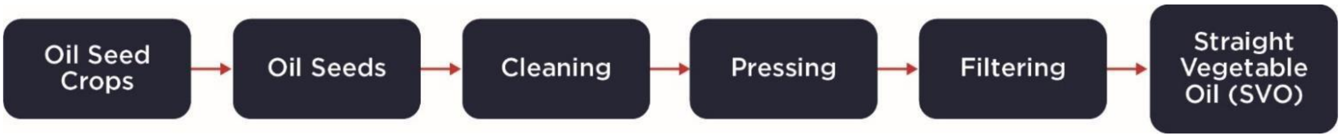


Figure 10. Production steps for Straight Vegetable Oil

Vessels that use intermediate fuel oil, or HFO (in combination with an exhaust-gas cleaning system), VLSFO (in combination with an exhaust-gas cleaning system when sailing in environmental control areas [ECA]), or ULSFO (in ECAs), can switch to SVO or a blend of fuel oil and SVO. Using a blend, rather than SVO alone, would help to lessen the risks of engine damage caused by the build-up of carbon deposits and thickening lubricating oil on some smaller engine types, which can be caused by the high viscosity and boiling point of SVO (IEA Bioenergy, 2017).

***Pyrolysis oil***

Pyrolysis oil is a bio-oil or biocrude made through a pyrolysis process (see Figure 11, below). In the process, biomass feedstock is heated at high temperature (typically between 300° and 650°C) for a few seconds, in the absence of oxygen. Instead of being combusted, the feedstock decomposes into combustible gases and charcoal. Some gases condense to form pyrolysis oil. There are different processes, which produce different combinations of gases, pyrolysis oil and charcoal. The share of pyrolysis oil is typically 60% to 70%.

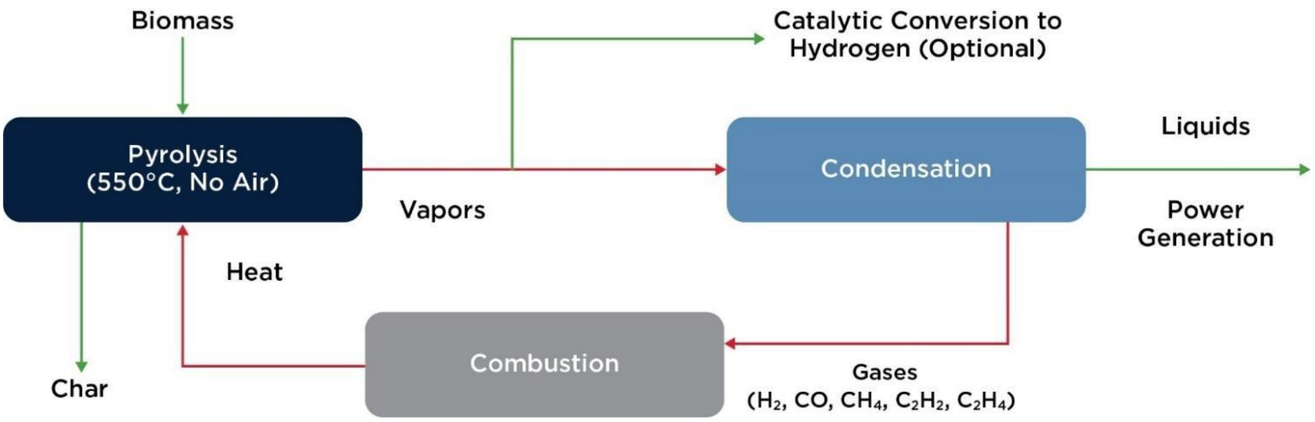

Figure 11. Biomass liquefaction via pyrolysis, adapted from (Zafar 2021)

Two main types of production processes are slow pyrolysis and fast pyrolysis. In slow pyrolysis, low heating rates and temperatures of 500° to 600°C lead to a high yield of char and a lower production volume of bio-oil (10 to 15 weight % [wt]). In fast pyrolysis, biomass is rapidly heated to 400° to 600 °C in an inert atmosphere with a high nitrogen content at ambient pressure. In this type of process, the bio-oil yield is much higher, with a liquid product yield of about 70 wt%, a water content of 15 to 30 wt%, and an oxygen content of 35 to 40 wt%. Fast pyrolysis also can be achieved by using a catalyst (catalytic fast pyrolysis), which improves the quality of the pyrolysis oil, or in the presence of pure hydrogen at higher pressure (hydropyrolysis), which enhances dehydration of the bio-oil and reduces carbon loss and coke formation (Nami, et al., 2021).

The common feedstocks for producing pyrolysis oil are lignocellulosic and other energy crops. The biomass fed into the reactor must be milled and have a moisture content below 10%, which may require pre-treatment (IEA Bioenergy, 2017).

The physical and chemical properties of pyrolysis oil depend to a large degree on the used biomass feedstock and process conditions, notably temperature, pressure, heating rate and residence time. The elemental composition resembles that of used biomass (Nami, et al., 2021).

Pyrolysis oil therefore has a poor compatibility with existing marine engines (ICCT, 2020). It is not a drop-in fuel, and its use would require marine engines and fuel systems to be modified or replaced. Pyrolysis oil has different characteristics than vegetable or petroleum oils; it is acidic and corrosive. Because the viscosity of pyrolysis oil increases during storage (which may lead to incomplete combustion and the particle deposits, causing engine damage), it should not be stored for more than a few months (Ecofys, 2012). Also, the water content increases over time, which leads to phase-separation phenomena (Nami, et al., 2021). Marine engines are often equipped with heaters and coolers to perform online control of the viscosity of the fuel, and this system also can be used for pyrolysis oil. Pyrolysis oil is expected to have a lower calorific value than MDO (due to the high oxygen content of 35 to 50 wt%), so the fuel-oil supply system, which includes pumps, pipes, fuel boosters and fuel injectors, needs to be expanded to a higher capacity.

Pyrolysis oil has a high polarity, which makes it immiscible with fossil oils. However, it can be blended with emulsion biofuels to increase thermal efficiency and reduce the output of particulate matter from engines. But given its problematic features, such as high viscosity and corrosiveness, pyrolysis oil should be processed further to make it suitable for use in fuel engines. For example, a catalytic-upgrading process can improve its fuel characteristics and stability enough to produce a drop-in fuel. This process involves hydrogenation and produces a 'hydrogenated pyrolysis oil' that may be suitable for diesel engines (IEA Bioenergy, 2017).

***Hydrothermal Liquefaction (HTL) biocrude***

HTL biocrude is a crude-like bio-oil that is produced from biomass using hydrothermal liquefaction technology (see Figure 12, below). The production process uses temperatures between 250° and 550°C, with pressures of 5-25 MPa for 20 to 60 minutes. Catalysts are used to maximise production yields. The water becomes either subcritical or supercritical and acts as a solvent, reactant and catalyst during the process. The oxygen in the biomass is removed through dehydration or decarboxylation (IEA Bioenergy, 2017).

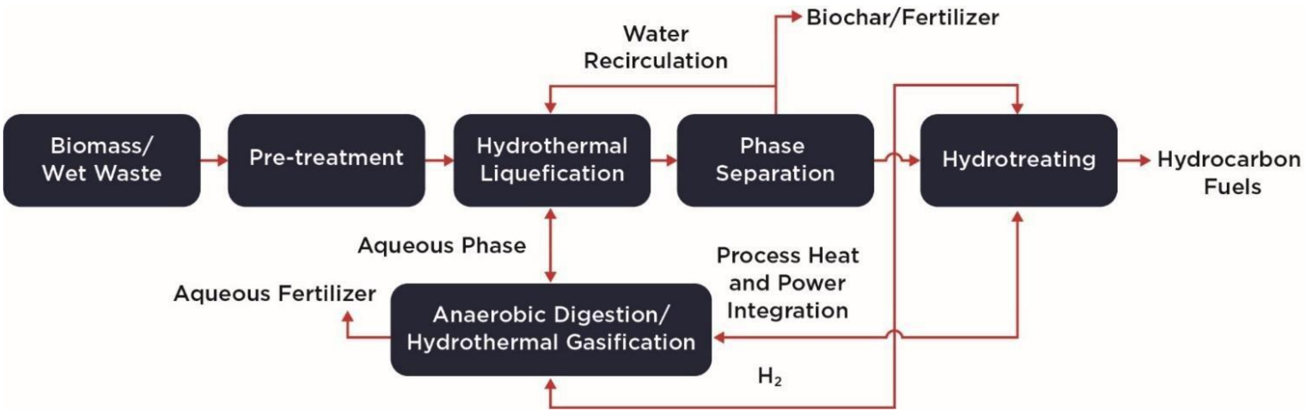

Figure 12. Conversion of lignocellulosic biomass using hydrothermal liquefaction, adapted from (Gollakota, et al., 2018)

Unlike the pyrolysis process, HTL can process wet biomass (see Figure 13, below). Non-processed agricultural residues and lignocellulosic biomass are ideal feedstocks, because they offer a mix of carbohydrates and low-lignin content to reduce the risk of charring. Algae also can be used as a feedstock.

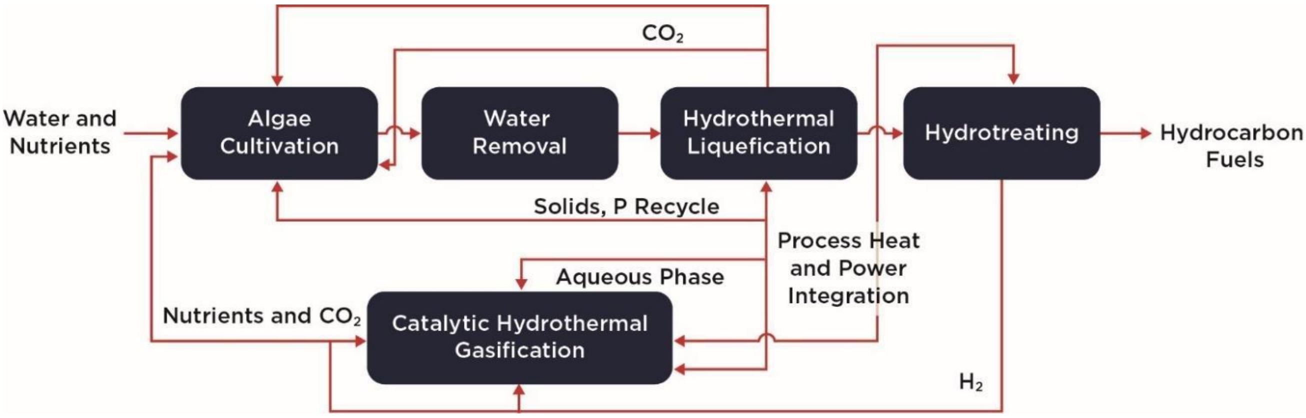

Figure 13. Hydrothermal liquefaction process of algal biomass/wet biomass, adapted from (Gollakota, et al., 2018)

HTL biocrude has poor compatibility with existing marine engines and is not considered a drop-in fuel. But it can be used in engines in blends with residual fuels. Alternatively, HTL biocrude can be further upgraded to produce a drop-in MGO or MDO (ICCT, 2020; IEA Bioenergy, 2017; Ramirez, et al., 2015).

***Solvolysis oil***

Solvolysis is a comparable process technology to hydrothermal liquefaction, but it uses a supercritical organic solvent under pressure at a temperature of 300°-450°C. It is a thermal process (see Figure 14, below) in which biomass is liquefied into a bio-oil, which can be blended with marine diesel oil, or further processed into a drop-in fuel with a low oxygen content. A residual product is biochar. Hydrotreating is not needed as a prerequisite for blending. Moreover, no catalysts are needed in the solvolysis process.

The main advantage of solvolysis is that lignin-rich biomass feedstocks can be used. Also, lignin that is produced as a by-product during the hydrolysis process in bio-ethanol production plants can be used as feedstock, providing a possible synergy with bio-ethanol production (Sebhat, et al., 2020). Using hydrolysis, lignin creates high concentrations of silica (ash), which is a concern for maintaining a clean system, but it precludes having to create another step to remove the silica (IEA Bioenergy, 2017).

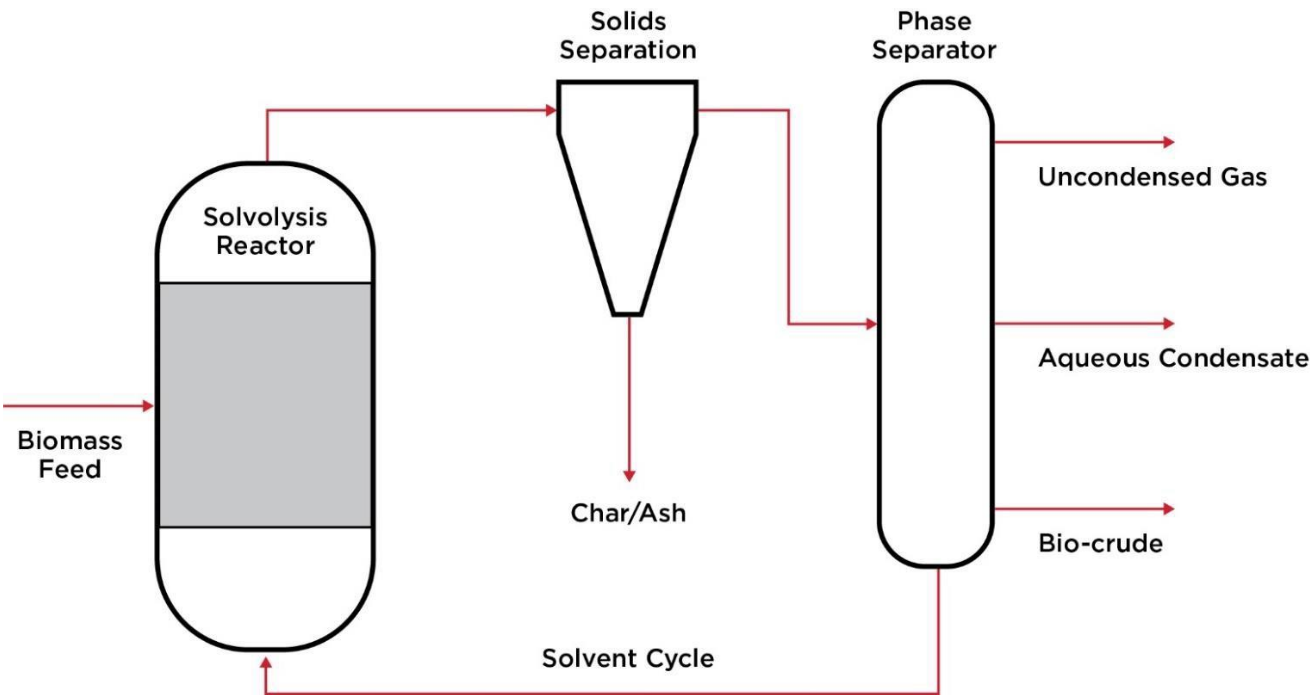


Figure 14. Scheme of solvolysis/ HTL process, adapted from (IEA Bioenergy, 2020)

#### 2.1.2.4 Gaseous biofuels

Gaseous biofuel is biomethane. The production pathway is shown in Figure 15. Biomethane can be produced via two main production pathways: anaerobic digestion and gasification. Both are discussed below.

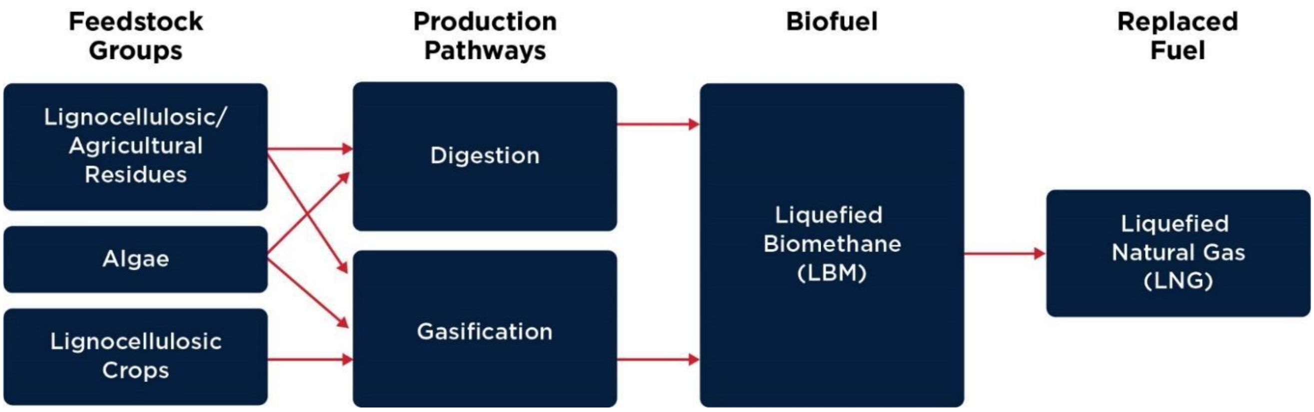


Figure 15. Production pathways of biomethane

**Anaerobic digestion**

In anaerobic digestion, biomass is digested by bacteria in an anaerobic environment to create biogas, which mainly consists of methane and carbon dioxide (see Figure 16, below). Separating the $CO_2$ from the methane creates biomethane, which has a methane content that typically exceeds 80%. Wet biomass feedstocks are needed for this process; woody biomass cannot be used. The common feedstocks are energy crops, agricultural residues, residues from the food industry, manure, sewage sludge and organic waste. Algae could be used, either the original biomass or the residual mass once the lipids are extracted to produce liquid biofuels (IEA Bioenergy, 2017). Depending on the reactor, methane may escape, which is undesirable from a climate perspective and should be avoided.

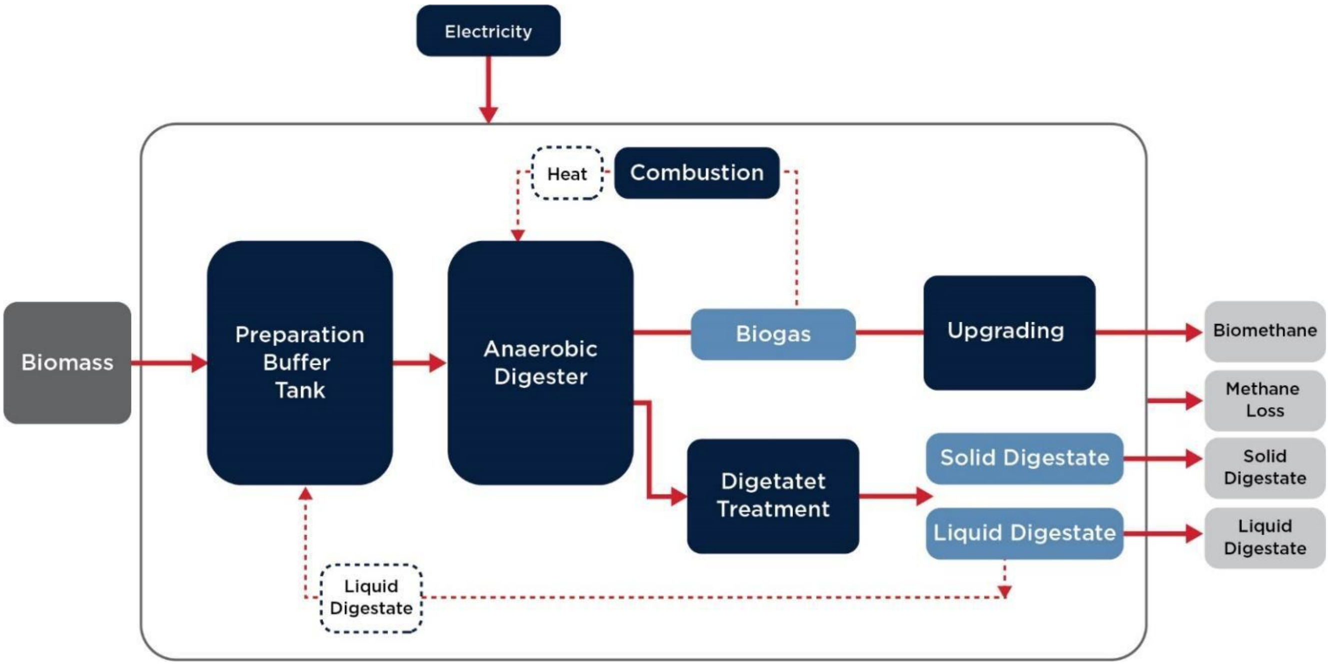


Figure 16. Anaerobic digestion, adapted from (Moghaddam, et al., 2019)

***Gasification***

Gasification has a higher conversion efficiency than anaerobic digestion, but a lower level of technology readiness (TRL), which indicates how far a fuel pathway is from commercially available production. In the gasification step (see Figure 17, below), biomass is converted into synthesis gas (syngas). In a consecutive methanation process (also known as the Sabatier process), the $H_2$, CO and $CO_2$ in the syngas react with each other to form biomethane at temperatures between 300° and 400°C (IEA Bioenergy, 2017).

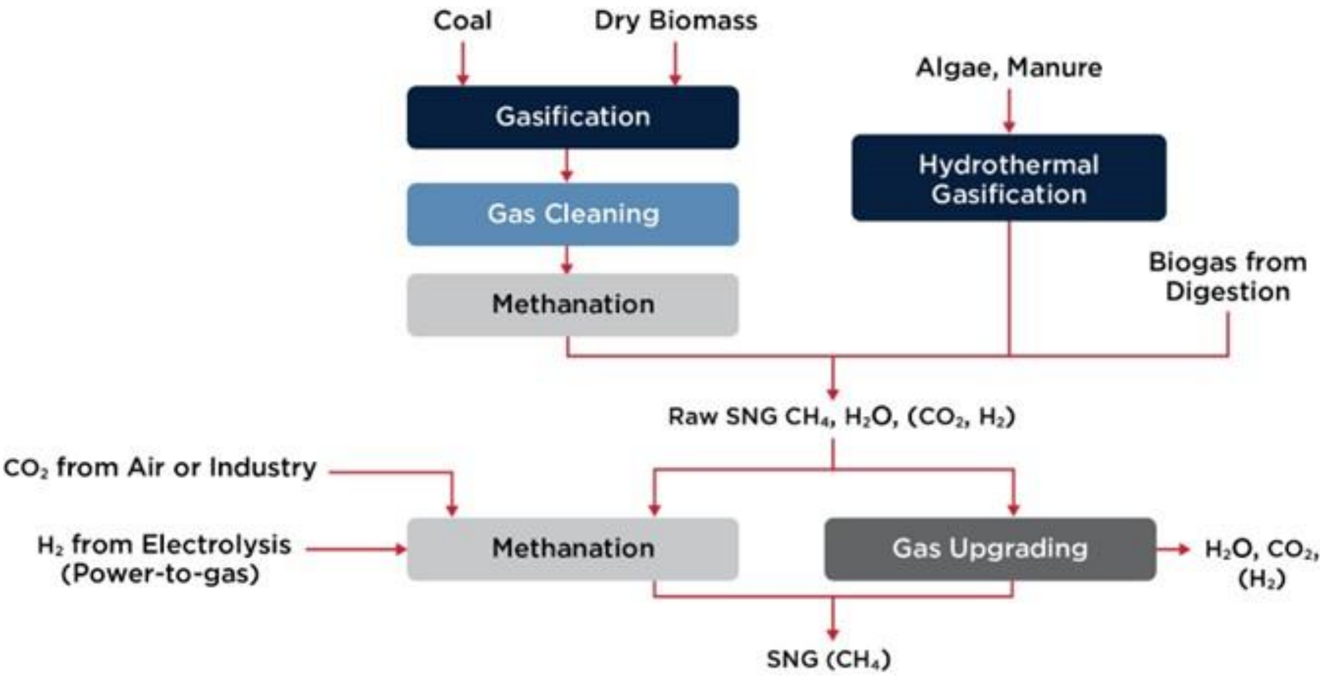


Figure 17. Biomass gasification, adapted from (Deremince & Königsberger, 2017)

A distinction needs to be made between thermal and supercritical water gasification (SCWG). Thermal gasification is more conventional and is the most suitable method to convert dry, lignocellulosic biomass. SCWG is an iteration of the conventional thermal gasification process that uses supercritical water as a reaction medium to convert biomass – primarily into $H_2$, $CH_4$ and $CO_2$ – at temperatures between 400° and 700°C and pressures above 221 bar (Boukis & Stoll, 2021).

Unlike thermal gasification, SCWG can convert all types of biomasses, including wet feedstocks; biomethane is one of its products. However, its TRL is lower than thermal gasification. The hydrogen and $CO_2$ that is produced can be combined in a subsequent methanation step to increase the methane output, or the $CO_2$ can be used to produce more fuels.

As compressed biomethane has a low volumetric energy density, its use as a fuel in ships requires it to be converted into LBM, which improves the energy density by a factor of three compared to compressed biomethane. Before the biomethane can be liquefied, it must be purified to more than 99.9% methane, so the following specifications are met: $CO_2$ < 50ppm; $H_2S$ < 4ppm; and $H_2$ < 1ppm (CE Delft, 2018). In the liquefaction process, the methane is cooled to a temperature below -162°C (the boiling point of methane), a process that is energy intensive.

For its application on ships, similar to LNG, the storage of LBM will need to account for a possible pressure build-up in the tank due to the formation of boil-off gas (evaporation). LBM will need to be stored in specially designed fuel tanks so that the IMO’s requirements for its use onboard ships are satisfied.

Boil-off gas management plans could involve the consumption of excess boil-off gas by dual-fuel auxiliary engines, a dual-fuel boiler, or even the use of a reliquefaction unit, the latter being a viable option mainly for LNG carriers where the amount of boil-off gas is significant and could justify the installation of such a unit; this process is associated with significant energy losses (Tybirk, et al., 2018). The adaptation of LBM as a marine fuel is therefore an option for LNG-fuelled ships that are equipped with LNG tanks, the relevant fuel-gas supply system (FGSS) and dual-fuel engines running on methane.

### 2.1.3 Production pathways: levels of maturity

Not all biofuel options have the same level of maturity, which differs between commercially available biofuels and more innovative advanced production pathways that may lack significant output capacity. Often, there are different production pathways to produce the same type and grade of fuel; whereas the supply chain after production is equal for all pathways.

For new production pathways, the TRL measures the maturity of a technology. A TRL level from 3-5 indicates a pathway in the development phase; TRL levels from 5-7 indicate phases in demonstration mode; TRL levels from 6-8 indicate phases of system and subsystem development; and TRL levels 7-9 indicate phases of systems testing for launch and operations. A TRL level of 10 indicates a proven, mature technology (see Table 1, below).

Table 1. Technology Readiness Levels (Verbeek, et al., 2020)

| Fuel category | End product | Production pathway | Fuel production | |
|---|---|---|---|---|
| | | | TRL 2019 | TRL 2030 |
| Biodiesels | FAME | Transesterification | 10 | 10 |
| | HVO | Hydrotreatment | 10 | 10 |
| | HVO (from wood) | Wood extractives pulping/ catalytic upgrading | 8/9 | 8/10 |
| | HVO (from algae) | Algae/oil extraction / catalytic upgrading | 4/5 | 4/5 |
| | FT diesel | FT synthesis | 6/8 | 8/9 |
| | DME | Lignocellulosic Gasification | 6/8 | 8/9 |
| Bio-alchohols | Bioethanol | Fermentation | 10 | 10 |
| | | Waste based | 8/9 | 10 |
| | | Lignocellulosic hydrolysis | 8/9 | 9/10 |
| | Bio-methanol | Waste based | 8/9 | 10 |
| | | Black liquor gasification | 6/8 | 8/9 |
| | | Lignocellulosic gasification | 6/8 | 8/9 |
| Biocrudes | SVO | | 10 | 10 |
| | Pyrolysis oil | Lignocellulosic Pyrolysis/ catalysed upgrading | 5/6 | 6/8 |
| | HTL biocrude | Lignocellulosic Hydrothermal liquefaction/ catalytic refining | 2/4 | 4/5 |
| | Solvolysis oil | Lignocellulosic hydrolysis / solvolysis | 4/5 | 6/8 |
| Gaseous biofuels | Liquefied biomethane | Sludge/maize/manure/ residues Fermentation / digestion | 10 | 10 |
| | Liquefied biomethane | Lignocellulosic Gasification | 6/8 | 8/9 |

FAME, HVO, fermentation-based ethanol and biomethane from digestion can be produced based on fully developed technologies. Waste-based and cellulosic ethanol are close to reaching commercial scale, followed by wood-based HVO, and FT diesel and DME; SVO biocrudes and renewable from algae are at earlier stages of development.

## 2.1.4 Developments in production capacity

### 2.1.4.1 Biodiesel

Global production levels for biodiesel, coupled with short-term forecasts, indicate there are five main regions for biodiesel production: the EU, the United States, Indonesia, Brazil and Argentina; the EU is the main producer. For reference, according to the 4th IMO GHG study, total shipping $CO_2$ emissions (including international, domestic and fishing) were 1,056 million tonnes in 2018, or around 340 million tonnes of fuel. International shipping alone accounted for 919 million tonnes of $CO_2$ in 2018 (295 million tonnes of fuel). One billion litres of biodiesel is approximately 0.88 million tonnes. The estimated 50 billion litres of biodiesel that will be produced from 2023 to 2025 (averaged) by the top 5 producing regions, equates to 44 million tonnes of biodiesel or, 12.9% of shipping's demand for fuel in 2018.

In 2020, 811m tonnes of $CO_2$ was emitted from shipping, compared with 866m tonnes in 2019, according to World Energy Outlook 2021 from the IEA (IEA, 2021).

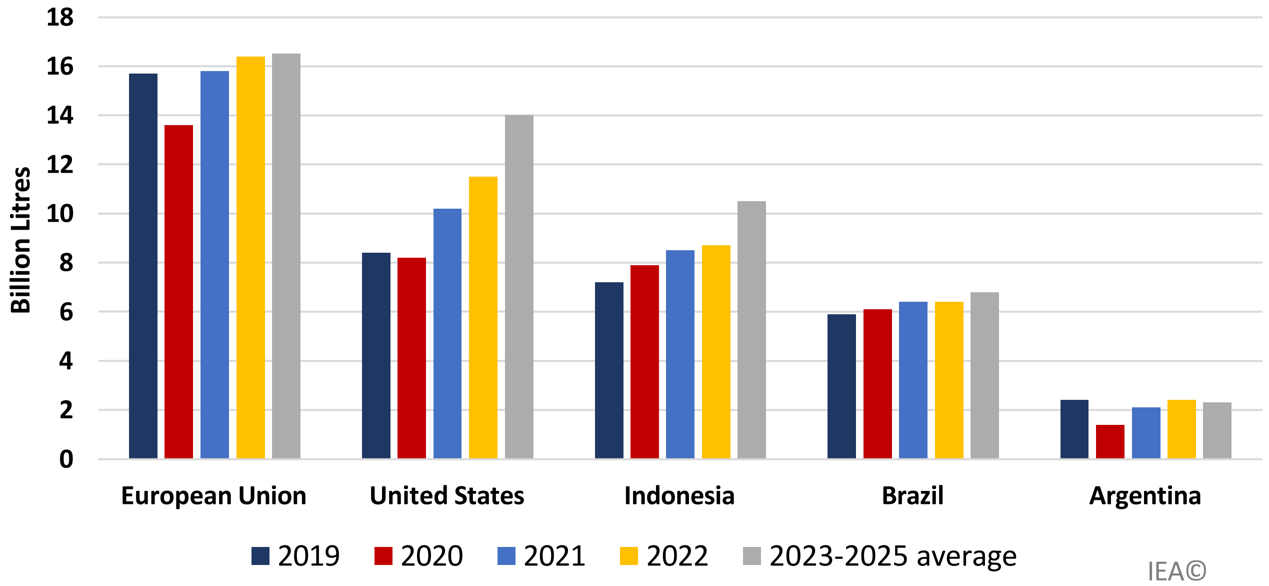


Figure 18. Biodiesel (incl HVO) production overview, key global markets, 2019-2025 (IEA, 2020)

Table 2 (below) shows the development of the EU's production capacity for biodiesel (FAME) and renewable diesel (HVO) from 2011 to 2020. EU producers mainly make FAME and HVO for the European market, complemented by a small share of imports.

FAME production facilities have decreased significantly at many biorefineries. Total production does not equal production capacity, because the facilities do not operate at full capacity. The share of capacity being used has improved over the years, but it is still relatively low, at around 60%. The number of facilities that produce HVO is limited but has more than tripled to 15 from four facilities in the past decade.

Table 2. EU Production of biodiesel (FAME) and renewable diesel (HVO) (Flach, et al., 2021)

| Year | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|
| Production Capacity, Biodiesel/FAME (Million Litres) | | | | | | | | | | |
| **Number of Biorefineries** | 284 | 244 | 220 | 201 | 196 | 187 | 186 | 186 | 187 | 187 |
| **Nameplate Capacity** | 25 490 | 25 025 | 22 830 | 21 930 | 21 520 | 20 124 | 21 030 | 21 130 | 21 230 | 21 230 |
| **Capacity Use** | 40.90% | 41.80% | 49.20% | 54.40% | 58.30% | 64.80% | 58.20% | 60.80% | 56.20% | 58.10% |
| Production Capacity, Renewable Diesel/HVO (HDRD) (Million Litres) | | | | | | | | | | |
| **Number of Biorefineries** | 4 | 5 | 10 | 11 | 11 | 13 | 14 | 15 | 15 | 15 |
| **Nameplate Capacity** | 1 695 | 1 830 | 2 830 | 3 395 | 3 395 | 3 606 | 3 610 | 5 210 | 5 210 | 5 280 |
| **Capacity Use** | 56.60% | 87.70% | 81.70% | 72.80% | 64.50% | 71.60% | 74.90% | 56.40% | 69.30% | 71.60% |
| **Beginning Stocks** | 575 | 580 | 520 | 565 | 590 | 610 | 670 | 930 | 750 | 730 |
| **Production** | 11 382 | 12 064 | 13 549 | 14 397 | 14 728 | 15 622 | 14 946 | 15 781 | 15 534 | 16 110 |
| **>HDRD Production** | 960 | 1 604 | 2 311 | 2 470 | 2 190 | 2 582 | 2 705 | 2 938 | 3 610 | 3 780 |
| **Imports** | 3 294 | 1 392 | 631 | 540 | 629 | 1 332 | 3 781 | 3 613 | 3 106 | 3 100 |
| **Exports** | 115 | 416 | 181 | 244 | 408 | 372 | 645 | 759 | 465 | 530 |
| **Consumption** | 14 556 | 13 100 | 13 954 | 14 668 | 14 929 | 16 522 | 17 822 | 18 815 | 18 195 | 18 660 |
| **Ending Stocks** | 580 | 520 | 565 | 590 | 610 | 670 | 930 | 750 | 730 | 750 |

Germany and France are the two main producers of FAME, followed by Spain, Poland, the Netherlands and the UK (see Table 3, below). The largest HVO producer is the Netherlands, followed by Italy, Spain and France (see Table 4).

Table 3. Main producers of FAME in the EU (Flach, et al., 2021)

| Production of FAME in Million Litres | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** |
| **Germany** | 3 106 | 3 307 | 3 808 | 3 505 | 3 543 | 3 644 | 3 799 | 4 070 | 3 862 | 4 100 |
| **France** | 2 175 | 2 170 | 2 386 | 2 866 | 3 152 | 3 135 | 2 806 | 2 556 | 2 045 | 2 045 |
| **Spain** | 538 | 659 | 1 017 | 1 103 | 1 319 | 1 721 | 2 008 | 1 835 | 1 550 | 1 450 |
| **Netherlands** | 974 | 790 | 1 056 | 795 | 638 | 1 112 | 1 010 | 1 081 | 1 102 | 1 100 |
| **Poland** | 673 | 736 | 786 | 861 | 985 | 1 019 | 1 001 | 1 091 | 1 081 | 1 090 |
| **Italy** | 326 | 521 | 452 | 625 | 398 | 599 | 511 | 616 | 616 | 620 |
| **Other** | 1 214 | 1 638 | 1 179 | 1 600 | 2 007 | 1 320 | 606 | 974 | 1 118 | 1 335 |
| **Total** | **9 006** | **9 821** | **10 684** | **11 355** | **12 042** | **12 550** | **11 741** | **12 223** | **11 374** | **11 740** |

Table 4. Main producers of HVO in the EU (Flach, et al., 2021)

| Production of HVO in Million Litres | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** |
| **Netherlands** | 410 | 872 | 1 013 | 1 192 | 1 154 | 1 218 | 1 218 | 1 218 | 1 218 | 1 220 |
| **Italy** | - | - | 323 | 323 | 323 | 323 | 323 | 397 | 910 | 910 |
| **France** | - | - | - | - | - | - | 128 | 150 | 385 | 500 |
| **Spain** | 73 | 179 | 377 | 262 | 418 | 465 | 482 | 549 | 480 | 460 |
| **Finland** | 317 | 392 | 439 | 533 | 135 | 383 | 354 | 424 | 423 | 420 |
| **Sweden** | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 160 | 230 |
| **Portugal** | - | - | - | - | - | 32 | 37 | 37 | 32 | 32 |
| **Czech Republic** | - | - | - | - | - | - | 3 | 3 | 3 | 3 |
| **Total** | **960** | **1 603** | **2 312** | **2 470** | **2 190** | **2 581** | **2 705** | **2 938** | **3 611** | **3 775** |

### 2.1.4.2 Bio-alcohols

As with biodiesels, bioethanol production is a mature global market that has witnessed steady growth in the past two decades (see Figure 19, below). The U.S. and Brazil dominate the ethanol market, but Asian countries such as China, India and Thailand also play significant roles in global production. Note that one million barrels is around 159 million litres, which equates to around 125,450 tonnes of ethanol. Since the calorific value of ethanol is around half that of diesel, this equates to around 78,740 tonnes of diesel equivalent.

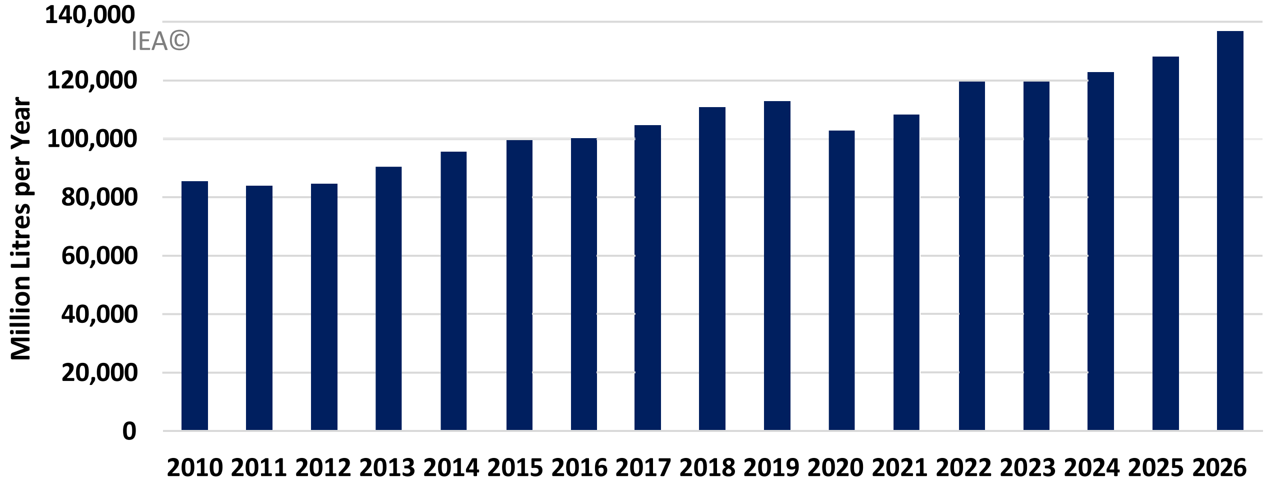


Figure 19. Global bioethanol production in million of litres per year (IEA, 2020)

***The EU***

In 2020, there were 57 production facilities for first-generation ethanol, while only two of these facilities produced cellulosic ethanol (see Table 5, below). Ethanol production is more equally distributed among EU countries, led by France (see Table 6).

Table 5. Ethanol used as fuel and other industrial chemicals (Flach, et al., 2021)

| Year | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Production (Million Litres)** | 5 348 | 5 741 | 5 949 | 6 080 | 5 887 | 6 037 | 6 101 | 5 861 | 5 468 | 5 615 |
| Fuel Production | 4 658 | 5 000 | 5 190 | 5 165 | 5 159 | 5 373 | 5 497 | 5 281 | 4 747 | 5 000 |
| % > of which is cellulosic | 0 | 0 | 50 | 50 | 50 | 40 | 10 | 10 | 25 | 50 |
| **Consumption (Million Litres)** | 7 206 | 6 653 | 6 506 | 6 484 | 6 231 | 6 394 | 6 938 | 7 490 | 7 082 | 7 545 |
| Fuel Consumption | 5 676 | 5 370 | 5 380 | 5 399 | 5 315 | 5 535 | 5 904 | 6 108 | 5 495 | 6 050 |
| **Refineries Producing First Generation Fuel Ethanol (Million Litres)** | | | | | | | | | | |
| Number of Refineries | 70 | 71 | 66 | 60 | 55 | 58 | 57 | 56 | 57 | 57 |
| Capacity | 6 595 | 7 111 | 7 215 | 7 030 | 7 153 | 7 502 | 7 299 | 8 112 | 8 150 | 8 150 |
| Capacity Use | 71% | 70% | 71% | 73% | 71% | 71% | 75% | 65% | 58% | 61% |
| **Refineries Producing Cellulosic Fuel Ethanol (Million Litres)** | | | | | | | | | | |
| Number of Refineries | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | 5 |
| Nameplate Capacity | 0 | 0 | 50 | 50 | 50 | 50 | 60 | 60 | 90 | 200 |
| Capacity Use | 0 | 0 | 100% | 100% | 100% | 80% | 17% | 17% | 28% | 25% |

Table 6. Main producers of ethanol (Flach, et al., 2021)

| Production of Ethanol in Million Litres | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| France | 1 018 | 1 039 | 987 | 1 000 | 1 138 | 1 299 | 1 049 | 1 095 |
| Germany | 920 | 870 | 882 | 810 | 799 | 676 | 875 | 950 |
| Hungary | 456 | 591 | 633 | 633 | 645 | 689 | 639 | 640 |
| Netherlands | 519 | 563 | 443 | 532 | 563 | 570 | 538 | 570 |
| Spain | 454 | 494 | 328 | 377 | 522 | 547 | 487 | 480 |
| Belgium | 557 | 557 | 570 | 620 | 646 | 620 | 380 | 380 |
| Poland | 181 | 214 | 241 | 258 | 259 | 286 | 277 | 285 |
| Austria | 230 | 223 | 224 | 235 | 251 | 254 | 241 | 255 |
| Total | 4 335 | 4 551 | 4 308 | 4 465 | 4 823 | 4 941 | 4 486 | 4 655 |

The production of 5 billion litres of ethanol corresponds to 3.95 million tonnes of ethanol. Considering that the calorific value of ethanol is about half that of diesel, this translates to about 2.48 million tonnes of equivalent diesel or 0.73% of shipping's fuel demand in 2018. In contrast to bio-ethanol, much less statistical information is available about bio-methanol. Production plants are operational in Denmark, Germany, Canada and The Netherlands (Hobson, 2018). The largest plants, producing up to 1,000 kt/year, typically co-feed biomethane and natural gas, while smaller plants, producing several kt/year, produce bio-methanol as a byproduct from wood pulping (IRENA and Methanol Institute, 2021).

**Biomethane**

Biomethane production has been rising steadily in the past decade but is still very small compared to the global market for natural gas, which reached a value of 4.115 trillion cubic metres in 2019 (IEA, 2021). Figure 20 shows the global production of renewable natural gas (RNG). It can be seen that global production has been increasing over the years reaching almost 4.0 billion cubic meters. The line shows the annual increase in production of RNG in billion cubic metres from 2011 to 2019; an acceleration of the production can be observed, especially between years 2017 and 2019.

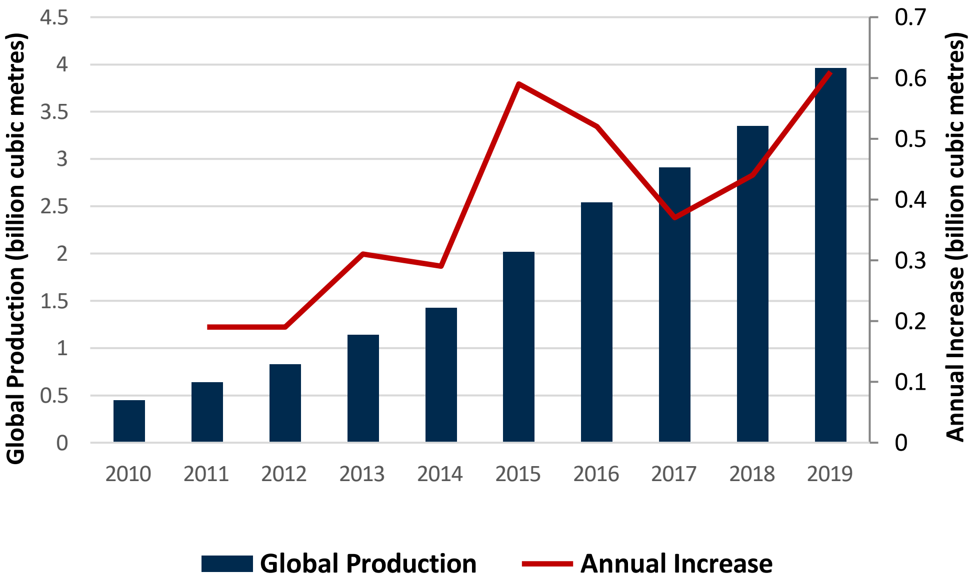


Figure 20. Global Renewable Natural Gas production (in billion cubic metres - bcm) between 2010-2019 (graphic adapted from (Cedigaz, 2021))

### 2.1.4.3 Global production capacity for advanced biofuels

According to a 2019 report from CIT, a financial institution (Nystrom, Bokinge, & Franck, 2019), the global production capacity for advanced biofuels represented less than 3% of production and less than 0.1% of the energy used for their transportation. About 96-97% of advanced biofuel production consisted of HVO; other advanced biofuels were far more limited.

#### 2.1.4.4 EU production capacity for advanced biofuels

The organisation ETIP Bioenergy (2021) provided insights into the developments of advanced biofuel production in the EU, including detailed information about the production pathways for advanced biofuels, defined as priority value chains (PVC). Figure 21 shows the current operational production capacity (358,828 tonnes/year [t/y]), the capacity currently under construction (151,900 t/y), and the planned (announced) capacity per production pathway (1,742,760 t/y in total).

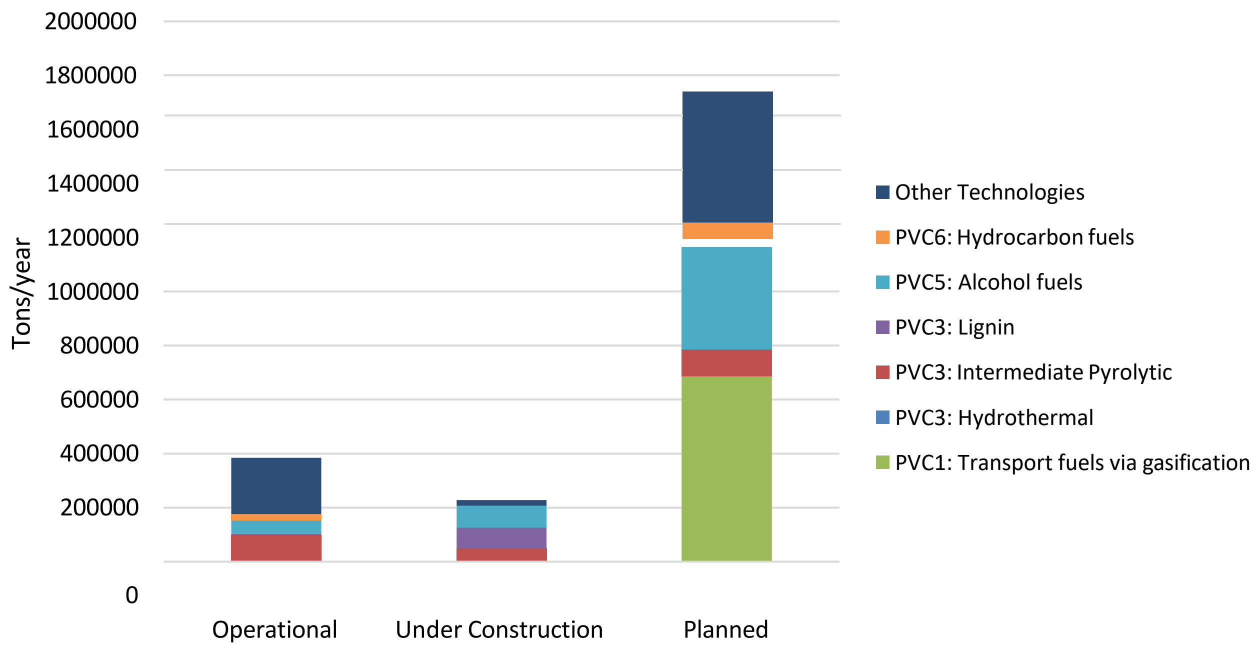


Figure 21. European production capacity (tonnes/year) of advanced biofuels, by status (ETIP BIoenergy, 2020)

In terms of pathways (Figure 22), the largest operational capacities currently produce pyrolysis oil (74,000t/y) and alcohols from cellulosic sugars (49,420t/y). In terms of planned capacity, gasification pathways are the highest (685,760t/y), covering a range of pathways and products; alcohols from cellulosic sugars (380,000t/y) were also significant.

The largest contribution from other technologies is the 500,000t/y planned for diesel from tall oil (residues from the pulp/paper or forestry industries). Overall, ethanol, pyrolysis and methanol are currently the most common advanced fuel products.

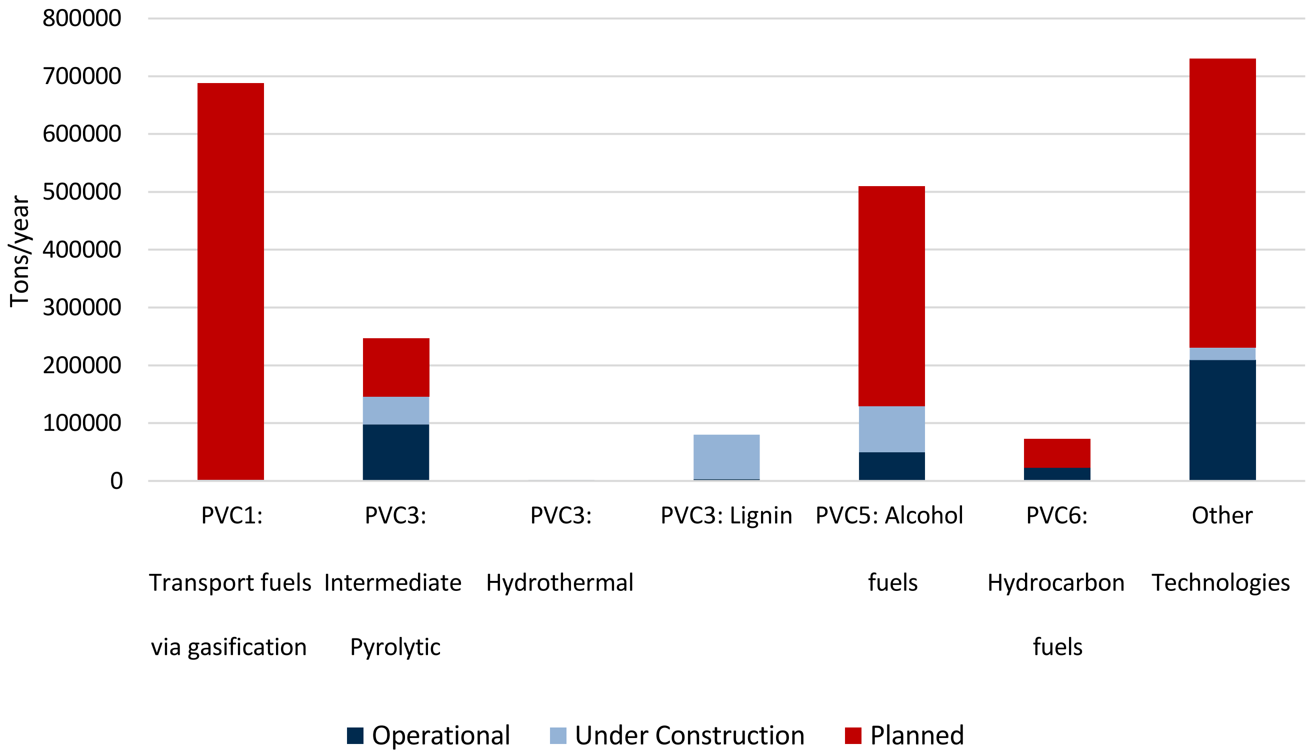


Figure 22. European production capacity (tonnes/year) of advanced biofuels by pathway (ETIP BIoenergy, 2020)

### 2.1.5 Pilot projects and R&D activities

Based on current installed production capacity and the levels of maturity for biofuel production pathways, many pathways are still in the R&D and pilot phases. This section examines the pilot projects and R&D activities.

Significant R&D activity is supporting general biofuel production processes, without a direct link to the use of biofuels in marine engines (IRENA, 2016). This section examines R&D projects with a clear maritime focus.

**EU (co-)funded projects**

Projects that are co-funded by the EU are mainly funded under the Union's framework programmes for research and innovation (FP1 to Horizon 2020) or by the Connecting Europe Facility (CEF) Transport. EU Framework programmes typically target the lower TRLs, while CEF Transport aims at technologies with a high TRL.

The number of projects with a specific focus on both biofuels and marine applications is relatively small (Table 7), and these projects focus on biocrudes and alcohols. Given the difference between marine fuels and jet fuels, it is surprising that several projects aim both at application of the fuels in the marine sector and in aviation.

In addition to the projects aiming to develop biofuels for use in marine engines, several projects aim to support scalability in biofuels or alternative fuels, as shown in Table 8. These projects cover a wide range of fuels.

Finally, CEF Transport supports the deployment of biofuels in two projects: one aiming at the use of biodiesels in ferries between France and the UK, and the other at blending biogas in LNG, as shown in Table 9.

Table 7. Overview of H2020 programmes covering fuels for maritime shipping (CORDIS, 2022)

| Project acronym | Project title | Type | Reference |
|---|---|---|---|
| BioSFerA | Biofuels production from syngas fermentation for aviation and maritime use | RIA | 884208 |
| BL2F | Black liquor to fuel by efficient hydrothermal application integrated to pulp mill | RIA | 884111 |
| FLEXI-GREEN FUELS | Flexible and resilient integrated biofuel processes for competitive production of green renewable jet and shipping fuels | RIA | 101007130 |
| FReSME | From residual gasses to methanol | RIA | 727504 |
| GLAMOUR | Glycerol to aviation and marine products with sustainable recycling | RIA | 884197 |
| IDEALFUEL | Lignin as a feedstock for renewable marine fuels | RIA | 883753 |

Note: details of the projects are available at https://cordis.europa.eu/

Table 8. HORIZON2020 related to Innovation action projects with a focus on supporting scalability in biofuels or alternative fuels (CORDIS, 2022)

| Project acronym | Project title | Type | Reference |
|---|---|---|---|
| STEELANOL | Production of sustainable, advanced bio-ethanol through an innovative gas-fermentation process using exhaust gases emitted in the steel industry | IA | 656437 |
| TO-SYN-FUEL | Demonstration of waste biomass to synthetic fuels and green hydrogen | IA | 745749 |
| Torero | 'TORrefying' wood with ethanol as a renewable output: large-scale demonstration | IA | 745810 |
| FlexJET | Sustainable jet fuel from flexible waste biomass | IA | 792104 |
| REWOFUEL | Residual soft wood conversion to high characteristics drop-in biofuels | IA | 792104 |
| FLITE | Fuel via low carbon integrated technology from ethanol | IA | 857839 |
| SteamBioAfrica | Innovative large-scale production of affordable clean-burning solid biofuel and water in southern Africa: transforming bush encroachment from a problem into a secure and sustainable energy source | IA | 101036401 |

Note: details of the projects are available at https://cordis.europa.eu/

Table 9. CEF Transport-funding programmes

| Start year | Project title | Reference |
|---|---|---|
| 2014 | Study and deployment of integrated gas & water cleaning system and biofuel-MGO blend for Atlantic corridor upgrade | 2014-EU-TM-0723-M |
| 2019 | Bio2Bunker: BLNG as the solution for decarbonising the maritime industry | |

Note: details of the projects are available on the CEF Transport website https://ec.europa.eu/inea/en/connecting-europe-facility/cef-transport

#### 2.1.5.1 Pilot projects in shipping with biofuel blends

Several biofuel producers and traders have joined forces with maritime-shipping stakeholders to test the use of their blends. The Global Maritime Forum's 'Getting to Zero' coalition is looking to map zero-emission pilots and demonstration projects. For biofuel projects, only biofuel production from second- and third-generation technologies (lignocellulosic and algae/marine feedstocks) are included, due to the maturity and commercial viability of other biofuels (Fahnestock & Bingham, 2021). Table 10 lists the biofuel and biomethane pilot projects. There is also a long list of pilot projects focussed on methanol, but those mainly focus on synthetic methanol; it is not completely clear whether bio-methanol was involved.

Table 10 Biofuel projects Getting to Zero coalition (Global Maritime Forum, 2022)

| Biofuel pilot and demonstration projects | |
|---|---|
| CMA CGM White Shark-Biofuel Refuelling<br><br>Timeline: 2020 –<br><br>Demonstration in normal operations<br><br>Large ship size | A partnership between the Swedish furniture retailer IKEA, CMA CGM, the sustainable initiative the GoodShipping Program and the Port of Rotterdam saw the world's first ocean freight bunkered with marine biofuel.<br><br>After having announced their three-month biofuel trial, leading short sea shipowner UECC and the GoodShipping Program have now partnered with premium car manufacturer BMW Group to continue to test marine Bio Fuel Oil (BFO) on UECC's 'roll on, roll off' (ro-ro) car carrying vessels. BMW Group joins UECC and the GoodShipping Program in the previously announced trial, where BFO is being tested on UECC's 140m, 2,080-vehicle carrier *M/V Autosky*. |
| DFDS MASH Project<br><br>Timeline: 2019 –<br><br>Laboratory test | DFDS has bought a stake in start-up company MASH Energy, which produces biofuel from agricultural waste, currently from the byproducts of nut processing in India. In order to minimise the operational risks involved in implementing the new generation of biofuel, Alfa Laval have agreed to test the biofuel at their testing centre in Aalborg. |
| HAM 316<br><br>Timeline: 2019 –<br><br>Type of project: Demonstration in normal operations<br><br>Large ship size | Together with Shell, Van Oord is testing the use of biofuel on its trailing suction hopper dredger HAM 316: "We're testing a "second-generation" biofuel made from waste products such as cooking oil. Moreover, it is ISCC certified, which means that the entire chain is certified by a third party.<br><br>Current calculations show that the biofuel is an effective and affordable method of reducing $CO_2$ emissions. The test will indicate whether the fuel can be used in practice in existing vessels. The local emissions of the vessel will be measured during the work and after completion the engine will be inspected." |
| Maersk Biofuels<br><br>Timeline: March 2019 -<br><br>Type of project: Demonstration in normal operations<br><br>Large ship size | Convinced of the urgency to act on climate, a group of Dutch Multinationals, all members of the Dutch Sustainable Growth Coalition (DSGC), will join forces with A.P. Moller - Maersk to take a tangible step towards the decarbonisation of ocean shipping.<br><br>The pilot uses up to 20% sustainable second-generation biofuels on a large triple-E ocean vessel will sail 25,000 nautical miles from Rotterdam to Shanghai and back on biofuel blends alone, a world's first at this scale, saving 1.5 million kilograms of $CO_2$ and 20,000 kilograms of sulphur. |

#### 2.1.5.2 Cost reductions from R&D activities

An IEA Bioenergy report published in 2020 highlighted the potential for cost reductions in advanced biofuels. It found that R&D, experience at commercial plants and earlier demonstrations have collectively suggested that, as capital spending and the number of commercial plants increase, overall production costs could fall by 5-27% compared to current levels.

The strengthening of market confidence inherent in that also could lower financing rates and terms, resulting in a further cost reduction of 5-16%.

The current production costs are 65-158 Euro/MWh (17-44 Euro/GJ) from biomass feedstocks and 48-104 Euro/MWh (13-29 Euro/GJ) from waste-based production.

Clearly, quicker progress along the biofuels learning curve could bring the kind of large-scale rollouts of production technology that would lower capital and operating costs. But more research is needed to accurately predict the feedstock costs as demand rises.

### 2.1.6 Conclusions

FAME and HVO are the most mature production pathways, along with first-generation ethanol and biomethane. Their TRL differences are mostly related to the required shift from food and feed crops to other more advanced feedstocks, including woody biomass. Examples include the transition of biomethane from anaerobic digestion to more advanced gasification of woody biomass, and the shift from sugar and starch-based ethanol to cellulosic ethanol.

Although most of the current production capacity remains linked to food and feed crops, overall industry demand has decreased for FAME, HVO and SVO from vegetable oils. Furthermore, the industry's interest is limited for ethanol (at least for maritime shipping) and for HTL biocrude (ICCT, 2020).

Analysis of the CORDIS database for pilot and innovative projects offers many feedstock-oriented research programmes, with a strong focus on lignin-based fuels and biorefinery concepts. This is in line with the relatively low TRL ratings for those concepts.

Due to the limited focus on the production of biofuels, CORDIS has few projects linked to the direct application of biofuels onboard ships. Those type of pilot projects are highlighted by initiatives such as the 'Getting to Zero' coalition, which aims to map zero-emission pilots and demonstration projects.

Most pilot projects are aimed at the technological feasibility rather than large scale cost reductions, which is more likely to be the next step. The technology readiness levels are given in Table 11 below. An estimation of the TRL levels in 2030 can be found in Table 1.

Table 11. Levels of maturity per production pathway (Verbeek, et al., 2020)

| Fuel category | End product | Production pathway | Technology readiness (2019) |
|---|---|---|---|
| Biodiesel | FAME | Transesterification | 10 |
| | HVO | Hydrotreatment | 10 |
| | HVO (from wood) | Wood extractives pulping/ catalytic upgrading | 8/9 |
| | HVO (from algae) | Algae/oil extraction / catalytic upgrading | 4/5 |
| | FT diesel | FT synthesis | 6/8 |
| | DME | Lignocellulosic Gasification | 6/8 |
| Bio-alcohols | Bioethanol | Fermentation | 10 |
| | | Waste based | 8/9 |
| | | Lignocellulosic hydrolysis | 8/9 |
| | Bio-methanol | Waste based | 8/9 |
| | | Black liquor gasification | 6/8 |
| | | Lignocellulosic gasification | 6/8 |
| Biocrudes | SVO | - | 10 |
| | Pyrolysis oil | Lignocellulosic Pyrolysis/ catalysed upgrading | 5/6 |
| | HTL biocrude | Lignocellulosic Hydrothermal liquefaction/ catalytic refining | 2/4 |
| | Solvolysis oil | Lignocellulosic hydrolysis / solvolysis | 4/5 |
| Gaseous biofuels | Liquefied biomethane | Sludge/maize/manure/ residues Fermentation / digestion | 10 |
| | Liquefied biomethane | Lignocellulosic Gasification | 6/8 |

## 2.2 Sustainability

### 2.2.1 Introduction

Since biofuels are often considered in the context of the decarbonisation of shipping, it is important to clearly understand their benefits in terms of potential emission reductions when compared to conventional fossil fuels. For biofuels, the lifecycle footprint – or, in maritime parlance, the WTW perspective - is important. WTW emissions are defined as the greenhouse gas (or other) emissions produced from when the fuel is made to when it is used on the ship, including combustion and exhaust.

WTW emissions are the sum of 'well-to-tank' (upstream) emissions – those produced from the fuel's primary production, storage and transport to the ship's tank -- and 'tank-to-wake', its downstream emissions. The tank-to-wake portion represents the emissions from the ship's fuel tank to the exhaust (IMO, 2021).

In principle, biofuels can be seen as a carbon-neutral solution, because the biogenic $CO_2$ absorbed by the feedstock during their lifetime returns to the atmosphere after combustion. Within WTW-calculations, the absorbed carbon is often counted as negative emissions under the well-to-tank emissions, while the emissions from combustion are equal to comparable fossil fuels. However, well-to-tank emissions may be adversely affected by non-renewable or non-sustainable production practices during feedstock growth and harvesting, such as changes in land-use. At the stack, the only difference in the carbon that is emitted is that biogenic $CO_2$is emitted, rather than fossil $CO_2$.

Biofuel pathways can result in overall negative carbon emissions when more carbon is stored than emitted; for example, when using carbon capture and storage technologies. Although biofuels are in principle carbon-neutral, other steps in the supply chain, such as transport and conversion, can produce additional emissions (van der Kroft, 2020). WTW calculations can differ when allocation methodologies change.

This sustainability section describes the tank-to-wake emissions in 2.2.2, followed by WTW emissions in 2.2.3. The related emission factors are averages. Paragraph 2.2.4 describes fugitive emissions. Consequently, 2.2.5, 2.2.6 and 2.2.7 examine sustainability issues related to biomass cultivation and how feedstock classification and sustainability criteria can help to limit the environmental impact of biofuels. In 2.2.8 and 2.2.9 emissions that pollute the air and or cause other environmental impacts are briefly described.

### 2.2.2 Tank-to-Wake emissions (TTW)

When TTW emissions are produced from biofuels, the amount of $CO_2$ from combustion is determined by the carbon content of the fuel, as well as the combustion engine. The energy density (or heat content) is determined by the carbon and hydrogen content.

As presented in Table 12 (see below), the $CO_2$ emissions during combustion are similar to fossil fuels. Because the carbon of biofuels is biogenic, TTW emissions are often not counted (perceived as zero emissions), at least in inventories based on the guidelines from the UN's Intergovernmental Panel on Climate Change (IPCC, 2006).

Table 12. $CO_2$ mass emitted per quantity of energy by fuel (Data from IEA Bioenergy, 2017 (IEA Bioenergy, 2017))

| Fuel | Carbon Content (%) | Combustion $CO_2$ Emissions (g/MJ) |
|---|---|---|
| HFO | 86 | 69-76 |
| MDO | 86 | 71-74 |
| Diesel | 86 | 72-74 |
| Gasoline | 87 | 67-73 |
| Propane | 82 | 60-65 |
| Natural gas | 75 | 50 |
| Bioethanol (1$^{st}$ Gen) | 52 | 72-81 |
| Bioethanol (2$^{nd}$ Gen) | 52 | 72-81 |
| FAME | 77 | 75 |
| HVO | 77 | 75 |

### 2.2.3 Well-to-Tank (WTT) emissions

WTT emissions include all carbon emissions from the energy and processing required to grow, procure, harvest, gather, process, generate, store, maintain and transport from the feedstock source to the fuel tank. These types of emissions are often overlooked, but they can contribute a significant amount to the fuel's lifetime emissions profile.

WTT emissions are usually most affected by the type of feedstock and the production methods. Feedstock dedicated to oil and energy production, such as algae, soy or palm, may have a more negative impact on the environment than those comprised of waste materials that otherwise would be discarded. These waste feedstocks include, for example, corn stover, forestry wastes, biowaste or used cooking oils.

Direct effects also can contribute to WTT emissions, such as the amount of natural carbon released when wooded areas or food cropland are cleared to make way for energy crops. Changes in land use to generate biofuels can be more harmful to the ecosystem, or emit more carbon, than the fuels save.

For this reason, many policy directives and sustainability standards include provisions for biofuel generation, sources and other fuel production, storage or transportation methods that contribute to WTT emissions. Due to their nature, the emissions profiles of the fuels address the responsibilities of all links in the fuel's supply chain, rather than just those related to quality and combustion properties.

Often, this requires turning the focus away from marine regulations to address the issue as changes in natural-resource management and energy governance.

For hydrotreated fuels, the source of the hydrogen affects the WTT emissions. If hydrogen is produced by steam-reforming methane, as is common, $CO_2$ is released in the process. If hydrogen is produced by electrolysis of water, the emissions depend on the emission factor of the power used. Only when the power has zero GHG emissions does the hydrogen does not add to the WTT emissions.

***GHG performance as sustainability criteria in the Renewable Energy Directive (RED)***

The first version of the Renewable Energy Directive (RED), introduced in 2009, was an important driver for biofuels in transport in the past decade; it was the first directive with binding sustainability criteria.

Although a more detailed description of the RED is presented in 3.3.4, it is important to understand that the directive was the impetus for many discussions on the sustainability of biofuels and how to govern environmental sustainability in ways that ensure decarbonisation.

The Renewable Energy Directive II includes a specific 'RES-T' target for transport to reach at least 14% renewable energy[6] in final energy consumption by 2030.

Biofuels and bioliquids must achieve a minimum reduction of lifecycle GHG emissions compared to the fossil fuels they replace, based on a WTT assessment (all phases of the supply chain except combustion). Table 13 (below) presents the minimum thresholds for GHG savings, as included in the RED II.

The thresholds vary depending on the start dates for each plant's operations. Annex V of the RED II lists the default values for GHG emissions, and the calculation rules for liquid biofuels. Based on technological developments, the European Commission might update those values. Aside from the default values, economic operators could choose to calculate actual values (EU, 2018).

Table 13. WTT Greenhouse gas savings thresholds (EU, 2018)

| Start date for plant operations | Transport biofuels | Transport renewable fuels of non-biological origin | Electricity heating and cooling |
|---|---|---|---|
| Before October 2015 | 50% | - | - |
| After October 2015 | 60% | - | - |
| After January 2021 | 65% | 70% | 70% |
| After January 2026 | 65% | 70% | 80% |

E4Tech, an international consultancy, has provided an overview of the reduction ranges for biofuels' WTT emissions as compared to marine fuels, presented in Figure 23 (below). Both FAME and HVO have a wide range of comparative savings from GHG emission, depending on the feedstock types.

The potential WTT GHG savings from FAME can be as high as 88% when waste oils and fats are used as feedstock, whereas FAME produced from primary vegetable oils would struggle to meet the threshold for GHG-emissions saving set by the RED (it sets a limit of 60% as the benchmark).

[6] In the RED, 'renewable energy' is defined as energy from renewable non-fossil sources. Examples mentioned in the Directive are wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas.

HVO produced from waste oils or fats also has a comparative reduction potential of 88%. But the typical savings of GHG emissions declines to 40-68% when HVO from vegetable oils is compared.

For conventional ethanol, the potential WTT GHG reduction is set at 32%-71%, with 32% representing the minimum level for wheat ethanol and 71% representing sugarcane ethanol. Cellulosic ethanol can result in emission reductions of about 75-90%.

Bio-methanol (90-95%), bioDME (92%-94%) and FT-Diesel (93%-95%) from woody biomass all have very high typical GHG emission savings. GHG savings above 100% are possible with carbon capture and sequestration or replacement.

The WTT GHG emissions savings from using crude pyrolysis oil and upgraded pyrolysis oil are similar to those of FT-Diesel (i.e., very high) when the upgrade takes place on-site at the fast pyrolysis unit and uses biomass for internal energy consumption. There is also some potential for the capture of $CO_2$ to improve GHG savings. If the upgrade takes place in a conventional refinery, the GHG-reduction potential is lower when fossil-produced hydrogen is used in the process.

Biomethane produced from organic waste or dry manure in anaerobic digestion offers GHG reductions of 71-82%, but this depends on the electricity source for liquefaction, and any fugitive emissions (see 2.2.4, below). When carbon capture and sequestration is applied, the GHG savings eclipse 100%, because the $CO_2$ is separate from the biomethane (E4Tech, 2018).

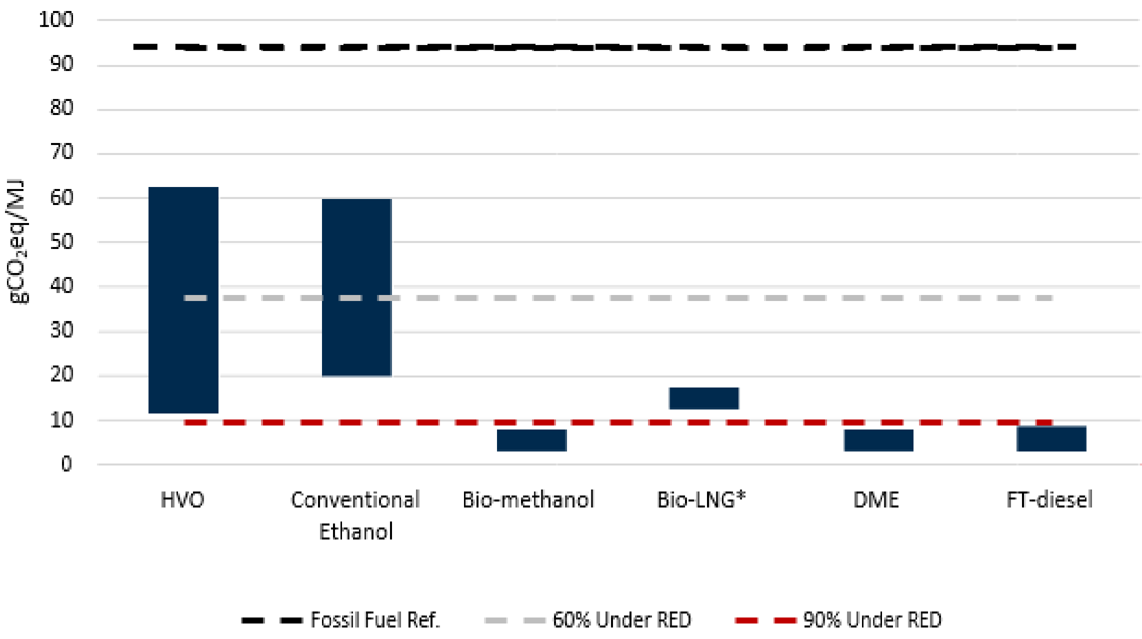


Figure 23. WTT GHG emission factors for marine fuels and selected biofuels adapted from (E4Tech, 2018) using RED I (marked with *) and RED II typical values (EC, 2018; EC, 2009)

### 2.2.4 Fugitive emissions

Fugitive emissions can occur during production, transport or onboard. The fugitive emissions from production and transport are included in the WTT emissions (see section 2.2.3). The fugitive emissions onboard are caused by the amount of fuel that does not reach the combustion chamber, or that is not consumed by the energy converter. Those emissions are vented, leaked or not combusted along the supply chain (EC, 2021).

Fugitive emissions of LNG-fuelled vessels comprise methane, which has a higher global warming potential than $CO_2$ and could offset the emission reductions from using biogas (ICCT, 2020). The level of onboard fugitive emissions from the exhausts created by internal combustion engines, so called 'methane slip', is highly dependent on the type of engine and combustion concept. Other potential sources of methane emission and venting also exist from operations, such as methane gas being present in the crankcase gases of 'Otto' combustion engines, fuel system blowdowns from fuel changeovers or safety trips, venting to manage the accumulation of pressure in LNG tanks, etc. Engine solutions exist to reduce the amounts of slip, but this is an area that requires further investigation, regulation, control measures and technology development.

### 2.2.5 Changes in indirect land use

WTT emission factors for biofuels include the GHG emissions associated with changes in cultivation and direct land use, but do not account for emissions caused by changes in indirect land use.

The cultivation of crops for biofuel production often takes place on cropland that was previously to grow food or feed. The demand for food or feed has not fallen, which implies that land might be converted elsewhere to allow agricultural production to continue.

Land conversion, which could include areas with high carbon stock -- such as forests, wetlands and peatlands -- has the potential to add GHG emissions. This effect is referred to as indirect land use change (ILUC), and ILUC emissions could undo any of the GHG savings depicted in Table 13 (above).

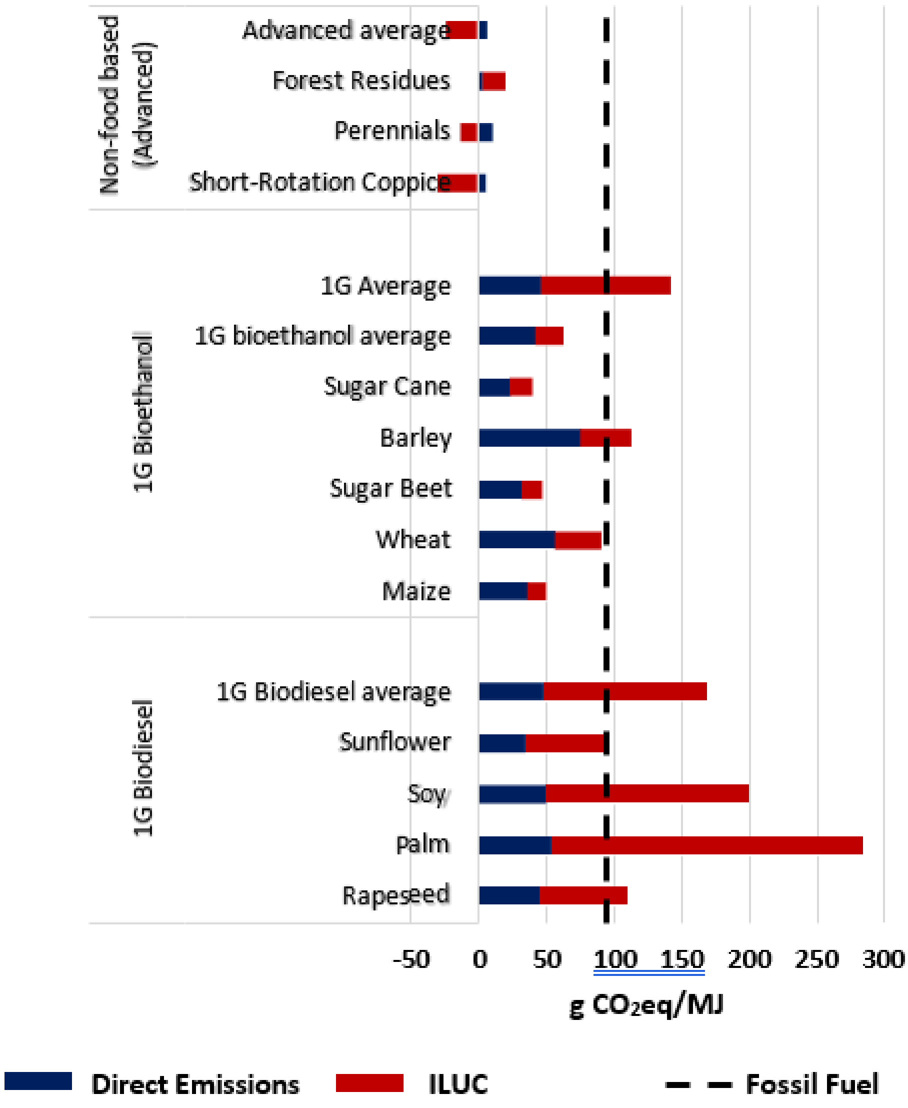


Figure 24. Biofuels emissions from different feedstocks (Transport & Environment, 2016).

The GLOBIOM study for the European Commission indicated that the GHG performance of biodiesel from palm oil is three times worse than regular diesel. High ILUC emissions mostly occur from biodiesel production.

The ILUC emissions from bioethanol produced from food and feed crops are less substantial and often result in a reduction. Because the feedstocks for non-food-based advanced biofuels are produced from waste and residues and not crops on agricultural land, their ILUC emissions are low.

There is no broad scientific consensus on the exact volumes of additional emissions caused by ILUC, nor how to incorporate those emissions into policy. Therefore, EU policymakers have chosen to introduce a system based on caps and sub-targets for the different feedstock groups. The RED II sets limits on high ILUC-risk biofuels, bioliquids and biomass fuels, which can be counted towards the national renewable energy targets of member states.

The limits were frozen at 2019 levels for 2021-2023. After 2023, high-risk ILUC biofuels should gradually decrease to zero by 2030. Some member states already have decided to phase out high-risk ILUC biofuels from 2020. The European Commission has classified palm oil as high-risk ILUC biofuel. Biodiesel from soy is two times worse than reference fossil fuel (VLSFO) due to ILUC but has not been classified as a high-risk ILUC biofuel, which various NGOs regret (Transport & Environment, 2016). The RED II also contains an exemption for biofuels certified as low-risks from ILUC (EU, 2018).

Although the RED II probably will have a small direct impact on biofuels in maritime shipping, other policy initiatives continue to build on its sustainability framework.

### 2.2.6 Feedstock classification

To assess the negative environmental impact from ILUC emissions, the RED classifies feedstocks in groups. Other industry stakeholders use similar differentiators to group biofuels based on their sustainability. The RED limits the use of biofuels from food and feed crops. While Annex IX Part A and Part B of the directive presents waste and residues as a feedstock with potential to produce advanced biofuels.

Part A contains many feedstocks, with a strong focus on lignocellulosic biomass sources and waste fractions. Part B covers waste fats and oils – which are also waste streams, but with limited availability. From a sustainability perspective, the European Commission through the RED hopes to move away from food and feed crops towards advanced biofuels in Annex IX Part A. Consequently, and following a general sustainability debate, it would be preferable if the growth of biofuels for maritime shipping came from those feedstocks.

Table 14. Sources of advanced biofuels, Part A and Part B of Annex IX in RED II (Flach, et al., 2021)

| Part A | Part B |
|---|---|
| • *Algae if cultivated on land in ponds or photobioreactors*<br>• *Biomass fraction of mixed municipal waste*<br>• *Biowaste from private households subject to separate collection*<br>• *Biomass fraction of industrial waste not fit for use in the food or feed chain*<br>• *Straw*<br>• *Animal manure and sewage sludge*<br>• *Palm oil mill effluent and empty palm fruit bunches*<br>• *Crude glycerin*<br>• *Bagasse*<br>• *Grape marcs and wine lees*<br>• *Nut shells*<br>• *Husks*<br>• *Cobs of corn cleaned of kernels*<br>• *Biomass fraction of wastes and residues from forestry and forest-based industries*<br>• *Other non-food cellulosic material*<br>• *Other lignocellulosic material except saw logs and veneer logs* | • *Used cooking oil*<br>• *Some categories of animal fats* |

### 2.2.7 Sustainability criteria (in the RED, excluding GHG performance)

The RED II (2018/2001) (EC, 2018) applies some of the same sustainability criteria for biofuels and bioliquids as those suggested to meet the 2030 targets in the original RED. However, some of the criteria have been reformulated, or are new. The biggest proposed differences from the RED are the new criteria introduced for forestry feedstocks, and the GHG criteria for solid and gaseous biomass fuels.

Also, the proposal for the RED II further strengthens the sustainability criteria for forest biomass to ensure its use is in line with the EU's biodiversity objectives (E4Tech, 2018) (EC, 2021) (EC, 2021a).

Besides the minimum thresholds for GHG emissions, the sustainability criteria cover other potential environmental impacts from Article 29, including on biodiversity, carbon stock, peatland, as well as impacts on forest conservation and management.

**Biodiversity**

According to the RED, biofuels, bioliquids and biomass fuels produced from agricultural land should not be produced on:

- Primary forest and other wooded land
- Highly biodiverse forest and other wooded land
- Areas designated to protect nature, or the specific ecosystems or species recognised by international agreements
- Highly biodiverse grassland

**Carbon stock and peatland**

According to the RED, biofuels, bioliquids and biomass fuels from agricultural land should not be produced on wetlands, continuously forested areas and land spanning more than one hectare with trees higher than five metres and a canopy cover of 10 % to 30 %, or trees able to reach those thresholds in situ.

Nor should biofuels be produced from agricultural biomass derived from raw materials obtained from land that was peatland in January 2008.

**Forestry biomass**

Due to concerns on the sustainability of woody biomass, requirements have been added to limit the use of forest biomass derived from non-sustainable production. Laws should be in place in the countries of harvest that ensure the legality of harvesting operations, forest regeneration in harvested areas, maintenance of soil quality and biodiversity risks. There are similar requirements for management systems and land use, land use change and forestry criteria to be met as well.

The directive has more specific requirements and exceptions to those provisions. According to a study by Joint Research Centre (JRC, 2021) about energy production in the EU, the forest-based sector is part of the solution for many global challenges and that woody biomass should be a key contributor to the EU's objectives. The EU also sets policies to protect the sector and guide management of the forests and their related ecosystems. This complicates assessments of the trade-offs between climate mitigation and biodiversity conservation.

It is often mentioned that biomass should be sustainable. In the discussion on sustainability, EU member states support the principle of multifunctional forests and the concepts of sustainable forest management (to maintain and balance of these multiple functions over time). However, this support strongly depends on the context. In some areas of the continent, the focus is on the conservation of nature, while wood production is more important in other areas.

JRC notes the increasing demand for woody biomass, but also reveals considerable inconsistencies in reported data: the amount of woody biomass used for wood-based products and energy production (in the period 2009-2015) exceeded the amount reported by more than 20% (including large differences among member states). This gap can be attributed to the energy sector, according to the study.

Often the origin of woody biomass is reported as ‘unknown’. This is especially so when consumption appears to exceed to supply.

Reliable data on the origin of the wood used for energy production, including biofuel production, is crucial to safeguarding sustainability. Although biofuel pathways from woody biomass residues are promising options to decarbonise shipping, these types of challenges need to be addressed to ensure biofuels become truly sustainable (JRC, 2021).

### 2.2.8 Air pollution

In addition to carbon accounting and $CO_2$ emissions, other air emissions are impacted by using biofuels. The International Council on Clean Transportation (ICCT) offers a detailed review of the downstream air pollution emissions from conventional marine fuels and five biofuels. The minimum and maximum emission reductions for sulphur oxides (SOx), nitrous oxides (NOx) and particulate matter (PM) are presented in Table 15 (below).

Table 15. Emission performance of Biofuels, compared to fuel oil as baseline (ICCT, 2020)

| Fuel Type | SOx | NOx | | PM | |
|---|---|---|---|---|---|
| | Decrease | Decrease | Increase | Decrease | Increase |
| FAME | 89-100% | 29% | 13% | 38-90% | |
| HVO | 100% | 0% - 20% | | 38% | 30% |
| FT diesel | 100% | 0% - 20% | | 24% | 18% |
| Bio-methanol | 100% | 30% - 82% | | 61% - 100% | |
| DME | 100% | | 20% - 26% | 23% - 58% | |

Aside from the potential to reduce GHGs compared to conventional marine fuels, all biofuels also can reduce emissions from downstream air pollution. Biofuels are often used in blends. The table above indicates that a 100% reduction of emissions is possible compared to conventional marine fuels but, generally, the blends’ potential to reduce emissions is proportional to the blend rate.

Reductions in air pollutants are mainly the result of lower sulphur contents; consequently, they usually materialise in the forms of reduced SOx and PM emissions. Because combustion conditions have improved, some biofuels also offer lower nitrogen oxide (NOx) emissions, although this is not applicable to all biofuels. The extent to which such reductions may occur depends on the type of biofuel (feedstock), engine design, combustion process and operating conditions. For these reasons exhaust gas emissions from the combustion of these fuels in internal combustion engines are currently evaluated on a case-by-case basis by engine designers.

Using 100% FAME offers more than a 90% reduction in SOx; PM reductions are 38% to 90%. However, NOx emissions vary from the combustion of FAME biodiesel: reductions up to 29% are possible, but an increase of more than 10% is also possible. More details are provided in Section 4.3 (HAZIDS) where FAME and HVO are compared.

HVO and FT diesel are sulphur-free biofuels, resulting in zero SOx emissions when applied ‘neat’ as a fuel. Using HVO and FT diesel in blends or as neat fuels, can reduce NOx emissions by as much as 20%, depending on engine load and speed. PM can be reduced by as much as 38%, compared to conventional marine fuels, although there have also been reports where exhaust measurements recorded increases in PM up to 30% compared to low sulphur marine fuels (Table 15).

DME and methanol (including their bio-based alternatives) are also sulphur-free fuels, resulting in zero SOx emissions. Emission testing of marine engines burning DME has been limited, but PM reductions almost 60% are possible. NOx emissions can increase at lower engine loads, but significant reductions are possible at higher loads and higher DME blend fractions. Methanol can reduce PM emissions 60% to 100%.

Using LNG generally reduces NOx, PM and (for ships) SOx more than 75%. Biomethane delivers the same advantages (Verbeek & Verbeek, 2015).

The non-GHG emission-reduction potential of biofuels are substantial, according to the E4Tech report (2018), but further testing and research is desirable to establish a more solid comparison basis, especially with regard to the comparative impact of specific uses, such as blend levels (E4Tech, 2018).

### 2.2.9 Other environmental impacts

Biofuels are generally biodegradable. When leaked, they do not cause as much as concern as fossil fuels. Therefore, using pure biofuels in shipping could reduce health, safety and environmental costs (Ecofys, 2012).

We are grateful to the authors of the U. S. DOE report Spill Behavior, Detection, and Mitigation for Emerging Non-traditional Marine Fuels for their comprehensive overview on the subject of spill response to alternative fuels,covering HVO, FAME, SVO, Pyrolysis oil, DME, ethanol, methanol, HFO blends and more. This section contains a summary of the main findings in that report, courtesy of Oak Ridge National Laboratory, U.S. Dept. of Energy (Kass, Sluder, & Kaul, 2021).

HVO can be made from a variety of feedstocks and does not contain any of the aromatic structures found in petroleum, which likely means that it will be less toxic than distillates. The spill profile is expected to be similar to diesel, based on viscosity. However, since it is colourless, HVO will form a clear oily slick on the water surface. There are few studies on toxicity to marine organisms, but it is likely to be more susceptible to biodegradation than petroleum-derived distillates, but less than FAME.

FAME and SVO are both highly biodegradable (approximately four times faster than diesel fuels) and have low toxicity. They will form a surface slick when released, although since SVO has a higher viscosity, it will form a much thicker slick that will not spread as much as HVO.

SVO can solidify at temperatures below 15°C, resulting in a solid floating mass when released into the sea. FAME may cause aquatic birdlife and mammals to lose water repellency of their feathers or coats on contact, reducing the insulating properties and increasing risk of exposure. It has much lower toxicity than diesel – the examples cited (from von Wedel 1999) indicate that the concentration to kill 50% of the fish population in a pond (based on a release of FAME into surface water) was 578 ppm versus 27 ppm for diesel fuel, and 122 ppm versus 2.9ppm for shrimp.

Pyrolysis oils tend to have a higher density than water and so will be suspended in the water column either as slick or dispersion which will polymerise over time, increasing in density, and eventually sink. Pyrolysis oils are complex mixtures, so some components will biodegrade rapidly, while others (such as the main lignin fraction) will remain in the environment for longer than HVO.

Pyrolysis oils consist of a number of highly toxic substances that cause harm to aquatic life and are considered to be very toxic to aquatic life with long-lasting effects. The oils readily adhere to surfaces on contact and can be expected to coat any marine organisms that it touches.

Since DME is gaseous at temperatures above -24°C, it will likely form a white vapour cloud above the water surface (as it is heavier than air). The suffocation of marine life is possible at the surface near the point of release. However, fire and explosions are the key risk at the point of release; DME also dissipates rapidly and would be diffused before spill any response is able to begin.

HFO blends will tend to take on the heavy slick spill profile of HFO, especially for blend levels up to 30% of the alternative fuel. However, DME and FAME blends may cause the mixture to float instead of sink. The added fuel will not significantly impact the degradation rate or toxicity of HFO.

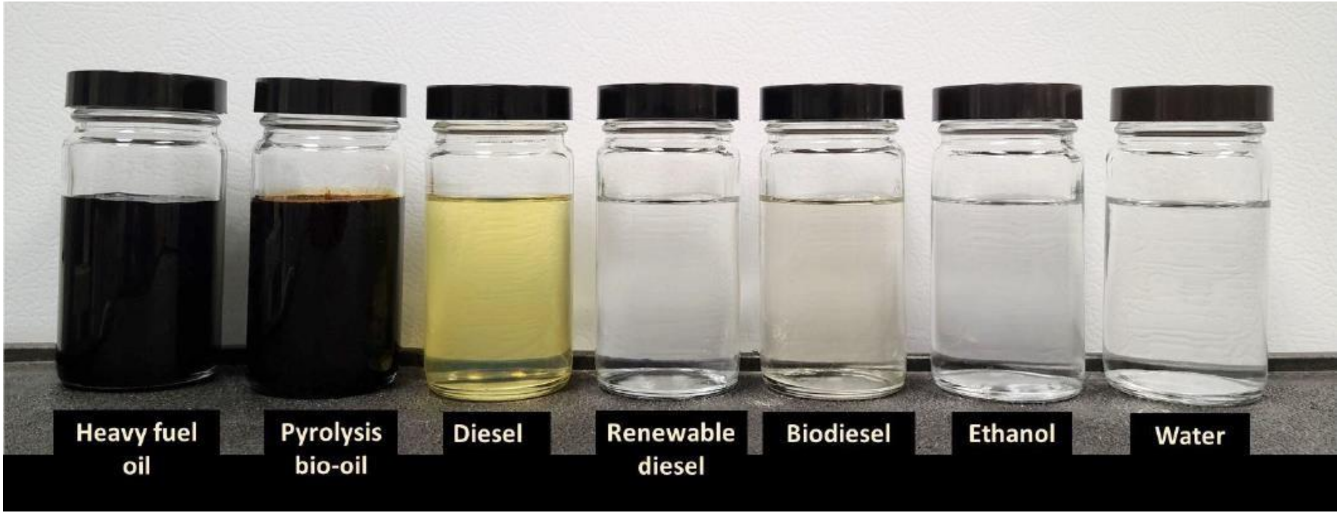


Figure 25. Photograph of selected alternative liquid marine fuels compared to water, courtesy of Oak Ridge National Laboratory (Kass, Sluder, & Kaul, 2021).

The photograph above shows the difference in appearance between alternative fuels. Note that renewable diesel is HVO, while biodiesel is FAME.

Table 16. Summary of spill characteristics of large, sudden releases of each alternative fuel, courtesy of Oak Ridge National Laboratory (Kass, et al., 2021)

| Fuel type | Behaviour when spilled | Degradation rate | Ecological impact | Flammable/ explosion risk | Toxicity | Air displacement and suffocation risk to crew | Spill cleanup | Detection probability with current practice |
|---|---|---|---|---|---|---|---|---|
| **HVO** | Will behave as a diesel spill and rapidly spread out as a clear oily film | Moderate: Expected to take up to a week or more | No long-erm impacts are expected. Aquatic life may become coated | Low | Low | None | Boom containment is most optimal | Moderate |
| **FAME** | Will form a slick on the water surface | Moderate: Can take up to a week or more | Aquatic life may become coated | Low | Low | None | Boom containment is most optimal | High |
| **SVO** | Will form a slick on the water surface | Moderate: Can take up to a week or more | Aquatic life may become coated | Low | Low | None | Boom containment is most optimal | High |
| **Pyrolysis** | Will be suspended in the water column and eventually sink | Slow | Aquatic life may become coated and poisoned | Low | High | None | | Moderate |
| **DME** | Will form a vapour cloud on the water surface | Fast, unless contained | No long-term impacts, but marine life at the water surface in the spill zone may suffocate | High | Low | Possible | Will dissipate before cleanup can begin | Low |

**Spill Response**

DME absorbs infrared radiation (IR) light, however, since commercial use of DME is not extensive, few if any commercial detectors exist. In any case, DME will have dissipated before any spill response arrives.

HVO and FAME will require similar spill-response measures. These fuels will form a slick on the sea surface, with wave action causing emulsification with sea water over time. Therefore, traditional spill response (such as the use of booms to prevent spread) and cleanup processes for petroleum spills are likely to be very effective in mitigating spills of vegetable oils and biodiesel.

Both HVO and FAME have a lower environmental toxicity, so in situ cleanup methods may be preferred, while in situ burning may not be successful, due to the low volatility of the fuels. Again, both HVO and FAME degrade more quickly than diesel.

Pyrolysis oils contain a complex mixture of substances, the soluble portions of which may not be recovered; the buoyant components may be contained with booms until emulsification with sea water causes portions of the spill to sink. In situ methods for mitigating the spill may be partially effective but are not likely to completely remove the spill from the environment.

### 2.2.10 Conclusions

Biofuels can significantly reduce WTW GHG emissions, due to the biogenic nature of the carbons. Advanced biofuels from woody biomass can reduce emissions by more than 90%; when used in combination with carbon capture storage and sequestration more than 100% is possible. Biofuels from food and feed crops have less potential to reduce emissions; they can even increase emissions in ILUC cases.

Biofuels derived from food and feed crops or from woody biomass also can negatively impact the environment - for example, biodiversity and carbon stocks - when they do not meet specific criteria for sustainability.

As result of ILUC discussions, authorities are trying to shift from food and feed crop-derived biofuels to advanced biofuels from waste and residues, primarily woody biomass. Woody biomass is, however, not automatically sustainable.

There has been large-scale demand for woody biomass from all sectors since the emergence of the ‘bio-economy’, putting the kind of pressure on forest-management practices that could result in poor conservation, and biodiversity concerns. Monitoring and quality of statistics needs to improve significantly to ensure that biomass residues extracted from forests do not result in a wider negative environmental impact and deforestation (including any reduced carbons sequestered in the oil).

Overall, current discussions on sustainable biofuels tend to favour woody biomass and other waste and residues, but there are many unresolved issues, on which scientists and policymakers do not agree.

From an air-quality perspective, most biofuels are sulphur free, or they significantly reduce sulphur emissions. FAME and bio-DME either can reduce or increase NOx-emissions, depending on engine loads. Other biofuels can result in modest reductions in NOx-emissions, or up to 82% in the case of bio-methanol.

For PM emissions, some biofuels offer modest increases (depending on the engine setting), but most significantly reduce them. Because air-polluting emissions strongly depend on engine loads, there is no clear ranking for biofuels.

Table 17. Sustainability assessment of WTT GHG reduction potential (EU, 2018)

| Fuel | Production pathway | Feedstock | GHG reduction potential |
|---|---|---|---|
| FAME | transesterification | FOGs | + |
| FAME | transesterification | vegetable oils | -- |
| HVO | hydrotreating | FOGs | + |
| HVO | hydrotreating | vegetable oils | -- |
| FT diesel | gasification + FT synthesis | lignocellulosic biomass | ++ |
| DME | gasification + fuel synthesis | lignocellulosic biomass | ++ |
| Bio-methanol | gasification then fuel synthesis | lignocellulosic biomass | ++ |
| Biomethane | digestion | waste and residues | 0 |
| Biomethane | gasification | lignocellulosic biomass | + |

Table 17 presents the GHG-reduction potential (scored on a five-point scale (--, -, 0, +, ++) of the most promising biofuels, according to their TRL and industry interest. Based on this scoring methodology, biofuels from vegetable oils could be excluded because they can add emissions. Biofuels from FOGs and biomethane from waste and residues offer only modest reductions in emissions compared to the woody biomass production pathways.

In addition, it is also possible the industry will see a growth in fraudulent practices around establishing the sustainability of some sources of biomass. If this becomes widespread, it could lead to a lower cost for biofuels, but it also would have huge consequences for biodiversity as most of world's biomass is potentially available from countries where controls are seen as less stringent.

One example of how residue production may "increase" due to market conditions. For example, if wood residues from a furniture manufacturer meet the sustainability requirements, the business owner may receive approval to supply it for fuel production. In difficult times and if prices are high for wood residues, it will become more tempting for the manufacturer to simply increase the volume of wood residues, by whatever means. To tackle this kind of potential for fraud, it will require strict controls on feedstock. Blockchain technology is seen as a possible way to discover these types of frauds.

## 2.3 Availability

### 2.3.1 Introduction

The sustainability of biofuels is often discussed together with the availability of sustainable feedstocks. When demand for those feedstocks exceeds the volumes that can be sustainably supplied, non-sustainable practices arise, causing negative environmental impacts such as deforestation and decreased biodiversity. Analysis of availability issues is important because many industrial sectors are looking at using biomass to reach climate-change objectives and a circular and bio-based economy. Demand from other sectors depends on their alternatives for using biomass, including alternatives that may yet have to be developed, and their willingness to pay. Several observers expect the competition for biomass to increase after 2030, which will drive up the price of biomass and make biofuels uncompetitive for shipping, especially when e-fuels become available (Hendriksen, et al., 2021).

All these issues also make it difficult to reach firm conclusions on biomass or biofuel availability for a specific sector: while estimates of the amount of biomass the earth can produce may have an acceptable range of uncertainty, taking into account sustainability criteria increases the uncertainty considerably, and an analysis of the demand functions of all sectors is almost impossible.

The future energy demands of maritime shipping, especially when compared to road transport, raises concerns about availability of feedstocks, especially since policy discussions on availability also call for the use of biomass in sectors which have fewer options to decarbonise.

The analysis is in part drawn from studies on biomass availability for the EU's chemical industry (CE Delft, forthcoming). It focusses on sustainable potential in terms of the primary energy of the biomass (energy losses during conversion are not accounted for).

### 2.3.2 European availability

The Joint Research Centre (JRC) recently developed 'ENSPRESO' dataset on biomass availability for the purpose of energy modelling (JRC, 2020; Ruiz, et al., 2019). To develop this dataset, the JRC estimated the potential availability of sustainable biomass for a range of feedstock categories, years, and scenarios.

For the purposes of this report, this dataset offered the most recent and complete overview of the potential for sustainable biomass in Europe. In Table 18 (below), the sustainable biomass potential for the 'low' and 'high' JRC scenarios are offered for the target years of 2030 and 2050.

The scenarios use different sets of assumptions relating to the strictness of the applied sustainability criteria and the productivity of agriculture and forestry. The key parameters vary between scenarios include:

- Available land for the growth and productivity cultivation of energy crops (including yield increase) and harvesting techniques
- The share of agricultural residues available for energy and feedstock, which depends on competition from alternative uses and collection ratios
- Competing use for stemwood and residues from the forestry, wood, pulp and paper industries
- Collection ratios and competing uses for biomass waste streams.

(Note: the JRC data did not include used cooking oil and algae. These biomass feedstocks will be discussed in 2.3.5 and 0, respectively.)

The JRC's 'low scenario' applies the strictest sustainability criteria, and it is also most conservative regarding increases in productivity rates. Moreover, the scenario assumes that fewer policy-stimulation measures are in place, leading to lower levels of mobilisation of domestic biomass supplies.

Table 18. Sustainable biomass potential (EJ) in the EU (JRC, 2020)

| Biomass feedstock category | 2030 | | 2050 | |
|---|---|---|---|---|
| | Low | High | Low | High |
| Sugar crops | 0.8 | 0.8 | 0.9 | 1.0 |
| Starch crops | 0.3 | 0.3 | 0.3 | 0.3 |
| Oil crops | 0.1 | 0.2 | 0.2 | 0.2 |
| Lignocellulosic crops | 1.4 | 3.0 | 1.3 | 3.0 |
| Agricultural residues | 0.7 | 2.0 | 0.6 | 2.0 |
| Manure | 0.5 | 1.6 | 0.6 | 1.6 |
| Municipal solid waste | 0.4 | 0.6 | 0.4 | 0.8 |
| Sewage sludge | 0.02 | 0.04 | 0.03 | 0.06 |
| Roundwood | 2.0 | 2.4 | 2.2 | 3.0 |
| Primary forestry residues | 0.9 | 5.6 | 0.5 | 5.7 |
| Secondary forestry residues | 0.2 | 1.1 | 0.1 | 1.0 |
| Landscape care wood | 0.1 | 0.6 | 0.1 | 0.6 |
| **Total** | **7.3** | **18** | **7.0** | **19** |

Note: the energy demand from shipping in 2018 was approximately 14 EJ (Faber, et al., 2020)

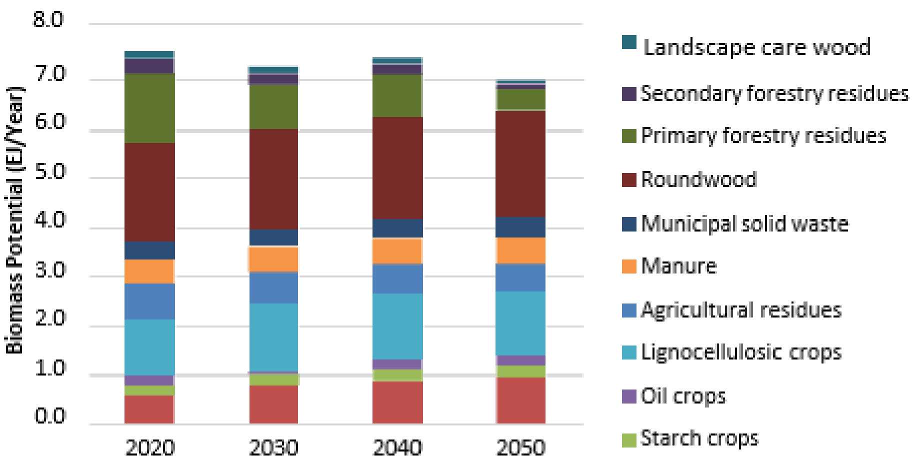


Figure 26. JRC's 'low' scenario for sustainable biomass potential in the EU (EJ/year) (JRC, 2020)

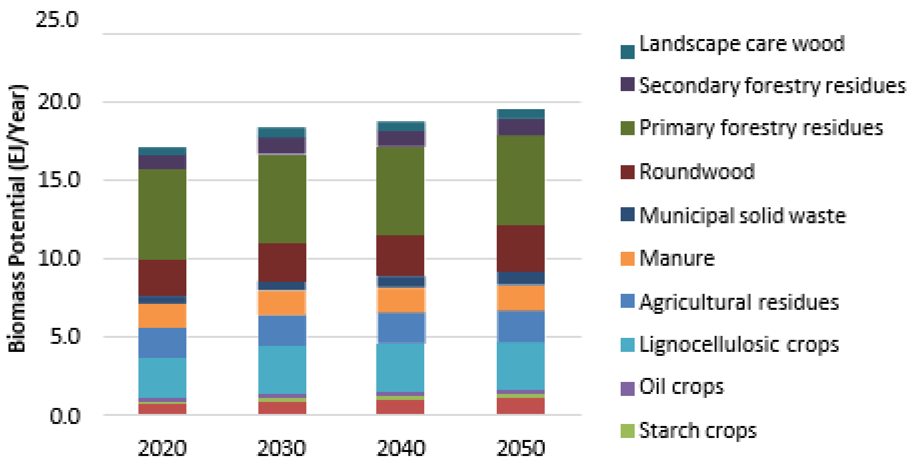


Figure 27. JRC's 'high' scenario for sustainable biomass potential in the EU (EJ/year) (JRC, 2020)

An examination of the above estimations for the EU's biomass potential reveals that:

- Biomass streams from agriculture and forestry have similar contributions to the total sustainable biomass potential in Europe.
- The potential in the high scenario is 2.5 to 2.8 times higher than in the low scenario.
- The range in biomass availability is mainly due to varying estimates for primary forestry residues in the scenarios, followed by lignocellulosic crops, agricultural residues and manure.

The European Commissions Impact Assessment for the 2030 Climate Target Plan (EC, 2020) estimates that the range of sustainable biomass that is available and consumed in the EU is 6.3 to 8 EJ by 2030, and 6.7 to 14.7 EJ in 2050. These ranges are in line with the results this report. There is, however, a higher upper boundary of 18 to 19 EJ/year, which may be explained by an EC analysis that estimates 'actual' biomass production and use in Europe, instead of the available potential.

### 2.3.3 Worldwide availability

The Bio-Scope study (CE Delft & RH DHV, 2020) offers extensive analysis of the global biomass volumes that could become available for energy and industry feedstock. The main results from the study are shown in Figure 28, below.

These results show the estimated sustainable potential from agriculture in 2050 to be similar to the maximum potential in 2030.

The availability of energy crops (production stream) is expected to reduce between 2030 and 2050, but the estimated increase of the potential from primary agricultural residues is much higher. This could materialise if more food crops are grown (leaving less land to produce energy crops) and better agricultural practices concurrently improve land productivity, causing a large increase in primary residues from crops.

Although more efficient farming and the use of degraded lands for the cultivation of high-yield lignocellulosic crops could increase the sustainable-biomass potential for energy and feedstock, a growing world population and the potential for less arable land due to soil depletion, desertification and flooding may counteract any benefits.

The estimated sustainable potential from forestry in 2050 is in the same range as estimates for 2030, indicating that the availability of sustainable biomass from forests may not increase during that period.

In many climate-modelling scenarios from the IPCC and other institutes, afforestation and forest conservation are important measures to mitigate global warming, limiting the availability of forest resources for economies. These measures are also important to protect ecosystems. Therefore, it is conceivable that the sustainable potential of biomass from forestry will stabilise between 2030 and 2050, despite any improvements in forestry management.

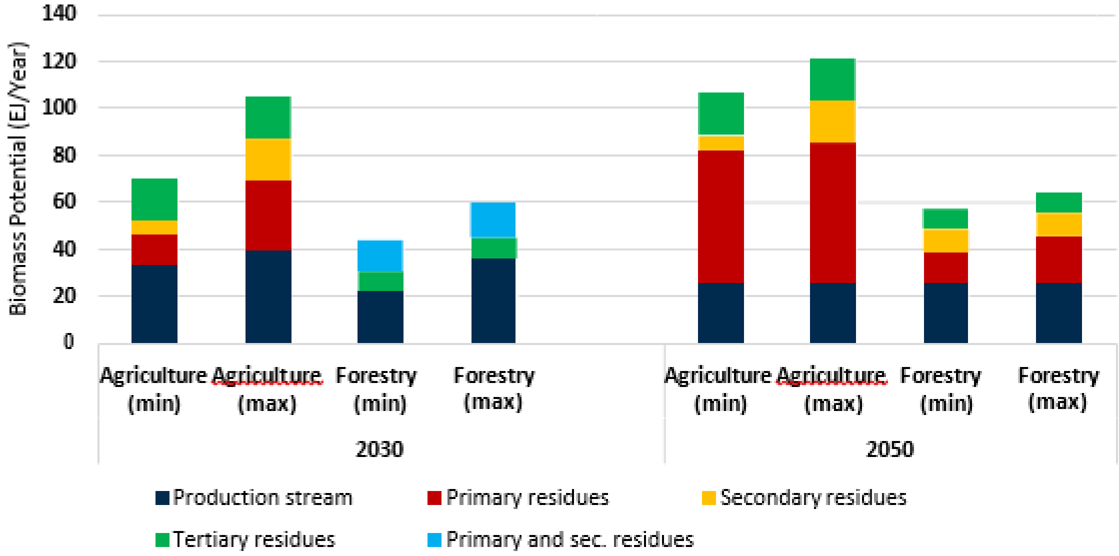


Figure 28. Sustainable biomass potential worldwide (CE Delft & RH DHV, 2020)

The data in Table 19 (below) indicate sustainable biomass in the world outside the EU. This analysis was derived by taking the following steps:

- The main input data was taken from the Bio-Scope study presented above (see Figure 28).
- We subtracted the Bio-Scope estimations of the EU potential from the estimations of the global biomass potential from the same study to create an estimation of the potential for the rest of the world.
- The biomass categories used in Bio-Scope were reclassified to match the list of categories used in the ENSPRESO data (JRC, 2020), and the data adapted accordingly. This process involved the following:
- The agricultural-production stream from Bio-Scope was divided into sugar crops, starch crops and oil crops using the shares of these biomass types that were given in the ENSPRESO data for the EU.
- The potential for lignocellulosic crops was not included in the Bio-Scope data and needed to be added. For 2050, a potential of 3.6-57 EJ was included, based on an estimation of 'global tradable resources' in (CCC, 2018). It is assumed that 25% of this potential will be reached in 2030.
- Specific estimates of municipal solid waste, sewage sludge, manure and landscape care wood were not included in the Bio-Scope data. We assume that these biomass resources would not be available for global trade.
- The Bio-Scope estimation of tertiary residues from forestry were added to the secondary forestry residues category.

Table 19. Sustainable biomass potential (in EJ) in the rest of the world (CE Delft & RH DHV, 2020)

| Source | 2030 | | 2050 | |
|---|---|---|---|---|
| | Low | High | Low | High |
| Sugar crops | 22 | 20 | 15 | 15 |
| Starch crops | 7 | 7 | 4 | 4 |
| Oil crops | 1 | 5 | 3 | 3 |
| Lignocellulosic crops | 1 | 14 | 4 | 57 |
| Agricultural residues | 17 | 43 | 60 | 75 |
| Manure | 0 | 0 | 0 | 0 |
| Municipal solid waste | 0 | 0 | 0 | 0 |
| Sewage sludge | 0 | 0 | 0 | 0 |
| Roundwood | 18 | 30 | 17 | 17 |
| Primary forestry residues | 5 | 5 | 12 | 19 |

| | | | | |
|---|---|---|---|---|
| Secondary forestry residues | 12 | 11 | 16 | 17 |
| Landscape care wood | 0 | 0 | 0 | 0 |
| **Total** | **83** | **134** | **131** | **207** |

As a working assumption, the Sustainable Shipping Initiative arrived at a worldwide sustainable biomass availability in 2050 of 50 to 100 EJ per year to assess the potential availability of biofuels for maritime shipping (SSI, 2019). However, this assumption was the result of a stakeholder roundtable discussion, where only a broad consensus could be reached, whereas projections from the IEA show a range of 130 to 240 EJ per year and a recent report by the Energy Transition Commission estimated the global sustainable availability for energy uses to be 30 – 50 EJ, which could be increased to 120 EJ at most if the world turned to a plant-protein based diet (Energy Transitions Commission, 2021). The IEA projection is in line with the results of the Bio-Scope study shown above (which examined a much larger body of biomass availability literature).

### 2.3.4 Availability for Europe

Not all the biomass available in the rest of the world will be available for export to Europe: a part will be used in the countries of origin and another part will be to other regions. In the European ADVANCEFUEL study, (Hoefnagels & Germer, 2018) the export potential to the EU of solid biomass and biofuels was examined. It provided the data to estimate the EU's import potential in 2030 and 2050; see the first row in Table 20, below. When the sustainable biomass potential in the rest of the world (estimated in the previous section) is compared with the EU import potential, a maximum EU import share of 2% emerges.

Table 20. Estimated EU share of global biomass imports (Hoefnagels & Germer, 2018)

| | 2030 | | 2050 | |
|---|---|---|---|---|
| | Min | Max | Min | Max |
| EU import potential, based on ADVANCEFUEL study (EJ) | 0.55 | 2.74 | 0.72 | 3.87 |
| Biomass potential in rest of the world (see previous section) (EJ) | 83 | 134 | 131 | 207 |
| EU import share based on ADVANCEFUEL | 0.7% | 2.0% | 0.6% | 1.9% |

According to that ADVANCEFUEL study, an EU import share of 1% to 2% is not unexpectedly low. Sourcing countries can be expected to first fulfil their own biomass demand in a competitive market. Moreover, the capacity to mobilise and process biomass resources in sourcing countries is an important limiting factor for export. Nevertheless, these import shares may be somewhat conservative for two reasons: The studies/scenarios collected by (Hoefnagels & Germer, 2018) examine a limited number of countries and they do not consider all of the biomass streams from the Bio-Scope study. After these considerations, it is estimated that the EU's share of imports could increase to 3% of the global potential outside the EU.

To estimate the availability of sustainable biomass for the EU, we have applied the 3% value of the continent's import share to the estimated biomass potential in the rest of the world from Section 2.3.3, and added it to the EU's sustainable biomass estimate from Section 2.3.2. This leads to the outcomes shown in Figure 29 and Table 21.

This process indicates:

- Most of the available sustainable biomass will come from the EU itself. The share of sustainable biomass that could come from outside the EU is limited to 25-36% of the total availability in the low scenario, and 18-24% in the high scenario (see Figure 26 and Figure 27 above).
- The sustainable biomass potential increases over time in the high scenario. The estimated availability increases by 12% between 2030 and 2050 in the low scenario and by 15% in the high scenario.
- Biomass streams from agriculture and forestry have a similar contribution, especially in the high scenario. In the low scenario, the share of agricultural biomass rises from about 56% in 2030 to about 62% in 2050.
- The potential in the high scenario is 2.3 times higher than in the low one.

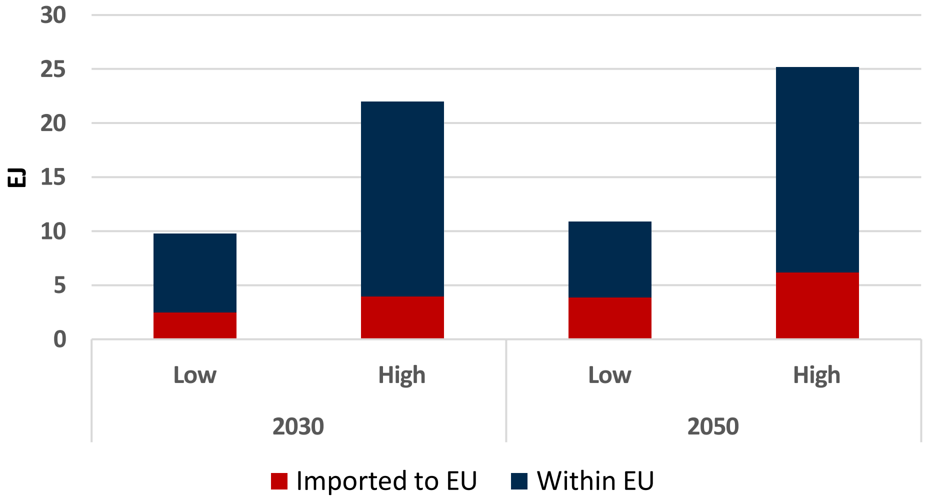


Figure 29. Sustainable biomass potential (in EJ) within the EU, and imported to the EU

Table 21. Availability of sustainable biomass (in (EJ) for the EU, including imports (Hoefnagels, 2021)

| Biomass | 2030 | | 2050 | |
|---|---|---|---|---|
| | Low | High | Low | High |
| Sugar crops | 1.4 | 1.4 | 1.4 | 1.5 |
| Starch crops | 0.5 | 0.5 | 0.4 | 0.4 |
| Oil crops | 0.1 | 0.4 | 0.3 | 0.3 |
| Lignocellulosic crops | 1.4 | 3.5 | 1.4 | 4.7 |
| Agricultural residues | 1.2 | 3.3 | 2.4 | 4.3 |
| Manure | 0.5 | 1.6 | 0.6 | 1.6 |
| Municipal solid waste | 0.4 | 0.6 | 0.4 | 0.8 |
| Sewage sludge | 0.0 | 0.0 | 0.0 | 0.1 |
| Roundwood | 2.6 | 3.3 | 2.7 | 3.5 |
| Primary forestry residues | 1.1 | 5.7 | 0.8 | 6.3 |
| Secondary forestry residues | 0.6 | 1.5 | 0.6 | 1.5 |
| Landscape care wood | 0.1 | 0.6 | 0.1 | 0.6 |
| **Sum** | **10** | **22** | **11** | **26** |

### 2.3.5 Availability of specific types of biomass

Three types of biomass require special attention: biowaste, used cooking oil and algae.

***Biowaste***

To establish a competitive biofuel industry for shipping, the infrastructure for collecting biowaste would have to be established. While it is available worldwide as a feedstock, producing biofuels from locally sourced biowaste would make it more cost-competitive and limit the emissions from transportation.

A local conversion process also may have local benefits in less-developed nations. Air pollution from households that rely on inefficient cook stoves was directly linked to nearly 500,000 premature deaths in sub-Saharan Africa in 2018, and 2.5 million globally. There are also around 4.2 million deaths1 attributable to outdoor air pollution each year, half of which are in China and India (WHO, 2022).

The intentional practice of burning the crop stubble that remains after grains have been harvested is a major contributor to air pollution. There have been attempts to restrict this practice, but it remains common in many developing economies (in India, on peak days, stubble burning can account for up to 40% of the air pollution in Delhi).

Turning organic waste such as animal manure or crop residues into biogas via a simple household biodigester would offer a way to support rural development and to alleviate these health impacts. In China, for example, subsidy support for diverting household sewage into biodigesters had major positive health impacts.

The IEA's 2020 Outlook for Biogas and Biomethane concluded that biogas and biomethane both have enormous potential to contribute to clean-energy transitions and help to achieve some of UN's energy-related Sustainable Development Goals. Despite previous waves of enthusiasm for these gases, today they meet only a fraction of the demand for energy.

In general, this is because they are more expensive than natural gas and have not enjoyed the same level of policy support as renewable sources of electricity, such as wind and solar PV cells. If biogas and biomethane are to play a more prominent role in the future energy mix, it will be critical to recognise the benefits they provide over natural gases and the enduring importance of gaseous energy carriers. The IEA report cited above outlines some potential approaches\ for governments and other stakeholders who are seeking to promote biogas and biomethane market development to consider (IEA, 2020).

However, two key features of any policy framework would be to:

- Support the competitiveness of biogas and biomethane against oil, natural gas and coal via $CO_2$ or GHG-pricing mechanisms. This should include recognising the significant GHG emissions- abatement potential of biogas/biomethane, which avoid direct methane emissions from feedstock decomposition. There are many examples of existing and planned policies that do this globally, including the Low Carbon Fuel Standard in California and the forthcoming Netherlands SDE++ policy.
- Ensure coordinated policymaking across agriculture, waste management, energy and transport to deliver an integrated approach to developing the biogas and biomethane sectors. There are several co-benefits of developing a biogas industry, including employment and income for rural communities, health benefits from less air pollution and proper waste management, the reduced risk of deforestation and greater overall resource efficiency. These benefits cut across the competencies and jurisdictions of different government departments. Ultimately a holistic approach is required that adequately values these benefits, and hence incentivises public and private investment in their development.

***Used cooking oil***

Used cooking oil (UCO) is labelled as an Annex IX Part B biomass feedstock in the RED II and is considered a relatively cheap feedstock. It is already a popular feedstock for producing biodiesel, but its availability is limited by how much cooking oil is used. Because this feedstock is not included in the literature study based on JRC data in Section 2.3.2, its supply potential is discussed here, using information from (CE Delft, 2020) on this topic.

UCO is 'produced' in the food-processing industry, in restaurants, other catering companies and households. To make it available as a feedstock or fuel in other sectors, it needs to be collected. Collecting UCO from industry and restaurants is generally easier and less costly than collection from households, because it is available in larger quantities, requiring fewer locations. Moreover, households may need to be convinced to bring their UCO to collection points. As a result, UCO collection from industry and restaurants is currently much more developed and practiced than collection from households.

A lot of UCO is collected already, especially in the professional sector in Western Europe. Restaurants form a major source of UCO, followed by food processors and households. In restaurants and catering organisations in Eastern Europe 'quite a big potential of additional UCO that is not yet captured exists' (GREENEA, 2016) . Furthermore, the collection of UCO from households in most European countries was relatively undeveloped in 2016. In countries such as Romania, Malta, and Cyprus, less than 50% of the recyclable UCO was collected from restaurants (Ecofys, 2019).

To boost the collection rate, governmental support for public-promotion campaigns is essential, as individuals must be convinced to bring their UCO to collection points.

To estimate the potential of UCO within the EU, current potential estimated in the study in (CE Delft, 2020) is assumed to be valid for the years 2030 and 2050. This means that consumed volumes of cooking oil are assumed to have remained the same over time. The import potential is assumed as equal to the imported volume of UCO and UCO-based biodiesel import to the EU in 2019. In future, it expected that export countries will use those volumes themselves. The estimated UCO supply potential is shown in the below table.

Table 22. UCO supply potential (in EJ/year) for the EU (CE Delft, 2020)

| | 2030 | | 2050 | | Remarks |
|---|---|---|---|---|---|
| | Min | Max | Min | Max | |
| Domestic | 0.063 | 0.070 | 0.063 | 0.070 | Results from study, considering current potential |
| Import | 0.052 | 0.052 | 0.052 | 0.0520 | Based on UCO and UCO-based biodiesel imports in 2019. |
| **Total** | **0.12** | **0.12** | **0.12** | **0.12** | The minimum values are 0.115EJ; the maximum values are 0.122EJ. |

The availability of used cooking oil for Europe is about 0.12 EJ/year, or about 0.5 to 1% of the total sustainable biomass availability for Europe presented in the previous sections. Although the current share of UCO as a feedstock for biodiesel is about 19%, it can be expected to drop considerably over time. Moreover, the serious concerns about fraud risks, which have emerged due to high UCO prices, give reason to be more cautious about the use of UCO as a feedstock for biofuels (CE Delft, 2020).

***Algae***

Because macro-algae (seaweed) can be cultivated on the ocean surface, a huge surface area is theoretically available. However, offshore macro-algal production and harvesting systems are still in development (JRC, 2015). Coastal and nutrient-rich waters are the most suitable for algae production at sea. The production yield per square metre depends on temperature, light, the water’s salt content and its movement.

Growing algae in the oceans does not compete with food production, in the way the production of energy crops does. However, algae also can be used as ingredient for food and animal feed products, and used as a feedstock for chemical products, which are more valuable applications. Therefore, an economically viable development may consist of biorefineries that produce food and chemicals and convert by-products to biofuels and energy (IEA Bioenergy, 2017).

Very large surface areas would be needed to make a meaningful contribution to biomass supply for biofuel production. Ecosystems and migrating marine species might be negatively affected by mass algae production at sea. Algae (farms) could extract too many nutrients from the water, which other species need to survive. But its cultivation also could lead to an oversupply of nutrients (eutrophication), which could damage the ecosystem.

As there is little experience with marine-algae cultivation, it is not clear how sustainable mass production could be.

Studies that provide an estimate of the global primary energy potential of aquatic biomass are scarce. Knowledge is lacking on the production yield of macro-algae, the suitability of different ocean regions, the technical feasibility of production and the impact on ecosystems. Referencing the work of a previous study (CE Delft, 2020), the results are presented below.

(Ecofys, 2008) investigated the potential of different options to produce aquatic biomass for energy applications worldwide. If the algae are grown on horizontal lines between offshore infrastructure, a potential area of 550 million hectares is available worldwide, which would lead to 110 EJ.

If only densely used coastal areas (up to 25 km) are used, an area of around 370 million hectares, a production of 35EJ could be reached. If macro-algae are cultivated in the biological deserts of the open oceans, an area of over five billion hectares becomes available. Utilising this area, a production amount of 6,000EJ/year could theoretically be achieved.

(Lehahn, et al., 2016) calculated the theoretical potential of macro-algae production at sea for ‘the next 50 years’. The results show that, in theory (since the technology is not currently available, therefore assuming no technological or ecological restrictions), macro-algae can be cultivated from about 10% of the world's oceans. If algae are only produced in areas with water depths under 100 metres and within 400 kilometres of the shore, the potential is much smaller (18 EJ, instead of 2,052 EJ).

(Froehlich, Afflerbach, Frazier, & Halpern, 2019) discussed the potential for macro-algae to capture and store $CO_2$, and thereby contribute to mitigating climate change. In this context, they mapped out the nutrient levels and temperatures in ocean water within national jurisdictions (exclusive economic zones)[7] using oceanographic, biological and production data. They then found about 48 million $km^2$ to be 'ecologically available' for producing macro-algae, accounting for the nutrient and temperature requirements for a large set of macro-algae species. Algae production potential was not measured but applying a macro-algae production yield of 2,000tn/$km^2$ (Hughes, Kelly , Black , & Stanley, 2012) and an energy content of 19MJ per kilogram of dry matter (Lehahn, Nivrutti Ingle, & Golberg, 2016), indicates 1,824EJ could be grown in this area.

[7] The ocean areas within national jurisdictions are the areas that are near the coastlines. They make up 36% of the total surface of the oceans.

Table 23. Estimates for global seaweed potential in 2050

| Source | Potential (EJ/year) | Type of potential | Remarks |
|---|---|---|---|
| (Ecofys, 2008) | 35 | Technical | Cultivation in densely used coastal areas (up to 25km from the coast) |
| | 110 | | Cultivation using horizontal lines between offshore infrastructures |
| | 6,000 | | Macro-algae are cultivated in the biological deserts of the open oceans |
| (Lehahn, et al., 2016) | 18 | Technical | Production in areas with a water depth less than 100 meters and closer than 400 kilometres to the shore |
| | 2,052 | | Production in 10% of the world's oceans |
| (Froehlich, et al., 2019) | 1,824 | Sustainable | Calculated potential, using the finding that 48 million $km^2$ of ocean area is suitable for macroalgae production |

By 2050, it is estimated that the global potential for sustainable macro-algae production will be 750 to 1,500 EJ. The global potential for the year 2030 is technically constrained by the speed at which cultivation and harvesting systems can be developed on a large scale. Furthermore, many researchers state that macro-algae production will not reach profitability by 2030. Therefore, we estimate the potential in 2030 of 50 to 100 EJ (CE Delft, 2020).

To estimate the European the potential share of global macro-algae production volumes in different parts of the world, (Lehahn, et al., 2016) was referenced, revealing a European share of 13%. When this share is added to the previously mentioned EU import share of 3%, it suggested a sustainable seaweed potential for Europe of 8-16 EJ in 2030 and 120-240 EJ in 2050 (see Table 24, below).

Table 24. Available sustainable potential of seaweed for Europe in 2030 and 2050 (in EJ)

| | 2030 | | 2050 | | Remarks |
|---|---|---|---|---|---|
| | Min | Max | Min | Max | |
| Global sustainable potential | 50 | 100 | 750 | 1500 | Results from (CE Delft, 2020) |
| Availability in Europe | 6.6 | 13 | 100 | 200 | Estimation based on (Lehahn, et al., 2016) |
| Potential import to Europe | 1.3 | 2.6 | 20 | 39 | Assuming an EU import share of 3%, as used above for other biomasses (see 5.4). |
| **Availability for Europe** | **8** | **16** | **120** | **240** | |

Compared to the estimated sustainable potential of biomass from agriculture and forestry (10-22EJ in 2030, and 11-26EJ in 2050), macro-algae may have close to 10 times higher sustainable potential in 2050. The contribution of aquatic biomass could potentially overshadow that of agricultural and forestry biomass. However, there are multiple technical and economic barriers to overcome to realise that potential, and environmental risks may pose additional restrictions to the development of seaweed farms.

### 2.3.6 Availability of capital

Methanol produced from the gasification of biomass and methanol synthesis after adding hydrogen from electrolysis has been found to be a cheaper option than e-methanol produced from either the direct air capture of $CO_2$ or from carbon capture of flue gas from biofuel operated in powerplants (Hendriksen, et al., 2021). However, the renewable electricity has to be produced in areas with cheap solar and wind energy; the Sahara, Western Australia and Chile have been identified as suitable locations but, as they are far from available sources of biowaste, the significant transportation costs would have to be considered.

Building large renewable facilities to produce electricity requires significant initial investment; most of the expense from producing electricity over the lifetime of the solar and wind turbines comes in the form of CAPEX. They cost comparatively little to maintain and operate.

The same can be said about the electrolysis used to produce the hydrogen needed for bio-methanol. Even with the selection of the best-suited- location, the cost for methanol is still 3-4 times higher than for methanol produced from fossil fuels. Most cost projections foresee a reduction of the production costs by roughly a factor 2 between 2020 and 2050, as exemplified by Table 25.

Table 25. example of cost projection of selected green, grey, black and blue fuels (€/GJ.)

| Fuel | 2020 | 2030 | 2050 |
|---|---|---|---|
| | €/GJ | €/GJ | €/GJ |
| Green methanol "Bio-E-methanol" | *36.4* | *28.6* | 22.8 |
| Green methanol CCU (from biofuel flue gas) | 44.9 | 33.4 | 23.5 |
| Green methanol DAC | 53 | 41 | 28 |
| Grey methanol | 9.7 | 7.4 | 7.6 |
| Green ammonia | 38.5 | 28.8 | 19.1 |
| Blue ammonia | 30.0 | 24 | 21.1 |
| Grey ammonia | 10.7 | 8.2 | 8.3 |
| Pyrolysis oil | 24.0 | 25.1 | 27.1 |
| VLSFO | 10.2 | 9.0 | 8.1 |

*Source:* (Hendriksen, et al., 2021)

Green bio-e-methanol will be cheaper to produce when the cost of renewable electricity reduces over time and production at scale is established. In 2050, the production cost of bio-e-methanol will be lower than for liquid biofuels, represented by the pyrolysis oil in the study. This is also in line with the findings in the 2021 IRENA report, Innovation Outlook: Renewable Methanol (IRENA and Methanol Institute, 2021). Compared to other bio-based materials and fuels, the report concludes, biomethanol and bio-DME have, together with BioSNG and biomethane, the lowest production costs, considerably lower than cellulosic ethanol and FT-type products. This is also backed up by (Maniatis et al., 2018; Brown et al., 2020).

In its report *Advanced Biofuels – Potential for Cost Reduction* the IEA finds significant potential for cost reduction through research and development and through experience being gained in the current generation of demonstration and early commercial plants. If a number of additional commercial plants are built, it is anticipated that capital and operating costs could be significantly reduced, but the scope for reducing the cost of feedstocks is more limited.

Large scale deployment of the technologies, in line with the strategies needed to meet the ambitions for advanced biofuels found in several low-carbon scenarios, could lead to significantly more cost reductions from technology learning, if plant capital and operating costs fall in line with the learning curve.

These savings could be significant, given a large-scale roll-out of the technologies (potentially up to 50% further reductions) in the most optimistic cases studied. Although, given the range of complicating factors, it is difficult to estimate their scope precisely.

### 2.3.7 Links with other sectors

The maritime sector is not the only EU sector where growing demand for sustainable biomass to reduce GHG emissions can be anticipated, so it only can count on receiving a portion of the EU's available biomass. The share depends on the alternatives that other sectors have for using biomass, the required biomass quality and the demand functions. It is beyond the scope of this report to analyse all these issues. Instead, this section refers to modelling that has been done in the context of the Fit for 55 proposals of the European Commission, made in July 2021.

According to the EC's FuelEU Maritime proposal, the EU's maritime sector's consumption of biomass could grow from 0.2 EJ in 2030 to 1.6-1.9 EJ in 2050 (EC, 2021). In 2030, most of this would come from forestry products (30%) and wood waste (18%); in 2050, annual crops were expected to contribute 36% of the biomass consumed by maritime shipping.

The proposal also estimated the sector's share of the available domestic biomass to reach 1.7-1.8% in 2030 and 11-14% in 2050. Therefore, the availability of domestic biomass can be projected to reach 10 EJ in 2030 and 14

EJ by 2050. Its share of the potential biomass volumes could range from 1-2.4% by 2030 and from 10-22% by 2050.

The maximum biomass potential may appear higher because the estimates use ‘potential availability’, rather than actual production and use. See Table 26, below.

Table 26. Relative use of available sustainable biomass by EU’s maritime sector

| | 2030 | | 2050 | | Remarks |
|---|---|---|---|---|---|
| | Low | High | Low | High | |
| Biomass production in the EU (*EC proposal*) (EJ) | 10 | 10 | 14 | 14 | Calculated based on (EC, 2021). Estimated production (only domestic biomass). |
| Biomass potential in the EU (this study) (EJ) | 10 | 22 | 11 | 26 | Estimated biomass potential (only domestic). |
| Biomass consumption from EU maritime sector (EJ) | 0.2 | 0.2 | 1.6 | 1.9 | (EC, 2021) |
| Share used by EU maritime sector, using availability figures from EC proposal | 1.7% | 1.8% | 11.5% | 14.2% | Calculated percentages for the sum of biomass feedstocks. |
| Share used by EU maritime sector, using availability figures from this study | 2.4% | 1.0% | 22.4% | 9.9% | |

The EU’s maritime sector must overcome several barriers to use the continent’s domestic sustainable biomass volumes, as indicated by European Commission (2021). The conversion of woody biomass to marine biofuels will require more development of its production technologies. It also has to become cheaper.

Also, the availability of biofuel-production capacity depends on the willingness of the market to invest in infrastructure, which will be influenced by state financial support, biomass feedstock prices and other factors. In addition, other sectors will compete with the maritime sector for available biomass.

### 2.3.8 Conclusions

***Availability within the EU***

Biomass streams from agriculture and forestry are expected to have similar contributions to the total sustainable biomass potential in Europe. Many biomass sources from the JRC’s availability figures are wood based. Primary crops are available only to a limited extent, which explains why a shift will be required from food-based biofuels to the advanced biofuels that convert woody biomass and other residual flows.

The range in biomass availability is mainly due to different estimates for the potential of primary forestry residues, lignocellulosic crops, agricultural residues and manure. In 2030 and 2050, the potential is estimated to be 2.5-2.8 times higher in the JRC’s ‘high’ scenario than in its ‘low’ scenario, implying a large range of uncertainty.

The range across scenarios for sustainable biomass that will be available and consumed within the EU in the ‘Fit for 55’ proposal is 6.3-8.0 EJ in 2030 and 6.7-14.7 EJ in 2050. These are different than the JRC figures, reflecting the differences in scope and assumptions, especially for the higher ends of the range.

Aside from the feedstocks in the JRC analysis, used cooking oil (UCO) and algae are also much discussed feed-stocks. The availability of UCO in Europe is equal to about 0.12 EJ/year, or just 0.5-1 % of the total sustainable biomass available in Europe. Although UCO represents 19% of the feedstocks used for biodiesel, the share is still likely to rise over time as a result of its limited availability and growing demand from transport modes. However, concerns about fraud risks need to be taken seriously.

Compared to the estimated sustainable potential of biomass from agriculture and forestry (10-22 EJ in 2030 and 11-26 EJ in 2050), the sustainable potential of macro-algae in 2050 is about 10 times higher. In other words, the potential of aquatic biomass could overshadow those of agricultural and forestry biomass. The realisation of that potential, however, is hindered by some technical and economic barriers and its success will depend on the development of sustainability frameworks.

***EU potential in relation to the worldwide potential***

The global and EU potential for biomass is depicted in Table 27, below. In 2030, maritime shipping is projected to consume 1-2.4% of the EU's potential biomass. For 2050, this range varies from 9.9-22.4%, with the highest share occurring in the JRC's 'low' potential scenario. A maximum of 3% of worldwide potential could end up being exported to the EU.

Table 27. EU sustainable biomass potential (in EJ) in 'low' and 'high' scenarios for 2030 and 2050 (JRC, 2020)

| | 2030 | | 2050 | |
|---|---|---|---|---|
| **JRC's biomass scenario** | **Low** | **High** | **Low** | **High** |
| **EU potential** | **7.3** | **18** | **7.0** | **19** |
| **Worldwide potential** | **83** | **134** | **131** | **207** |

The potential availability of FAME and HVO from FOGs scores low due to the limited availability of feedstock, while lignin-based biofuels score well on availability (Table 28).

Table 28. Potential availability of feedstock for biofuels

| Fuel | Production pathway | Feedstock | Feedstock availability |
|---|---|---|---|
| FAME | transesterification | FOGs | - |
| HVO | hydrotreating | FOGs | - |
| FT diesel | gasification + FT synthesis | lignocellulosic biomass | ++ |
| DME | gasification + fuel synthesis | lignocellulosic biomass | ++ |
| Bio-methanol | gasification then fuel synthesis | lignocellulosic biomass | ++ |
| biomethane | digestion | waste and residues | 0 |
| biomethane | gasification | lignocellulosic biomass | ++ |

## 2.4 Suitability

### 2.4.1 Introduction

Most biofuels have had very limited use in ships. Because ISO usually develops fuel standards only after practical experience is gained, many related standards are still under development (Methanol Institute, 2018).

To evaluate the suitability of biofuels for use in marine transport, the biofuel's properties must be examined. The 'suitability' analysis in this section focuses on the physical and chemical properties of the biofuels and assesses whether each fuel and property can meet the industry standards for the fossil alternatives they would replace. When a biofuel meets all applicable standards, it is thought to be a suitable replacement.

This section first analyses the suitability of liquid biofuels as a replacement for petroleum fuels by collating evidence on their properties and comparing them to ISO 8217 standards. The second subsections analyse bio-alcohols, and the third biomethane, which is compared with the standards set in ISO 23306.

It is noted that in several cases, the fuels can have a rather wide range of chemical and physical properties, depending on the feedstock and production process, and that reliable information was not available to review.

### 2.4.2 Biodiesel and biocrudes

***Fatty acid methyl ester (FAME)***

FAME has a higher flash point (149°C) and cetane rating than fossil diesel. The lower calorific value (LCV) is a bit lower: 38 MJ/kg, compared to 43 MJ/kg for marine diesel oil (MDO). It degrades quickly in water and has a high cloud point, which may cause filters to clog and poor fuel flow at temperatures below 32°C. The exact cloud point depends on the combination and quality of the feedstock oils used to produce the fuel (IEA Bioenergy, 2017).

This biofuel has good ignition and lubricity properties. It reduces smoke, soot and the odour of burnt diesel from engine exhaust; it also protects fuel and injector pumps from wear. However, the acid degradation products of FAME are "suspected of causing damage to fuel pumps, injectors and piston rings, leading to an acid number limit in marine-fuel specifications", according to (IEA Bioenergy, 2017).

Table 29. Comparison of fossil marine distillate and residual fuel requirements with biodiesel properties (World Fuel Services, 2017; ABS, 2021; CONCAWE, 2009)

| Property | | Distillate fuels | | | | Residual fuels | | | | | | | Biofuels[4] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ISO 8217:2017 specifications | | | | | | | | | | | Properties | |
| | | DMX | DMA/ DFA | DMZ/ DFZ | DMB/ DFB | RMG | | | | RMK | | | FAME | HVO |
| | | | | | | 180 | 380 | 500 | 700 | 380 | 500 | 700 | | |
| Kinematic viscosity ($mm^2/s$)[1] | Max | 5.5 | 6.0 | 6.0 | 11.0 | 180 | 380 | 500 | 700 | 380 | 500 | 700 | 4.0-5.0 [5] | n.a. |
| | Min | 1.4 | 2.0 | 3.0 | 2.0 | | | | | | | | n.a. | n.a. |
| Density at 15 °C ($kg/m^3$) | Max | - | 890 | 890 | 900 | 991 | | | | 1010 | | | 885 [3] | 780 [3] |
| Lower calorific value (MJ/kg) | - | 43 | | | | 39 | | | | | | | 38 | 43 |
| CCAI (-)[2] | Max | | | | | 870 | | | | 870 | | | n.a. | n.a. |
| Cetane number (-) | Min | 45 | 40 | 40 | 35 | | | | | | | | 56 | 80-99 |
| Flash point (°C ) | Min | 43 | 60 | 60 | 60 | 60 | | | | 60 | | | 101°C (min.) | >70 |
| Sulphur (mass %) | Max | 1.00 | 1.00 | 1.00 | 1.50 | Statutory req. | | | | | | | 0.002 | n.a. |
| Hydrogen sulphide (mg/kg) | Max | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | | | | 2.00 | | | n.a. | n.a. |
| Acid number (mg KOH/g) | Max | 0.5 | 0.5 | 0.5 | 0.5 | 2.5 | | | | 2.5 | | | 0.3 | n.a. |
| Total sediment (mass %) | Max | - | - | - | 0.10 | 0.10 | | | | 0.10 | | | n.a. | n.a. |
| Oxidation stability ($g/m^3$) | Max | 25 | 25 | 25 | 25 | | | | | | | | n.a. | n.a. |
| Carbon residue (mass %) Micro method on the 10% volume distillation residue | Max | 0.30 | 0.30 | 0.30 | - | | | | | | | | n.a. | <0.1 |
| Carbon residue – Micro method | Max | - | - | - | 0.3 | 18 | | | | 20 | | | n.a. | n.a. |
| Cloud point (°C) Winter | Max | -16 | report | report | - | | | | | | | | -5 to 20 [5] | "several winter grades available" |
| Cloud point (°C) summer | Max | -16 | - | - | - | | | | | | | | n.a. | n.a. |
| Pour point – winter (°C) | Max | - | -6 | -6 | 0 | 30 | | | | 30 | | | n.a. | n.a. |
| Pour point – summer (°C) | Max | - | 0 | 0 | 6 | 30 | | | | 30 | | | n.a. | n.a. |
| Water (volume %) | Max | - | - | - | 0.30 | 0.50 | | | | 0.50 | | | n.a. | <0.01 |
| Ash (mass %) | Max | 0.010 | 0.010 | 0.010 | 0.010 | 0.10 | | | | 0.15 | | | 0.02 | <0.001 |
| Vanadium (mg/kg) | Max | | | | | 350 | | | | 450 | | | n.a. | n.a. |
| Sodium (mg/kg) | Max | | | | | 100 | | | | 100 | | | n.a. | n.a. |
| Aluminium + silicon (mg/kg) | Max | | | | | 60 | | | | 60 | | | n.a. | n.a. |
| Lubricity – corr. Wear scar diam. (µm) | Max | 520 | 520 | 520 | 520 | | | | | | | | n.a. | n.a. |
| Used lubricating oil contents (mg/kg) | - | | | | | Calcium>30 and zinc >15, or calcium>30 and phosphorus>15 | | | | | | | n.a. | n.a. |

Remarks: [1]: At 40 °C for distillate fuels and FAME, and at 50 °C for residual fuels; [2]: Calculated Carbon Aromaticity Index; [3]: density at 20° C; [4]: Actual values (not requirements); [5]: depending on feedstock; n.a.: not applicable

FAME has a higher oxygen content than fossil diesel, which leads to reduced oxidation stability, and it more easily degrades fuel and forms peroxides, acids and other insoluble compounds. Furthermore, FAME is prone to water contamination, leading to lower fuel efficiency, higher microbial growth and accelerated gelling at low temperatures (IEA Bioenergy, 2017).

Many of these problems can be mitigated by blending FAME with VLSFO or ULSFO. ISO 8217:2017 contains standards for distillate fuels containing up to 7.0% v/v of FAME. Media reports are available of tests with higher blends containing up to 50% FAME, and several fuel suppliers already offer blends of B10, B20 or B30, where the number represents the volume percentage of FAME blended with the fuel. However, the use of such blends is subject to the relevant regulations and standards, with more details provided in Section 3.2.

***Hydrotreated vegetable oil (HVO)***

HVO has a much higher cetane number than FAME and has a higher energy density than FAME but similar to MDO (43 MJ/kg LCV, compared to 38 MJ/kg for FAME). It is low in sulphur and has no oxygen content (which is removed in the hydrogenation process), resulting in higher fuel efficiency and a much longer shelf life than FAME, due to reduced risk of fuel oxidation (IEA Bioenergy, 2017).

A comparison of the properties of HVO and FAME with a fossil-marine distillate and residual-fuel requirements is presented in Table 29 on the next page.

***Fischer-Tropsch (FT) diesel***

FT diesel often has a lower energy density, currently 9% lower than MDO in average (39.1 MJ/kg) but with perspective of achieving similar values MDO and contains more impurities; however, it also has a low-sulphur content (IEA Bioenergy, 2017).

***Dimethyl ether (DME)***

DME has a low flash point, which poses challenges for safe handling. It has a high cetane number, a lower boiling point and lower energy density than fossil diesel (29 MJ/kg LCV, compared to 43 MJ/kg for diesel). It also has a simple chemical structure and a high oxygen content (Patil & Thipse, 2012).

An important advantage of DME is that its combustion generates very low levels of particulate matter, $NO_x$ and CO (IEA Bioenergy, 2017). DME is also miscible in water, so it can be blended with water; it could be used in the same way as water-blended methanol to meet NOx Tier III MARPOL Annex VI requirements (Section 3.2.3.2). Furthermore, due to its high cetane number, it may also become a pilot fuel to ignite methanol.

On the downside, DME will dry out running surfaces or bearings in engine components such as injectors, which may lead to seizures. Sealing oil or a friction coating may therefore be needed.

Further details about the performance of DME as a marine fuel can be found in Section 4.3.

***Pyrolysis oil***

Pyrolysis oil is a dark brown liquid with a lower energy density than that of fossil bunker fuels (17 MJ/kg LCV). It is acidic and corrosive and its viscosity increases during storage. It is vulnerable to oxidation and features a high oxygen content. Its water content is between 15-30 wt%, but it can reach up to 60 wt%, reducing its storage life.

The high oxygen content (~35-50 wt%) is responsible for a lower calorific value (LCV) of ~17 MJ/kg and high polarity, which makes it immiscible with conventional petroleum-derived oils (McCormick, et al., 2015).

With the relatively low LCV, pyrolysis oil is an unlikely candidate for use in today's marine engines without modification of fuel-supply system, piping, injection system and adapting larger fuel oil tanks. With a catalytic upgrading process, its oxygen can be removed to increase fuel stability and meet the specifications for a drop-in fuel (IEA Bioenergy, 2017). However, this process can have a negative impact on the bio-oil yield.

***HTL biocrude***

This biofuel is a crude-like bio-oil that is produced through hydrothermal liquefaction. It has a high hydrogen-to-carbo ratio and a high energy density (higher than pyrolysis oil): the lower calorific value is 34 to 37 MJ/kg. The oxygen content is 5-20 wt% (IEA Bioenergy, 2017).

***Solvolysis oil***

Solvolysis oil is a bio-oil with no or little sulphur content. The oil that is produced using a process patented by the Danish Technical University and the University of Copenhagen, lignin diesel oil, is of superior quality to pyrolysis oil: it is non-acidic and stable.

***Comparison of fuels against standards***

Fuel oils are often categorised according to fuel specifications in ISO 8217. The most popular biodiesels are FAME and HVO. Table 29 compares the properties of these fuels with requirements in the ISO standard.

Many properties of FAME and HVO have not been documented, which makes it hard to draw definitive conclusions on their suitability for use in conventional marine-diesel engines. Having said that, most of the known properties fall within the specifications (with the possible exceptions of ash and cloud point), which suggests that these biofuels are suitable for use in conventional diesel engines.

Insufficient information was available to compare other fuel alternatives with fuel standards.

### 2.4.3 Bio-alcohols

***Bioethanol***

Bioethanol has a lower cetane number and a lower energy density than biodiesel. Second-generation bioethanol produced from lignocellulosic biomass has a zero or very low sulphur content (depending on the type of pre-treatment process).

***Bio-methanol***

Bio-methanol is a liquid, colourless and volatile biofuel. It is flammable, has a low flash point and is highly toxic. It has a relatively low calorific value (20 MJ/kg LCV) but is nevertheless increasingly used as a marine fuel (Faber, et al., 2020).

Both bioethanol and bio-methanol are chemically identical to their fossil counterparts. Bio-methanol can therefore be considered a drop-in fuel for engines running on methanol. Much less information is available about the use of ethanol in marine engines (an exception is (Wang & Li, 2022)).

Table 30. Methanol specifications properties. (Note: Pr. = property)

| Property | | Methanol | Sources |
|---|---|---|---|
| Purity (on dry basis) (wt%) | Min | 99.85% | (IMPCA, 2015) |
| Density at 16°C (kg/m$^3$) | Pr. | 794.6 | (Andersson & Salazar, 2015) |
| Boiling point at 1 bar (°C) | Pr. | 65 | (ABS, 2021b) |
| Auto-ignition temperature (°C) | Pr. | 450 | (ABS, 2021b) |
| Flashpoint | Pr. | 11 | (Andersson & Salazar, 2015) |
| Cetane number | Pr | < 5 | (ABS, 2021b) |
| Octane number | Pr. | 109 | (ABS, 2021b) |
| Flammability limits (vol % in air) | Pr. | 6.72 to 36.5 | (Andersson & Salazar, 2015) |
| Water (volume %) | Max | 0.1 | (IMPCA, 2015) |
| Acetone (mg/kg) | Max | 30 | (MAN B&W, sd), (IMPCA, 2015) |
| Ethanol (mg/kg) | Max | 50 | (IMPCA, 2015) |
| Chloride (as $Cl^-$) (mg/kg) | Max | 0.5 | (MAN B&W, sd) |
| Sulphur (mg/kg) | Max | 0.5 | (MAN B&W, sd) |
| Carbonisable Substances (Pt-Co) | Max | 30 | (IMPCA, 2015) |
| Iron in solution (mg/kg) | Max | 0.10 | (IMPCA, 2015) |
| Acidity (acetic acid) (mg/kg) | Max | 30 | (IMPCA, 2015) |
| Distillation range at 760 mm Hg (°C) | Max | 1.0 to include 64.6 +/- 0.1 | (IMPCA, 2015) |
| Specific Gravity (20°/20°) | | 0.7910-0.7930 | (IMPCA, 2015) |

In 2018, the IMO invited ISO to develop a fuel standard for methanol and ethanol as marine fuels. The standard for methanol (ISO/AWI 6583) was under development at the time of writing. IMPCA Methanol Reference Specifications (IMPCA, 2015) also provides a reference for some of the properties. Table 30 can be used as a format for establishing its suitability as a marine fuel.

### 2.4.4 Gaseous biofuels

The properties of Liquefied biomethane (LBM) are very similar to those of LNG and "for all practical means they can be considered identical" (DNV GL, 2019). This physio-chemical similarity is confirmed by ISO, which indicates that its ISO 23306:2020 standard applies to LNG from any source, including biomass.

Table 31. LNG specification that also apply to LBM (Andersson & Salazar, 2015).

| Property | LNG |
|---|---|
| Density at 16°C (kg/m$^3$) | 431 to 464 |
| Boiling point at 101.3 kPa (°C) | -160 to -161 |
| Auto-ignition temperature (°C) | 580 |
| Flashpoint | -136 |
| Cetane number | 0 |
| Flammability limits (vol % in air) | 4.2 to 16.0 |
| Sulphur content (%) | <0.06 |

### 2.4.5 Conclusions

In conclusion, some biofuels currently being produced can be considered drop-in fuels. Table 32 provides an overview based on section 2.1, detailing for each type of biofuel the replaced fossil equivalent, the properties (in terms of % of blend) and a few remarks to consider for specific cases.

Table 32. Drop-in properties of biofuels

| Biofuel | Replaced fossil fuel | Drop in properties/blend % | Remarks |
|---|---|---|---|
| FAME | Distillates | Up to 100% v/v | Subject to confirmation by Engine Designer for blends above 7% v/v FAME |
| HVO | Distillates | Up to 100% v/v | Subject to confirmation by Engine Designer |
| FT diesel | Distillates | Up to 100% v/v | Subject to confirmation by Engine Designer |
| DME | Distillates – LPG in dual fuel engines | Up to 20-30% v/v – up to 100% v/v | Subject to confirmation by Engine Designer |
| Bio-methanol | Methanol | Up to 100% v/v | For Methanol DF Engines and Fuel Supply System |
| Bio-ethanol | Distillates in Otto engines – Methanol in dual fuel 2-stroke engines. | Up to 100% v/v | Not enough information about use in marine engines – probably doable by introducing minor modification to the methanol fuel injection system |
| SVO | Fuel oil | Up to a limited share | Subject to confirmation by engine Designer |
| Pyrolysis oil | Fuel oil | Not a drop-in fuel | Properties vary widely and change with ageing. Acidic and corrosive. Can be upgraded to a drop-in fuel. |
| HTL biocrude | Fuel oil | Up to a limited share | Little information about use in blends in marine engines. Can be upgraded to a drop-in fuel. |
| Solvolysis oil | Fuel oil | Up to a limited share | Little information about use in blends in marine engines. Can be upgraded to a drop-in fuel. |
| Liquefied biomethane | LNG | Up to 100% v/v | For DF and Gas Engines, and Fuel Gas Supply System |

A more detailed evaluation of the suitability of biofuels for use in marine engines, presented in this section, is hampered by a lack of data on the properties of biofuels. While examples are known in which biofuels are blended with fossil fuels, the fuel specifications of the bio-fraction in the blend are often not publicly available.

## 2.5 Cost developments

### 2.5.1 Introduction

This section looks at developments in the cost of the study's biofuels, HVO, FAME, FT-diesel, bio-methanol and biomethane. It projects the total cost of ownership (TCO), defined here as the sum of annuities of capital expenditures (CAPEX) and annual operational expenditures (OPEX), for 2020, 2030 and 2050. This is calculated for 70 ship types and the size categories defined in the Fourth IMO Greenhouse Gas Study 2020[8]. Focus is given to the TCO calculations for newbuild vessels. As many of the fuels considered in this report are drop-in fuels to some extent: they are either fully compatible with conventional fuels (e.g., biomethane can replace LNG without engine modifications, and HVO can be used in fuel oil engines), or can be blended up to certain limits (e.g., FAME). When the fuel properties fall outside of the scope of fuel standards, minor modifications in engine management may be required, but these would not have a material impact on the TCO. As cost estimates proved to be very scarce and ship-specific, and difficult to generalise, in this study, the retrofit TCO estimates from fuel oil to biomethane and bio-methanol and for the case of a container vessel (a segment in which uptake of these fuels is observed) are provided.

The next two sections define capital and operational costs, respectively, to obtain indications for ship specific TCOs. A description of the cost elements is followed by examples of how the TCO of ships running on different types of biofuels compares to the TCO of ships sailing on conventional fuels.

Across the sections, the cost figures are presented in USD and EUR using the year average exchange rate of 2020 (1 EUR = 1.1422 USD) based on Eurostat (Eurostat, 2020).

### 2.5.2 CAPEX

Capital expenditures are fixed costs borne from a newbuild vessel, including the cost of the engine, aftertreatment, storage (tanks) and fuel supply system (FSS). These costs do not depend on the frequency and intensity of the use of the vessel.

***Engine costs***

Engine costs are major factors in the ownership of vessels. The cost of engine systems depends on the power capacity of the ship (kW). Engine costs are examined from both retrofit and newbuilt perspectives. For retrofitting a conventional fuel oil-powered ship, the costs of adjusting the system are included. For the use of biomethane in an LNG-powered ship, there is no additional cost. Engine CAPEX is assumed as an annual cost over a 25- year lifetime with the weighted average cost of capital (WACC) at 7%, based on the reported ranges of the WACC by several maritime freight operators[9].

For the biofuels FAME, HVO[10], FT-diesel and bio-methanol, a 2-stroke low speed diesel internal combustion engine (ICE) is considered. For vessels on biomethane, a natural gas Otto 2-stroke ICE is considered. Engine costs are from (Hendriksen, Sørensen, & Münster, MarE-Fuel: Sustainable Maritime Fuels: Executive Summary Report, 2021). The estimated costs of tanks and fuel systems are from (Horvath, 2017). No improvements in ICE technology are assumed over the timeframe of the analysis.

System costs for the storage tanks vary by fuel type and are dependent on the vessels' power capacity. Engine cost ranges from 220 USD/kW for conventional fuel ICE to 380 USD/kW for methanol engines. Total CAPEX depends on the average installed power of a vessel. An indication of cost per kW is presented in Table 33.

[8] The ship types and sizes which have to report to the EU MRV are considered. See Appendix 0 for an extensive list of all ship types and sizes considered.
[9] The reported ranges of the WACC by several maritime freight operators (Hapag-Lloyd 7.7-10.1%; Yang Ming Marine Transport 6.4-8.3%; Moller-Maersk 7.8%).
[10] We assume 100% HVO blend, for a cost indication. HVO is produced using hydro-processing treatment. In practice, we acknowledge HVO is used as a drop-in fuel with a lower blending rate combined with a fossil fuel component

Table 33 - Engine cost input for alternative suitable ICE (Hendriksen, et al., 2021), (Horvath, 2017)

| Ship category | Fuel type | Ship size | Engine Cost per kW (USD) | Storage cost per kW[a] (USD) | Engine Cost per kW (EUR) | Storage cost per kW[a] (EUR) |
|---|---|---|---|---|---|---|
| Small vessels | Fuel Oil* | All vessel types* with size up to 15,000 dwt | 290 USD | 70 USD | 250 EUR | 60 EUR |
| Large vessels | Fuel Oil* | All vessel types* with size above 15,000 dwt | 230 USD | 70 USD | 200 EUR | 60 EUR |
| Containerships | Fuel Oil* | All sizes containerships | 220 USD | 70 USD | 190 EUR | 60 EUR |
| Short sea vessels | Biomethane | All vessel type with size up to 15,000 dwt | 340 USD | 250 USD | 300 EUR | 220 EUR |
| Deep sea vessels | Biomethane | All vessel types with size above 15,000 dwt | 290 USD | 250 USD | 250 EUR | 220 EUR |
| Containerships | Biomethane | All sizes containerships | 250 USD | 250 USD | 220 EUR | 220 EUR |
| Short sea vessels | Bio-methanol | All vessel type with size up to 15,000 dwt | 380 USD | 110 USD | 330 EUR | 100 EUR |
| Deep sea vessels | Bio-methanol | All vessel types with size above 15,000 dwt | 320 USD | 110 USD | 280 EUR | 100 EUR |
| Containerships | Bio-methanol | All sizes containerships | 270 USD | 110 USD | 240 EUR | 100 EUR |

* Fuel oil include the fuel types: ULSFO, VLSFO, HFO, MGO, FAME, FT-Diesel
[a] Storage sufficient for 30 days continuous sailing is assumed

***Aftertreatment system costs***

Aftertreatment costs are those borne by the system and treatment of harmful substances or elements which cannot be released into the environment (air or ocean waters) due to regulation. An example of aftertreatment cost is the cost of a selective catalytic system (SCR) required to bring NOx emissions in line with regulatory limits.

For the fuels considered in this analysis, no aftertreatment is necessary, as the baseline is a ship sailing on very low sulphur fuel oil (VLSFO). Therefore, it is assumed that the cost for aftertreatment will be zero for all vessels.

***Onboard storage and fuel tanks and piping***

Dedicated onboard tanks and piping systems are needed to receive and store fuel. The cost of these components and materials is assumed to be proportional to the vessel's use of engine power. It is included in the CAPEX with the engine cost, see Table 33.

When ships are retrofitted, depending on the fuel, tank and piping alternations needed, these can make up a large part of the CAPEX of a vessels' TCO. For newbuild vessels, the tank and piping are provided by the manufacturer in accordance the chosen fuel. As previously stated, only the cost for newbuild systems is considered in this report.

### 2.5.3 OPEX

Operational expenditures (OPEX) are variable costs, depending on the use of the vessel.

***Carbon cost***

The maritime shipping sector will be included into the European Emissions Trading System (EU ETS). This means that, from 2024 on, shipping companies will be obliged to surrender allowances for the $CO_2$ emissions that their ships emit on voyages to and from EEA ports as well as in EEA ports. Thus, next to the fuel costs, also carbon costs will accrue if, within the geographical scope of the EU ETS, fossil fuels are combusted on board ships (for more details see Section 3.3.3).

For the calculation of the carbon costs, as part of the TCO analysis, an ETS price of 46 EUR per tonne $CO_2$ in 2030 and of 150 EUR per tonne $CO_2$ in 2050 (EC, 2021) are considered. In addition, it is assumed that carbon costs accrue for each tonne of $CO_2$ emitted. For the $CO_2$ emitted on voyages between EEA and non-EEA ports, however, only for 50% of the emissions allowances will have to be submitted, leading to lower carbon costs on these voyages. And if vessels do not call at EEA ports at all, the baseline carbon costs for VLSFO will also be lower than assumed here, at least provided that no other policy measures, implementing a carbon price, were adopted at international level/in other regions.

Figure 30 illustrates the 2030 and 2050 carbon costs per tonne of VLSFO for the above mentioned ETS prices. For biofuels, we assume that the Tank to Wake $CO_2$ emissions can be accounted for as zero and that therefore no carbon costs accrue.

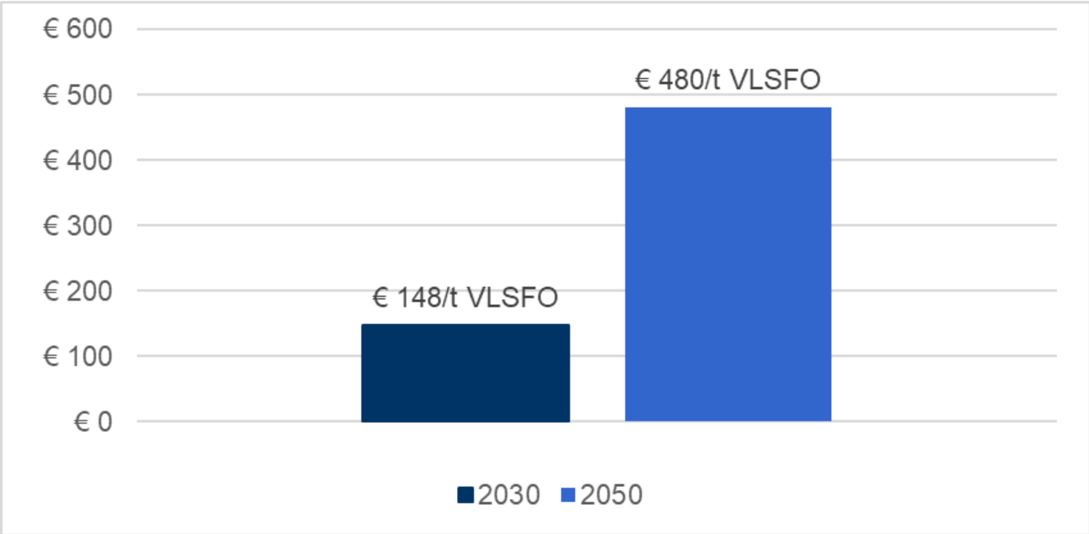


Figure 30 – Carbon cost per tonne of VLSFO

***Fuel cost***

Fuel costs are a major item in the cost of owning and operating a vessel; they are estimated and projected in this report for 2020, 2030 and 2050. The costs are derived from the production costs, multiplied by the average amount of fuel consumed by each of the 70 ship categories and should be perceived as a minimum level of cost, because fuel producers and merchants tend to raise prices.

Fuel cost prices of biofuels (per GJ) are gathered from institutional sources and previous studies (Hendriksen, et al., 2021) (IEA Bioenergy, 2020) (IRENA and Methanol Institute, 2021) (Münster, 2021). The production costs of the fuels do not represent future market prices, which may be higher than the production costs because of competition for biomass. Alternative fuels are from various production locations. An average price of fuels from different production locations is used in the analysis. Fuel prices may vary according to the location of production in the future. When high quality grade drop-in biofuels are selected, a 100% blend can be used in the existing main engine. Therefore, in the following TCO analysis FAME, HVO and FT are assumed to be used as a 100% blend. The cost for bio-methanol and biomethane in the analysis is based on the feedstock market price. Bio-methanol as considered here is initially a product of digestion or fermentation of biomass and later in time methanol produced from $CO_2$ captured from biomass fired power stations (Münster, 2021). See Figure 31 for the projected ranges of fuel cost in 2030 and 2050. The estimated impact of EU ETS on the cost of VLSFO is indicated by a purple bar. In the TCO analysis, the lower value of the fuel cost range and the carbon cost for the use of VLSFO are considered.

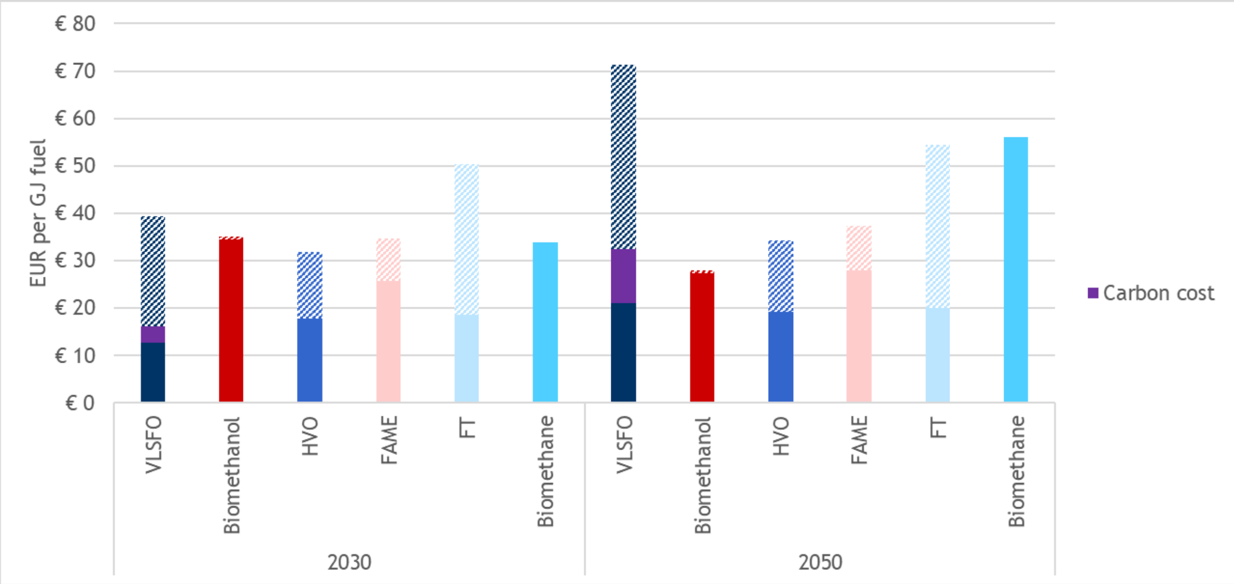


Figure 31 – Projected fuel cost of biofuels and VLSFO (including carbon cost for the use of VLSFO)

A 20% improvement in ship-energy efficiency is factored in for 2030, in line with recent regulations from the IMO's Carbon Intensity Indicator. This is an estimation of the anticipated efficiency gains from the recent introduction or emergence of several energy-saving technologies and operational measures, partly stimulated by regulations in the energy-efficiency index.

No further improvements in energy efficiency are assumed after 2030, so 2050 projections also reflect a 20% improvement in efficiency (compared to 2020).

### *Bunkering cost*

Bunkering costs are derived from storing fuels in a port and/or delivering them to the ship. They vary per type of fuel. These costs are estimated proportional to the yearly energy consumption. The bunkering costs are derived from TNO (2020) (2020a; 2020b). Bunkering costs are levied for handling of the bunkering process, not for the fuel bunkered.

Some alternative fuels have significantly lower volumetric energy density than VLSFO (e.g., bio-methanol), which has cost implications for bunkering; for example, a vessel on bio-methanol would have to increase its bunkering frequency to maintain a similar transport performance to sailing on VLSFO. This leads to higher bunkering costs by a factor of the fuel's volumetric energy density. We calculate the additional bunker cost by the increased rate (frequency) of bunkering a vessel, while keeping the onboard fuel storage equal for all vessels (for every fuel type). The difference ratio of volumetric density of an alternative fuel relative to VLSFO is therefore the factor at which the vessel has to increase bunkering. The increased bunkering factor of alternative fuels is displayed in Table 34.

Table 34 – Energy density and necessary increased bunkering frequency factors (DNV GL, 2019).

| Fuel type | MJ/L | Volumetric density % of VLSFO | Factor increased bunkering |
|---|---|---|---|
| VLSFO | 36 | 100.0% | 1.00 |
| Bio-methanol | 15 | 41.7% | 2.40 |
| HVO/FAME/FT | 32 | 88.9% | 1.13 |
| Biomethane (LNG) | 13 | 36.1% | 2.77 |

### *Maintenance and repair*

Maintenance and repair (M&R) costs occur annually for every ship. A factor of the ships' CAPEX was applied for the M&R costs. For bio-methanol, the M&R costs are higher due to the fuel properties and the need to adjust handling by maintenance personnel. They are 3% of the CAPEX for bio-methanol, 1.5% for all other alternative fuels in this analysis.

***Training cost***

The use of alternative fuels brings different risks associated with handling the fuel. For example, bio-methanol is a corrosive substance with a low flash point, so it requires specialised handling during bunkering, system maintenance and use as a fuel. For this, additional training is necessary to ensure safe and adequate handling by the crew. However, this cost is very small compared to other cost components and is not considered here.

### 2.5.4 TCO retrofit estimation

Retrofitting vessels is the process of replacing engine systems with adapted models that can combust alternative fuels, such as bio-methanol and biomethane. This process involves cost from the (main) engine conversion, shipyard work, supplier work, new fuel-gas supply systems, bunker, tanks and vent mast. These costs are all CAPEX-related; OPEX costs are considered to be consistent with those itemized in Section 2.5.3. A retrofit can be completed in six to ten weeks depending on ship size and type, therefore there are revenue losses related to transport being missed. Moreover, depending on contracts, additional costs also may arise from retaining the crew while the vessel is idle, and extra fuel from rerouting to and from the shipyard. In Table 35, an indication of retrofit costs is presented for an engine of a medium-sized containership suitable for the combustion of bio-methanol and biomethane, based on best engineering judgment.

Table 35 – Indicative ship retrofit cost for alternative gaseous biofuels

| Type of vessel | Fuel type conversion | Additional cost to newbuilt CAPEX | Indicative ship conversion cost* (million USD) | Indicative ship conversion cost* (million EUR) |
|---|---|---|---|---|
| Medium-sized Containership | Fuel oil to bio-methanol | ~13-17% | 19.0 – 25.0 | 16.6 – 21.8 |
| Medium-sized Containership | Fuel oil to bio-methane | ~15-20% | 22.0 – 30.0 | 19.2 – 26.2 |

Source: based on best engineering judgement, based on assumed 150 million USD newbuilt CAPEX for the containership.

The increased tank volumes required for the storage of bio-methanol and bio-methane result into a significant impact on the cargo capacity and hence total lifetime costs (lost cargo revenue). In some cases, lost cargo space can be reduced by placing tanks under the accommodation in modern containership designs, but this must be prepared for at newbuild, which increases newbuild costs and the risks associated with committing to a particular future fuel.

Additional to the CAPEX retrofit cost, some other costs have to be considered for the conversion process. These costs are shipyard work, owner supply work, project management. Due to a lack of data we cannot present any quantitative examples on the cost of these aspects, but these can be expected to impact the retrofit cost significantly. The actual cost also depends on the type of vessel and its size. Retrofit costs are associated with a higher risk as it is a tailor-made design, and it is carried out in a shipyard which may not have substantial previous experiences. Converting vessels only makes economic sense on longer timelines to pay back the investment. The timeline can be shorter if reduced range (smaller fuel tank capacity) options are selected, this also reduces cargo loses.

### 2.5.5 TCO newbuild estimation

The analysis below offers a detailed TCO comparison for two ship types, bulkers and containerships. First the yearly TCO is calculated as the sum of all yearly operational costs and the annuity of capital expenditures for the use of a vessel for the period of one year, where the annuity of CAPEX is defined as: $r*CAPEX/[1-(1-r)^{-n}]$, with $r$ = WACC and $n$ = 25 year. The yearly operational costs are fuel cost and maintenance and repair cost for use of a vessel for one year. CAPEX is the cost for the engine, fuel storage and fuel supply system. The investment cost items of CAPEX have been calculated as annual depreciation over the lifetime of 25 year. For every vessel category, the TCO is calculated for the fuel types VLSFO, bio-methanol, HVO, FAME, FT-diesel and biomethane. VLSFO-fuelled ships are considered the reference, because VLSFO is the dominant fuel in shipping (Faber, et al., 2020).

For a comparison of the TCO for similar vessels using different biofuels, the TCO results for alternative-fuelled vessels are presented as total TCO and from the perspectives of CAPEX, non-fuel OPEX and fuel costs. The fuel cost is significant, so it is presented separately from other OPEX. Other OPEX includes bunkering costs and maintenance and repair costs. By showing the cost figures by cost component next to the reference, a clear comparison of the TCO ratio for alternative-fuelled vessels and the VLSFO reference can be made. Alternative fuels are assumed to have been acquired at the lowest documented production-cost price. The figures for the TCO using the upper-range fuel costs are available in Appendix B.1.

***Bulkers***

The TCO for bulkers sailing on biofuel in the 35,000-59,999 deadweight-tonnes (DWT) category is indicated in Figure 32 as a percentage of the VLSFO[11]. All fuels have a lower volumetric energy density than VLSFO (about 9% lower), meaning they offer a lower energy (MJ) content per litre of fuel. Due to the lower energy density, a higher frequency of bunkering is necessary to fulfil the ship's annual transport activities, which are stated as equal for all ships, as explained in *Bunkering Costs* above.

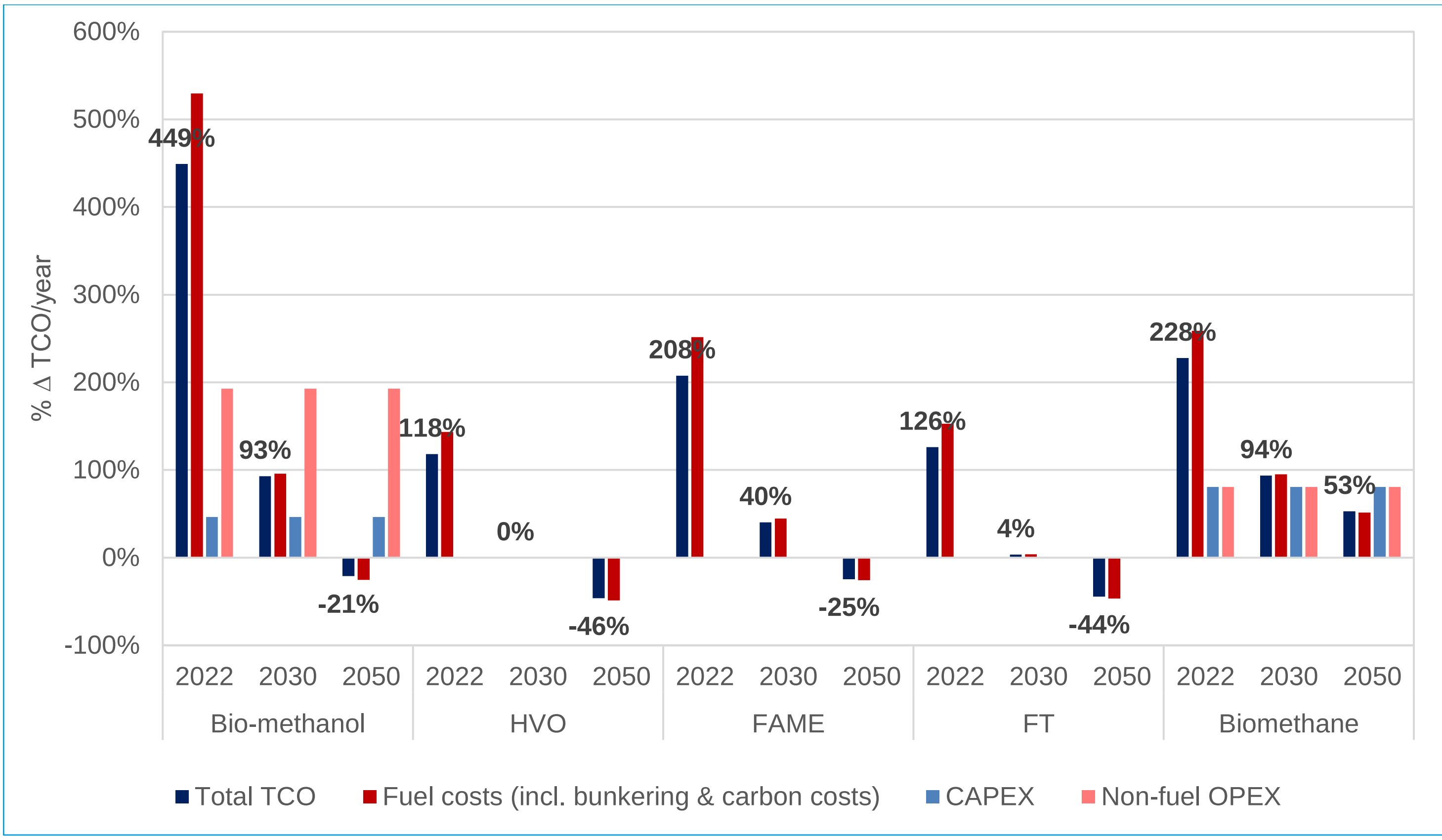


Figure 32. Annual difference in TCO of alternative fuelled bulk ships (35,000-59,999 dwt) with increased bunkering frequency

Figure 32 indicates the TCO increase for a bulker running on all the alternative shipping fuels. The highest cost component of the TCO for all alternative fueled ships is the fuel cost. The total difference in TCO per year is indicated in % figures in the graph.

The following significant outcomes concerning the difference in yearly TCO of alternative fueled bulkers is outlined:

- In the projected year 2030, the TCO of some alternative fuels (HVO and FT) is at a similar level as the estimated TCO for VLSFO. For the other alternative fuels, the TCO is still at a higher level though clearly lower than in 2022. This is due to the projected increase of the oil price as well as carbon costs and a consequent decrease in the cost difference between biofuels and VLSFO.
- In the projected year 2050, considering a carbon price of 150 EUR per tonne $CO_2$, all biofuels except biomethane show a lower TCO compared to VLSFO-fuelled bulkers in 2050.
- Upfront CAPEX is about 3-4 million USD for bio-methanol-fueled bulkers in this size category. When presented as an annuity, this cost item is about 30% higher than CAPEX of VLSFO powered bulkers.

[11] The price of VLSFO is based on the EU ETS revision and from open market data on bunkering.

This is also confirmed in studies by MAN indicating CAPEX of about 3-5 million USD higher compared to conventional fuel oil-powered vessels (MAN Energy Solutions, 2018) (MAN Energy Solutions, 2018).

- By definition of drop-in fuels, there is no difference in CAPEX for drop-in fuels because VLSFO engines and fuel systems can be used.
- The CAPEX for biomethane is about 80% higher compared to CAPEX for VLSFO powered vessels.
- OPEX of bio-methanol vessels, which represents maintenance and repair cost, is almost three times as high as the M&R cost of VLSFO-powered vessels.

Still, operating alternative-fuelled vessels may be not cost-competitive as the availability of alternative fuels is not optimal in every port, and conventional bunkering infrastructure should be available at those ports. Bio-methanol and biomethane offer lower energy density than VLSFO, resulting in higher bunkering cost for these two fuels. The bio-diesel types of fuels have the same CAPEX as VLSFO ships, as they can be used in conventional engines.

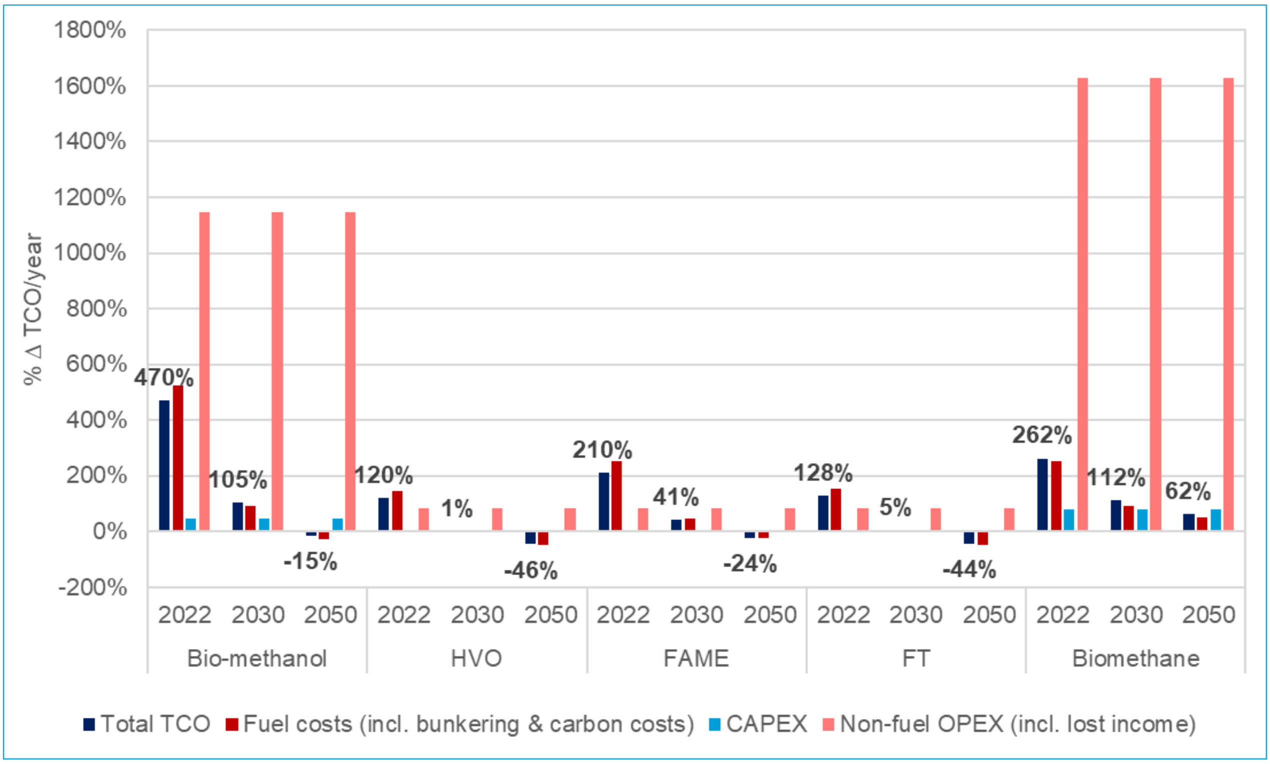


Figure 33. Annual TCO of alternative-fuelled bulk ships (35,000-59,999 dwt) with increased fuel storage

Another option for addressing the differing energy density of alternative fuels is to increase onboard storage to avoid more frequent bunkering. In this situation, vessels would have to increase their fuel storage in line with the difference in the volumetric density of the fuel.

Tanks are assumed to have been adjusted to carry a similar energy content per bunkering (compared to bunkering VLSFO). In this way, similar bunkering frequency can be maintained, which may be practical for the transport schedule of the vessel.

A consequence of altering onboard fuel storage is that the tanks are expanded at a cost to the vessels' cargo-carrying capacity. In Figure 33 (above) the annual cost of less cargo capacity is seen as a component of the TCO if the same bunkering frequency was continued for the bulker. The cost of the lost capacity is calculated by factoring in the amount of capacity sacrificed for larger fuel tanks. In practice, this means a lower amount of bulk can be transported, leading to a loss of revenue and greater unit operating costs. This is included in the totals of the vessels' calculated TCO and under non-fuel OPEX. The total difference in TCO per year is indicated in % figures in the graph.

The estimated loss of revenue when the onboard fuel storage is expanded at the expense of cargo capacity can be significant, which is reflected in the increased additional non-fuel OPEX. This is the case especially for bio-methanol and even more for biomethane, compared to the case in which frequency of bunkering is increased, due to the significantly lower energy density of these fuels. For these fuels, the strategic option is clearly a higher bunkering frequency, as the loss in revenue due to lower cargo capacity outweighs the cost of more frequent bunkering.

***Container ships***

The TCO for container ships in the 14,500–20,000 TEU range is indicated in Figure 34 The fuel properties are applied, leading to higher bunkering costs for lower energy-dense fuels. The total difference in TCO per year is indicated in % figures in the graph.

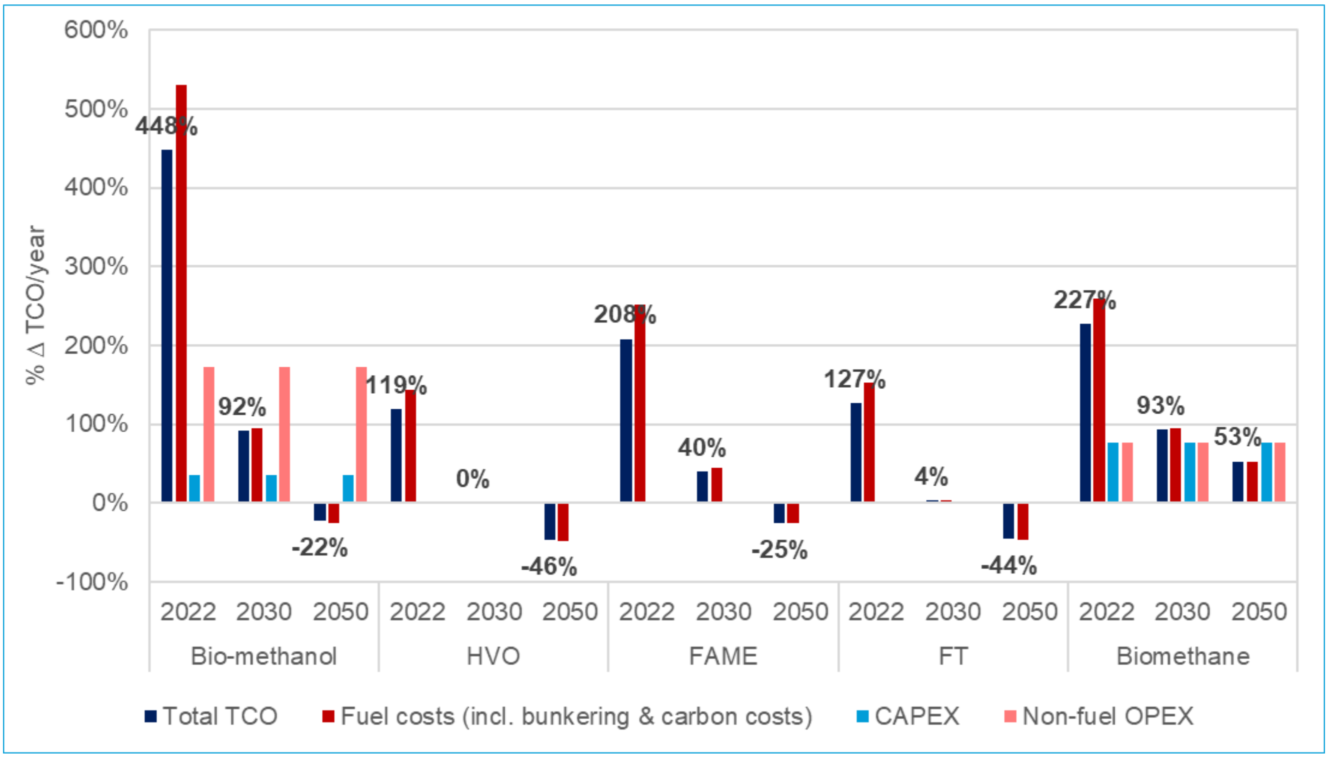


Figure 34. Annual difference in TCO of alternative-fuelled container ships (14,500–20,000 TEU) with increased bunkering frequency

The following significant outcomes concerning the difference in yearly TCO of alternative fuelled container ships is outlined:

- The cost estimates present similar TCO trends for container ships and bulker vessels.
- The largest cost component in the TCO for all alternative-fueled ships is the fuel.
- The fuel cost, including bunkering and carbon costs, of the alternative fuels remains higher than of VLSFO in the projected year 2030, though the difference for an HVO- and FT-fuelled ship is small. In 2030, the TCO of HVO and FT is therefore also at a similar level as the estimated TCO for VLSFO.
- In 2050, due to rising fuel oil prices and higher carbon costs, the cost of most alternative fuels, except biomethane, is projected to be lower than of VLSFO.
- Other cost aspects as CAPEX and OPEX show similar cost differences for container ships as indicated for bulkers. Upfront CAPEX for biomethane is approximately 12 million USD higher than CAPEX for an VLSFO containership. For bio-methanol, the difference in CAPEX is about 6 million USD.

Container ships could expand onboard fuel storage to avoid higher bunkering frequencies. The associated loss of revenues, indicated as an additional cost in the TCO (see non-fuel OPEX), is presented in Figure 35.

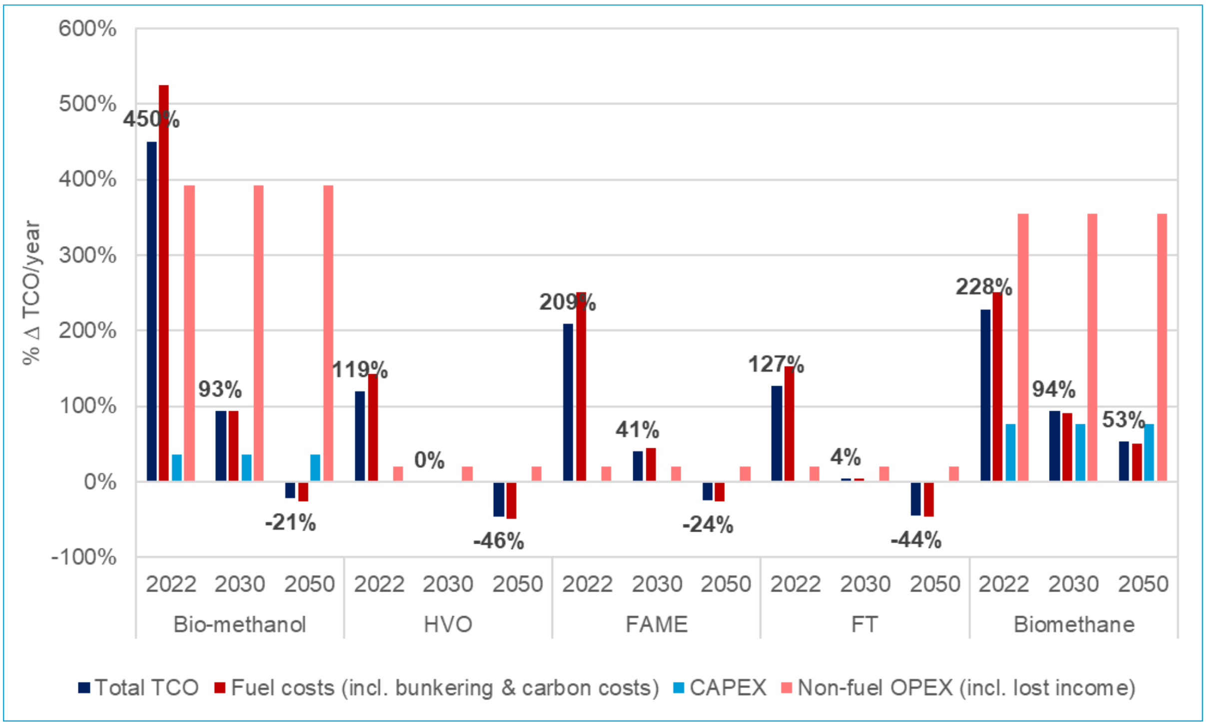


Figure 35. Annual difference in TCO of alternative-fuelled containerships (14,500–20,000 TEU) with increased fuel storage

The estimated revenue lost when onboard fuel storage is expanded at the expense of cargo capacity is lower for the container ships than for the bulkers considered here. This may be attributable to the significantly larger size of the container ship being studied. Higher bunkering rates also increase costs. The loss in revenue is estimated to be slightly higher for all fuels compared to when a ship increases bunkering frequency. Still, the strategic option is to increase the bunkering frequency, as the loss in revenue from lower cargo capacity outweighs -- in most cases and for most fuels -- the cost of more frequent bunkering.

### 2.5.6 Conclusions

Alternative-fuelled vessels are currently not cost competitive with vessels operating on conventional VLSFO. In 2030, considering carbon costs for VLSFO, the TCO of some alternative fuels (HVO and FT) is at a similar level as the estimated TCO for VLSFO. Depending on the actual fuel oil price (including excise duty), the TCO for HVO and FAME can be either higher or lower than fuel oil. Most alternative fuels show promising TCO figures from 2030 onwards (see table below), with approx. 20-45% lower annual costs compared to VSLFO in 2050, considering carbon costs for VLSFO. Especially bio-methanol shows significant cost reduction. Only biomethane-fuelled ships still show a higher TCO in 2050 compared to VLSFO-fuelled ships.

Table 36. Comparison of Biofuel Cost Developments*

| Fuel | Feedstocks | Cost 2030 | Cost trend 2030 - 2050 |
|---|---|---|---|
| FAME | FOGs (fats, oils and grease) | -€ | Falling |
| FAME | Vegetable oils | -€ | Falling |
| HVO | FOGs | V | Stable |
| HVO | Vegetable oils | V | Stable |
| FT diesel | Lignocellulosic biomass | V | Falling |
| DME | Lignocellulosic biomass | V | Falling |
| Methanol | Lignocellulosic biomass | -€ | Falling |
| Ethanol | Sugar & starch crops | -€ | Falling |
| Ethanol | Lignocellulosic biomass | V | Falling |
| SVO | Vegetable oils | -€ | Stable |
| Pyrolysis bio-oil | Lignocellulosic biomass | - | Stable |
| HTL biocrude | Lignocellulosic biomass | V | - |
| Liquefied Bio Methane (LBM) | Waste and residues (digestion) | €€ | Increasing |
| Liquefied Bio Methane (LBM) | Lignocellulosic biomass | V | Stable |

*-€: lower than 2020 prices; V: similar to 2020 prices; €€: higher than 2020 prices

In cases where fuel tanks are expanded and the cost of cargo-capacity losses are included in the TCO, there is a significantly higher cost for bulkers sailing on bio-methanol and biomethane, due to the significantly lower energy density of these fuels. This is the case even when considering lower bunker costs compared to the situation in which alternative-fuelled vessels have no expanded fuel storage and have to increase bunkering frequency.

## 2.6 Discussion state of play biofuels in shipping

The previous sections discussed the levels of technology readiness for the shipping-related biofuel options, as well as their potential for GHG reduction and other aspects of sustainability, such as availability of feedstocks, suitability and cost developments. Those aspects were used to identify the most promising biofuel options, which were scored on a five-point scale (--, -, 0, +, ++).

***Technology readiness***

Those symbols are translated into a numerical representation in the table below, according to their levels of technology readiness:

Table 37. Assessed level of maturity per production pathway.

| Fuel category | End product | Production pathway | Technology readiness (2019) | |
|---|---|---|---|---|
| Biodiesel | FAME | Transesterification | ++ | 10 |
| | HVO | Hydrotreatment | ++ | 10 |
| | HVO (from wood) | Wood extractives pulping/ catalytic Upgrading | + | 8/9 |
| | HVO (from algae) | Algae/oil extraction / catalytic upgrading | - | 4/5 |
| | FT diesel | FT synthesis | 0 | 6/8 |
| | DME | Lignocellulosic gasification | 0 | 6/8 |
| Bio-alcohols | Bioethanol | Fermentation | ++ | 10 |
| | | Waste based | + | 8/9 |
| | | Lignocellulosic hydrolysis | + | 8/9 |
| | Bio-methanol | Waste based | + | 8/9 |
| | | Black liquor gasification | 0 | 6/8 |
| | | Lignocellulosic gasification | 0 | 6/8 |
| Biocrudes | SVO | Vegetable oils | ++ | 10 |
| | Pyrolysis oil | Lignocellulosic Pyrolysis/ catalytic upgrading | - | 5/6 |
| | HTL biocrude | Lignocellulosic Hydrothermal liquefaction/ catalytic refining | -- | 2/4 |
| | Solvolysis oil | Lignocellulosic hydrolysis / solvolysis | - | 4/5 |
| Gaseous biofuels | Liquefied biomethane | sludge/maize/manure/ residues Fermentation / digestion | ++ | 10 |
| | Liquefied biomethane | Lignocellulosic Gasification | 0 | 6/8 |

To reduce the long list, the biofuel options with a poor score on TRL and those without major industry interest, such as SVO and the bioethanol options, were excluded.

***Sustainability based on potential for GHG reduction***

The biofuels with a relatively good TRL score are then scored on their GHG-reduction potential as a main indicator for sustainability. Food and feed crops, such as vegetable oils, score poorly, because they can increase rather than reduce emissions. FOGs (waste fats, oil and grease) and biomethane from lignocellulosic biomass can emit up to 23.5 $gCO_2/MJ$ (on a WTW basis), while the biofuels scoring ++ only emit between 3.1 and 8.2 $gCO_2/MJ$.

Biomethane from digestion scores ‘0’ due to its large range of emission-reduction potential. Its potential to reduce $CO_2$ emission can be limited, but negative emissions also could occur as result of avoided emissions (in the case of manure).

Table 38. Sustainability per production pathway

| Fuel | Production pathway | Feedstock | Sustainability |
|---|---|---|---|
| FAME | transesterification | FOGs | + |
| FAME | transesterification | vegetable oils | -- |
| HVO | hydrotreating | FOGs | + |
| HVO | hydrotreating | vegetable oils | -- |
| FT diesel | gasification + FT synthesis | lignocellulosic biomass | ++ |
| DME | gasification + fuel synthesis | lignocellulosic biomass | ++ |
| Bio-methanol | gasification then fuel synthesis | lignocellulosic biomass | ++ |
| biomethane | digestion | waste and residues | 0 |
| biomethane | gasification | lignocellulosic biomass | + |

### *Feedstock availability*

The availability of feedstock is an important indicator of sustainability, because it determines the extent to which scaling up (to meet the large demands of shipping, for example) would be possible without high risks to the environment.

It is reasonable to conclude that lignin biomass would be highly available as feedstock, while waste and residues for digestion would be more moderately available. FOG is available to a limited extent. These conditions may be problematic when scaling up those production pathways.

Table 39. Feedstock availability per production pathway

| Fuel | Production pathway | Feedstock | Feedstock availability |
|---|---|---|---|
| FAME | transesterification | FOGs | - |
| HVO | hydrotreating | FOGs | - |
| FT diesel | gasification + FT synthesis | lignocellulosic biomass | ++ |
| DME | gasification + fuel synthesis | lignocellulosic biomass | ++ |
| Bio-methanol | gasification then fuel synthesis | lignocellulosic biomass | ++ |
| biomethane | digestion | waste and residues | 0 |
| biomethane | gasification | lignocellulosic biomass | ++ |

### *Suitability*

In terms of suitability, the biofuels that can be used as drop-in fuels score ++, while FAME scores + due to the minor modifications needed. Biomethane would also score ++ once it emerges as a drop-in fuel to replace fossil-derived LNG.

Table 40. Suitability per production pathway

| Fuel | Production pathway | Feedstock | Suitability |
|---|---|---|---|
| FAME | transesterification | FOGs | + |
| HVO | hydrotreating | FOGs | ++ |
| FT diesel | gasification + FT synthesis | lignocellulosic biomass | ++ |
| DME | gasification + fuel synthesis | lignocellulosic biomass | 0 |
| Bio-methanol | gasification then fuel synthesis | lignocellulosic biomass | ++ |
| biomethane | digestion | waste and residues | ++ |
| biomethane | gasification | lignocellulosic biomass | ++ |

Table 41. Projected cost trends for Biofuels

| Fuel | Feedstocks | Cost 2030 | Cost trend 2030 - 2050 |
|---|---|---|---|
| FAME | FOGs | -€ | Falling |
| FAME | Vegetable oils | -€ | Falling |
| HVO | FOGs | V | Stable |
| HVO | Vegetable oils | V | Stable |
| FT diesel | Lignocellulosic biomass | V | Falling |
| DME | Lignocellulosic biomass | V | Falling |
| Bio-methanol | Lignocellulosic biomass | -€ | Falling |
| bioLNG | Waste and residues (digestion) | -€ | Falling |
| bioLNG | Lignocellulosic biomass | V | Stable |

*-€: lower than 2020 prices; V: similar to 2020 prices; €€: higher than 2020 prices

***Selection of biofuels for chapters 3 and 4***

The above individual scores have been combined into an overall score. Based on an equal weighting of criteria (with 5 points for ++, 4 for +, etc; and 5 points for -€ and falling trend towards 2050, 3 points for V and falling and 1 point for V and stable) the shortlist of biofuels is ranked as follows:

1. Bio-methanol, FT diesel, biomethane from digestion of waste and residues and DME arrive very close together at the top three highest scores
2. FAME from FOGs, biomethane from gasification arrive close together at the following two scores
3. FAME from vegetable oils, HVO from FOGs and from vegetable oils arrive in the following three scores

Although they appeared ranked as above, the top three fuels have very similar scores. As the knowledge about these fuels (production efficiencies, costs, suitability, sustainability, etc) is constantly evolving the order of the ranking may change if the analysis is repeated in the future.

All the biofuels on the short list are further analysed in Chapter 3 and 4 below. Only biomethane and methanol were excluded from the HAZID analysis (Task 3) as these fuels are pure drop-in fuels on vessels that are already operating on LNG and methanol, respectively.

# 3. Safety and environmental regulations, standard and guidelines

## 3.1 Bunkering, on-board storage, handling and use of Biofuels - Introduction

Liquid or gaseous biofuels are often considered advantageous from the technical perspective, due to their potential to 'drop-in' and replace fossil-derived fuels, take advantage of existing infrastructure and equipment, and reduce carbon emissions.

Furthermore, adoption is encouraged by regulatory regimes for biofuels often referring to existing standards, rules, or codes of practice for handling the corresponding petroleum or fossil-based fuel types.

However, the practice of including liquid biofuel in petroleum fuels as blends has been limited; road fuels have the most experience with blending biodiesel, in proportions up to 20%. Applications in other sectors are less frequent.

Also, the regulatory development of quality standards for marine biofuel relies on experience gained with biofuel blends across multiple applications, together with experience from the use of fossil fuel equivalents and is typically facilitated by performance testing on land or at sea.

Shipping's advantage over other sectors is that marine engines, particularly slow speed 2-stroke engines and large medium speed engines, are specifically designed to handle residual and distillate fuels with a wide range of properties, and a widening portfolio of dual-fuel capabilities. They are therefore better suited to accommodate drop in biofuels without having to change hardware.

This section provides an overview of the current safety standards, regulations and guidelines related to biofuels, together with an overview of the policies driving demand for renewable fuels and including requirements for bunkering, onboard storage, handling and their use for propulsion or power generation on vessels.

## 3.2 International

The following subsections discuss current global regulations, standards and guidelines related to the use of biofuel in marine applications.

### 3.2.1 International Organization for Standardization (ISO)

***ISO Marine Fuel Oil Quality Standard***

The most widely used fuel standard in the marine industry, which covers the conventional residual or distillate fuel grades, is ISO 8217:2017. The standard -- *Petroleum products – Fuels (class F) – Specifications of marine fuels* -- specifies the requirements for fuel oils for use in marine diesel engines and boilers prior to conventional onboard treatment. There are seven categories of distillate fuels and six for residual fuels.

The ISO standard defines fuel as hydrocarbons from petroleum crude oil, oil sands and shale and hydrocarbons from synthetic or renewable sources similar in composition to petroleum distillate fuels. Where permitted, it includes blends of the previously mentioned products with a fatty acid methyl ester (FAME) component and provides specifications for distillate (DM) grades, distillate FAME (DF) grades and residual (RM) grades of marine fuel oils.

The 2017 edition introduced additional grades of FAME distillates (DFA, DFZ and DFB grades), including provisions for biofuel blends containing up to 7% v/v FAME in the category DF grade fuels. Other marine fuel grades DMA, DMZ, DMB and RM may only include a minimum ('*de minimis*') volume blend of FAME, meaning a blend proportion that is acceptable for applications not designed specifically to handle FAME (Table 42).

Table 42. Distillate and Residual Marine Fuels according to ISO 8217

| Fuel Type (ISO 8217 Ref.) | ISO-F- Fuel Grade | FAME Allowed v/v |
|---|---|---|
| Distillate Marine Fuels (Table 1) | DMX | 0% |
| | DMA, DMZ, DMB | *De minimis* |
| | DFA, DFZ, DFB | 7% |
| Residual Marine Fuels (Table 2) | RMA, RMB, RMD, RME, RMG, RMK | *De minimis* |

Within the ISO 8217 standard, the FAME used for blending is defined as meeting the quality requirements of EN14214 or ASTM D6751. Additional information on bio-derived products including FAME is provided in Annex A of ISO 8217.

At the time of publication (2017), the standard recognised that some fuels were being offered to the marine market -- generally to meet the IMO's regulations on sulphur limits in fuels, but also due to the increased interest in biofuels – that did not conform to categories of conventional distillate or residuals. The intention was to update the standard to cover these fuels as industry experience develops. Currently, the next revision of the standard is shown as at a preparatory stage of development as ISO/AWI 8217.

To assist industry with the adoption of the so called '2020 fuels', the ISO's related technical committee (ISO TC28/SC4/WG6) offered an interim solution in September 2019 with the publicly available specification ISO/PAS 23263. Developed in cooperation with ship owners, ship operators, classification societies, fuel testing services, engine designers, marine fuel suppliers, traders, fuel additive suppliers and the petroleum industry, this specification defines general requirements that apply to all 0.50 mass % sulphur fuels and confirms the applicability of ISO 8217 for those fuels. It gives technical considerations which might apply to particular fuels covering the following characteristics:

- Kinematic viscosity
- Cold flow properties
- Stability
- Ignition characteristics
- Catalysts fines

Additionally, it provides considerations on the compatibility between fuels and additional information on Annex B (Deleterious materials) of ISO 8217:2017.

The working group is also developing 'performance' requirements for each grade of marine fuel that could allow for up to 50% blend of FAME that meets the quality standards of either ASTM D6751 or EN 14214. This is particularly relevant since ISO 8217:2017 indicates that the specific energy of marine fuels can be calculated as given in Annex H (Specific energy) to the standard. However, industry experience suggests the formulae are not accurate for biofuels and the calorific value has to be measured in order for the operator to be aware of the fuel properties and for the engines to run efficiently. This remains a gap in the existing ISO marine fuel standard.

***ISO Marine LNG Fuel Quality Standard***

In response to growing industry interest and applications for LNG and demand for an internationally recognised standard for marine fuels, the ISO developed 23306:2020, a standard for the *Specification of liquefied natural gas as a fuel for marine applications*.

While it was formed from industry experiences with the application of fossil-derived LNG, the standard also applies to LNG derived from other sources, including shale gas, coalbed methane, biomethane or synthetic methane. It therefore can be applied to both LNG derived from fossil fuels or other renewable sources.

As with all international standards, this was developed by a broad range of stakeholders, including members of CIMAC (the International Council on Combustion Engines). However, concerns have been raised about the robustness of the standard, in particular the method for determining the methane number (MN) of the LNG and the potential for particles or debris. The standard contains information on particles in Annex E, but it does not set quality limits.

The MN is calculated from the LNG's composition and gives an indication of how resistant a fuel is to auto-ignition, which causes an engine to 'knock' when operated.

The ISO 23306:2020 standard does not define a minimum the MN value, but it requires the method for calculating MN and the minimum value to be agreed between the supplier and user. The specifications of the original equipment manufacturer (OEM) need to be considered and the fuel supplier needs to calculate the MN at point of delivery.

MN can be calculated in accordance with the PKI (Propane Knock Index) method. The MWM method described in Annex A of the CEN EN 16726 standard, which is the method preferred by the OEMs, is also acceptable.

For more information on the impact of variances in the quality of gas see the CIMAC position paper *Impact of Gas Quality on Gas Engine Performance*.

Other ISO Standards applicable to LNG as fuel for ships, include:

- ISO/TS 18683:2015. Guidelines for systems and installations for supply of LNG as fuel to ships. Published 2015-01
- ISO 20519:2017. Ships and marine technology – Specifications for bunkering of liquefied natural gas-fuelled vessels. Published 2017-02
- ISO 28460:2010. Petroleum and natural gas industries – Installation and equipment for liquefied natural gas – Ship-to-shore interface and port operations
- ISO 21593:2019. Ships and marine technology. Technical requirements for dry-disconnect/connect couplings for bunkering liquefied natural gas
- ISO/PRF 20519 Ships and marine technology — Specification for bunkering of liquefied natural gas fuelled vessels

***ISO Marine Methyl/Ethyl Alcohol Fuel Quality Standard***

During the development of IMO's safety requirements for the use of methyl/ethyl alcohols as marine fuels, it was recognised that the marine industry would benefit from the development of a marine fuel standard such as those that apply to conventional distillate and residual fuels and LNG. Following the request from IMO, the ISO's standard for marine applications of methanol fuel -- ISO/AWI 6583 *Specification of methanol as a fuel for marine applications* -- is currently being prepared. It is not clear if this will also cover ethanol, or if a separate standard will be developed. However, the standard is expected to follow the approach of LNG ISO 23306 standard and cover methanol derived from fossil and renewables. It is also not clear how the ISO standard will align with existing industry reference specifications, such as the reference methanol specification from the International Methanol Producers and Consumers Association (IMPCA).

Methanol is synthesised, commercially traded and transported at high levels of purity, and it therefore does not face the same challenges as LNG, which has wide range of properties, depending on the origin of the fossil fuel. However, the lack of an ISO methanol marine fuel standard remains one of the barriers to take up.

### 3.2.2 ASTM International

The ASTM International D6751-20a *Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels* is an internationally recognised standard for biofuel blend fuel stocks of various grades, classified by their sulphur and partially reacted glyceride contents. This specification is limited to pure (B100) biodiesel, specified as mono-alkyl esters of long chain fatty acids derived from vegetable oils and animal fats.

In addition to its requirements for fuel chemicals and characteristics, this standard includes information in ASTM D6751-20a Appendix X2 about the long-term storage of B100 biofuels. In general, it provides guidance on fuel storage, fuel additives for stability, the frequent testing and monitoring of fuel and its storage temperatures, and for creating storage conditions free from water or corrosive materials.

ASTM carries the following relevant standards from the Subcommittee D02.E0 on Burner, Diesel and Non-Aviation Gas Turbine Fuels:

- ASTM D7544-12:2017 Standard Specification for Pyrolysis Liquid Biofuel. Two grades of pyrolysis liquid biofuels are defined, but neither are allowed for use in marine applications without modifications. Typical engine modifications to accommodate the use of biofuels, including pyrolysis liquid biofuels, include adjustments in engine timing, fuel pump and injection rates and capacities, possible changes to the filter systems, and tank or pipe sizing due to differences in stored energy density of the fuels.
- ASTM D7467-20a Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20). Where D6751 defines specifications for unblended B100 biofuels, this specification applies to the blended fuels of various percentages.

The ASTM D975-21 international standard covers seven grades of diesel fuel oils suitable for various types of diesel engines. The grades No.1-D S15, No.1-D S500 and No.1-D S5000 cover light middle distillates with 15ppm, 500ppm and 5000ppm maximum sulphur content, with the No.2-D S15, No.2-D S500 and No.2 D S5000 covering the middle distillate diesel with the same maximum sulphur contents. Grade No.4 D is a heavy distillate fuel or blend of distillate and residual fuel.

In the absence of standards covering specific biofuels, particularly marine standards, it is typical that compliance with existing land-based diesel fuel standards such as ASTME D975-21 are used to benchmark the fuels at the commercial level. For European countries this is the EN 590 diesel fuel standard. For example, the so-called drop in renewable diesels such as HVO meet the EN 590 and ASTM D975 diesel fuel standards.

### 3.2.3 International Maritime Organization Requirements

#### 3.2.3.1 SOLAS

The IMO's International Convention for the Safety of Life at Sea (SOLAS, 2020), as amended, lays out the basic safety regulations for most ships travelling internationally. While biofuels are not explicitly discussed, aspects such as overall structure, layout, fire protection, firefighting measures, ship subdivision, machinery space and equipment requirements are included, and are applicable to fuel systems and equipment using biofuels or biofuel blends.

The SOLAS convention comes from a time when coal-powered ships were in operation and it was the start of the transition to oil-fuelled ships. As such, the majority of its requirements for fuels are based on the distillate and residual fuels derived from petroleum refining.

Historically, SOLAS has prohibited the use of fuel oils with less than a 60˚C flashpoint, except for use in emergency generators (where the flashpoint limit is 43˚C) and subject to other requirements detailed in SOLAS Chapter II-2 Regulation 4.2.1.

To accommodate growing interest in the application of gaseous and liquid fuels with flashpoints under 60˚C, the IMO adopted the *International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels* (IGF Code) by including a new Part G to SOLAS II-1. See Section 3.2.3.4 for more information on the IGF Code.

All liquid biofuels, or biofuel blends, intended as 'drop-in' fuels to replace conventional residual or distillate fuel oils must meet the SOLAS requirements for a flashpoint (closed cup test) of not less than 60˚C.

In the years preceding the adoption of the IMO global fuel sulphur limit of 0.50% in 2020, concerns were raised on the availability of sufficient quantities of fuel to meet the switch in fuel demand. Those concerns proved largely unfounded, but it was suggested that the marine industry may see more blending of fuel oils derived from the land-based supply chain, which are subject to lower regulatory limits on flashpoints (typically 52-55˚C).

Acceptance of lower SOLAS flash points for fuel oils has proven to be a contentious issue. Currently, the IMO has asked the CCC sub-committee to consider how best to proceed with developing draft amendments to the IGF Code that will address new safety provisions for ships using low-flashpoint oil fuels.

There is recognition of the need for IMO requirements for such fuels, and it has been suggested that these provisions should cover an increased range of oil-based fossil fuels, liquid biofuels, synthetic fuels -- and any mixture thereof -- with flashpoints under 60˚C. However, this topic is one of a number within a heavy CCC work programme, and the way ahead has yet to be finalised.

The lack of current regulation for fuel oils with a flashpoint between 52˚ and 60˚C is not seen as a significant barrier to biofuel take-up (since many have flashpoints above 60˚C), however this is a gap in the current IMO instruments.

With regard to the application of liquid biodiesels under SOLAS, this is an area of debate and interpretation since SOLAS does not contain any prescriptive requirements for the use of biodiesels as fuel. The driving obligation on operators is that under SOLAS I/Regulation 11 "*The condition of the ship and its equipment shall be maintained to conform with the provisions of the present regulations* …".

Under SOLAS II-1/Regulation 3-1 there is also a requirement that "… *ships shall be designed, constructed and maintained in compliance with the structural, mechanical and electrical requirements of a classification society which is recognized by the Administration* …".

In the context of the application of fuel oils under SOLAS it has to be recognised that the instrument is deliberately limited in requirements. This to recognise the wide specifications of residual and distillate and blended fuels that are utilized in the maritime sector. IMO also does not mandate fuel supply in accordance with the ISO 8217 standard, and that standard itself does not preclude additional fuel handling and cleaning onboard required to enable use in the machinery and equipment onboard.

This approach supports the application of biodiesels with limited SOLAS actions beyond those already in place for operators and equipment designers utilising other grades or specifications of liquid fuel oils and liquid biofuels or biodiesels.

Effectively SOLAS currently only indirectly regulates this through the high-level SOLAS intent and application of classification society requirements. Further information on operator's obligations under the ISM Code, IACS/classification society requirements and how action at IMO to develop guidelines similar to those developed for the 2020 fuels can support clarification of the requirements under SOLAS and further application of biodiesels.

#### 3.2.3.1.1 ISM Code

The IMO's International Safety Management Code (ISM Code) provides an international standard for the safe management and operation of ships and to prevent pollution. Intended to have a widespread application, based on general principles and objectives, this Code requires operators to assess all risks to a specific company's ships, personnel, and the environment, and to establish appropriate safeguards.

With respect to biofuels, the fuel supplier's fuel specifications and BDN, MSDS sheets, equipment manufacturer's recommendations and industry stakeholder guidelines would provide the basis for operators to undertake their ISM Code obligations. While there are some risks to equipment and operation with certain biofuels, the 'drop-in' nature and similarity to conventional residual or distillate fuels makes application relatively straightforward.

The deep-sea fleet particularly are experienced with application of fuels with a wide range of properties and the operational practices for tank cleaning, separation, stability and compatibility checks, fuel changeover procedures, and machinery adjustments for the range of density, viscosity and combustion characteristics that are normal in marine fuel supplies.

For the air pollution obligations, many operators have been undertaking trials of biofuels under the provisions of IMO's MARPOL Annex VI regulations 3.2 or regulation 4 as 'equivalent' – see section 3.2.3.2.1 below. For the safety side, there are similarities to the guidance on the development of a ship implementation plan provided by IMO's MEPC.1/Circ.878 for the consistent implementation of the 0.50% fuel sulphur limit; the so called 2020 fuels.

That instrument considers that a ship implementation plan is not mandatory and could cover various items relevant for the specific ship, including the below items, as may be also interpreted as applicable for the application of biofuels:

- Risk assessment and mitigation plan (impact of new fuels)
- Fuel system modifications and tank cleaning (if needed)
- Fuel capacity and segregation capability
- Fuel changeover procedures
- Documentation and reporting

MEPC.1/Circ.878 contains other useful information that may be relevant for application to biofuels and therefore the lack of a similar biofuel specific recommendations is not seen as a barrier to take up, however industry may benefit from a similar biofuel publication to facilitate a harmonized approach and that can support the ISM Code obligations; this is identified as a gap in section 3.5 to this report.

#### 3.2.3.2 MARPOL

The IMO's International Convention for the Prevention of Pollution from Ships (MARPOL, 2017) sets out international requirements to prevent pollution from ships travelling internationally or between two member states. The MARPOL convention is divided into these annexes covering specific pollution controls:

- Annex I – Regulations for the prevention of pollution by oil
- Annex II – Regulations for the control of noxious liquid substances in bulk
- Annex III – Regulations for prevention of pollution by harmful substances carried by sea in packaged form
- Annex IV – Regulations for the prevention of pollution by sewage from ships
- Annex V – Regulations for the prevention of pollution by garbage from ships

The last annex to be added to the convention, Annex VI – Regulations for the prevention of air pollution from ships -- was adopted by the Protocol of 1997 to MARPOL. It introduced the IMO's regulatory framework for air pollution and some key air-pollutant controls for shipping, including ozone-depleting substances, nitrogen oxides (NOx), sulphur oxides (SOx), volatile organic compounds (VOCs), shipboard incineration and fuel oil quality. By later amendment, the IMO introduced additional regulations for energy efficiency and more recently carbon intensity.

Four regulations in MARPOL Annex VI are important when considering biofuels as marine fuel. They are:

##### 3.2.3.2.1 Regulation 13 – Nitrogen Oxides (NOx)

To reduce the harmful effects of NOx emissions on human health and the environment, regulation 13 of Annex VI set the limits for NOx emissions from ships' diesel engines. It mandates compliance for all marine diesel engines greater than 130 kW installed on vessels subject to MARPOL Annex VI with the applicable emission limit, except for engines used solely for emergencies.

Marine diesel engines are defined by the IMO as any reciprocating internal combustion engine operating on liquid or gaseous or dual fuels, including engines operating on the Diesel or Otto combustion cycles.

The regulation's NOx limits are based on engine rated speed (see Figure 36, below), with the lowest limits applicable to medium and high-speed engines. The application is tied to the date the ship was built.

When Annex VI entered into force on 19 May 2005, the Tier I NOx limit was retrospectively applied to engines fitted on ships with keels laid on or after 1 January 2000. Further NOx limits were introduced in 2008, when Annex VI and its NOx Technical Code was amended. Those amendments introduced the global Tier II limit from 1 January 2011.

The amendments also introduced the Tier III limit, which is only applicable in Emission Control Areas (ECAs) and reduced NOx emissions approximately 80% compared to the Tier I limit. The Tier III limits are applicable to NOx ECAs only after those regimes are recognised at the IMO.

Currently, the only active NOx ECAs are the North American coasts and United States Caribbean Sea, which entered into force on 1 January 2016, and the Baltic and North Sea ECAs, which were originally only designated SOx ECAs and became NOx ECAs from 1 January 2021.

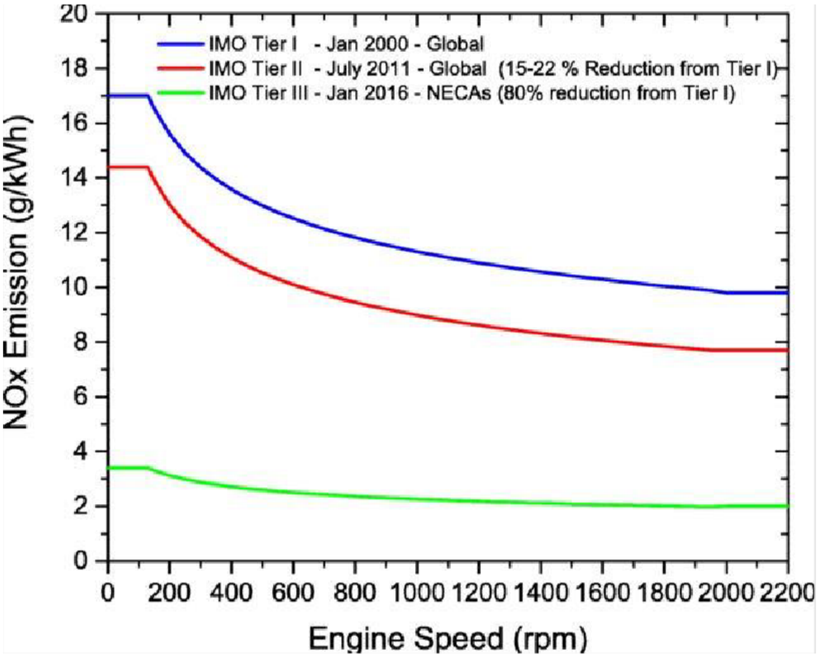


Figure 36. MARPOL 73/78 Annex VI Reg 13 - NOx emission limits with respect to engine speed

The key instrument supporting Regulation 13 is the NOx Technical Code (NTC), which is in large parts based on the ISO 8178 series of standards "Reciprocating internal combustion engines – exhaust emission measurement", specifically the following parts (showing current revision dates):

- ISO 8178-1:2020 Part 1: Test-bed measurement systems of gaseous and particulate emissions
- ISO 8178-4:2020 Part 4: Steady state and transient test cycles for different engine applications
- ISO 8178-5:2021 Part 5 – Test fuels
- ISO 8178-6:2018 Part 6 – Report of measuring results and test
- ISO 8178-7:2015 Part 7 – Engine family determination
- ISO 8178-8:2015 Part 8 – Engine group determination

As required by Annex VI, the NTC is applicable to the reference testing and certification of all marine diesel engines subject to the requirements of Regulation 13. The NTC sets the application-specific test cycles from which the cycle-weighted NOx emission value is determined for that group or family of engines, in accordance with the provisions of chapter 5 of the NTC.

As part of those provisions, the NTC requires the 'parent' engine test to be undertaken on a DM grade (distillate) marine fuel, in accordance with ISO 8217:2005, if a suitable reference fuel is not available. Furthermore, if a DM grade fuel is not available, the emissions testing for the parent engine is to use a RM-grade (residual) fuel oil.

In all cases, the fuel oil used during the parent engine test is sampled and analysed for use in the calculation of the NOx emissions. Most marine certifications of NOx emissions have used a DM grade fuel oil.

Marine engines, particularly the larger medium-speed and slow-speed engines, operate on many ISO 8217 distillate and residual fuel oils and have adjustable features that compensate for variations in fuel quality and ignition properties. This is the basis for defined engine group (rather than engine family) certification. The operating ranges are covered by the engine group's certification and an individual engine's technical file.

While the range of marine fuel oils varies significantly, including fuel-bound nitrogen and oxygen content, the IMO's regime for NOx certification is based on defined testbed testing on DM- or RM-grade fuels. It accepts that NOx emissions from operations will vary from the certified values, depending on the fuel oil.

This recognition is confirmed by the allowance of 10% NOx emissions for testing on-board using RM-grade fuel oils (refer to 6.3.11.2 of the NTC). This foundation comes from a knowledge base of RM- and DM-grade fuel oils and blends derived from petroleum refining.

There is limited emissions data from burning biofuels in marine engines. There is some evidence from land-based tests of liquid biofuels in internal combustion engines that indicates that NOx emissions may be higher than with conventional fuel oils; similarly, there is evidence that indicates NOx emissions may be lower. No clear trend exists and NOx emissions are very dependent on the engine type, engine load, adjustable features and fuel properties.

To an extent, Annex VI addresses this with provisions for the quality of fuel oil under regulation 18 of Annex VI where 18.3.2.2 restricts an engine from exceeding the applicable NOx emission limit when consuming fuels derived by methods other than petroleum refining. (See below for more detail on Regulation 18 requirements).

There continues to be uncertainty about the application of Regulation 18, with respect to its NOx implications for Regulation 13, particularly related to biofuel blends. This may limit the uptake of biofuels. However, there are provisions within Annex VI regulation 3.2 for shipowners and operators to apply to the flag Administration for trials permitted for emission-reduction and control-research purposes.

There are also the Annex VI regulation 4 'Equivalents' provisions which allow equivalent "… *fitting, material, appliance or apparatus or other procedures, alternative fuel oils, or compliance methods* …" to be applied under flag Administration agreement on a ship-specific basis. In February 2022, the IMO Secretariat reported that there were 13 reports in the Global Integrated Shipping Information System (GISIS) database of ships using biofuels as an 'equivalent' under regulation 4.2.

To raise awareness about the issues, the marine industry is seeking input on the application of Regulation 13 (and Regulation 18); several papers have been submitted to the IMO's Marine Environmental Protection Committee (MEPC).

These papers have highlighted the difficulty of undertaking NOx emissions trials at sea and proposed that the MEPC should clarify the regulatory framework for biofuels' compliance with NOx and encouraged continued research and development, with administrations invited to issue trial exemptions under Regulation 3.2.

MEPC also has been requested to add this work item to the MEPC intersessional working group on GHG emissions.

Information on NOx compliance from recent trials using biofuel blends onboard has also been submitted. In particular, some trials included testing a B20 biodiesel blended from a B100 FAME biodiesel (soya extract) to the ASTM D6751 standard with low-sulphur diesel to the ISO 8217:2010 DM grade standard. This B20 biofuel was tested on two coastal vessels. Onboard NOx emissions testing was conducted by using the NTC's simplified measurement method. On the first test ship, NOx emissions were reduced by approximately 2% compared to low-sulphur diesel and a 6%-28% reduction was seen on the second.

The trials therefore indicate that the B20 FAME biofuel burned in those engines did not cause an increase in NOx emissions; as a result, their NOx-certification status remained unchanged.

The latest information submitted to MEPC covers test bed testing on a 4-stroke medium speed marine engine and indicates that VLSFO fuels blended with B30 and B50 FAME content, and tested on the E2 test cycle, did not increase the overall emissions of NOx or black carbon (MEPC, 2022).

It will take some time for IMO to conclude this; in the interim, it may require a Unified Interpretation (see section 3.2.7 of this report) and/or further discussion by flag Administrations to facilitate implementation.

##### 3.2.3.2.2 Regulation 14 – Sulphur Oxides (SOx) and Particulate Matter

MARPOL Annex VI Regulation 14 restricts the amount of SOx and associated sulphate-based particulate matter (PM) emitted by all fuel oil-consuming equipment onboard ships by limiting the sulphur content of the marine fuels.

In line with Regulation 13 limits for NOx, the IMO adopted initial fuel sulphur content limits that were later updated with the 2008 revisions of Annex VI, and also provided separate fuel sulphur content limits to be applied globally and within ECAs. Starting initially with limits of 4.5% sulphur globally and 1.5% in ECAs, these limits were lowered to 0.5% for all ships and 0.1% for ships in ECAs on 1 January 2020 - see Figure 37.

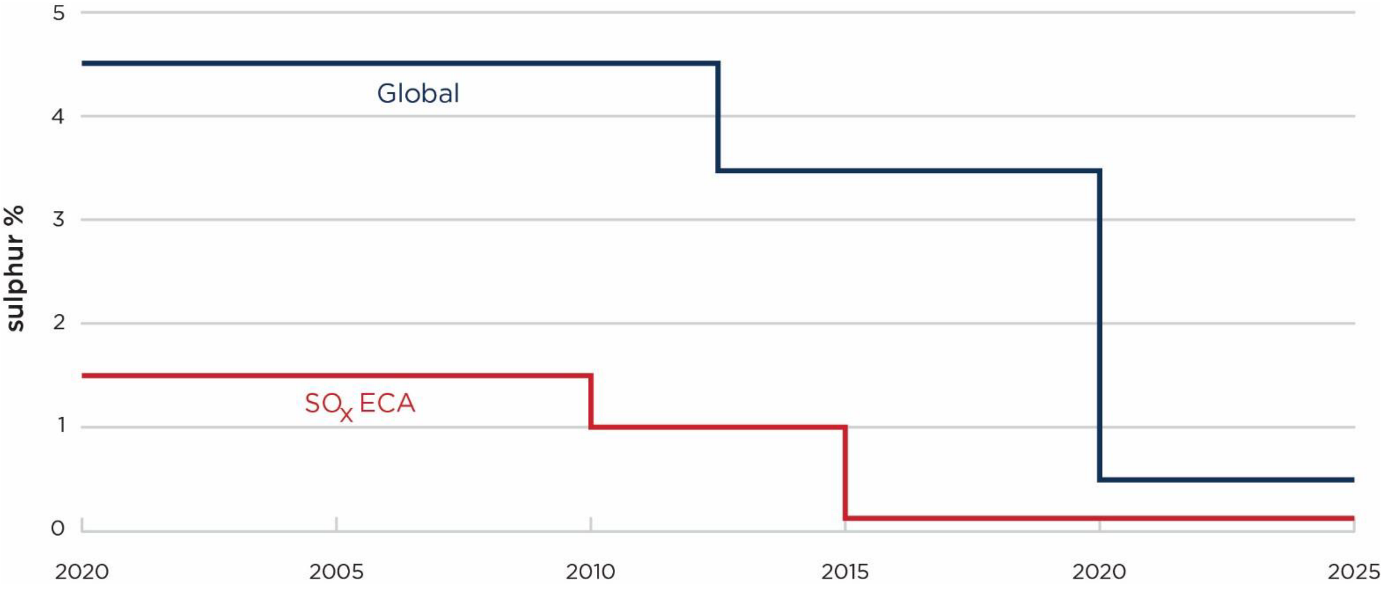

Figure 37. MARPOL 73/78 Annex VI Reg 14 – % Sulphur content in fuel limits

Biofuels are inherently low in sulphur, or are sulphur-free, so compliance with Regulation 14 is easily reached for many liquid or gaseous biofuels. However, the IMO's most stringent fuel sulphur limit of 0.1% in ECAs, which is 1,000 ppm, remains considerably higher than other land-based regulations, for which those limits may be as low as 10 ppm. Biofuels therefore provide a way to comply with the IMO's regulations, but they also offer a way to reduce the quantities of SOx emitted by the marine industry to levels significantly below the IMO's most stringent limits.

Further reductions in IMO's regulation 14 fuel sulphur limits would provide significant air quality benefits, but also encourage application of inherently low sulphur biofuels.

Figure 38 shows the result when a biofuel with 0% m/m sulphur is blended with a petroleum marine fuel with a higher sulphur content. It shows the final blends' sulphur contents by mass, based on the biofuel blend percentage.

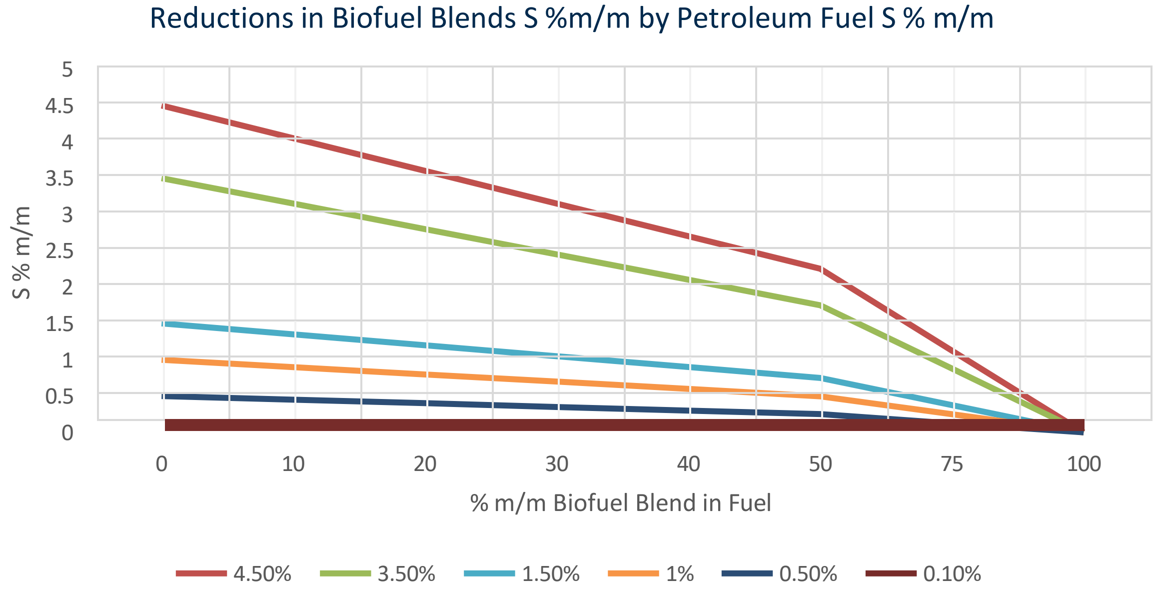

Figure 38. Reductions in % S in fuel with different Biofuel Blends

#### 3.2.3.2.3 Regulation 18 – Fuel Oil Availability and Quality

Regulation 18 in MARPOL Annex VI outlines requirements for the availability and quality of fuels to administrations, fuel suppliers and owner/operators. As defined by Annex VI, fuel oil is any fuel delivered to and intended for combustion purposes for the propulsion or operation onboard a ship, including gas, distillate and residual fuels.

These requirements include obligations on the fuel supplier to document the fuel-sulphur content (and other parameters) in the Bunker Delivery Note (BDN), which must be accompanied by a sealed sample of the fuel. Regulation 18.4 states, however, that the requirements for the BDN and fuel sample do not apply to gaseous fuels such as LNG or LPG. Similar exemptions are also therefore applicable to the equivalent gaseous biofuels.

Regulation 18.3 states the general fuel properties required for hydrocarbon fuel oils derived largely from petroleum refining, as well as fuel oil for combustion purposes derived by methods other than petroleum refining. Liquid biofuels fall into the latter category, but many of the high-level fuel requirements are applicable to fuels derived from both methods. The regulation restricts the fuels from:

- Containing inorganic acid
- Jeopardising the safety of ships or adversely affect machinery performance
- Harming or being harmful to personnel
- Contributing to additional air pollution

As detailed in the subsection on Regulation 13 above, the requirement under Regulation 18.3.2.2 that restricts fuels derived by methods other than petroleum refining from causing an engine to exceed the applicable NOx-emission limit is under discussion with respect to liquid biofuels. The requirement is not seen as an issue for gaseous biofuels or methyl/ethyl alcohol biofuels without the molecular complexity of conventional hydrocarbon or liquid biofuels.

It is, however, particularly challenging for suppliers to deal with, as they have no means of verifying this requirement without the support of the owner/operators and engine designers.

It can be argued that the Annex VI NOx certification regime accepts that these emissions will vary in operation depending on the fuel, giving some width to interpret the regulation’s application for liquid biofuels. Generally, most liquid biofuels and biofuel blends can be used in marine NOx-certified engines without any changes to the NOx-critical components or settings and limits to operating values provided in the engine’s related technical file.

If settings need to be adjusted, these usually could be covered by the flexibility provided in the engine group concepts; as given by 4.4.7.1 of the NTC, minor adjustments or modifications are allowed after pre-certification or final measurement of the test bed -- in particular for onboard adjustments of *“… injection timing for compensation of fuel-property differences …”* -- as per the example offered in NTC Regulation 4.4.7.2. See also Section 3.2.7 of this report for IMO developments on the unified interpretation of this with respect to biofuels.

While Annex VI has robust provisions for undertaking trials under the agreement of the flag Administration on a case-by-case basis, this regulatory uncertainty could hamper the widespread adoption of liquid biofuels.

#### 3.2.3.2.4 Required EEDI, EEXI and CII

At the IMO MEPC 62nd session in July 2011, further amendments to MARPOL annex VI were made with the adoption of MEPC.203(62), which introduced a new Chapter 4 that included energy-efficiency measures for ships. This chapter introduced new design and operational requirements for energy efficiency via the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP).

These set the reference lines (phases) applicable to different ship types and with different application years; each ship now needs to demonstrate that it does not exceed the applicable ‘required EEDI’ reference line. Regulation 24 of Annex VI details the required EEDI reference lines and phased reduction factors; the required value of the EEDI is based on ship type and deadweight (DWT), see Figure 39 and Figure 40, below. The value attained by the ship must be below these reference lines.

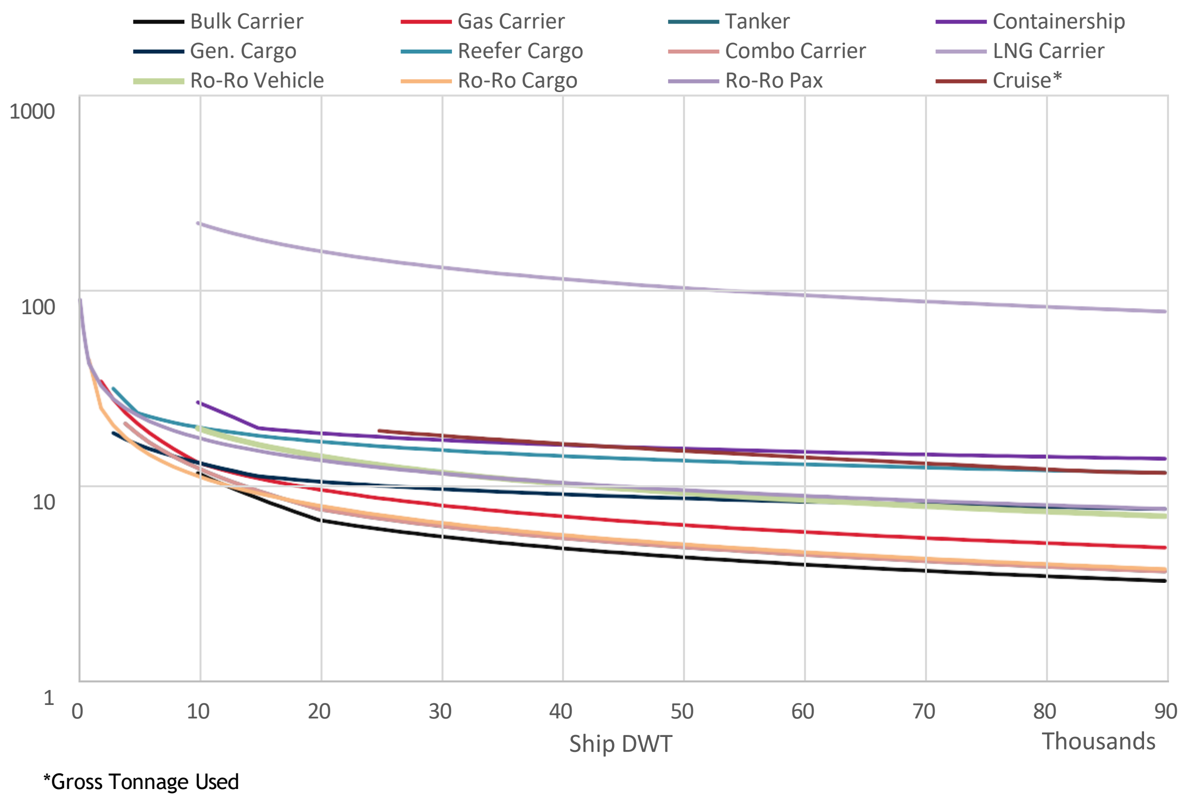


Figure 39. Required EEDI before 2025

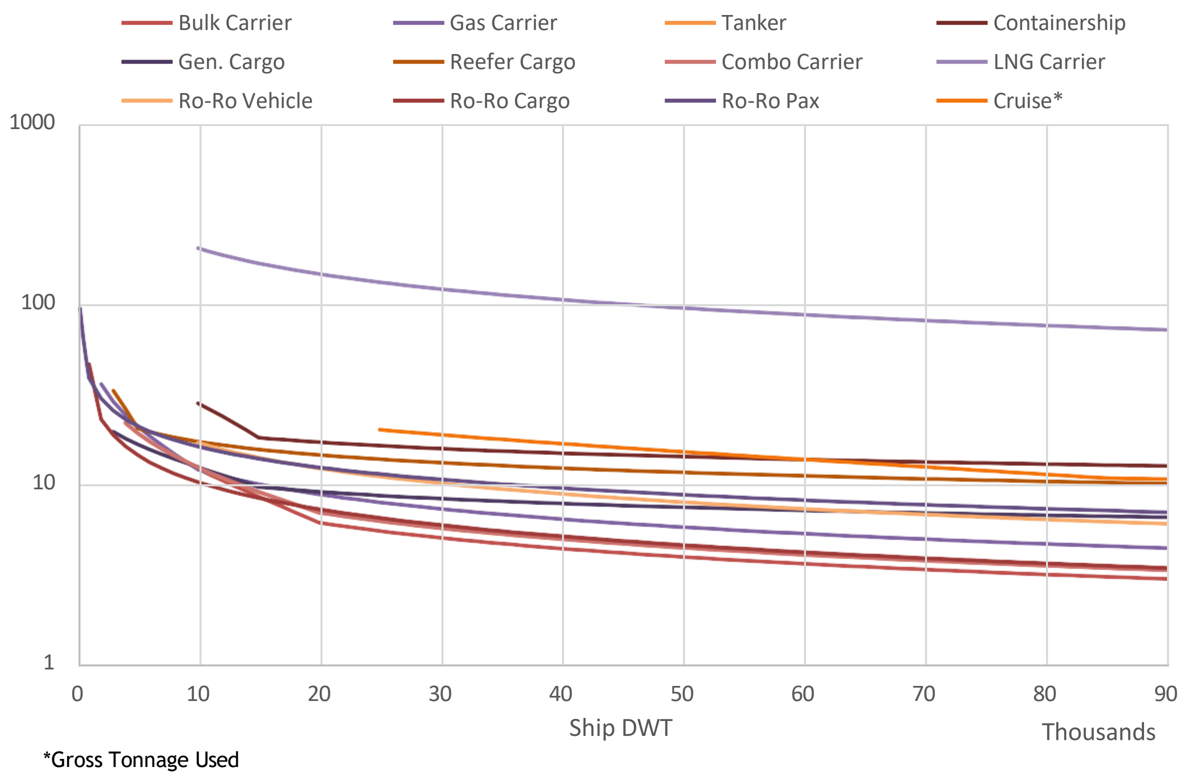


Figure 40. Required EEDI after 2025

The EEDI value that is calculated is a measure of the ships' energy efficiency, expressed in fuel consumption per cargo tonnage and distance carried (g/t nm). The formula includes many parameters, including fuel consumed by the main and auxiliary engines. The amount of $CO_2$ emitted during the consumption of that fuel is determined by multiplying the main and auxiliary engine powers, specific fuel consumption and the fuel-specific conversion factors, $C_F$, (conversion factor between fuel consumption and $CO_2$ emissions - which originate from IPCC values). The EEDI baselines were constructed using ships built between 1999 and 2008, assuming the use of HFO and a tank-to-wake carbon factor of 3.114.

While the IMO's ambition for reducing GHGs includes the intent to develop robust lifecycle fuel factors, the $C_F$ conversion factors only provide the tank-to-wake $CO_2$ emissions shown in Table 43, below.

Table 43. $C_F$ nondimensional conversion factors (MEPC, 2018)

| Type of Fuel | Reference | Lower Calorific Value (LCV) | Carbon Content | Cf (t-CO2/t-Fuel) |
|---|---|---|---|---|
| **MDO/MGO** | ISO 8217 Grades DMX through DMB | 42,700 | 0.8744 | 3.206 |
| **LFO** | ISO 8217 Grades RMA through RMD | 41,200 | 0.8594 | 3.151 |
| **HFO** | ISO 8217 Grades RME through RMK | 40,200 | 0.8493 | 3.114 |
| **LPG** | Propane | 46,300 | 0.8182 | 3.000 |
| | Butane | 45,700 | 0.8264 | 3.030 |
| **LNG** | - | 48,000 | 0.7500 | 2.750 |
| **Methanol** | - | 19,900 | 0.3750 | 1.375 |
| **Ethanol** | - | 26,800 | 0.5217 | 1.913 |

It is recognised that biofuels can contribute to reducing carbon emissions, and an agreed $C_F$ factor, or certified carbon content, value provided by the fuel supplier could account for the $CO_2$ reductions that may be applicable to that particular biofuel. This provision could account for the well-to-tank, as well as tank-to-wake, emissions resulting from biofuel feedstock extraction, production and transportation to end-use and provide an easy tool to apply within existing and developing instruments. Certification to the ISCC (International Sustainability and Carbon Certification) system is an example of how this can be recognised, and we understand has already been applied in certain cases.

However, there is uncertainty on how to apply this within the IMO framework and it is more frequently considered an operational measure that may be captured under IMO's Energy Efficiency Operational Indicator (EEOI), Carbon Intensity Indicator (CII) and/or Data Collection System (DCS) regulations. There is therefore a gap in the EEDI requirements if it is not possible to indicate the $CO_2$ footprint of a ship that is designed and intended to operate on lower carbon, or carbon-neutral, biofuels in service. The recognised design performance is a critical parameter to charterers and managers, not just for operational reporting purposes. However, there have been some initial calls for the EEDI framework to be converted into a pure energy-efficiency metric without the influence of carbon factors. This action would eliminate the need for more additions to this table to cover all fuels being applied and considered.

If pursued this proposal would have consequential implications to other requirements that refer back to this table in the EEDI Calculation Guidelines. The first is the Energy Efficiency Existing Ship (EEXI) index for existing ships that was agreed at MEPC 76, which broadly applies the EEDI concept to existing rather than new ships. The IMO Fuel Oil Consumption Database also refers to the carbon factors provided in the EEDI Calculation Guidelines.

Additionally, the IMO's CII requirements, which will enter into force in 2023, are built from the IMO's Fuel Oil Consumption Database and, by extension, this table of carbon factors will be used to calculate the attained CII. The IMO regulatory landscape is therefore changing and evolving rapidly.

There is also the issue that the EEDI framework and through-life monitoring does not obligate verifying ships to operate on the EEDI fuels for which they have been certified. This is captured to an extent by the operational fuel reporting obligations, but it remains a disconnect with the precedents from other parts of Annex VI. It also fails to recognise the significant differences in $CO_2$ footprints that may exist between different modes of ship operation: Tier II vs Tier III, oil mode vs gas mode, for example. Historically, Annex VI air pollution control regimes required compliance with the applied limit on all fuels, and all modes of operation, on a worst-case (highest emissions) basis. Therefore, these remain significant gaps in the EEDI regulation.

In the longer term, the IMO expects to develop guidelines that account for the lifecycle emissions of marine fuels. These may affect EEDI and other calculations or add additional processes, to verify that the sustainability of biofuels is incorporated in fuel-accountability schemes.

##### 3.2.3.2.5 Data Collection System (DCS)

The IMO DCS requires ships with a size of 5,000 GT or more to report their fuel oil consumption, by fuel oil type, to their Administration on an annual basis (Resolution MEPC.278(70)). The fuel oil types are the same as for the EEDI, namely diesel/gas oil; light fuel oil; heavy fuel oil; LPG; LNG; methanol and ethanol. The former three refer to ISO 8217, which means that, for example, FAME blends of up to 7.0% v/v would not be reported separately because they would be reported as diesel/gas oil. The DCS does not currently explicitly require ships to report the nature of the fuel. For example, when using methanol, there is no requirement to report whether the fuel is fossil, biological or synthetic.

There therefore remains uncertainty as to how to capture all fuels that are in use, and considered for future use, within the DCS reporting, particularly those from lower carbon and bio sources. This has been recognised but remains an area requiring regulatory clarification. The IMO secretariat reporting of the 2020 DCS data from the GISIS database included a recommendation for the MEPC to consider amending the EEDI calculation guidelines to include ethane and biofuels to facilitate reporting those fuels to the GISIS module. Those fuels typically being captured by using an “other” input field for fuel type and by specifying a user defined description and $C_F$ value.

There therefore also remains some uncertainty on how biofuels may have been captured in the DCS database. In the 2020 reporting period it was indicated that from a total of 203 million tonnes of fuel, 99.91% of that was heavy fuel oil, light fuel oil, diesel/gas oil or LNG. The 2020 reporting indicates that 27,792 tonnes of used cooking oil, 2,651 tonnes of biofuel and 19 tonnes of biogas were reported; together with the reported consumed ethane of 62,345 tonnes, the total usage on a quantity basis jointly represented 0.05% of global fuel usage.

##### 3.2.3.2.6 Guidelines for the Carriage of Blends of Petroleum Oil and Biofuels

Originally approved in 2011, and amended with Rev.1 in October 2012 (MEPC.1/Circ.761/Rev.1), these guidelines provided requirements for biofuels subject to MARPOL Annex II (Prevention of pollution by noxious liquid substances in bulk) blended with petroleum oils subject to MARPOL Annex I (Prevention of pollution by oil) when shipped in bulk.

The guidance included requirements for the equipment used to monitor oily discharge, deck fire-fighting systems based on SOLAS chapter II-2, and the conditions under which biofuel blends must be stored, depending on the blended biofuel percentage.

These guidelines were revoked by MSC-MEPC.2/Circ.17 in July 2019 (see Section 3.2.3.2.8 below).

##### 3.2.3.2.7 Guidelines for the Carriage of Energy-Rich Fuels and their Blends

These guidelines (MEPC.1/Circ.879) were issued following the recognition of the need to clarify how energy-rich fuels, or their blends with petroleum oils subject to Annex I of MARPOL and/or with biofuels subject to Annex II of MARPOL, can be shipped in bulk under the correct MARPOL Annex.

The guidelines describe energy-rich fuel as being obtained from biological origin or non-petroleum sources, or is a blend of petroleum-based fuel and a product obtained from biological or non-petroleum sources such as algae, GTL or HVO.

When carrying energy-rich fuels listed in annex 12 of the MEPC.2/Circular on *Provisional categorization of liquid substances in accordance with MARPOL Annex II and* the *IIBC Code,* the requirements of Annex I of MARPOL should apply.

The guidelines indicate that when carrying blends of energy-rich fuels and biofuels that are recorded in annex 11 of the MEPC.2/Circular, blends containing 75% or more of energy-rich fuels are subject to MARPOL Annex I, including oil discharge monitoring equipment, and that the fire-fighting requirements should use alcohol resistant foams when those biofuel blends contain ethyl alcohol.

When the biofuel blends contain less than 75% of energy-rich fuel they are subject to MARPOL Annex II.

##### 3.2.3.2.8 Guidelines for the Carriage of Blends of Biofuels and MARPOL Annex I Cargoes

Following the adoption of the aforementioned annex 12 MEPC.2/Circular regarding energy-rich fuels, and the need to include reference to SOLAS VI/5.2 regarding the prohibition of the blending of bulk liquid cargoes and production processes during sea voyages, the *2019 Guidelines for the Carriage of Blends of Biofuels and MARPOL Annex I Cargoes* were approved at MSC 101. The MSC-MEPC.2/Circ.17 circular revoked the 2011 MEPC.1/Circ.761/Rev.1 guidelines.

The 2019 guidelines apply to ships carrying bulk blends of biofuels and MARPOL Annex I cargoes subject to MARPOL Annexes 1 and II. Biofuels are defined as ethyl alcohol, FAME and vegetable oils as identified in chapters 17 and 18 of the IBC code or the MEPC.2/Circular. Biofuel blends are defined as mixtures resulting from the blending of those biofuels and a MARPOL Annex I cargo.

The guidelines indicate that when biofuel blends containing ≥75% of a MARPOL annex I cargo are carried, they are subject to MARPOL Annex I, including oil discharge monitoring equipment, and that the fire-fighting requirements should use alcohol resistant foams when those biofuel blends contain more than 5% ethyl alcohol.

Where the biofuel blends contain >1% but <75% of a MARPOL Annex I cargo, they are subject to MARPOL Annex II with the carriage requirements set out in chapter 17 of the IBC Code.

Biofuels blended with ≤1% of a MARPOL annex I cargo are not considered as blends and therefore shipped in accordance with the appropriate product entry in the IBC Code.

#### 3.2.3.3 SOLAS – IGC Code

Historically, the gas carrier regulations for burning cargo products as fuel, IMO's *International Code for the* Construction *and Equipment of Ships Carrying Liquefied Gases in Bulk* (IGC Code), only permitted burning natural gas (methane) as fuel. The adoption of the revised (2016) IGC Code by IMO Resolution MSC.370(93) in May 2014 introduced the option to burn other non-toxic cargoes as fuel.

For gas carriers, the use of natural gas as fuel is permitted under Chapter 16 of the IGC Code. With the adoption of the revised IGC Code in 2014, a new section 16.9 for 'alternative fuels and technologies' was introduced to permit combustion of other non-toxic cargoes, provided that the same levels of safety as methane are ensured.

Dialogue with the flag Administration is required to develop the roadmap for approval, and the criteria that will demonstrate equivalency. Typically, this includes a risk-based assessment, such as HAZID, and the application of 1.3 of the IGC Code for 'Equivalents'. When completed, the flag must notify the IMO through the GISIS (Global Integrated Shipping Information System) database.

It is this new provision in the IGC Code that has allowed ethane and LPG cargoes to be burned on the dedicated VLEC and LPG carrier fleets. Nothing within the IMO's statutory safety requirements would prevent gas carriers from transporting biofuel variants of these products, such as biomethane, from burning those products as fuel if the demand is established to transport them.

#### 3.2.3.4 SOLAS – IGF Code

In June 2015, by resolution MSC.391(95), the IMO adopted the *International Code of Safety for Ships using Gases or Other Low*-Flashpoint *Fuels*, the IGF Code. This introduced the regulatory safety requirements and framework for fuels with a flashpoint less than 60˚C, creating mandatory provisions for the use of natural gas and other low-flashpoint fuels and gases.

At the same time as adopting the IGF Code, the IMO adopted Resolution MSC.392(95), amendments to SOLAS making the IGF Code mandatory by including a new Part G to SOLAS II-1. Under the 'one-ship, one code' policy, the IMO clarified that, excluding ships that are subject to the IGC Code for burning cargoes as fuel, the IGF Code is applicable to all new ships, and ship conversions, over 500GT that use low-flashpoint fuels and for which the building contract was placed on or after 1 January 2017.

In the absence of a building contract, the IGF Code is applicable to all ships with a keel laid on or after 1 July 2017, or which were delivered on or after 1 January 2021.

The main structure of the IGF Code is detailed below, but it only includes detailed prescriptive requirements for natural gas (methane) under Parts A-1, B-1 and C-1. In the longer term, additional parts will be added as industry applications and experience grows. Prior to that, it is anticipated that the IMO will issue 'interim guidelines' to cover other low-flashpoint fuels and gases.

- Part A
  - General
  - Goal and Functional Requirements
  - General Requirements
- Part A-1 - Specific Requirements for Ships Using Natural Gas as Fuel
- Part B-1 - Manufacture, Workmanship and Testing
- Part C-1 - Drills and Emergency Exercises
- Part D - Training

The application of all low-flashpoint fuels and gases under the IGF Code includes a risk assessment, which is detailed under Part A 'General Requirements'. For natural-gas (methane) applications this only needs to be applied when specifically identified in the prescriptive requirements, but all other fuels require a full risk assessment to be conducted using acceptable and recognised techniques for risk analysis.

Other low-flashpoint fuels and gases may be applied, provided they meet the goals and functional requirements of Part A of the IGF Code and an equivalent level of safety. This approval process is met by applying the 'Alternative Design' criteria referenced under the 'General' section of part A of the IGF Code.

The equivalency is to be demonstrated as specified in SOLAS II-1/55 for 'Alternative design and arrangements', which refers to the application of guidelines in MSC.1/Circ.1212. It requires dialogue and approval from the flag administration, with engagement of all stakeholders to develop the roadmap for risk-based approval and the supporting documentation.

Although detailed prescriptive requirements are not given in the IGF Code for all the low-flashpoint fuels and gases under consideration, including their biofuel variants, the goal and risk-based provisions provide a way to apply and to get approval for these fuels. Furthermore, with no significant differences (from the safety perspective) between methane and biomethane, or methanol and bio-methanol, there are no barriers to adoption of biofuels under this IMO instrument.

#### 3.2.3.5 Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel

The IMO's requirements for using methyl/ethyl alcohol fuels were developed under the CCC sub-committee and approved in principle at the CCC 5 meeting held 10-14 September 2018. Unfortunately, due to workload and COVID delays, these were not approved until MSC 102 in 2020 when MSC.1/Circ.1621 the *Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel* was approved.

These interim guidelines adopted the same basic structure and layout as the IGF Code, including the detailed prescriptive requirements, but they were adapted to the specific fuel characteristics of methanol and ethanol. The provisions still include the option to apply the 'alternative design' process if deviating from the prescriptive requirements or applying novel arrangements. In all cases, this will require a risk-assessment.

This landmark publication supports the application of methanol or bio-methanol as fuel beyond the early trial project on the *Stena Germanica* and the methanol carriers owned and/or chartered by Waterfront Shipping as the shipping arm of Methanex that have burned methanol cargo as fuel. As indicated above, under the adopting SOLAS amendments for the IGF Code it was clarified that only IGC Code gas carriers that are exempt from the application of the IGF Code. Therefore, ships falling under the IBC Code, are also subject to the IGF Code when burning cargoes as fuel. The MSC.1/Circ.1621 interim guidelines facilitate the burning of methyl alcohol cargoes, including bio-methanol, on IBC Code ships

These interim guidelines are one of the factors driving increased interest in the application of methanol as fuel, demonstrated by recent construction orders for methanol-fuelled containerships and related projects in supplying e-methanol (Maersk, 2022).

As with all the low-flashpoint fuels and gases, there are additional safety requirements compared to conventionally fuelled ships. However, because methyl/ethyl fuels are liquid at ambient temperatures and pressures, these are simpler to store and distribute than cryogenic or gaseous fuels. The guidelines include requiring protective cofferdams to integral fuel tanks and nitrogen blanketing of fuel-tank vapour spaces but allow fuel to be stored next to the shell plating below the lowest possible waterline.

### 3.2.4 International Council on Combustion Engines (CIMAC)

***Fuels Working Group - WG7***

The CIMAC WG7 Guideline for Ship Owners and Operators on Managing Distillate Fuels up to 7% v/v FAME (biodiesel) provides guidance to fuel distributors, shipowners and operators on best practices to handle biofuel blends (CIMAC, 2013). The guidance is originally intended to cover biofuel blends up to 7% v/v, but the concepts and precautions may be applicable to higher percentage blends. It will be updated as more information becomes available.

Main precautions include:

- Testing for biodiesel percentage using ASTM D7371 or EN 14078 (for clear and bright distillates)
- Testing for stability using EN 15751 and ISO 8216
- Storage and handling
  - Confirmation of equipment material compatibility with biodiesel
  - Avoiding long storage periods (due to fuel instability and degradation)
  - Fuel condition monitoring for long term storage (oxygen stability, acidity, water content, microbial contamination, etc.)
  - Protection from heat sources or water ingress/accumulation
  - Fuel filter condition monitoring and cleaning
  - Cold weather protection (due to wax forming)
  - Tank cleaning
- Compatibility with high pressure common rail fuel-injection systems to avoid water in the fuel based on engine manufacturer’s guidelines.

Historically, the CIMAC WG7 Fuels working group has focused on supporting application of residual and distillate petroleum-derived fuels. But, as with the FAME guidelines, it is expanding guidance to include the lower sulphur fuels, biofuels and ‘alternative fuels’ in collaboration with other CIMAC WGs. The WG7 publications are available on the CIMAC website (CIMAC, 2022). A sample of publications is shown below:

- CIMAC Guideline: General guidance in marine fuel handling in connection to stability and compatibility
- CIMAC WG7 contributed to the Joint Industry Project guidance document on ‘The supply and use of 0.50% sulphur marine fuel’
- Guideline providing answers to FAQ from ISO 8217:2017
- Guideline on the Interpretation of Marine Fuel Analysis Test Results
- Guideline on Cold Flow Properties of Marine Fuel Oils

The CIMAC members work together to publish such guidance as may be applied to all members engine designs. However, there is a wide range in engine types and design features. Type approval for marine applications is based on IACS members Unified Requirements. Liquid biofuels (biodiesels) are not a type defining parameter and hence repeat of type testing is not required. Type testing is typically undertaken on a DM grade fuel and this can cover type approval for all liquid fuels for which a particular engine is designed. The suitability for residual fuel oils and other special fuels, such as biodiesels, is demonstrated through shipboard trial operation. See also 3.2.3.1 and 3.2.7 of this report.

Engine designers provide information on the application of biofuels through their generic publications and operational manuals. It is typical for designers to also cover specific guidance through the publication of recommendations or service letters applicable to the engine types. Engines are not specifically certified for HFO, VLSFO and biodiesels, but operators are advised to seek confirmation from the engine designer on suitability when applying biodiesels. In all cases, and where applicable, any changes to engine components or fuel systems affecting classification society required plans and particulars would require re-submission for approval as per usual practice regarding any change to type approved components. In many cases, particularly for the large bore marine engines applied to the deep-sea fleet, application of biodiesels does not require changes to the approved plans.

***Gas Engines Working Group – WG17***

The activities of the CIMAC WG17 working group focus on all aspects of gas-engine technology, including the use of natural-gas (methane) engines for the land-based power generation and marine sectors. With increased interest in other gaseous fuels such as hydrogen, LPG and ammonia, it is expected that WG17 will expand its publications to cover these fuels, including the biofuel variants (CIMAC, 2022).

Samples of WG17 publications include:

- Position Paper Gas Engine Aftertreatment Systems
- Impact of Gas Quality on Gas Engine Performance
- Guideline on methane and formaldehyde emissions of gas engines
- Transient response behaviour of gas engines
- About the influence of ambient conditions on the performance of gas engines
- Information about the use of LNG as engine fuel

Members of CIMAC include all global providers of marine engine and systems, who also provide the publicly available OEM guidance and information on the application of all conventional or alternative gaseous and liquid fuels, including biofuels.

### 3.2.5 International Bunker Industry Association

The International Bunker Industry Association (IBIA) is based in the United Kingdom, with branches in Africa and Asia, representing industry stakeholders. Its membership is broad and includes owner/operators, bunker suppliers, traders, brokers and port authorities. IBIA has consultative status at the IMO as a non-governmental organisation and is an important and active player in providing technical information to the IMO on marine fuel specifications, fuel sampling, etc.

IBIA develops positions on IMO regulations and industry guidance or best practice publications, both directly and as contributors. The joint-industry guidance document '*The supply and use of 0.50% sulphur marine fuel*' is an example.

To support industry adoption of alternative marine bunker fuels, IBIA has created the Future Fuels Working Group, which has been undertaking an assessment of the associated technologies and fuels, including biofuels.

As the results of this ongoing assessment become final, they will be available to IBIA members (IBIA, 2022).

### 3.2.6 International Methanol Producers and Consumers Association

In addition to the aforementioned reference methanol specification issued by IMPCA (current version 9 dated 10 June 2021), the organisation is also active in supporting the handling and transport of methanol, including the biofuel variants. The IMPCA "*Procedures for Methanol Cargo Handling on Shore and Ship*" intend to provide a standardised process for sampling that may be applied in the movement of methanol from producer to end user. Developed in consideration of other established standards and best practices from IMO, ISGOTT and others, these procedures can facilitate take up of bio-methanol as a marine fuel.

The IMPCA methanol specification is also incorporated in the Methanol Institute sponsored study by Lloyd's Register, '*Introduction to Methanol Bunkering Technical Reference'*, which provides a checklist and process flow approach to safely handle methanol bunkering transfers. This document also fills some of the regulatory and best practice gaps for supply of marine methanol and bio-methanol.

### 3.2.7 IACS Classification Societies

Classification societies play an active maritime role in assuring the safety of life, property, and the environment. The members of IACS collectively make a unique contribution to maritime safety and regulation by providing technical support, compliance verification (of statutory instruments in their role as Recognised Organizations) and research and development. The collaborative effort of multiple class societies in IACS leads to the implementation of common rules, unified requirements (UR) for typical Class Rules, unified interpretations (UI) of statutory instruments and other recommendations that are applied consistently by IACS members.

To facilitate harmonized application of MARPOL Annex VI Regulations 13 and 18, IACS submitted information to the MEPC and proposed a Unified Interpretation to regulation 18.3 and 18.3.2.2. Those proposals were agreed by IMO and added as additional interpretations with publication as MEPC.1/Circ.795/Rev.6 dated 10 June 2022.

This UI indicates that a fuel oil which is a blend of not more than 30% by volume of biofuel (B30) should meet the requirements of Regulation 18.3.1, i.e., is considered as a blend of hydrocarbons and not subject to the NOx implications applicable to fuel oil derived from methods other than petroleum refining.

With respect to application of 18.3.2.2, the UI indicates that engines already NOx certified to Regulation 13 on a DM or RM grade fuel to the ISO 8217:2005 standard (or those superseding the 2005 standard), which can operate on a biofuel or biofuel blend without changes to its NOx critical components or settings/operating values outside those given in the approved NOx Technical File, should be permitted to use such biofuels without undertaking the NOx assessment given by 18.3.2.2.

Furthermore, the UI indicates that fuels and engines not covered by the above interpretations, and subject to the NOx assessment of 18.3.2.2, may do so by application of the Annex VI onboard simplified measurement method, or the direct measurement and monitoring method, or by reference to relevant test bed testing.

This UI provides significant clarification on application of regulations 13 and 18 and will simplify application of liquid biofuels.

Regarding liquid biofuels (FAME, HVO and FT Diesel), no class rules include explicit discussion of biofuels, as the compatibility of the fuel with onboard equipment is already covered within ship-design concepts. During bunkering, it is the responsibility of the operators and fuel supplier to confirm appropriate fuel delivery, handling and maintenance. Due to the similarity of liquid drop-in biofuels to conventional petroleum marine fuels, additional rules and guides for the use and handling of biofuels on vessels may not warrant explicit introduction.

With reference to the application of classification society requirements under SOLAS II-1/3-1 given under 3.2.3.1 above, it is typical for Class societies to require demonstration onboard of the suitability of residual fuel oils, or other special fuel oils (which may be considered to include biofuels) to validate operation on such fuels. This is given in IACS members rules and originates from IACS UR M51, *Factory Acceptance Test and Shipboard Trials of I.C. Engines*, which requires that "*The suitability of the engine to operate on fuels intended for use is to be demonstrated*."

This requirement supports the type-approval of engines, however biodiesels are not a type defining parameter under IACS UR M71, *Type Testing of I.C. Engines*, and are grouped under the liquid fuels category. This means a repeat of the type test and engine recertification is not required. The verification of liquid fuels other than those used at type test (typically DM grade) is through the shipboard demonstration. For other liquid biofuels (biodiesels), the application of further shipboard trials is on a case-by-case basis in consideration of the specific liquid biofuel to be applied. Clarification of this under UR M51, or other IACS instrument, would facilitate harmonized application.

For biofuels such as bio-methanol, bio-methane (bio-LNG), or DME, additional rules and guidance may be available from class to standardise the use and handling of low-flashpoint fuel on vessels. While these may not be specific to biofuels, bio-derived fuels with similar chemical makeups to petroleum-based low-flashpoint fuels may fall under the scope of the same rules and guides. The shipboard trials referenced above would be applied for application of the fossil derived methanol or LNG during construction or conversion to the low flashpoint fuel and would not be required when that installation switches to the chemically consistent bio-methanol or bio-LNG products.

Low-flashpoint and gaseous fuels are typically handled and used very differently than conventional liquid petroleum marine fuels, so additional provisions and safety measures should be established onboard vessels. Class societies include these provisions in their rules or guides covering alternative, low-flashpoint, or gaseous fuels.

Some class rules and guides follow or take after IMO codes or guidelines, while others may preclude the adoption of such international instruments. In the latter case, after IMO requirements are adopted, adaptation of class rules and guides is usually required. Where IACS have adopted URs, these must be uniformly applied by IACS members in their rules. Similarly, where IACS UIs exist to statutory requirements, these are, by purpose, to facilitate harmonised application of the regulations. Currently no such IACS publications related to biofuels exist.

Where no class rules or guides exist for a biofuel, class societies may offer advisory or consultancy services regarding the adoption of biofuels and biofuel blends for use on vessels, including risk assessments, review of statutory requirements or international standards and recommendations for approval on a trial basis or as 'equivalent' arrangements. Most class societies have released guidance or informational publications for shipowners and operators considering biofuel as marine fuel.

## 3.3 Regulations for EU member states

### 3.3.1 Introduction

The European Commission has presented its so-called 'Fit for 55' package (FF55) in July 2021, which contains legislative proposals aiming to reduce the emissions of greenhouse gases by 55% by 2030 relative to 1990. FF55 encompasses all sectors of the economy, including maritime transport.

Five elements of the package directly affect maritime transport emissions or fuels:

- The revision of the EU emissions trading scheme (EU ETS), especially the proposal to include maritime transport emissions in the EU ETS.
- FuelEU Maritime, a new regulation requiring ships to reduce the GHG intensity of fuels used and to use onshore power at berth.
- The revision of the energy taxation directive (ETD) proposing to tax marine fuels.
- The Alternative Fuels Infrastructure Regulation (AFIR), replacing the eponymous Directive.
- The revision of the Renewable Energy Directive (RED), extending the scope of the requirements for transport fuels to marine fuels sold in the EU.

The RED and AFIR can be considered to address the supply of renewable fuels, including biofuels. FuelEU Maritime addresses the demand for fuels by ships visiting EU ports. The RED and the EU ETS address the price gap between fossil and sustainable fuels. Each of the proposals is presented below in separate subsections (Figure 41).

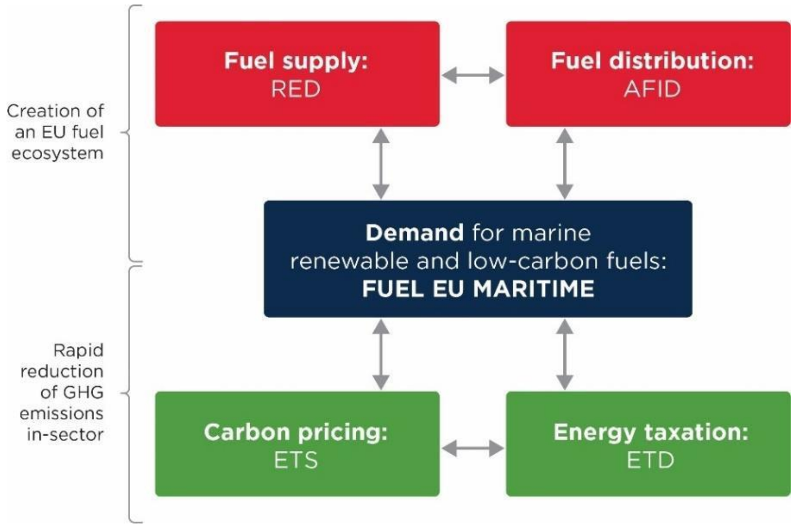


Figure 41. EU policies related to maritime transport

### 3.3.2 FuelEU Maritime

As part of the 'Fit for 55' package, the EC launched the FuelEU Maritime Initiative to increase the demand for renewable and low-carbon fuels (RLF) from ships sailing to and from EU ports. It also seeks to reduce emissions from navigation and at berth, and support EU and international climate objectives.

FuelEU Maritime sets a harmonised regulatory framework in the EU and aims to increase the share of RLF used in the fuel mix of international maritime transport, including: liquid biofuels, e-liquids, decarbonised gas (including bio-LNG and e-gas), decarbonised hydrogen and its derived fuels (including methanol and ammonia), and electricity.

The initiative will contribute to the wider goals by pursuing specific objectives to:

1. Enhance predictability by setting a clear regulatory environment for the use of RLF in maritime transport
2. Stimulate technology development
3. Stimulate production on a larger scale of RLF with sufficiently high technology readiness levels (TRLs) and reduce the price gap with current fuels and technologies
4. Create demand from ship operators to bunker RLF or connect to electric grid while at berth
5. Avoid carbon leakage

The current proposal focuses on demand policy which sets requirements for the fuel consumption of ships and complements the existing EU regulatory framework related to supply and infrastructure. (EC, 2021).

FuelEU maritime, if adopted as proposed, would require ships to use fuels with a 2% lower GHG intensity (measured in $gCO_2e/MJ$) than the average 2020 value, moving to 6% lower by 2030 and up to 75% lower by 2050.

Biofuels have a lower GHG intensity than fossil fuels on a well-to-wake basis, so they can be used to comply with 'Fit for 55' requirements, either by blending biofuels with fossil fuels or by sailing exclusively on biofuels and pooling compliance.

### 3.3.3 EU ETS

Another important part of the 'Fit-for-55' package is the proposal to gradually add shipping to the European Union Emission Trading system (EU ETS) from 2023. Under this system, shipowners must buy allowances for each unit of $CO_2$ they emit within the area where the system is in force. In contrast to FuelEU Maritime and the RED, emissions are accounted on a tank-to-wake basis. Consequently, no allowances need to be surrendered for the use of biofuels.

In the current version of the policy proposal, the emissions of cargo and passenger ships of 5,000 GT and above would be included in the EU ETS system with the following geographical scope:

- all emissions between EU ports count for 100%;
- all emissions from non-EU ports to EU ports count for 50%;
- all emissions from EU ports to non-EU ports count for 50%;
- all emissions between ports outside of the EU are outside the scope of EU ETS.

It has been proposed that from 2023 on, the emissions of maritime shipping will be included into the EU ETS and that the sector's requirements will be phased in over a period of three years.

The shipping company is proposed to be the responsible entity for the purpose of the EU ETS Directive. The shipping company is thereby defined as 'the shipowner or any other organisation or person, such as the manager or the bareboat charterer, that has assumed the responsibility for the operation of the ship from the shipowner and that, on assuming such responsibility, has agreed to take over all the duties and responsibilities imposed by the International Management Code for the Safe Operation of Ships and for Pollution Prevention, set out in Annex I to Regulation (EC) No 336/2006 of the European Parliament and of the Council'.

Under the proposed EU ETS Directive, the shipping company would be liable to surrender allowances in accordance with the verified aggregated emissions at company level (Article 3ga) and would have to pay an excess emissions penalty if not sufficient allowances were submitted on time (Article 16 (3)). Since the shipping company is proposed to be the responsible entity, the enforcement mechanisms are naturally applied to the shipping company. This also holds for potential expulsion orders.

If the shipping company does not surrender sufficient allowances by 30 April of each year to cover its emissions during the preceding year, the company is held liable for the payment of an *excess emissions penalty*. The penalty amounts to EUR 100 for each tonne of $CO_2$ equivalent emitted for which the company has not surrendered allowances and increases in accordance with the European index of consumer prices from 1 January 2013 onwards (see Article 16 (3), (3a) and (4)).

In case a shipping company has failed to comply with the surrender requirements for two or more consecutive reporting periods and where other enforcement measures have failed to ensure compliance, the competent authority of the Member State of the port of entry may issue an expulsion order and all Member States shall *refuse entry of the ships under the responsibility of the shipping company concerned into any of its ports* until the company fulfils its surrender obligations. (see Article 16 (11a)).

The aim of the inclusion of maritime transport in the EU ETS is to address greenhouse gas emissions of this sector and to ensure that shipping contributes to meeting the economy-wide emission reduction targets of the European Union.

### 3.3.4 RED II

The second phase of the Renewable Energy Directive (RED II) is an instrument from the EU to promote energy from renewable sources. The RED II sets a target for all modes of transport to use at least 32% renewable energy by 2030. It includes a specific 'RES-T' target of at least 14% renewable energy in the final energy consumption in transport by 2030, i.e., the energy used in road and rail transport, waterborne transport and aviation.

Renewable energy in transport could consist of biofuel, renewable fuels of non-biological origin (RFNBO) and may include recycled carbon fuels. At all times the sustainability requirements should be met. With respect to renewable fuels in maritime shipping, the RED II allows member states to apply those fuels towards their RES-T target.

The RED II's impact assessment identified an additional challenge specific to the maritime sector: the divided incentives for shipowners and operators do not stimulate the deployment of renewable fuels.

To introduce incentives for the maritime and aviation sectors, fuels supplied to either are measured at 1.2 times their energy content (except for fuels produced from food and feed crops) when demonstrating compliance with the renewable-energy target. This provision is meant to boost the uptake of renewable energy in these transport modes.

The 20% extra counting has implications for fuel volumes: because lower fuel volumes will be required to meet the target, the amount by which GHG emissions are reduced may be adversely impacted.

***Type of biofuels within the RED II***

The original RED required member states to oblige fuel suppliers within their jurisdiction to supply a minimum share of renewable energy to the transport sector and design their supply policies accordingly.

Although the RED only plays a limited role in increasing the share of biofuels in shipping, it remains relevant to the maritime sector, given its mature sustainability framework; lessons learned in the past for biofuels in the road-transport sector can help to shape a sustainability framework for use in shipping.

For sustainability reasons, the growth in the RED should come from advanced biofuels and RFNBO. According to the directive, advanced biofuels 'are produced from the feedstock listed in Part A of Annex IX (lignocellulosic energy crops, waste and residues)'. This is the same definition used for the advanced biofuels targets of at least 0.2% in 2022, at least 1% in 2025 and at least 3.5% in 2030. The biofuels produced from feedstocks from Part A of Annex IX count twice towards the target.

Although not specifically focussing on maritime shipping, the RED II includes other provisions which could influence policies that specifically target the transport sector. These provisions only apply to fuels counted towards the targets (Article 3 and Article 25) and include:

- the cap on food and feed crops of 1% above Member State (MS) level in 2020 or to a maximum of 7%;
- the cap on high ILUC biofuels at MS level in 2019 and decreasing to 0% between 2023 and 2030;
- the cap on biofuels produced from feedstocks listed in Part B Annex IX of 1.7%, which includes, for example, used cooking oil. (Member states might modify this cap based on the availability of feedstock.)
- the sub-target for advanced biofuels produced from feedstocks from Part A of Annex IX, which includes lignocellulosic energy crops, waste and residues. The contribution should be at least 0.2% in 2022, at least 1% in 2025 and at least 3.5% in 2030 (shares are after double counting which is allowed for these feedstocks).

Biofuels produced from feedstocks listed in Part A and Part B of Annex IX to RED II are allowed to count double towards the target. All biofuels and bioliquids should meet mandatory sustainability criteria.

***Revision of the REDII: the REDIII***

Because of the higher ambition of the Green Deal, the RED II is already being revised before many member states have transposed it into national legislation. The ‘Fit for 55’ package contains the proposal for the revised directive, referred to as the Renewable Energy Directive III.

To achieve the 2030 target, the proposal suggests increasing the overall binding target for renewables in the EU energy mix from the current 32% to 40%. This will be complemented by indicative national that show what each member state should contribute to secure the collective target.

The directive aims for large-scale renewables-based electrification. In transport and industry, with market segments that are harder to electrify, renewable fuels such as clean hydrogen should also play a major role.

The transport target, which aims for a certain share of renewables in final consumption, will be replaced by a GHG-intensity target: the GHG intensity of fuels (in $gCO_2$/MJ) is to be reduced by at least 13% by 2030 compared to the baseline. The Fuel Quality Directive’s ([FDQ], see more information below) target would be included in the RED and no longer form part of the FQD.

In addition to the sub-target for the share of advanced biofuels and biogas (based on feedstocks from Part A of Annex IX), the RED also introduces a 2.6% sub-target for the share of RFNBOs by 2030. The RED contains various multiplication factors that made some of the targets purely administrative. By abolishing these multiplication factors, the proposal for revision makes the targets more ambitious (Van Grinsven et al., 2022).

More details on the sustainability requirements are discussed in section 2.2.7.

### 3.3.5 Fuel Quality Directive

While the RED II sets a target for the minimum share of renewable energy in transport, the EU’s Fuel Quality Directive (FQD) has a reduction target for the average GHG intensity of fuels and includes the same sustainability criteria as the RED II. Use of renewable energy in transport thus would contribute to the FQD and the RED II targets.

While much of the directive aims to create policies that support sustainable sourcing and production of biofuel feedstock, an important aspect for owners and operators to consider is the reporting requirement, where emissions from fuels must be documented and submitted by each member state. This may require owners to report to authorities their fuel consumption and composition information.

No decision has been made to extend the FQD target to 2030, but with the GHG-intensity target proposed in the RED III, the FQD target seems likely to be incorporated in the RED methodology.

Aside from the reduction target, the FQD also offers fuel specifications that determine how much biofuel can be blended with regular road-transport fuels. Biofuel blends not meeting the fuel specifications for regular road transport fuels, such as ‘high blends’, must be marketed as a different product.

### 3.3.6 Energy Taxation Directive

Taxation initiatives at the EU and member state level help industries to reach the climate-policy goals by encouraging a switch to cleaner energy. The EU's Energy Taxation Directive (ETD) entered into force in 2003. The directive has structural rules and minimum rates for excise duties to tax the energy products that are used as motor and heating fuels and electricity.

Individual member states are free to set their own rates as long as the directive's minimum rates are respected.

Some sectors, such as aviation and maritime transport, are currently fully exempt from energy taxation in the EU. A revision of the ETD has been proposed in the EU's 'Fit-for-55' package; it introduces a new structure of tax rates based on the energy content and environmental performance of fuels and electricity. This will help the system to ensure the most polluting fuels are taxed the highest.

The revision also broadens the taxable base by including more products into the scope and removing some of the current exemptions and reductions. It will result in biofuels being taxed lower than fossil fuels (EC, 2021).

### 3.3.7 EU MRV

The EU MRV Regulation (Regulation (EU) No 2015/757) requires shipping companies, as of January 2019, to monitor the fuel consumption and other parameters of their ships above 5,000 GT within all ports under the jurisdiction of a Member State and on voyages to or from a port under the jurisdiction of a Member State that serve the purpose of transporting passengers or cargo for commercial purposes. From 2019 on, for each of these ships, the companies have to annually submit an emissions report to the Commission and to the authorities of the flag States concerned, reporting the ships' $CO_2$ emissions and other relevant information on an aggregated basis for the previous calendar year.

The EU MRV Regulation is currently being revised to take account of the global Data Collection System as implemented at the IMO level. In February 2019, the European Commission published a proposal for a revised EU MRV Regulation and in September 2020, the European Parliament adopted its position on the Commission proposal, including a proposition for the extension of the EU ETS to maritime shipping (P9_TA-PROV (2020)0219). The ensuing inter-institutional negotiations on the revision of the EU MRV system have not started yet. Moreover, the EU MRV is being revised as part of the proposed inclusion of shipping in the EU ETS. Since these proposals do not have a direct relevance for the use of biofuels, they are not further discussed in this report.

### 3.3.8 CEN/CENELEC Standards

CEN, the European Committee for Standardization, is one of three European standardisation organisations (together with CENELEC and ETSI) that bring together the national standardisation bodies of 34 European countries. Two key standards published under CEN cover biofuels:

CEN - EN 14214 - *Liquid petroleum products – Fatty Acid Methyl Esters (FAME) for use in diesel engines and heating applications – Requirements and test methods*. This standard specifies requirements and test methods for FAME to be used as fuel for diesel engines and heating applications at 100% concentration, or as FAME blended to distillate fuel in accordance with EN 590 up to 7% (v/v) FAME content.

CEN – EN 15940 – *Automotive fuels – Paraffinic diesel fuel from synthesis or hydrotreatment – Requirements and test methods*. This standard specifies requirements and test methods for paraffinic diesel fuel up to 7% (v/v) FAME for use in engines designed for paraffinic diesel fuel. HVO biofuels typically meet this standard.

CWA 17540:2020 - *Ships and marine technology - Specification for bunkering of methanol-fuelled vessels*. This CEN Workshop Agreement (CWA) was drafted and approved by a workshop of interested parties and submitted for approval in April 2020. Produced to meet an industry need for methanol bunkering standards, it can be applied to bio-methanol bunkers and acts as a guideline for requirements for bunkering methanol to vessels. This CWA covers four main elements:

- Guidelines for usage of hardware and transfer system,
- Operational procedures,
- Requirement for the methanol provider to provide a BDN, and

- Training and qualification of personnel involved.

In the absence of standards covering specific biofuels, particularly marine standards, it is typical that compliance with existing land-based diesel fuel standards are used to benchmark the fuels at the commercial level. For European countries this is the EN 590 standard detailed by EU Directive 2009/30/EC, which establishes minimum specifications for petrol and diesel fuels for use in road and non-road mobile applications. For example, the so-called drop in renewable diesels such as HVO meet the EN 590 and ASTM D975 diesel fuel standards.

## 3.4 Other relevant regulation from other Nations

### 3.4.1 United States

The U.S. regulation 40 CFR Part 1043 explains how Regulations 13, 14 and 18 of the MARPOL Annex VI are applied to U.S. flagged vessels operating domestically, as implemented by the Act to Prevent Pollution from Ships (APPS).

The U.S. also has the American Petroleum Institute Recommended Practice API RP 1640 Product Quality in Light Product Storage, which offers guidance for fuel handling at distribution and intermediate storage facilities, including procedures on the receipt, storage blending, additives and delivery. Its scope includes 'light' products, including biodiesel/FAME, and can be used when bunkering and storing liquid biofuels categorised as light products.

### 3.4.2 Other Nations' Coast Guards & Marine Authority Requirements:

#### 3.4.2.1 Canada

The Regulations for the Prevention of Pollution from Ships and for Dangerous Chemicals (SOR/2007-86, 30 March 2012) under the Canada shipping act are aligned with MARPOL Annex VI and require limits to ozone-depleting substances and offers fuel-quality specifications. In 2013, the country's 'Regulations Amending the Vessel Pollution and Dangerous Chemicals Regulations' implemented MARPOL Annex VI rules to reduce air pollution and the greenhouse gas emissions from vessels.

#### 3.4.2.2 China

The Chinese government has initiated plans to reduce emissions from shipping, first with restrictions of residual fuel oils at and near ports and by reducing the allowable SOx and particulate matter emissions from ships.

The introduction of domestic emission control areas (DECAs) intends to reduce the sulphur content in the marine fuels consumed in those areas, originally three major coastal regions: the Pearl River Delta; the Yangtze River Delta; and the Bohai Rim; the DECA was later extended to 12 nautical miles off the coast of mainland China (Song, 2017).

China also has intent to increase the number of domestically owned LNG-fuelled vessels plying its waters to reduce the volumes of heavy marine residual fuels. While the initiative is in place, there are current difficulties identifying a consistent way to evaluate the DECA policies nationwide. Therefore, guidance on further ship-emission controls is not clear.

Overall, the initial DECA policies reduced $SO_2$ and particulate-matter emissions between 2016 and 2019 by 29.6% and 26.4%, respectively, within China's 200 nm control zone[1]. The uptake of biofuels in these areas could continue to contribute to reduced SOx and particulate matter emissions.

However, NOx emissions from ships appear to have increased during the four years of the evaluation, likely due to the common use of older ships and low engine standards for the new ones. NOx emissions may be of particular concern when using some biofuels, so stringent limits on NOx may not encourage biofuel use. More clarity on government policy for ship emissions and fuels may appear if China's coastal waters receive international status as environmental control areas.

#### 3.4.2.3 Japan

Japan's 'Roadmap to Zero Emission from International Shipping (March 2020)' was jointly published by the Japan Ship Technology Research Association, The Nippon Foundation and the Japan Ministry of Land, Infrastructure, Transport and Tourism as a part of the Shipping Zero Emission Project. Aligned with the IMO's initial GHG Reduction Strategy to phase out greenhouse gases as soon as possible this century, the roadmap highlights two emission pathways for achieving the 2050 target and beyond.

- Emission Pathway I: "a fuel shift from LNG to carbon-recycled methane"
- Emission Pathway II: "the expansion of hydrogen and/or ammonia fuels"

Pathway I detailed the transition from petroleum-based LNG fuels to biomethane from 2025 and increased use of carbon-recycled methane from 2030. It assumes that carbon-recycled biomethane will account for approximately 40% of the energy consumption within international shipping in 2050, that carbon-recycled methane and biofuels will be become available in sufficient volumes and that they will be recognised by the IMO or other bodies as carbon-neutral fuels.

For this pathway to be realised, the report recognises that emerging regulatory measures from the IMO that promise guidelines for the lifecycle GHG and carbon-intensity of fuels also may need to address cross-border issues for carbon-recycled fuels and biofuels (JSTRA, 2020).

For coastal ships, Japan is discussing developing a decarbonisation roadmap. This may be a complicated process due to Japanese coastal marine industry being dominated by small enterprises and limited capital for change.

#### 3.4.2.4 South Korea

The recent adoption of domestic emission control areas for Korean ports -- including Incheon, Pyeongtaek-Dangjin, Yeosu-Gwangyang, Busan and Ulsan – has encouraged the adoption of alternative marine fuels to meet more stringent fuel sulphur limits.

From September 2020, ships anchored or at berth in those ECAs must use fuel with sulphur content limit of 0.10%; from January 2022, ships anywhere in the ECAs must adhere to the limits at all times.

Other methods of compliance include the use of scrubbers for cleaning exhaust gases; using clean fuel (e.g., LNG or biofuels) also will be accepted by South Korean authorities to meet the sulphur limits. In general, these limits could contribute to the to near-shore adoption and use of marine biofuels (Gard, 2020).

#### 3.4.2.5 Canal Requirements in Panama (Panama Canal) & Egypt (Suez Canal)

***Panama Canal*** According to the January 2020 NT Notice to Shipping No. N-1-2020 from the Panama Canal Authority (ACP), which acknowledges that the IMO MARPOL Annex VI regulation 14 ECAs do not include Panama, vessels entering the Panama Canal are required to use 'lighter' fuels.

Mainly, this is expected to involve switching from residual to marine distillate fuels, while recording the changeover and verifying proper engine operation with the lighter fuel. Using distillate manoeuvring fuel can reduce the particulate matter from stacks and improve the air quality around the canal.

The notice states that LNG or biofuels that are compliant with MARPOL Annex VI can supplement or replace marine distillate manoeuvring fuels while in Panama waters. This provision essentially adopts measures in annex VI regulations for vessels transiting the canal and could contribute to more bio-LNG or liquid drop-in biofuels being used.

***Suez Canal*** The Suez Canal Authority (SCA) Circular No. 8/2019 does not explicitly restrict fuel oils from being used during transits through the Suez Canal. It states that there are no restrictions on open-loop exhaust gas cleaning systems, except that the wash water cannot be discharged into canal waters.

In other words, a vessel may have an open-loop exhaust gas cleaning system, but it may not operate when transiting. Operators are free to turn the systems off and release exhaust gases from heavy marine fuel oils. This also appears to be the case until the Arab Republic of Egypt ratifies MARPOL Annex VI, which will likely impose restrictions on manoeuvring fuel in ships transiting through the canal.

However, most transiting vessels are under the authority of flag administrations who are signatories to MARPOL Annex VI, and therefore would be required to use low-sulphur fuel oil when an onboard open-loop exhaust gas cleaning system cannot be operated with heavy marine fuel oil.

The current fuel requirements for the canal do not contribute to the uptake of marine biofuels or encourage a switch to alternative marine fuels.

## 3.5 Gap Analysis

The regulatory framework for rules, standards, guidelines, recommendations and best practices, etc. for biofuels is tabulated in detail as Appendix J to this report. This highlights where the existing publications contribute to or restrain industry adoption of the biofuels under review.

As referenced throughout this section of the report, there are 'gaps' that will restrain adoption of biofuels. Notably, these gaps are within IMO safety and environmental regulation and ISO standards.

Discussion and recommendations are provided to encourage further consideration about developing policy to improve the adoption of biofuels.

The detailed gap analysis is shown in Appendix J, and a synopsis of the key findings is presented in Table 44 and Table 45.

Table 44. Gap Analysis Legend

| |
|---|
| No Gap or Changes needed to address biofuels |
| Small Gap or Minor Change to address biofuels |
| Medium Gap or Some Challenging Change to address biofuels |
| Large Gap or Many Challenging Changes to address biofuels |

Table 45. Synopsis on Regulatory Gap Analysis for Biofuels

| Subject | Rule/Guidance | Comment on Code/Standard - Gaps |
|---|---|---|
| Sustainability and Emissions Regulations | IMO Prevention of Pollution from Ships (MARPOL) Convention Regulations 13 - Nitrogen Oxides (NOx) and Regulation 18 – Fuel oil availability and quality | There are variations in NOx emissions from the use of biofuels and biofuel blends (it depends on the engine, load and specific fuel). The NOx Technical Code has limited provisions for the certification of NOx with biofuels and there is uncertainty about the application of Regulation 18.3.2.2. |
| | IMO Prevention of Pollution from Ships (MARPOL) Convention Regulation 14 - Sulphur Oxides (SOx) and Particulate matter | IMO's ECA fuel-sulphur limit of 0.1% (1,000 ppm) is less stringent than land-based regulations. Biofuels significantly exceed this standard but are not encouraged for adoption by the IMO's fuel sulphur limits |
| | IMO Prevention of Pollution from Ships (MARPOL) Convention Chapter 4 – Regulations on the Carbon Intensity of International Shipping | Required calculations for ships energy efficiency and carbon intensity using various methods, including EEDI, EEXI or CII are based on limited current fuel carbon factors. Clarification of how to incorporate biofuels into these calculations to meet EEDI, EEXI, or CII values and DCS reporting is needed. Ability to certify ships with alternative (certified) fuel carbon factors, at design and during operation, may encourage the uptake of biofuels as shipowners look for ways to reduce their carbon footprint and increase efficiency. |
| | EU Renewable Energy Directive (RED) 2009/28/EC | Could be more effective if provisions within the directive were officially recognized and/or adopted in non-member states and international governance policy. This would expand the applicability of the directive beyond the scope of the EU. |
| | EU Fuel-Quality Directive (FQD) 2009/30/EC | Could be more useful if it included provisions for more types of biofuels and was aligned with other regional, national and international reporting schemes |

| Subject | Rule/Guidance | Comment on Code/Standard - Gaps |
|---|---|---|
| Storage | American Petroleum Institute API RP 1640 *Product Quality in Light Product Storage* | Although covering ethanol, butane and FAME light product biofuel, could be more useful if it covered other commonly used liquid or gaseous biofuel types |
| Transportation & Handling | IMO Code for Construction and Equipment of Ships Carrying Liquefied Gases (IGC Code) | Could benefit from clarifying current Code covers transport of bio equivalents such as bio-LNG or updated as necessary |
| | International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code) | Considered covers carriage of biofuel equivalents such as bio-methanol in association with other IMO instruments covering energy-rich fuels and application of MARPOL Annexes I and II |
| | Guidelines for the Carriage of Energy-Rich Fuels and their Blends (MEPC.1/Circ.879) and Guidelines for the Carriage of Blends of Biofuels and MARPOL Annex I Cargoes (MSCMEPC.<br>2/Circ.17) | Considered covers carriage in bulk of biofuel blends and energy-rich fuels in bulk |
| | IBIA, IMPCA, Methanol Institute | Could include dedicated marine bunkering guidance for biofuels |
| Use & Consumption | IMO International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels (IGF Code) | Future amendments should include detailed prescriptive requirements for other gaseous and low flashpoint fuels, including the bio-derived variants, and prior to amendments can support take-up through the development of interim guidelines similar to the methyl/ethyl alcohol precedent. |
| | IMO International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) | Some differences between IGC Code and IGF Code hamper harmonized requirements. |
| | IMO MSC.1/Circ.1621 - Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel | No significant gaps for supporting application of bio-methanol as a marine fuel |
| | SOLAS and IMO International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels (IGF Code) | Fuel oils (which may include biofuels) with lower than 60˚C flashpoint currently not covered within SOLAS or IGF Code |
| | SOLAS ISM Code, SOLAS II-1/Regulation 3-1 and classification society requirements | SOLAS ISM Code requires operators to assess all risks to a company's ships. SOLAS also requires equipment compliance with classification society rules. Liquid biofuels (biodiesels) are not an engine type defining parameter, but onboard demonstration of suitability typically required. IMO guidance similar to MEPC.1/Circ.878 for biodiesels and clarification on application via IACS UR missing. |
| | CIMAC *Guideline for Ship Owners and Operators on Managing Distillate Fuels up to 7.0% v/v FAME (biodiesel) (2013)* | Additional publications could cover other blend percentages or other types of biofuels. Publication of specific engine type guidance from CIMAC engine designers should be encouraged. |
| Quality | ISO 8217:2017 Petroleum products – Fuels (class F) – Specifications of marine fuels | Limits allowed liquid biofuel blends to de minimis or only up to 7% FAME in the DFA, DFZ and DFB grades. Industry experience indicates the specific energy calculation is not accurate for biofuels. Standard could be revised to allow higher blend percentages of qualified biofuels in marine fuels. |
| | ISO/PAS 23263 Petroleum Products – Fuels (class F) – Considerations for fuel suppliers and users regarding marine fuel quality in | Could incorporate these considerations into the next ISO 8217 revision |

| Subject | Rule/Guidance | Comment on Code/Standard - Gaps |
|---|---|---|
| | view of the implementation of maximum 0,50% sulfur in 2020 | |
| | IMO Prevention of Pollution from Ships (MARPOL) Convention – Regulation 18 – Fuel Oil Availability and Quality | There is uncertainty on application of regulation 18.3.2.2 for NOx. Annex VI should add required clarifications for suppliers of liquid biofuels regarding the NOx emissions resulting from the biofuel and other relevant biofuel specific requirements such as BDNs and $C_F$ factors that may be applicable. |
| | ISO 23306:2020 Specification of liquefied natural gas as a fuel for marine applications | Standard does not define a minimum MN value (requires the minimum to be agreed between supplier and user) or a limit on debris, therefore could benefit from including limits for those characteristics. |
| | ISO/AWI 6583 *Specification of methanol as a fuel for marine applications* | Ongoing standard development should ensure coverage of fuels derived from renewable sources (i.e., bio-methanol). |
| | ASTM D6751-20a *Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels* | No significant gaps for supporting application of FAME biofuel as a marine fuel |
| | ASTM D7544-12:2017 *Standard Specification for Pyrolysis Liquid Biofuel* | Could apply this land-based standard to the marine industry |
| | ASTM D7467-20a *Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20)* | No significant gaps for supporting application of FAME biofuel as a marine fuel |
| Bunkering | ISO/TS 18683:2015 *Guidelines for systems and installations for supply of LNG as fuel to ships* | This is applicable to LNG (and therefore bio-LNG) but could be revised to include specific guidance for other bio-derived alternative fuels or used as basis for development of new standard(s) |
| Bunkering | ISO 20519:2017 *Ships and marine technology – Specifications for bunkering of liquefied natural gas-fuelled vessels.* | This is applicable to LNG (and therefore bio-LNG) but could be revised to include specific guidance for other bio-derived alternative fuels or used as basis for development of new standard(s), where similar low flashpoint, gaseous or toxicity risks to ports exist. |
| Bunkering | ISO 28460:2010 *Petroleum and natural gas industries – Installation and equipment for liquefied natural gas – Ship-to-shore interface and port operations* | This is applicable to LNG (and therefore bio-LNG) but could be revised to include specific guidance for other bio-derived alternative fuels or used as basis for development of new standard(s), where similar low flashpoint, gaseous or toxicity risks to ports exist. |
| Bunkering | ISO 21593:2019 *Ships and marine technology. Technical requirements for dry-disconnect/connect couplings for bunkering liquefied natural gas.* | This is applicable to LNG (and therefore bio-LNG) but could be revised to include specific guidance for other bio-derived alternative fuels or used as basis for development of new standards(s). |
| Bunkering | ISO 20519:2021 *Ships and marine technology – Specification for bunkering of liquefied natural gas fueled vessels* | This is applicable to LNG (and therefore bio-LNG), but could be revised to include specific guidance for other bio-derived alternative fuels or used as basis for development of new standard(s). |
| Bunkering | MI/LR: Introduction to Methanol Bunkering Technical Reference | Supports the adoption of methanol and bio-methanol as marine fuels |
| IACS Classification Societies Rules, Guides and Guidance | | More could be done to encourage industry adoption of biofuels. Currently no IACS publications related to biofuels exist. |
| Regional and National Rules for Marine Fuel, including Biofuels as Marine Fuel | | Regional and national regulations can lead developments at IMO level. Wider adoption of IMO (or regional or national regulations) in those locations lacking all such instruments, could uniformly support the adoption of biofuels |

## 3.6 Marine regulation conclusions

The ‘drop-in’ nature of biofuels can often be considered advantageous from the technical perspective and facilitates take up and replacement of fossil-derived fuels in suitable applications. Furthermore, the use of existing regulatory instruments, that are in many cases transferrable to the biofuel equivalents, supports such biofuel take-up.

The ongoing regulatory development revised and new standards, and industry guidance and best-practice publications are further facilitating the adoption of marine biofuels.

The basket of measures introduced by the European Commission under the ‘Fit-for-55’ initiative, which includes revising regulations, directives and new policy initiatives, signals a strong commitment from the EU to a decarbonised and sustainable future for shipping.

However, further initiatives and regulatory developments are required to facilitate the widespread use of biofuels and to fill some of the identified gaps.

Specifically, the following need to be considered:

- Update of the ISO 8217 marine fuels standard to accommodate greater blends of FAME than the current 7% specifications, also to address the wider range of biofuels being considered and applied by the marine industry and to address the differences in specific energy of biofuels compared to conventional residual or distillate fuels;
- To finalise and publish the ISO/AWI 6583 Specification of methanol as a fuel for marine applications to support the use of renewable methanol;
- New and updated CIMAC publications to support liquid biofuels (biodiesels) and further engine type specific guidance from the engine designers should be encouraged;
- The lack of current regulation under the IGF Code for fuel oils with a flashpoint between 52˚ and 60˚C is not seen as a significant barrier to biofuel take-up; however, this is a gap in the current IMO instruments;
- The lack of IMO specific guidance for application of biofuels, similar to that issued for the 2020 fuels under MEPC.1/Circ.878, is not seen as a barrier to biofuel take-up, however such a publication could support harmonized application under the ISM Code obligations and support application of classification society requirements called out by SOLAS II-1/regulation 3-1;
- Further reductions in IMO’s regulation 14 fuel sulphur limits would provide significant air quality benefits, but also encourage application of inherently low sulphur biofuels;
- The uncertainty on application of regulation 18.3.2.2 of Annex VI regarding engines exceeding the applicable regulation 13 NOx emission limit when consuming fuels derived by methods other than petroleum refining remains a significant barrier to widespread adoption. However, workarounds exist by application of regulation 3.2 for trials onboard or regulation 4 for ‘equivalents’, and the publication of UI MEPC.1/Circ.795/Rev.6 provides pragmatic interpretation for the application of fuels derived from methods other than petroleum refining. However, there is an urgent need to update Annex VI and the NOx Technical Code to provide further clarity and harmonised application for burning biofuels;
- While the recognition of certified lower carbon factors for biofuels may potentially be reported through operational indices such as EEOI, CII and MRV/DCS, there remain significant gaps in the carbon intensity regulations to recognise this. A means for recognising alternative fuel carbon factors at the design stage, and closing some of the existing Annex VI Chapter 4 gaps, is needed;
- Considering the challenges in developing and implementing changes to regulations in a timely manner, industry stakeholders such as IACS can facilitate biofuel take up and harmonised application by the development of Unified Requirements, Unified Interpretations and Recommendations, this should be encouraged;
- Development of industry best practice and guidance publications for biofuel handling, specifically bunkering and transfers, together with engine manufacturer design and operational guidance should be supported.
- In general, the existing and developing international fuel standards and regulations are leading the maritime industry to contribute to the adoption of alternative fuels, including liquid and gaseous biofuels, for decarbonisation and emissions reductions, albeit at present take up is currently relatively small.

# 4. Risk assessment using biofuels as Marine Fuel in Merchant ships

The safety regulations for the use of biofuels as marine fuels are still under development, as described in Section 3 – Task 2 Safety and environmental regulations, standard and guidelines. As part of this study, a HAZID assessment was carried out for generic ship types (RoPax, VLCC and VLGC) to help contribute to discussions regarding safety and risk management of biofuel-fueled ships. This part of the report therefore provides an analysis of key aspects of biofuel safety for use as marine fuel. Considering the biofuels described in 2.1 (Figure 1) the fuels that were adapted for the different HAZID studies were all the biodiesels. Bio-methanol and liquified biomethane (LBM) were excluded because these are pure drop-in fuels with no new risks anticipated from their use on vessels already operating on Methanol and LNG, respectively. The biocrudes (of Figure 1) were also not considered in this section due to their current very limited availability, technology readiness level and more importantly, the lack of available information for use in internal combustion engines.

The HAZID studies therefore focus on the Biodiesels listed in Figure 1 and these were matched to specific vessel types based on the likelihood of these fuels being used on these vessel types in the near future.

Due to the similarities between HVO and FT Diesel, the HVO study is considered representative for the use of FT Diesel as a marine fuel, therefore only the HVO HAZID study is presented.

The HAZID assessments in the following sections involve the application of the three biodiesels on three different vessel types, at different blending percentages, as depicted in Table 46 below.

Table 46: HAZID studies of different biofuels on various vessel types

| Fuel Type – Biodiesel | Vessel Type | Blending percentage |
|---|---|---|
| HVO (or FT Diesel) | RoPax | 100% |
| FAME (with VLSFO) | VLCC | 50% - 100% |
| DME (with LPG) | VLGC (LPGC) | 20% - 30% |

The purpose of these studies is to identify the potential major hazards relative to the operational configuration of a proposed bio-fueled vessel at an early stage of concept development; review the effectiveness of selected safety measures and, where required, expand those measures to achieve a tolerable residual risk.

Early identification and assessment of hazards provides essential input to decisions about concept development at a time when changing design has a minimal cost penalty.

The HAZID workshops were undertaken to evaluate and summarize key aspects of safety as they pertain to an actual installation on board a vessel. The workshops included participation from an ABS multi-disciplinary team, external experts and clients.

## 4.1 Biofuel safety

From a safety perspective, biodiesels are very comparable to conventional fuels, such as MGO and MDO, and existing IMO and class society rules for structural fire protection, safety, firefighting, fire and gas detection, safe handling, storage and bunkering seem sufficient to apply to these biodiesels. However, this may not be the case for all biodiesels as there are several limitations to their application, which arise from the amount of the biodiesel that can be used in the existing fuel tanks, fuel supply systems and engines.

The purpose of the HAZIDs is to identify the possible risks involved with the use of the different biodiesels at different amounts (blends with existing fossil fuels), and based on available information and current experience; to rank these hazards accordingly and make recommendations that could be used by policy makers to bridge the gaps identified in Section 3.5, Table 45.

The sections that follow apply for all three HAZIDs, whereas the specific assumptions made and HAZID results for each biofuel and vessel type are reported in Sections 4.4.1, 4.4.2, and 4.4.3 respectively.

## 4.2 HAZID Objectives, Process, Scope and Assumptions

This section explains the objectives, process, methodology and scope of the HAZID analysis for the different biofuels and vessel types in the study.

### 4.2.1 Objectives

The preliminary objectives of the HAZID study were to identify the risks of using biofuels as marine fuels for Ro-PAX, VLCCs and VLGCs, and to verify that their prospective use at the conceptual stage of design development will satisfy the intent of all the goals and functional requirements identified in the regulations. The study's objectives were:

- To identify potential and new hazards introduced by biofuels that require mitigation
- To determine the potential consequences of the hazards
- To identify safeguards for hazard prevention, control, or mitigation (including safeguards for each stage of the project)
- To propose recommendations to eliminate, prevent, control, or mitigate hazards
- To provide early safety and risk considerations for design and safety-management requirements
- To provide a clear framework for future safety-assessment studies that will help to anticipate major accidents
- To compare this safety performance with the current practice

The outcome of the study is a hazard register for each vessel type. This includes:

- Potential hazardous scenarios, including causes, consequences and existing safeguards
- The risks inherent in each developed scenario, evaluated according to the severity and likelihood of the consequences
- Opportunities to improve design or risk-mitigation measures to reduce the estimated safety risks

### 4.2.2 Common Scope

It is assumed that all vessel types are in full compliance with regulatory and classification requirements; the scope of this assessment looks at the introduction of biofuels to existing systems, and will include the:

- General arrangement of vessels
- Biofuel-bunkering arrangement
- Biofuel-storage arrangement and details
- Biofuel-handling
- Biofuel-supply, fuel-conditioning systems, and biofuel return systems
- Ventilation and vents, fuel-supply system, machinery space and consumers (engines)
- Hazardous area classification plans

The HAZID team members used a workshop environment to identify and analyse the boundaries of the study and to brainstorm potential 'what if' scenarios. 'Guidewords' and sub-categorisations were used to identify the potential threats and the existing controls that could be used to limit or prevent their impact. Where required, recommendations were generated.

The HAZID analysis was conducted in sessions, which individually addressed each arrangement, process and operation on the ships.

### 4.2.3 HAZID Workshop Methodology

A HAZID assessment is an extremely useful tool for performing high-level risk assessments of specific systems. ABS has used this approach in numerous risk-assessment projects, as a standalone analysis, and to compare similar situations.

The HAZID workshops were held via video-conference. After the workshops, a brief review was conducted with the participants. A flow diagram for the overall HAZID process is shown in Figure 42 below.

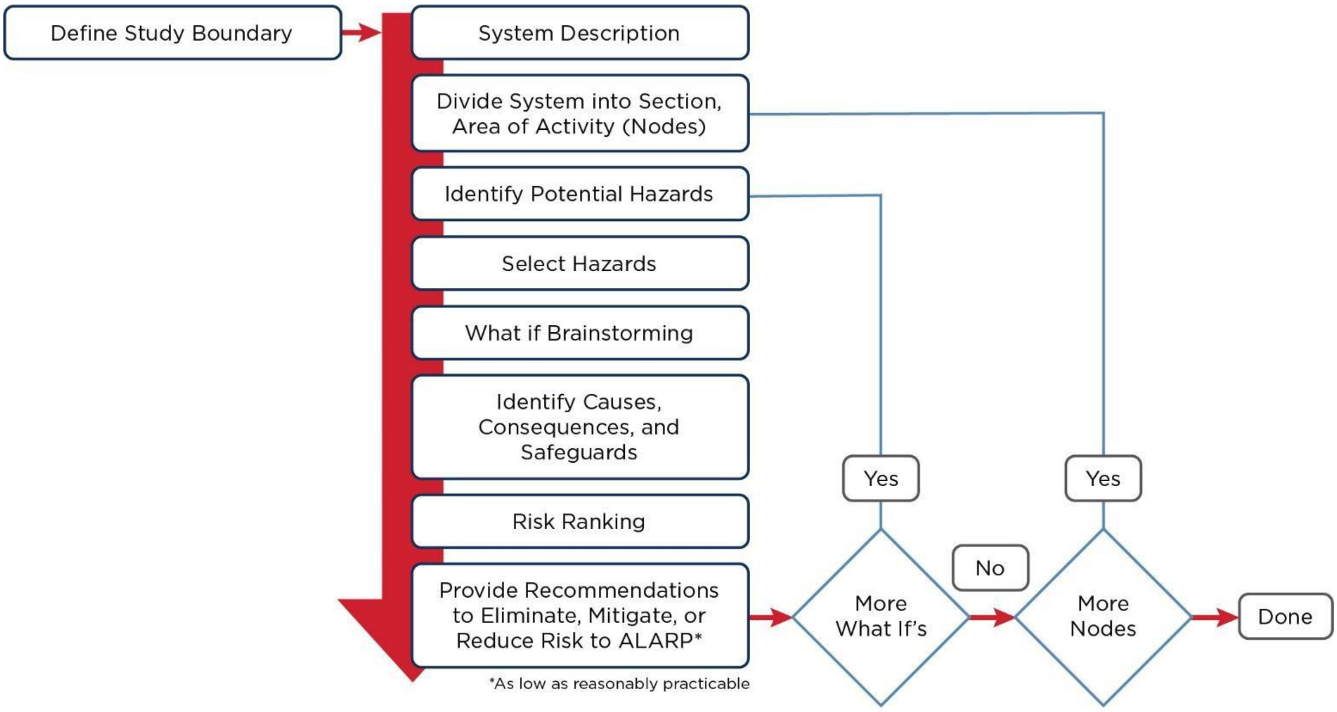


Figure 42. HAZID Process

During each workshop, a facilitator guided subject-matter experts through a structured discussion to identify and risk-rank the hazards. Participants were asked to provide input on preloaded scenarios (e.g., modifying, adding, or removing risk scenarios) within the hazard register, as well as to discuss the location of the scenario on a risk matrix. These discussions guided the focus areas, nodes and hazards to be considered before the study could be considered complete.

HAZID team members used a workshop environment to identify and analyse the boundaries of the study and to brainstorm potential 'what if' scenarios in a node. For clarity, a 'node' is a clearly defined, manageable section or system to be discussed in the brainstorming activity. 'Guidewords' are a set of conditions, such as "high pressure" or "vessel collision", that help streamline to brainstorming activity and identify potential hazards.

Guidewords and sub-categorisations were used to identify the potential threats and the existing controls that could be used to limit or prevent their impact. Where required, recommendations were generated.

The HAZID analysis was conducted in sessions, which individually addressed each arrangement, process and operation on the ships.

### 4.2.4 Limitations

The risk assessment involves a HAZID analysis based on the methodology described in the previous section. Although a HAZID study is the most appropriate way to identify the risks at the early stages of development (eg., vessel designs) or during service (e.g., use of drop-in fuels), some limitations do exist.

The limitations imposed to the three studies conducted involve the limited amount of information currently available about the use of these fuels on marine engines, the very limited tests performed so far with biofuels, and the different observations made due to the different engine designs available.

Although the study focused on the characteristics and properties of the biofuels that may impact safety and integrity of installation, it is acknowledged that the level of impact may also be affected by the amount of biodiesel that is blended with the conventional fuel oil, or the amount of DME to be blended with LPG.

### 4.2.5 Risk Ranking

A risk matrix (Appendix C) was used for a high-level evaluation of the risks from each hazardous scenario. The process used to rank the risks included:

- **Consequence review:** To identify the most credible worst outcome for each scenario. The HAZID team determined the outcome's location on the consequence axis.
- **Likelihood review:** The team determined the location of the undesired outcome along the frequency axis, considering the probability of failure for the preventive, detection and recovery safeguards designed to ensure that it does not take place.
- **Risk:** The intersection of the likelihood and consequence ratings produced the risk level for that specific hazard scenario
- **Action**: The risk ranking was used to help assess whether the current controls and safeguards are adequate and if not, then additional safeguards/controls were identified to potentially reduce the risk (or identify areas where further review or analysis would be applicable to each vessel type).

#### 4.2.5.1 General Groups of Systems/Areas

The following groups of systems and areas were considered (where applicable) for all three HAZIDs and represented the nodes of the risk registers as depicted in Table 49, Table 50 and Table 51 and Appendices D, F and H, respectively.

- Biofuel storage/tank
- Bunkering arrangement
- Biofuel system/arrangement/preparation room
- Machinery space
- Ventilation (venting system)
- Safety system (fire detection, firefighting, PPE, Emergency Generator etc.)
- Ship's operation
- Engines (Main and Auxiliary engines)

In addition, Because the use of DME as marine fuel requires a pressurized or refrigerated storage tank, the general arrangement of DME storage tank and associated risks were also discussed in the HAZID study for DME HAZID.

### 4.2.6 Hazards

The hazard scenarios used throughout the study to help the team identify potential loss scenarios were divided in three main groups, these being the biofuel-related hazards, the system-related hazards and ship-related hazards, as described in the following sub-sections

#### 4.2.6.1 Biofuel related Hazards

- Fire and Explosion Hazards
- Chemical Reactivity Hazards
- Toxicity Hazards
- Degradation/Stability
- High Detergency

- Material deposition in tank, filter etc.
- Acidic (leading to high wear, material degradation)
- Oxidation – long-term storage
- Long-term storage – gummy deposition on surface bottom
- Affinity to water and risk of microbial growth
- Compatibility
- Low viscosity
- Degraded cold flow properties
- Environmental – Water, Land
- Lubricity

#### 4.2.6.2 System related Hazards

- Process Hazards – e.g., release (loss of containment) of flammable inventory (for each area of the systems), ruptures, start-up/shutdown issues.
- Utility Hazards – e.g., fire-water system, fuel oil, heating/cooling mediums, power supply, drains/sumps, air, nitrogen, chemical injection, etc.
- Venting
- Maintenance Hazards – e.g., maintenance culture, provisions for safer maintenance, etc.
- SIMOPS – cargo operations loading/unloading, bunkering, supply, etc.
- Interface Issues – process, instrumentation, utilities, structural, etc.
- Emergency Response – access/egress, communication (alarms [audible/visual], call-points, CCTV, radio), fixed/portable firefighting equipment
- Any other hazards – lifting operations, structural failure, rotating machinery, cold/hot surfaces, etc.
- Any other issues or items of concern

#### 4.2.6.3 Ship related Hazards

Global Hazards*:

- Natural and Environmental Hazards – climatic extremes, lightning, seismic events, erosion, subsidence, etc.
- Movement/Floatation Hazards – grounding, collision
- Effect of Facility on Surroundings – proximity to adjacent installation, proximity to transport, proximity to population, etc.
- Effect of Man-Made Hazards – security hazards, social/political unrest, etc.
- Infrastructure – communication, supply support, mutual aid, emergency services, etc.
- Environmental Damage – discharges to air/water, emergency discharges, water disposal, etc.
- Product Hazards – oil
- Health Hazards – disease, carcinogens, toxic effects, occupational hazards

Note: (*) In some of the sub-categories (or 'guidewords") listed above, there may not be a hazard impact specifically attributable to the use of biofuels (either direct or indirect), in which case, it is not considered further.

### 4.2.7 General Assumptions – Applicable to all three HAZID studies

There were a number of critical assumptions made for the workshop. They are based on current documentation, and some were deemed of such importance to be considered as assumptions rather than be taken as recommendations. Most assumptions are considered as safeguards in the workshop records. Below are the common assumptions for both vessels:

- Biodiesels considered (FAME, HVO) have very similar properties to HFO/MGO – normal class rules/IMO rules will be sufficient. No major changes in the General Arrangement (GA) required.
- All vessels considered, Ro-Pax, VLCC and VLGC, will be designed and built-in compliance with Class/Statutory regulations, as applicable.
- For Fire Fighting system, structural fire protection, etc. the SOLAS/Class requirements are sufficient
- The Biofuel fuel system will be designed such that it will not release any biofuel to the atmosphere during normal operating conditions.
- Biofuel bunkering will be done in port in a very similar way to other marine fuels

- Cargo operations and bunkering can occur simultaneously.
- The fuel treatment/preparation room is very similar to that used by other marine fuels. It will have filters, purifier, heaters, pumps etc.
- Boilers and emergency gensets are not running on biofuel
- Lifeboats and fast rescue craft are not running on biofuel
- Modes of operation: Each mode of operation is considered for the entire lifecycle of vessel. The modes include (but are not limited to): bunkering, port departure, port entry, cargo loading/unloading in port, voyage (ballasted/loaded), standing by, maintenance, overhaul, emergency/upset situation, simultaneous operations, passenger loading/unloading in port and passenger (where applicable).

It is noted that the use of biofuels has been excluded from emergency gensets and LSA (Life-Saving Appliances) due to concerns and uncertainty over long term storage and stability, particularly for FAME. Should use of biofuel be contemplated for such systems, tests should be carried out.

## 4.3 Fuel properties considered in HAZID studies

This section identifies the key properties of the biodiesels that were considered in the HAZID study and focuses on those properties that give rise to potential risks and may have a direct impact on the systems and operation of the vessel.

Despite their similarities with conventional diesel (MGO), HVO and FAME have some very different properties which could affect their storage, transfer and use (combustion) in the engine. These specific properties are analysed in the sub-sections that follow and are directly compared in Table 47.

Similarly to DME, and although they may be blended with LPG without problems, it has some properties that are different which may have an impact on the LPG fuel-supply system and LPG-fuelled engines. These properties are addressed in the subsections that follow and directly compared in Table 48.

These observations may not apply to all engines and fuel-supply systems, due to the variances in the designs available. Furthermore, these may vary depending on the type of FAME/HVO and DME (eg., feedstock, production method, etc.), as well as the amount of blend used in combination with MGO and LPG, respectively.

### 4.3.1 Cetane Number

Cetane Number is a measure of the fuel's ignition and combustion quality. It affects engine performance and emissions.

HVO's higher cetane number will result in a shorter ignition delay and, therefore, in earlier combustion relative to MGO and FAME. Although the cetane number is a quality indicator of diesel fuels, the large difference between the cetane numbers for conventional diesel fuels and HVO may require some engine tuning adjustments (within the engine-control system) to compensate for earlier ignition.

Due to its high cetane number, DME has an excellent ignition ability and a short ignition delay. The cetane number of DME is significantly higher than LPG's and could be used to improve ignition characteristics when blended with LPG. This may lead to reduced amounts of pilot fuel oil required to ignite the LPG/DME mixture in a diesel-combustion cycle (it is currently set at about 3-10% for pilot fuel oil) and an improved GHG footprint and lower NOx emissions.

It is noted that Propane and Butane do not have a clearly defined Cetane number. Cetane number corresponds to measuring ignition delay. If the fuel does not self-ignite under the conditions defined in ASTM D6890-22 the Cetane number cannot be defined.

### 4.3.2 Kinematic viscosity

Kinematic viscosity is a measure of a fluid's resistance to flow under gravitational forces. The higher the kinematic viscosity, the more momentum per volume the fuel can transport: this is further enhanced if also combined with a lower density.

A low kinematic viscosity (below acceptable limits) may cause fuels to leak in the fuel-injection equipment, and even through the injection nozzles. The fuel's kinematic viscosity also may affect the fuel atomisation from the injectors and impact combustion quality and emissions. Low kinematic viscosity may therefore deteriorate combustion quality due to poor atomisation.

Although the typical kinematic viscosity of HVO is within specification, this should be confirmed by fuel analysis; if below specifications, a 'cooler' may be necessary to raise the viscosity and bring the fuel within specifications.

FAME has a relatively high kinematic viscosity, comparable to conventional diesel. However, a very high kinematic viscosity may deteriorate engine operability under cold conditions, and also may lead to coking of the fuel-injector nozzles, deposits, rings sticking, gelling of lube oils and other maintenance problems. To reduce the viscosity, it is possible to use a preheating system.

Both DME and LPG have very low kinematic viscosity compared to other biodiesels and this may lead to leakage problems within the fuel-supply and fuel-injection systems (eg., pumps and injectors). However, since dedicated LPG fuel-supply and injection systems will be designed to accommodate their low kinematic viscosity, it is anticipated that the kinematic viscosity of a mixture of LPG and DME will not impact the existing LPG systems significantly.

### 4.3.3 Lower Calorific Value (LCV)

The Lower Calorific Value (LCV), also known as lower heating value or net calorific value, of a fuel is an indication of the amount of heat released by combusting a specified quantity of that fuel; this directly affects the power output of the engine.

Most FAME qualities has a LCV of about 10-14% lower than MGO and HVO, due to its higher oxygen content (it is zero for MGO and HVO). Depending on the amount of FAME to be used for blending with MGO, this will have a negative impact on the power output of the engine.

The LCV of DME is significantly lower than that of LPG, about 40%. Depending on the amount of blending of LPG and DME, the mixture will impact significantly the power output of the engine. Furthermore, larger quantities of DME will be required and/or more frequent DME bunkering to transit the same distances. The anticipated engine derating and the increased DME quantities could have an impact on the size of the storage tanks, fuel-supply system components and possibly the design of the fuel-injection system.

### 4.3.4 Nitrogen Oxides (NOx)

NOx is emitted from the combustion process of fuels. The main factors that contribute to higher NOx emissions are the high temperatures of combustion and the amount of oxygen contained in the fuel, or the amount of air at the time of combustion.

There are several contradicting reports about NOx emissions from the use of FAME (Table 15). Some studies have reported NOx reductions while others found increases. Although the combustion performance of a fuel depends on its properties, it also depends strongly on the engine's combustion system; with different engine designs available, NOx emissions from FAME may vary from one engine to another. Due to the presence of oxygen in FAME, it is likely that NOx emissions will be higher than for MGO, however, this may not be the case for all engine designs.

The NOx emissions from HVO could be slightly lower or similar to those from MGO due to the former's shorter ignition delay, a result of its higher Cetane number.

For the same reason, the NOx emissions from DME are expected to be lower than those from LPG and will be lower to those from MGO.

For all the biodiesels considered in the HAZID, the maximum expected reductions of NOx are projected to be about 30%; this implies that using these biofuels onboard ships will require Selective Catalytic Reduction (SCR) systems or the Exhaust Gas Recirculating (EGR) systems to reduce the NOx output to Tier III limits, if the vessel is sailing in NOx ECAs.

### 4.3.5 Lubricity

Lubricity is a measure of the fuel's ability to reduce friction and damage to surfaces in relative motion under load, and to provide adequate lubrication for the components of the fuel-supply and fuel-injection systems (e.g., fuel pumps, injectors, etc.). The manufacturing precision of these components requires them to be adequately protected from scuffing and wear, which can affect their fuel-delivery characteristics.

FAME offers a good lubricity performance; whereas HVO, due to the absence of sulphur and oxygen compounds, combined with its other properties, has very low lubricity.

DME also has very low lubricity and, when combined with LPG (which also has low lubricity), this could become a matter of concern for the fuel-supply and injection system, subject to the amount the two fuels are blended. Engine systems are however equipped with a sealing oil system to secure that all running surfaces are continuous lubricated.

### 4.3.6 Oxidative Stability/Storage stability

Oxidative stability is a measure of the fuel's ability to resist oxidation during storage and use. Fuels with a lower oxidative stability are more likely to form the peroxides, acids and deposits that adversely affect engine performance.

MGO and HVO have lower oxidative stability and can be stored for longer periods.

FAME, due to its poor oxidative stability, may loosen the foulants – such as water, sludge and cat fines – in fuel-storage tanks and increase the accumulation of deposits on engine equipment. Fuel-treatment equipment also may become overloaded and lose some of its ability to remove harmful contaminants from the fuel. If these foulants are not reduced before they reach the engine, they can cause major damage.

Consequently, FAME may require additives to extend its storage and usage timelines. The need for additives may not apply to all engines and will depend on the amount of FAME being used, as well as on the engine type (eg., 4-stroke and 2-stroke engines). Additives has however been shown to be a large cost-up of the fuel, so they are a rarely used for fuels to the marine, so alternative coating can be applied in fuel tanks to extend the usage lifetime, alternative more frequent bunkering is also an option.

### 4.3.7 Cold Flow Properties

The cold flow properties of a fuel indicate its low-temperature operability. FAME has poor cold flow properties and if fuel storage temperatures are not properly controlled, they may accelerate instability, impact shelf life and the fuel's suitability for use. For these reasons, CIMAC recommends maintaining fuel temperatures at least 10ºC above the pour point. A "primary preventative action" is to heat fuel-storage tanks, piping and filters. But if heating is not practicable, it is recommended to treat the fuel with cold-flow improvers.

HVO also may have poor cold flow properties, but these are improved significantly through isomerisation, which is the step in HVO's production process that converts the n-alkanes into more branched structures, iso-alkanes, and impacts significantly the low-temperature properties of the HVO.

Table 47. Fuel property comparisons between Diesel, FAME and HVO (Garrain, et al., 2010; Garrain, et al., 2014; Dimitriadis, et al., 2018; Pechout, et al., 2019; Advanced Biofuels USA, 2020)

| Fuel Property | Units | MGO – Diesel (Petroleum based) | FAME (Biodiesel) | HVO (Renewable Diesel) |
|---|---|---|---|---|
| Cetane Number | - | 40 – 55 | 50 – 65 | 80 – 99 |
| Density at 15°C | $Kg/m^3$ | 0.82-0.85 | 0.88 | 0.77-0.78 |
| Kinematic viscosity at 40°C | $mm^2/s$ | 2.5-4.5 | 4.5 | 2.5-3.5 |
| LHV | MJ/Kg | 42-44 | 37-38 | 34-44 |
| Oxygen content | % | 0 | 11 | 0 |
| Sulphur content | ppm | < 10 | < 10 | < 10 |
| NOx Emissions (from combustion) | % | Baseline | +10% | -10% to 0 |
| Lubricity | - | Baseline | Good | Poor (may require additives) |
| Oxidative Stability / Storage stability | - | Baseline | Poor (Antioxidants to increase storage life or stability, or frequent bunkering is more likely) | Good |
| Cold Flow Properties | - | Baseline | Poor | Good (only with isomerisation) |

Table 48: Fuel property comparisons between Diesel, DME and LPG (Stepanenko & Kneba, 2019; Styring, et al., 2021; IEA, 2022)

| Fuel Property | Units | MGO – Diesel (Petroleum based) | DME | LPG | |
|---|---|---|---|---|---|
| | | | | Propane | Butane |
| Cetane Number | - | 40 – 55 | 55 – 60 | * | * |
| Density at 15°C | $Kg/m^3$ | 0.82-0.85 | 0.66 | 0.5 | 0.61 |
| Kinematic viscosity at 40°C | $mm^2/s$ | 2.5 – 4.5 | 0.12–0.15 | 0.2 | 0.2 |
| LHV | MJ/Kg | 42-44 | 28 | 46 | 45 |
| Oxygen content | % | 0 | 34.8 | 0 | |
| Sulphur content | ppm | < 10 | 0 | 0.01 | |
| Expected NOx Emissions (from combustion) | % | Baseline | - 20% | - 10% to 15% | |
| Lubricity | - | Baseline | Poor | Between Baseline and Poor | |

* The Cetane number of Propane and Butane is not clearly defined. Please see section 4.3.1

## 4.4 HAZID Results – Findings and Recommendations

During the workshop, all high-level risks were considered, and the safeguards required by codes/standards/regulation were identified; the appropriate risk-rankings were developed and are listed in a risk register for the three subject vessels, a RoPax, a VLCC and a VLGC.

The majority of the risks identified were related to the loss of assets. Such risks, if not properly addressed, may compromise the integrity of systems, machinery and components. These risks could be mitigated at the design stage of the vessel, or through upgrades, by selecting the appropriate materials, testing processes and quality controls.

The subsequent sections address the HAZID conducted for each subject vessel that was fuelled with the specified biodiesel, as already depicted in Table 46.

Based on the findings listed in the HAZID registers, (Appendices D, F and H) several recommendations were developed for each vessel and fuel, listed in Appendices E, G and I, respectively.

### 4.4.1 Ship 1: A RoPax fuelled with HVO

An existing RoPax ship operating in Europe was examined for study. The vessel has two full-length vehicle decks and a lower hold. It also features two 4-stroke main engines driving two shafts, three four-stroke gensets with two separate engine rooms and an emergency generator sized to supply essential services. The general arrangement of the vessel is shown in Figure 43 below.

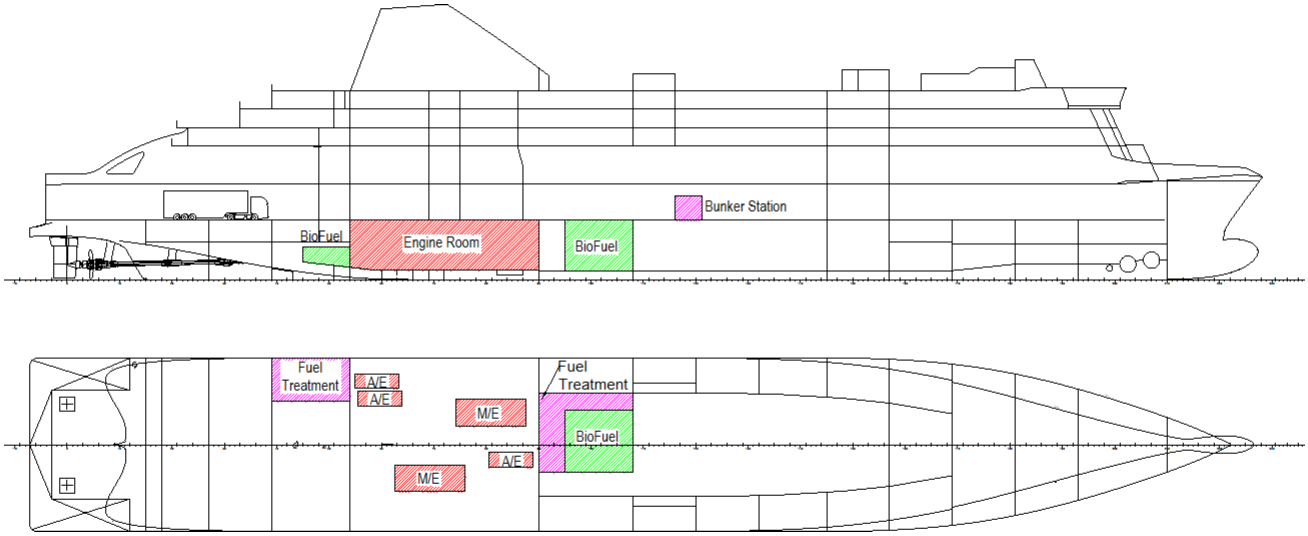


Figure 43. General Arrangement of the RoPax Vessel

#### 4.4.1.1 Assumptions

In addition to the general assumptions listed in section 4.2.7, some additional assumptions are listed below:

- The biofuel was 100% HVO (ie., no blend with MGO or other low-sulphur diesels)
- The RoPax meets regulations for a safe return to port.
- Any biofuel bunkering will be done at port and in similar ways to standard practices for RoPax vessels

#### 4.4.1.2 Results and Recommendations

Although shipping has limited operational experience with the use of HVO onboard vessels, the findings suggest that the impact of this fuel on engine components and fuel-supply systems is likely to be low, or even insignificant.

The HAZID register identifies the hazards and documents the recommendations. Eight system- and operational-level nodes were considered with various scenarios for each node, as described in the HAZID register (Appendix D), and the summary of the risk rankings is outlined in Table 49.

A total of 67 risk scenarios were identified and ranked accordingly, including four high-risk scenarios, 19 medium-risk and 44 low-risk scenarios.

The four high-risk scenarios will require mitigation as design and testing progress further. For all of the high-risk scenarios, and some of the medium-risk ones, recommendations were documented in Appendix E.

There were no unresolvable or unmitigable risks identified during the preliminary HAZID that would prevent the successful deployment of HVO as a fuel for marine applications.

Table 49. HAZID Risk Ranking Summary – RoPax (fueled with HVO)

| Key system level HAZID nodes | Risk Ranking of Hazards Identified | | | |
|---|---|---|---|---|
| | Low | Medium | High | Extreme |
| Node 1: Biofuel storage/tank | 27 | 11 | 2 | 0 |
| Node 2: Bunkering Arrangement | 0 | 0 | 0 | 0 |
| Node 3: Biofuel system / arrangement / preparation room | 5 | 1 | 0 | 0 |
| Node 4: Machinery Space | 0 | 0 | 0 | 0 |
| Node 5: Ventilation | 0 | 0 | 0 | 0 |
| Node 6: Safety System | 0 | 0 | 0 | 0 |
| Node 7: Ship's Operation | 5 | 3 | 0 | 0 |
| Node 8: Engines | 7 | 4 | 2 | 0 |
| **Total per Risk Level (out of 67 risks)** | 44 | 19 | 4 | 0 |

The key findings and recommendations about the use of HVO on a RoPax vessel and the possible risks are outlined below:

- If the kinematic viscosity of HVO is relatively low and below specification it could impact the operation of the fuel-supply system, the associated components and the engine performance.
- It is recommended to confirm through fuel analysis that the fuel viscosity is within specification.
- The lubricity of the HVO may be lower compared to other biodiesels and may require lubricants to ensure efficient operation of the fuel-supply and fuel-injection system components.
- It is recommended, especially for smaller engines (eg., 4-stroke) that the lubricity of the fuel is addressed and, to avoid having to use additives, to use blending amounts that will not significantly affect the lubricity of the mixture.
- The cold flow properties of HVO are in general satisfactory, as long as isomerisation is part of its production process.
- It is recommended to confirm with the fuel supplier that the supplied HVO had undergone the relevant production steps that will not affect its cold flow properties.
- To ensure that the above are within specification, in addition to performing the relevant fuel analysis, it is also recommended to perform frequent inspections, and follow closely the recommended cleaning and maintenance procedures
- Although HVO demonstrates the characteristics of a drop-in fuel, care should be taken to ensure that those properties satisfy the industry standards, and that the fuel's quality is sufficient for use onboard and that it is according to the specifications of the equipment supplier and engine designer.

### 4.4.2 Ship 2: A VLCC fuelled with FAME

A typical VLCC was considered for this risk study. The fuel (in this case, FAME) is stored in tanks inside the engine room. The side shell is double-walled. The esterified biofuel is comparable to MGO, therefore a standard MGO layout for the fuel-oil system was used for the HAZID analysis.

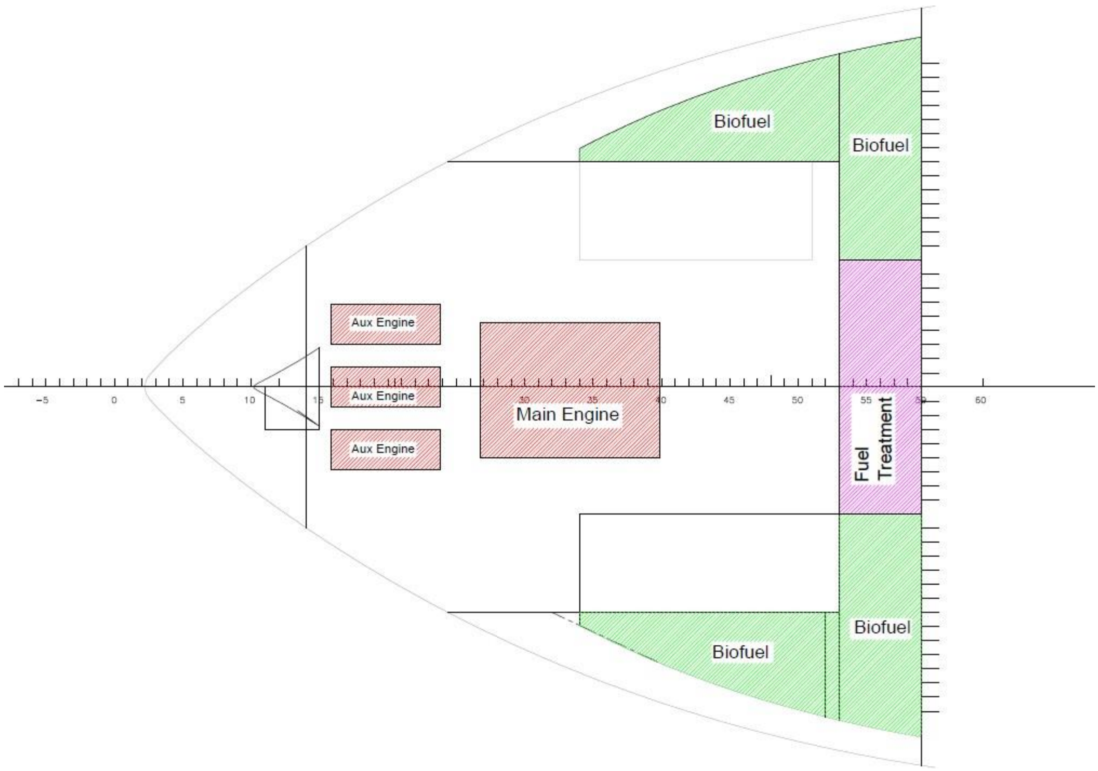


Figure 44. General Arrangements of the VLCC vessel

#### 4.4.2.1 Assumptions

In addition to the general assumptions listed in section 4.2.7, the other assumptions are listed below:

- The biofuel used to fuel the VLCC was a blend of FAME and MGO, and proportions could vary between 50% and 100% FAME.
- A standard fuel-oil system layout was considered for the VLCC
- Proper fuel-oil temperature management and viscosity controls were in place

#### 4.4.2.2 Results and Recommendations

The HAZID register created during the workshop identified the hazards and documented the recommendations. Eight system and operational level nodes, similar to the HVO HAZID study, were considered. The various scenarios for each node are described in the register included in Appendix F, and the summary of the risk ranking is outlined in Table 50. A total of 67 risk scenarios were identified and ranked accordingly, including 10 high-risk scenarios, 32 medium-risk and 25 low-risk scenarios.

Table 50. HAZID Risk Ranking Summary – VLCC (fuelled with FAME)

| Key system level HAZID nodes | Risk Ranking of Hazards Identified | | | |
|---|---|---|---|---|
| | Low | Medium | High | Extreme |
| Node 1: Biofuel storage/tank | 13 | 22 | 5 | 0 |
| Node 2: Bunkering Arrangement | 0 | 0 | 0 | 0 |
| Node 3: Biofuel system / arrangement / preparation room | 2 | 3 | 1 | 0 |
| Node 4: Machinery Space | 0 | 0 | 0 | 0 |
| Node 5: Ventilation | 0 | 0 | 0 | 0 |
| Node 6: Safety System | 0 | 0 | 0 | 0 |
| Node 7: Ship's Operation | 3 | 5 | 0 | 0 |
| Node 8: Engines | 7 | 2 | 4 | 0 |
| **Total per Risk Level (out of 67 risks)** | 25 | 32 | 10 | 0 |

The high-risk scenarios will require mitigation as design and testing progress. For all of the high-risk scenarios, and some of the medium-risk scenarios, recommendations were documented in Appendix G.

There were no unresolvable or unmitigable risks identified during the preliminary HAZID that would prevent the deployment of FAME as a fuel for marine applications.

The key findings and the possible risks are outlined below:

- FAME has an LCV that is about 14% lower than that of MGO, and this may impact the power output of the engine, the fuel consumption and the amount of biofuel to be bunkered for a specific cruising ranges
- It is recommended to perform calculations to accommodate any possible effects on cruising ranges and plan accordingly for extra bunkering, if needed
- NOx emissions may increase from the use of FAME and may compromise the NOx compliance of the engines and the vessel
- It is recommended to confirm with the engine designer that the use of FAME at the given blending ratio will not affect the NOx emissions from the engine
- FAME may not be compatible with existing components of the fuel system – such as seals, gaskets and hoses – and may swell the seals, leading to possible biofuel leakage
- It is recommended that prior to the use of FAME to obtain confirmation by the equipment suppliers about its compatibility with the fuel-system components
- FAME may loosen foulants in the fuel-storage tanks and can increase the accumulation of deposits in the fuel-system and engine components, leading to possible engine damage
- It is recommended, prior to the use of FAME, to clean fuel tanks thoroughly. Post use of FAME, it is also recommended to clean filters and perform inspections of the fuel-system components frequently
- Due to its poor cold flow properties, uncontrolled fuel storage temperatures may accelerate FAME's instability, impact shelf life and its fitness for purpose. This may require thermal management onboard to control the storage temperatures, or to use products that improve cold flows.
- It is recommended to consult with the fuel supplier about FAME's cold flow properties and possible instability for the expected storage durations and temperatures (to minimize requirement for heating, and to avoid the use of additives)
- The impact of the above characteristics of FAME on systems and engine performance depends on the amount of FAME that is to be blended with conventional diesel. Limited operational experience is currently available to reach any conclusions, but the limited feedback indicates that blends of up to 30% (ie., B30) may be possible without significant changes to the fuel-supply system and engine components. The HAZID analysis indicates that, for higher blending percentages (B50 up to B100), the likelihood of impact to the fuel-supply systems and engine increases; upgrades may be needed to adapt to higher percentages of FAME, subject to specifications and recommendations by the engine designer and the provider of the fuel-supply system.
- All the above highlight the importance of performing fuel analysis prior to the use of FAME, compatibility checks with exiting equipment onboard, as well as frequent inspections, cleaning and maintenance procedures. Guidance and confirmation from equipment suppliers and engine designers will be important.

### 4.4.3 Ship 3: VLGC fueled with DME/LPG blend

A 84,000 $m^3$ class of LPG carrier (LPGC) was examined for the risk study. The engine is a dual-fuel engine that can run either on conventional fuel oil (MGO), or on LPG. According to the engine manufacturer, the engine during the LPG mode also may operate with a mixture of LPG and DME. The blend of LPG and DME considered for this study is up to 30% DME (and 70% LPG).

The General Arrangement of the LPGC is shown in Figure 45, and the schematics depicting the arrangement of the fuel tanks, fuel-supply system and main engine are depicted in Figure 46. During normal operation with LPG (ie., without DME), fuel from one of the cargo tanks is pumped to the LPG service tank located on deck. From the service tank the LPG goes through the fuel-supply system (FSS) and fuel valve train (FVT) and supplied to the engine at the pressure and temperature of 50 bar and 45ºC, respectively.

The return line from the engine (where the fuel may contain debris and sealing oil) goes through the FVT and back to the service tank, to be recirculated back into the engine. This return fuel is not sent back to the cargo tanks to prevent possible contamination of the cargo.

For the operation of the engine with a mixture of LPG and DME, the two fuels are delivered to a mixing tank at the required ratio, taking into account the fuel mixture returning from the engine. The tanks used for storing and mixing the fuels are Type C, where they are stored at pressurised conditions of 18 bar and 8 bar, respectively, in liquid form at atmospheric temperature. In case of an emergency/shutdown, the safety system for operation in LPG mode will function the as when the engine is operating in the LPG/DME mode.

The details of the FSS are shown in Figure 46. It can operate either on LPG fuel only, or in LPG/DME fuel mode. During operations using LPG/DME mode, the fuel blend in the mixing tank is pumped to the FSS upstream of the high-pressure pumps. The pumps raise the pressure of the mixture to about 50 bar and the cooler/heater adjusts the temperature of the fuel to about 45ºC.

Prior to entering the FVT, the fuel mixture goes through 10-micron filters that clean any impurities contained in the fuel. The fuel enters the FVT at the pressure, temperature and cleanliness levels specified by the engine designer. The return line from the engine is circulated back to the mixing tank.

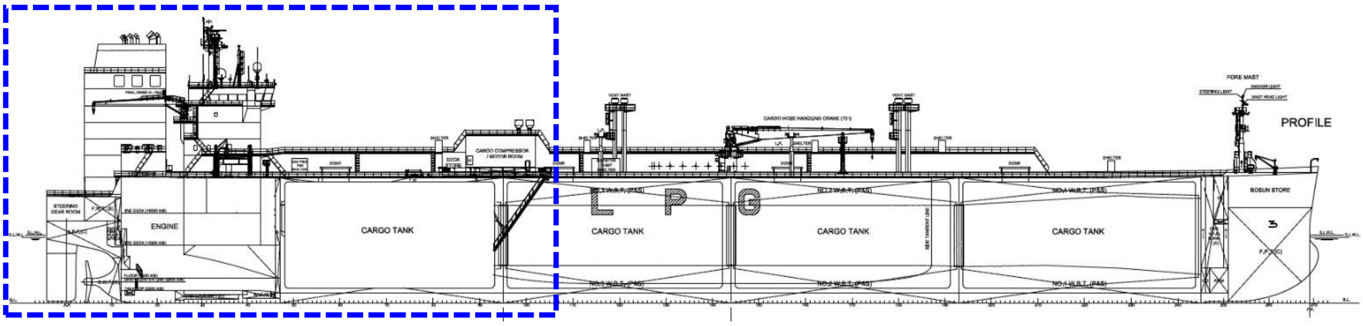


Figure 45. General Arrangement of LPGC

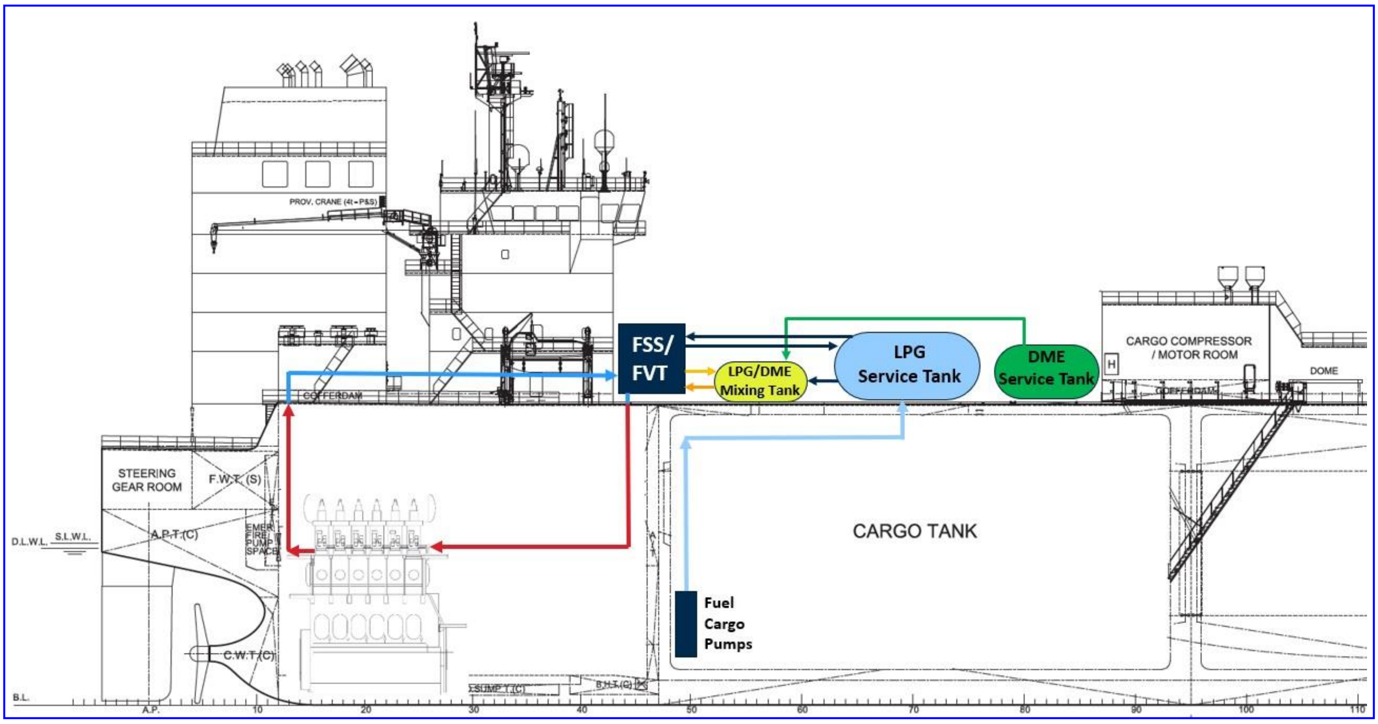


Figure 46. Schematic of proposed setup of fuel-containment and fuel-supply systems for LPG and DME (for illustration purposes only)

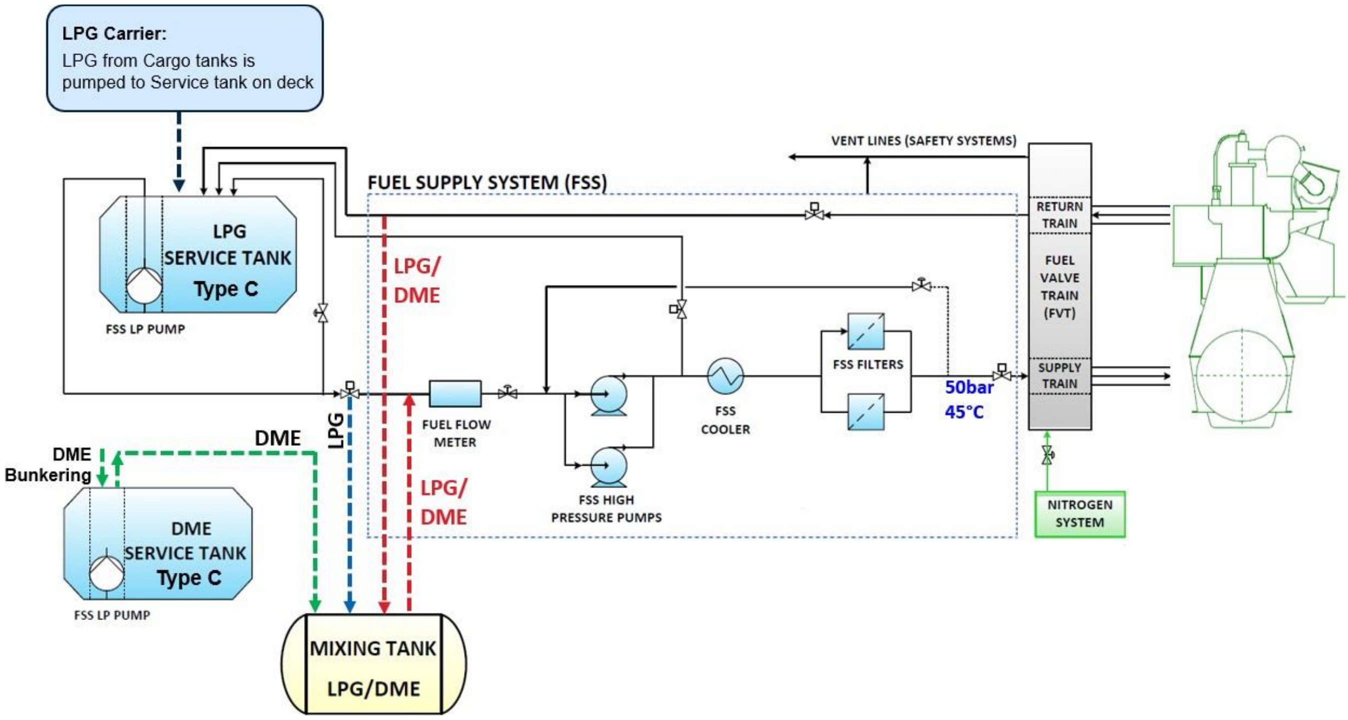


Figure 47: Schematic of the LPG/DME fuel supply system (for illustration purposes only).

#### 4.4.3.1 Assumptions

In addition to the general assumptions listed in section 4.2.7, other assumptions include are listed below:

- The fuel considered for the VLGC was a mixture of DME and LPG, at a maximum blending ratio of 30/70 (DME/LPG)
- The VLGC is a standard LPG carrier with no special fittings for DME
- DME is stored in Type C tanks located on deck in the cargo area and in compliance with IGC Code requirements
- DME is mixed with the LPG in a mixing tank to the required ratio and the mixture is pumped to the fuel-supply system of an LPG dual-fuel engine
- The mixing tank is a pressurised tank
- An additional bunkering manifold is to be installed for DME
- DME venting is independent by discharge and at the same common location as LPG

#### 4.4.3.2 Results and Recommendations

The HAZID register created during the workshop identified the hazards and documented the recommendations. Eleven nodes at system and operational levels were considered with various scenarios for each, as described in the HAZID register (Appendix H). A summary of the risk ranking is outlined in Table 51. A total of 42 risk scenarios were identified and ranked accordingly, including 15 high-risk scenarios, 16 medium-risk scenarios and 11 low-risk scenarios.

The high-risk scenarios will require mitigation at a later stage of design and testing. For selected high-risk, medium-risk and low-risk scenarios, 43 recommendations were developed to reduce the likelihood of the initiating events, to provide additional prevention barriers, or to mitigate the worst-case consequences. These recommendations, which serve as suggestions for design and operational changes or further studies, are documented in Appendix I.

Overall, there were no unresolvable or unmitigable risks identified that would prevent the deployment of a DME/LPG mixture as a fuel for marine applications.

Table 51. HAZID Risk Ranking Summary – VLGC (fueled with DME and LPG)

| Key system level HAZID nodes | Risk Ranking of Hazards Identified | | | |
|---|---|---|---|---|
| | Low | Medium | High | Extreme |
| Node 1: General Arrangement | 1 | 1 | 1 | 0 |
| Node 2: DME storage tank | 6 | 8 | 1 | 0 |
| Node 3: Bunkering arrangement | 3 | 1 | 2 | 0 |
| Node 4: Fuel system/preparation | 1 | 3 | 5 | 0 |
| Node 5: Supply system/vapour handling | 0 | 0 | 1 | 0 |
| Node 6: Cargo Compressor/Motor Room | 0 | 0 | 1 | 0 |
| Node 7: Engines | 0 | 0 | 4 | 0 |
| Node 8: Ventilation and Venting System | 0 | 0 | 0 | 0 |
| Node 9: Safety System | 0 | 2 | 0 | 0 |
| Node 10: Ship's Operations | 0 | 1 | 0 | 0 |
| Node 11: Emergency Escape, Evacuation, Rescue (EER) | 0 | 0 | 0 | 0 |
| **Total per Risk Level (out of 42 risks)** | 11 | 16 | 15 | 0 |

The key findings from the preliminary HAZID study on the use of DME and LPG mixture as a fuel for a VLGC and the possible risks involved are outlined below:

- Due to its low energy density, DME storage may require larger storage tanks for marine vessel usage.
- It is recommended that tank quantity, capacity, location and storage conditions are factored into the vessel's design to ensure that DME storage capacity is sufficient without impacting structural loading.
- DME has low viscosity and poor lubrication properties, which may impact engine performance.
- It is recommended to consult equipment manufacturers about the use of appropriate sealing materials for possible upgrades, and about lubrication oil that is compatible for use with DME.
- DME is expected to emit lower NOx emissions than LPG.
- It is recommended to obtain confirmations from the engine designer about the use of different DME and LPG blends to ensure engine's operational efficiency and compliance with statutory requirements (NOx emission limits).
- Available information about the toxicity of DME and its applicability onboard vessels is limited. The study demonstrated that appropriate personal protective equipment (PPE) will be required and selected for its suitability for DME exposure, fire etc.
- It is recommended that further research on DME toxicity is conducted to understand possible health impact from personnel exposures to DME. Research findings can guide the detection and alarm levels for toxicity and the development of maintenance procedures to minimise personnel exposure.
- For its use with LPG, DME will be stored under pressurised conditions, which will also require bunkering in pressurised conditions.
- It is recommended that bunkering systems be designed for such conditions, and appropriate training, procedures and safety zones developed, in addition to those already in place for LPG.
- It is also recommended that detailed risk studies on bunkering procedures should be conducted to identify any additional risks and to develop safety zones.
- Pressurised DME is to be mixed with refrigerated LPG and will require an additional fuel-supply system and procedures to be followed.
- It is recommended that these systems are addressed in detail through an independent HAZOP study to reduce possible risks
- It is recommended that a standalone day tank/mixing tank is installed to ensure the proper mixing of DME and LPG at the desired ratios prior to entry to the engine. The fuel-mixing ratio will need to be continuously monitored and maintained at the desired level to obtain maximum benefit from the use of DME

## 4.5 Overall conclusion from biofuels HAZID

The HAZID studies demonstrated that there were no unresolvable or unmitigable risks identified that would prevent the successful deployment of biodiesels, such as HVO (and FT Diesel), FAME and DME mixtures as fuels for marine applications.

The number of risks that were identified for each biodiesel were different, and these are summarised below:

- HVO (FT Diesel): 4 High-risks, 19 Medium-risks and 44 Low-risks
- FAME: 10 High-risks, 32 Medium-risks and 25 Low-risks
- DME/LPG: 15 high-risks, 16 Medium-risks and 11 Low-risks

These reveal that some fuels may be easily adapted in marine applications (e.g., HVO, FT Diesel), while others (e.g., FAME, DME) may require modifications or upgrades of the fuel-supply systems, and possibly retrofits of new components on the engines. The studies also showed that the degree of modifications may depend on the degree of blending of these biofuels with conventional fossil-based fuels.

The fuels that scored the lowest number of high-risks are those considered to be drop-in fuels, as already defined in Sections 1.3.1 and 2.4.5.

Regardless of how easily these biofuels may be adapted in marine applications, the HAZID studies show that their applicability and relevant risks depend strongly on the properties of the fuels, which are affected by the production processes and feedstock used to produce them. The variety of such processes and feedstock demonstrate the need for standards to ensure adequate biofuel specification, as well as maximum/minimum property ranges for these fuels to be fit for purpose.

Furthermore, the biofuel properties that may impact the reliability of equipment should be tightly controlled by appropriate quality control-processes and certification schemes.

The adaptation of these biofuels in marine applications also depends on investigations engine designers will conduct to demonstrate that their applicability does not compromise safety, that operational reliability is unaffected and that the emissions from the combustion of these fuels do not exceed the limits.

It is likely that biofuels will require the development and implementation of more frequent inspections, cleaning and maintenance procedures onboard ships, compared to conventional fuel oils. However, as experience with the use of biofuels grows, it is expected that the frequency of inspections and the processes implemented will revert to similar levels as those used with fuel oil.

### 4.5.1 Risk-Based Road Map for Using Biofuels as Marine Fuel

The HAZID studies identified common high risks stemming from biofuel storage tanks, bunkering systems, and vessel engines. The road map below provides a checklist to address high-level risks at the engineering design, bunkering and operation phases.

Table 52. Biofuels Checklist Roadmap for Risk Assessment

| Checklist | Product Phase | HVO | FAME | DME/LPG blend |
|---|---|---|---|---|
| **Biofuel storage tank related risks:** Fuel quantity, varying biofuel grades, biofuel degradation in storage tanks can lead to equipment damage, engine issues and shutdown, and fuel system leakage. | | | | |
| Conduct fuel analysis and compatibility testing according to applicable standards | Engineering Design | ✓ | ✓ | ✓ |
| Conduct a material compatibility study with all elastomeric materials to verify swelling, absorption, and degradation of the materials used for seals | Engineering Design | ✓ | ✓ | ✓ |
| Consider biofuel characteristics, fuel specifications requirements, and operating conditions early in the system design, including appropriate equipment and materials selection. | Engineering Design | ✓ | ✓ | ✓ |
| Determine adequate lubricity of the standalone biofuels, and of the fuel and additives mixtures for the system. | Engineering Design | ✓ | ✓ | ✓ |
| Check biofuel specifications and system designs to address isomerisation in HVOs. | Engineering Design | ✓ | | |
| Ensure that system and engine components are appropriately selected considering the biofuel lubricity and properties. | Engineering Design | ✓ | ✓ | ✓ |

| Checklist | Product Phase | HVO | FAME | DME/LPG blend |
|---|---|---|---|---|
| To bring the fuel within specification and to prevent the biofuel from leaking from the fuel-injection system, consider system designs which can deliver fuel within acceptable ranges of viscosity. | Engineering Design | ✓ | ✓ | |
| Develop Fuel Management System onboard and thermal management system at the fuel storage tank, fuel-supply system, etc. to monitor biofuel parameters (e.g., temperature, viscosity, pressure etc.). | Engineering Design | ✓ | ✓ | ✓ |
| Design Fuel Management System to maintain FAME temperature to be at least 10ºC above the pour point (ref CIMAC). | Engineering Design | | ✓ | |
| Ensure biofuel storage tank design, type selection and coating meet class and international regulatory requirements, including appropriate detectors and tank parameter monitoring and alarms (level, pressure) as part of vessel-control systems. | Engineering Design | ✓ | ✓ | ✓ |
| Evaluate and test the coating for the FAME storage tank and evaluate its compatibility, as well as those of the selected biofuel mixtures and additives. | Engineering Design | | ✓ | |
| Provide proper ventilation arrangement for DME storage tank. | Engineering Design | | | ✓ |
| Add bunkering manifold to the design when using DME/LPG blend. | Engineering Design | | | ✓ |
| Since the LCV of DME is significantly lower than conventional fuels (e.g., LPG), depending on the specific LPG/DME blend, conduct DME onboard storage feasibility study and determine the quantity of DME needed for vessel operations, DME storage tank size, weight, dynamic loads to ensure that the deck can withstand the tank load. | Engineering Design | | | ✓ |
| Evaluate the FSS components and fuel-injection system for the engine when using DME/LPG blends. Due to the low LCV of DME, increased DME quantity and engine degradation is expected. | Engineering Design | | | ✓ |
| Perform a toxicity study to understand the personnel exposure to DME in case of leakage from storage tank or dropped object damaging the tank. | Engineering Design | | | ✓ |
| Based on toxicity study, determine appropriate toxicity vapour detection such as detector type, alarm and shutdown detection setpoints per manufacturer recommendations. IGC Code requires additional vapour detection and closed gauging for DME applications in the marine industry. | Engineering Design | | | ✓ |
| Develop process to mix DME and LPG blend in a separate mixing tank before sending fuel blend to the engine and provide appropriate fuel management system to keep DME/LPG blend within the operating conditions. | Engineering Design | | | ✓ |
| Ensure proper documentation of fuel usage, consumption rate, and fuel quality before loading fuel to storage tank | Operation – Biofuel loading | ✓ | ✓ | ✓ |
| Since FAME's oxidative stability/biodegradable nature can loosen foulants (water, sludge, etc.) in the storage tank, implement proper tank coating and tank cleaning prior to using FAME mixture. | Operation – routine sampling, inspection | | ✓ | |
| Consider frequent sampling of biofuel in the storage tank, frequent injection of additives (e.g., biocides) to the storage tank, frequent inspection and drainage of storage tank and equipment to prevent biofuel degradation and equipment damage. | Operation – routine sampling, inspection, and maintenance | ✓ | ✓ | ✓ |

| Checklist | Product Phase | HVO | FAME | DME/LPG blend |
|---|---|---|---|---|
| Implement monitoring of biofuel temperatures and viscosity in the storage tank and engine as part of the vessel-control systems and as part of the crew's routine duties. | Operation – routine monitoring | ✓ | ✓ | ✓ |
| Implement routine storage tank cleaning schedule, based on key indicators from crew routine inspection and monitoring systems | Operation – maintenance | ✓ | ✓ | ✓ |
| Implement entry procedures for confined spaces and provide adequate PPE to minimise personnel exposure to toxic atmosphere during tank entry for inspection and service. | Operation – maintenance | ✓ | ✓ | ✓ |
| Due to biofuel lubricity may cause potential scuffing and wearing on rotation components in the fuel system (e.g., pump), consider developing a critical spare parts list and ensure parts are available for equipment changeout. | Operation – maintenance | ✓ | ✓ | ✓ |
| Due to FAME's oxidative stability/biodegradable nature, use antioxidants at an early stage and reduce degradation possibility for long-term fuel storage. | Operation – long-term storage | | ✓ | |
| Provide appropriate PPE for crew working near DME storage tanks, including masks, rubber and/or plastic gloves. | Operation | | | ✓ |
| Implement crane operator training and procedures to minimize the likelihood of damages from dropped object on biofuel storage tanks. | Operation | ✓ | ✓ | ✓ |
| **Bunkering related risks:** When bunkering under pressurised conditions, there is potential for DME/LPG blend leakage during vessel bunkering, leading to personnel exposure to DME, equipment damage due to fire and/or explosion | | | | |
| Before bunkering operation, conduct fuel sampling and compatibility check | Bunkering | ✓ | ✓ | ✓ |
| Bunker procedural HAZOP/HAZID to be conducted to identify additional risk during DME bunkering operation | | | | ✓ |
| When switching from diesel to biofuel mixture, implement procedures to flush the system. | Bunkering | ✓ | ✓ | ✓ |
| Implement proper bunkering procedures and provide crew training for the application of biofuels. | Bunkering | ✓ | ✓ | ✓ |
| Implement Fuel Management Procedures (Fuel Implementation Plan) with considerations for selected biofuel characteristics and consumption rates. | Bunkering | ✓ | ✓ | ✓ |
| Due to FAME's oxidative stability/biodegradable nature, avoid bunkering the FAME for long-term storage prior to use. | Bunkering | | ✓ | |
| Design DME bunkering system and piping so that the system can be purged with inert media. | Engineering Design – Bunkering | | | ✓ |
| **Engine and Engine Room related risks:** Due to biofuel related issues (compatibility, low fuel grade quality, lubricity, etc.) there is increased wear and potential damage on engine rotating equipment, excessive exhaust emissions higher than allowable limits, reduced engine performance, and fuel leakage from fuel injection components. | | | | |
| Analyse the applicability of selected biofuel mixture for specific engine types and select the appropriate engine model, operating conditions. | Engineering Design | ✓ | ✓ | ✓ |
| Engine and engine-room (ER) design to comply with IMO and class requirements, including continuous ventilation from ER space. | Engineering Design | ✓ | ✓ | ✓ |
| For the selected biofuel mixture, evaluate the desired power output and required fuel consumption with respect to the vessel voyage and operating profile. Also, because there is potential for increased fuel consumption leading to increased bunkering fuel quantities (comparing to diesel fuel), determine the appropriate size of the storage tank and fuel consumption for the design. | Engineering Design | ✓ | ✓ | ✓ |

| Checklist | Product Phase | HVO | FAME | DME/LPG blend |
|---|---|---|---|---|
| Considering the lower LCV of DME, consider the use of pilot oil or higher pump capacity to improve engine power output. | Engineering Design | | | ✓ |
| Provide suitable sealing oil for engine injectors systems when using DME/LPG blend. | Engineering Design | | | ✓ |
| Conduct explosion study to understand potential explosion scenarios due to unburned DME/LPG mixture in the engine exhaust drains. | Engineering Design | | | ✓ |
| Engine type testing by engine manufacturers to address emissions issues when using the selected biofuel mixture. | Engineering Design – Engine type testing | ✓ | ✓ | ✓ |
| Verify NOx emissions are within allowable limits in engineering simulations and prototype testing for the selected biofuel mixtures. | Engineering Design – Prototype Testing | ✓ | ✓ | ✓ |
| Consult engine manufacturers and evaluate the compatibility of engine components with the selected biofuel mixture and implement appropriate changes/upgrades to existing engine components. | Engineering Design | ✓ | ✓ | ✓ |
| Consider adding Selective Catalytic Reduction and NOx traps in the design to minimise NOx emissions | Engineering Design | ✓ | ✓ | ✓ |
| After an engine model is selected, determine the proper engine lubricant with respect to the selected biofuel mixture. Conduct lubricant testing to confirm selection. | Engineering Design – Lubricants | ✓ | ✓ | ✓ |
| Develop appropriate maintenance procedures and equipment changeout plan for engine and components, as contents in biofuel may lead to equipment clogging issues and deteriorating exhaust gas after-treatment systems. | Operation – Routine maintenance | ✓ | ✓ | ✓ |
| Develop engine tuning adjustments procedures to account for earlier ignition delay when using biofuel mixture and to optimize engine performance and minimise emissions. | Operation | ✓ | ✓ | ✓ |

# 5. Conclusions of Biofuels study

This study provides an update on a previous study developed by EMSA on biofuels, including an overview of the 'state of play' on the use of biofuels in the shipping sector. It reviews the applicable regulations and standards and analyses the safety implications for a range of biofuels.

Some of the characteristics that distinguish biofuels from other alternative fuels is their potential for being used as a drop-in fuel and as an alternative to existing fossil fuels either as part of a blend or neatly. These characteristics provide a readily available and feasible route to contribute to the decarbonisation of the bulk of the existing shipping fleet, as well as help with attaining peak emission targets as soon as possible. This contrasts with the large-scale retrofitting that would be required otherwise if the industry was to adopt other fuel alternatives such as hydrogen or ammonia.

Drop-in fuels also have the advantage that the existing logistics and bunkering infrastructure can still be used, as opposed to the need to build out bunkering infrastructure for other alternative fuels.

The definition adopted for this report of drop-in fuels is: *"Fuels that can be used as an alternative to conventional petroleum refined hydrocarbon fuels without substantial modifications to the engine, fuel tanks, fuel pumps and the overall fuel-supply system".* For clarity, this means for drop-in biodiesels and bio-crudes (whether in blends, or at 100%) could replace distillates and residual fuels; bioalcohols could replace the current use of alcohols, DME could replace LPG and biomethane could replace the use of LNG.

The overall ranking of biofuels in relation to their potential as a feasible alternative for shipping was conducted based on evaluations of production pathways, TRL and sustainability, feedstock availability, suitability and cost trends, and is as follows:

- HVO from FOGs, and biomethane from digestion of waste and residues
- FT diesel, biomethane from gasification (both produced from lignocellulosic biomass) and FAME from FOGs
- Bio-methanol from lignocellulosic biomass
- DME from lignocellulosic biomass

The overall sustainability, $CO_2$ and air quality benefit of biofuels can vary widely, depending on feedstock; generally, the feedstocks from lignocellulosic biomass and waste seem to be better with regards to $CO_2$ savings on a well-to-wake basis.

However, safeguards do need to be put in place to ensure $CO_2$ savings and sustainability, particularly since there is large-scale demand for lignocellulosic biomass from all sectors that could result in poor conservation and biodiversity concerns.

Today, fats, oils and grease feedstocks (FOGs) dominate the biofuels that are used in shipping. Although there is some uncertainty on how biofuels may have been captured in the IMO DCS, for 2020 the database reported the use of 27,792 tonnes of used cooking oil, 2,651 tonnes of biofuel and 19 tonnes of biogas. For biofuel, a similar quantity of 2,978 tonnes was reported in 2019. However, there are some concerns about the availability and scalability of FOGs to the volumes that would allow them to be used as a dependable feedstock for meeting FAME and HVO demand.

From the scalability and availability perspective, biofuels based on lignocellulosic biomass are more promising, but Fischer-Tropsch diesel and DME have other issues with which to contend, including:

- The quantities of Fischer-Tropsch diesel produced from bio sources is very small (there is much more produced as gas-to-liquid) and there is a lack of published data on it. Additional research and tests will be needed to understand the potential of this fuel
- Although DME has a reasonably mature production pathway and scores well on $CO_2$ savings, it does not appear to have made any inroads into shipping. Part of the reason for this is likely that it may be considered a drop-in fuel against diesel only at very low blending percentages (5-10%) and is thus self-limiting in terms of potential for $CO_2$ reduction. At higher blending percentages, it requires dedicated gas-storage and fuel-handling systems and special handling and safety procedures. As such, it does not meet

the definition of a drop-in fuel for conventional fuel oil installations. For newbuilds, it comes into competition with other alternative fuels, such as methanol, for which the ship installations are already being developed; the full-installation costs will be cheaper when compared to DME. In this study, DME was considered as a blend with LPG; many of the existing systems on LPG-fuelled vessel can handle DME. LPG-powered ships are currently in the minority, which limits the potential of DME. However, new LPG carriers that use their cargo as fuel have almost become an industry standard, so DME as a renewable fuel to replace LPG could have potential on this smaller shipping segment.

Biomethane and bio-methanol are direct replacements for LNG and methanol, respectively, and scored well in the ranking. Bio-methanol appears to score better from a sustainability perspective, while biomethane has a more mature production pathway: both appear to have cost challenges in the short term to 2030.

Recent announcements on bio-methanol-powered ships appear to corroborate the analysis, while the industry also has signalled the potential for the current LNG-fuelled fleet to move towards biomethane. However, the supply of biomethane for shipping seems to have strong competition from other segments because it can be fed directly into local (commercial and residential) heating systems, and into the local gas grid to replace natural gas.

Using the biomethane locally also saves having to use the more energy-expensive liquefaction process. The question is how much will ultimately become available for shipping.

Further research is needed to investigate the cumulative energy demand of the different production pathways and feedstocks, as information on the energy intensity for the production of the different fuels is lacking. The number of production pathways for biofuels is huge, and biomass is expected to be a limited resource, especially with the current expectations for protecting biodiversity. This will be an important factor when distinguishing between and selecting the most energy-efficient production pathways and feedstocks.

Other competitive uses for these biogenic carbon sources could come into play in this evaluation; the available biomass ultimately could be found to be more beneficial to society if used to produce plastics, building materials and other chemicals commonly used in local households. Further research is clearly needed to compare and contrast the different pathways for the use of biocarbon.

The total cost of ownership (TCO) model that was developed for the three vessel groups examined in this study – containers, bulk carriers and tankers – compared the use VLSFO with other biofuels. It showed that, currently, the alternative-fuelled vessels would not be cost competitive with vessels operating on conventional VLSFO.

In 2030, the TCO is expected to be higher for vessels fuelled with FAME, bio-methanol and bio-methane compared to VLSFO. For HVO and FT, the TCO has a very similar level as compared to fuel oil, therefore, depending on the fuel oil price at the time (including excise duty), the final value could be either higher or lower than fuel oil. Most alternative fuels show promising TCO figures from 2030 onwards, with approx. 20-45% lower annual TCO than VLSFO in 2050. Only biomethane still shows a higher than VLSFO TCO in 2050.

Applying a retrofit into use of either bio-methanol and biomethane, are adding both cost, complexity and risk compared to installing the fuel equipment in a newbuild. Further if the ship is not prepared for a retrofit the loss of cargo can be significant, all this adds to the operational cost for the ship and will make retrofitted ship less competitive compared to owners who order newbuild vessels.

There is considerable uncertainty regarding the availability of biomass for shipping in 2030 and in 2050. Availability will naturally also have a huge impact on the prices of those fuels at that time; as many observers forecast shortages for biomass sources, it is reasonable to expect to see the price for biofuels increase.

It is also possible the industry will see a growth in fraudulent practices around establishing the sustainability of some sources of biomass. If this becomes common, it could lead to a lower cost for biofuels, but it also would have huge consequences for biodiversity. More research is needed to identify best practices for how fraud associated with the declarations on biofuel waste can be tackled worldwide, and how any controls can be enforced.

To illustrate the complexity of this matter, this report offers this simple example. If wood residues from a furniture manufacturer meet the sustainability requirements, the business owner may receive approval to supply it for fuel production. In difficult times and if prices are high for wood residues, it will become more tempting for the manufacturer to simply increase the volume of wood residues, by whatever means. To tackle this kind of potential for fraud, it will require strict controls on feedstock. Blockchain technology is seen as a possible way to discover these types of frauds.

On the regulatory side, the following recommendations need to be considered:

- An update of the ISO 8217 marine fuels standard to accommodate greater blends of FAME than the current 7% specifications. It would also help to address the wider range of biofuels being considered and applied by the marine industry, and address the differences in the specific energy of biofuels compared to conventional residual or distillate fuels;
- To finalise and publish the ISO/AWI 6583 Specification of methanol as a fuel for marine applications to support the use of renewable methanol;
- The current lack of regulation under the IGF Code for fuel oils with a flashpoint between 52˚ and 60˚C is not seen as a significant barrier to biofuel take-up; however, there is a gap in the current IMO instruments;
- Further reductions in IMO Regulation 14’s fuel-sulphur limits would provide significant air quality benefits, but it may also encourage the application of inherently low-sulphur biofuels.
- The uncertainty regarding the application of Regulation 18.3.2.2 of Annex VI (for engines exceeding the applicable Regulation 13 NOx emissions limit when consuming fuels derived by methods other than petroleum refining) remains a significant barrier to widespread adoption. While a workaround exists by applying Regulation 3.2 for trials onboard, or Regulation 4 for ‘equivalents’, there is an urgent need to update Annex VI and the NOx Technical Code to provide clarity and harmonise the applications for burning biofuels.
- While the recognition of certified lower carbon factors for biofuels could be reported through operational indices such as EEOI, CII and MRV/DCS, there remain significant gaps in the EEDI regulations to recognise this. A way of recognising alternative fuel carbon factors at the design stage, and closing some of the existing EEDI gaps may be needed.
- Considering the challenges in developing and implementing changes to regulations in a timely manner, industry stakeholders such as IACS can facilitate the rate of biofuel adoption and harmonised application by developing Unified Requirements, Unified Interpretations and Recommendations; this should be encouraged.
- The development of industry best practices and guidance publications for biofuel handling, specifically bunkering and transfers, together with engine manufacturer designs and operational guidance, should be supported.

The HAZID studies in this report identified no unresolvable or unmitigable risks that would prevent the deployment of biodiesels, such as HVO (and FT Diesel), FAME and DME mixtures as fuels for marine applications, so the pathway for the use of those fuels in shipping appears to have no major issues. Still, additional focus will be needed to monitor the daily use of those fuels in pumps, tanks and engine systems to ensure that the wear and tear of components parts is discovered and rectified as early as possible.

Issues such as higher acid content can lead to corrosion in the fuel system, but the mitigation is relatively easily solved by selecting the materials that are compatible with higher acid contents. In particular, seals must be replaced more regularly when some biofuels are adopted. The presence of high acid content in some fuels has been raised by engine makers, so it is reasonable to expect that will be reduced in future biofuels.

The long-term storage of some biofuels may result in bacterial and fungal growth and coagulation in storage tanks, leading to corrosion and filter blockage. More frequent bunkering, or perhaps the application of new tank coatings that prevent bacterial growth, can solve these issues.

Engine performances also were found to be slightly affected when using biodiesel fuels; in particular, the lower caloric value and increased NOx emissions of some biofuels may be on the borderline for some of the engines in operation. Those relatively minor performance issues could be solved by introducing further tests on engine testbeds using those biofuels. These could lead to specific engine optimisations by applying new parameters for using those fuels, which could lead to that engine being certified for biofuel operations.

***Summarising**, in absence of other alternative fuels, biofuels are currently a viable fuel option to support shipping's decarbonisation. This is mainly due to its drop-in nature allowing its direct use onboard without (any) substantial retrofitting or unsurmountable risk related implications. In addition, many of these biofuels are currently available, although not in sufficient quantities. Lastly, although regulation could be updated and improved for better inclusion of biofuels, many of the current regulations can be directly or indirectly applied to biofuels due to their similarity to fossil fuels. All these combined are the main facilitators for the adoption of biofuels currently.*

*Naturally, there are still barriers preventing a wider adoption of biofuels. One of them relates to their fuel costs which could benefit from a levy or an emission trading mechanism. Currently, operating on a biofuel can double or triple the fuel costs. Although at a regional scale, the future adoption of the Fit-for-55 package is expected to provide a major incentive to these fuels. With the upcoming discussions on Market Based Measures at IMO, it is expected that this barrier to be unlocked in the coming years.*

*Currently, one of the biggest barriers to the adoption of biofuels is the lack of international and cross-industry regulations/standards on the sustainability criteria. As depicted in the study, there is a multitude of pathways to produce biofuels and some of them may present a bigger harm to nature than their fossil equivalent. There are currently several standards outlining the greenhouse impact of the production of these fuels and the sustainability criteria to which they need to comply, and they differ among themselves. As shipping, road transportation, aviation, industry and others are and will be competing for the supply of biofuels, although IMO is currently discussing the creation of maritime fuels lifecycle guidelines (which is a necessary and important step), it is important to seek consistency with the other equivalent guidelines from the other industries. This is to ensure a harmonized and equitable consideration of the biofuels across industries.*

*A harmonized set of suitable criteria can support a proper focus of investments and a set of carbon tax or fuel levies promoting the adoption and the production of biofuels that present a real potential to decarbonise shipping.*

*Although seen as a viable option for deepsea shipping, as demonstrated in this report, some aspects such as its limited (and regional) availability may make it also a perfect fit for segments of the industry demanding a lower usage of fuels such as short-sea shipping, fishing vessels, offshore energy production supporting vessels, tugs, etc.*

Table 53 (below) provides a summary of the observations detailed in this report, together with some proposed solutions and suggestions.

Table 53. Summary of the Observations

| Subject | Observation/Mitigations/Suggestions |
|---|---|
| Production | **Observation**<br>• FAME, HVO and 1st generation ethanol and methane have the most mature production pathways;<br>• Transition towards more advanced feedstock is on the way for these fuels and others;<br>• Although most of the production for biofuels is based on crops, there is increased demand for FAME, HVO and SVO.<br>• There is limited interest for ethanol and HTL biocrude;<br>• There is a strong focus on lignin-based fuels and biorefinery concepts, which may lead to an increase of the TRL levels of the respective biofuels;<br>• Most of the pilot projects are focused on technology feasibility rather than on large scale cost reductions.<br>• Lately, there has been a fast development of companies targeting production of green methanol<br><br>**Mitigations and Suggestions:**<br>• In the short term, it is advisable to rely on the available biofuels, although produced from crops. This should enable the faster development of supply chains, storage and bunkering facilities for biofuels. However, rapidly the industry needs to evolve to more advanced and more sustainable biofuels;<br>• In the medium to long term, increase focus is to be put into lowering the production costs for these fuels rather. |
| Sustainability | **Observation**<br>• Due to the biogenic nature of the carbons, biofuels have a capacity to reduce the WTW GHG emissions;<br>• Advanced biofuels can reduce up to 90% the WTW emissions, even reaching 100% reducing if combined with carbon capture sequestration technologies;<br>• Biofuels produced from food and crops can produce less reduction in emissions due to ILUC. In some cases, the effects can be negative to the environment, especially when considering effects on biodiversity and carbon stocks;<br>• There is a movement towards shifting from crops to waste and residues, although it cannot be directly assumed that waste and residues are automatically sustainable;<br>• Most of the biofuels are sulphur-free or with significant lower levels of sulphur. Biofuels can also reduced the NOx emissions, depending on the engine loads;<br>• There is an increase of fraudulent practices around the sustainability of biomass. |

**Mitigation and suggestions**

- There is a need for clear, harmonized and cross-industry sustainability criteria to promote wider adoption of sustainable biofuels. Industry actors, governments and non-governmental organization need to work together towards unified standards for lifecycle guidelines including relevant sustainability criteria.;
- As industry focuses on biofuels, it is important to not only consider the GHG emissions but also a series of other sustainability criteria such as land usage, effect on biodiversity, impact on food production;
- It is important to put in place control, verification and certification mechanism to avoid and mitigate for the appears of fraudulent cases.

**Availability**

**Observation**

- In EU, there is a limited availability of food crops which explains the expected shift towards sustainable biomass, mostly wood based;
- There is a large uncertainty in the projections of available biomass in towards 2030 and 2050. The values vary from 7.3 to 18 EJ in 2030 and from 7.0 to 19 EJ in 2050, according to JRC estimates (JRC, 2020);
- The estimates from the Fit for 55 package seem to be more conservative, predicting lower availability;
- Used Cooking Oil currently represents a high portion of the used biomass for biodiesels, and although they represent just a small percentage of the available biomass in Europe, their usage is expected to increase over the years;
- There is a high potential for marine biomass (macro-algae) in Europe, over 10 times those from agriculture and forestry. Techno-economical barriers hinders the potential of this biomass currently;
- The global availability of biomass is about 10 times higher than the one in EU;
- Fuels-wise, those produced from lignocellulosic biomass provide the most promising long-term availability (FT Diesel, DME, bio-methanol and biomethane. Those produced from FOGs present the less promising availability.

**Mitigations and Suggestions:**

- Focus on developing or accelerating the development of the biofuels produced from lignocellulosic biomass is advised as these have the best potential in terms of available biomass in the long term;
- In the short term, fuels produced from waste and residues can provide a good alternative. However, it is important to consider sustainability criteria carefully as highlighted in the section concerning sustainability above.
- There is a need for studying the most efficient pathways for the use of different sources of biomass, to conclude on where it could be best used.

**Suitability**

**Observation**

- Most biofuels can be considered as drop-in, requiring little to no retrofitting. The following table summarizes the suitability of biofuels:

| Biofuel | Replaced fossil fuel | Drop in properties/blend % | Remarks |
|---|---|---|---|
| FAME | Distillates | Up to 100% v/v | Subject to confirmation by Engine Designer for blends above 7% v/v FAME |
| HVO | Distillates | Up to 100% v/v | Subject to confirmation by Engine Designer |
| FT diesel | Distillates | Up to 100% v/v | Subject to confirmation by Engine Designer |
| DME | Distillates – LPG in dual fuel engines | Up to 20-30% v/v – up to 100% v/v | Subject to confirmation by Engine Designer |
| Bio-methanol | Methanol | Up to 100% v/v | For Methanol DF Engines and Fuel Supply System |
| Bio-ethanol | Distillates in Otto engines – Methanol in dual fuel 2-stroke engines. | Up to 100% v/v | Not enough information about use in marine engines – probably doable by introducing minor modification to the methanol fuel injection system |
| SVO | Fuel oil | Up to a limited share | Subject to confirmation by engine Designer |
| Pyrolysis oil | Fuel oil | Not a drop-in fuel | Properties vary widely and change with ageing. Acidic and corrosive.<br>Can be upgraded to a drop-in fuel. |
| HTL biocrude | Fuel oil | Up to a limited share | Little information about use in blends in marine engines.<br>Can be upgraded to a drop-in fuel. |
| Solvolysis oil | Fuel oil | Up to a limited share | Little information about use in blends in marine engines.<br>Can be upgraded to a drop-in fuel. |
| Liquefied biomethane | LNG | Up to 100% v/v | For DF and Gas Engines, and Fuel Gas Supply System |

- There is lack of sufficient data to allow for a more detailed analysis of the suitability of the biofuels.

**Mitigations and Suggestions:**

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| | • There is a need for more transparency and cooperation into sharing data and experience on the usage of biofuels. As such IMO could play a role, inciting owners, operators, engine manufacturers, class societies and others to share experiences;<br>• As the usage of the biofuels increases, it is important to keep monitoring and survey mechanisms to track for potential incompatibilities and issues due to the usage of biofuels. |
| **Techno-economical** | **Observation**<br>• The total cost of ownership shows that with a time horizon of 2030, HVO and FT diesel can present similar TCO values as those of VLSFO. Towards 2050, these fuels present TCO values lower than VLSFO, especially if carbon pricing is considered;<br>• With a time horizon of 2030, biomethane and bio-methanol TCO is expected to be about twice the VLSFO TCO. However, looking into 2050, bio-methanol provides promising TCO figures, capable of reaching values comparable to VLSFO and even reaching lower values compared to VLSFO if carbon pricing is considered;<br>• With the same time horizon of 2030, FAME TCO lies in between HVO / FT diesel TCO on the one hand and bio-methane and bio-methanol TCO on the other hand. Towards 2050 FAME TCO is expected to reach competitive TCO values against VLSFO, especially if carbon pricing is considered. FAME TCO is then expected to be comparable to bio-methanol TCO and in between HVO / FT diesel TCO and bio-methane TCO.<br><br>**Mitigations and Suggestions:**<br>• To ensure the adoption of biofuels, regulations may need to be put in place to bridge the price gap between it and conventional fuels;<br>• Market pressure also may play an equivalent or support role in the transition towards biofuels;<br>• It is important for the industry to focus into initiatives to lower the cost of production of biofuels rather, switching from technology demonstration;<br>• As biofuels uptake develops, the whole infrastructure (such as bunkering) and availability will increase which is expected to drive the prices of the biofuels downwards. Therefore, it is important to continue to incentivize the uptake of biofuels as it may support lowering the TCO values as presented in this study, however competition for the use of the same biomass in other sectors will likely drive up the cost on the sustainable biomass |

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| **Rules and Regulation** | **Observation**<br>• Due to the drop-in nature of the biofuels, in many cases existing rules and regulations are transferable from fossil to bio equivalents. This aspect provides a support to the uptake of the biofuels;<br>• There are recent and ongoing regulatory developments are further facilitating and supporting the uptake of biofuels. Noting the recent update on the Unified Interpretation facilitating compliance of biofuel fuels with NOx requirements;<br>• Also, industry guides or best-practices have been published in recent years, allowing a dissemination of the acquire knowledge so far;<br>• However, knowledge transfer and transparency could be higher, allowing for a faster development of the regulations and increased uptake of biofuels;<br>• Although reporting of biofuels consumption is possible via the DCS, there is a lack of clear regulations around it. As result, biofuels are not fully accounted in the current energy efficiency regulations (EEDI, EEXI and CII) developed by the IMO and there is a lack of carbon factors dedicated for biofuels;<br>• Regulations tackling the GHG impact of fuels in the maritime industry (including biofuels) are about to be implemented (Fit-for-55) or being discussed (IMO level). At the IMO level, both lifecycle guidelines and market-based measures are being discussed which include considerations on biofuels.<br><br>**Mitigations and Suggestions:**<br>• Update of the ISO 8217 marine fuels standard to accommodate greater blends of FAME than the current 7% specifications, also to address the wider range of biofuels being considered and to address the differences in specific energy of biofuels;<br>• To finalise and publish the ISO/AWI 6583 Specification of methanol as a fuel for marine applications to support the use of renewable methanol;<br>• New and updated CIMAC publications to support liquid biofuels (biodiesels) and further engine type specific guidance from the engine designers should be encouraged;<br>• Develop the IGF Code to include for fuel oils with a flashpoint between 52˚ and 60˚C;<br>• Encourage discussions and further work in terms of the application of SOLAS II-1/regulation 3-1, to support a harmonized application and usage of biofuels under ISM Code and provide a solid support for classification societies requirements called out by SOLAS.<br>• Reduce IMO's regulation 14 fuel sulphur limits to encourage application of inherently low sulphur biofuels;<br>• There is an urgent need to update Annex VI and the NOx Technical Code to provide further clarity and harmonised application for burning biofuels;<br>• Develop clear guidance and regulatory framework to account for biofuels in the EEDI, EEXI, CII and DCS regulations;<br>• Considering the challenges in developing and implementing changes to regulations in a timely manner, industry stakeholders such as IACS can facilitate biofuel uptake and harmonised application by the development of Unified Requirements, Unified Interpretations and Recommendations, this should be encouraged;<br>• Development of industry best practice and guidance publications for biofuel handling, specifically bunkering and transfers, together with engine manufacturer design and operational guidance should be supported; |

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| | • In general, the existing and developing international fuel standards and regulations are leading the maritime industry to contribute to the adoption of alternative fuels, including liquid and gaseous biofuels, for decarbonisation. |
| **Risk & Safety** | **Observation:**<br>• Overall there is no unresolvable or unmitigable risk identified in the HAZIDs performed on FAME, HVO, FT diesel and FAME<br>• This reveals the some of the fuels (e.g., HVO and FT diesel) may be readily applicable for maritime applications<br>• Others may require modification or upgrades of the fuel-supply system and possible change of some of the components of the engine<br>• Regardless of how easily these biofuels may be applied in the maritime environment, the study also revealed that the level of modification is dictated by the biofuel mixing considered and by the chemical composition of the same (which in term depends on the biomass feedstock used).<br><br>**Mitigations and Suggestions:**<br>• The HAZIDs demonstrate the need for standards to be put in place ensure adequate biofuel specification, as well as maximum/minimum property ranges for these fuels to be fit for purpose (depending also on the feedstock and production pathway).<br>• Guidelines detailing the biofuel properties that may impact the reliability of equipment's and requirements for close monitoring of the same should be developed by the industry<br>• Further demonstration studies of fit for purpose of the engines and other components are necessary. In these studies, focus is to be put on demonstrating that applicability of the biofuels does not affect safety, operational reliability and overall emissions.<br>• It is likely that the application of biofuels will require more frequent inspections, cleanings and maintenance procedures onboard. Engine manufacturers, components providers, classification societies, owner and operators are invited to develop guidelines to support the industry in this matter<br>• A lessons-learnt mechanism can be put in place to track incidents relating to the usage of biofuels with their proper root cause analysis and mitigation measures.<br>• In the body of the study report, a detailed biofuels checklist roadmap for risk assessment is provided. This could serve as basis for an IMO publication in view of supporting the uptake of biofuels |

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## Appendix A - Overview of pilot and demonstration projects

Biofuel and biomethane projects (Getting to Zero coalition, March 2021)

| | **Biofuel pilot and demonstration projects** |
|---|---|
| CMA CGM White Shark- Biofuel Refuelling<br><br>Timeline: 2020 -<br><br>Demonstration in normal operations<br><br>Large ship size | A partnership between the Swedish furniture retailer IKEA, CMA CGM, the sustainable initiative the GoodShipping Program and the Port of Rotterdam saw the world's first ocean freight bunkered with marine bio-fuel. After having announced their three-month biofuel trial, leading short sea shipowner UECC and the GoodShipping Program have now partnered with premium car manufacturer BMW Group to continue to test marine Bio Fuel Oil (BFO) on UECC's 'roll on, roll off' (ro-ro) car carrying vessels. BMW Group joins UECC and the GoodShipping Program in the previously announced trial, where BFO is being tested on UECC's 140m, 2,080-vehicle carrier M/V Autosky. |
| DFDS MASH Project<br><br>Timeline: 2019 -<br><br>Laboratory test | DFDS has bought a stake in start-up company MASH Energy, which produces biofuel from agricultural waste, currently from the by-products of nut processing in India. In order to minimise the operational risk involved in implementing the new generation of biofuel, Alfa Laval have agreed to test the biofuel at their test-centre in Aalborg. |
| HAM 316<br><br>Timeline: 2019 -<br><br>Type of project:<br>Demonstration in normal operations<br><br>Large ship size | Together with Shell, Van Oord is testing the use of biofuel on its trailing suction hopper dredger HAM 316: "We're testing a "second-generation" biofuel made from waste products such as cooking oil. Moreover, it is ISCC certified, which means that the entire chain is certified by a third party. Current calculations show that the biofuel is an effective and affordable method of reducing CO2 emissions. The test will indicate whether the fuel can be used in practice in existing vessels. The local emissions of the vessel will be measured during the work and after completion the engine will be inspected." |
| Maersk Biofuels<br><br>Timeline: March 2019 -<br><br>Type of project:<br>Demonstration in<br>normal operations<br><br>Large ship size | Convinced of the urgency to act on climate, a group of Dutch multinationals all members of the Dutch Sustainable Growth Coalition (DSGC), will join forces with A.P. Moller - Maersk to take a tangible step towards the decarbonization of ocean shipping. The pilot uses up to 20% sustainable second-generation biofuels on a large triple-E ocean vessel will sail 25.000 nautical miles from Rotterdam to Shanghai and back on biofuel blends alone, a world's first at this scale, saving 1,5 million kilograms CO2 and 20.000 kilograms of sulphur. |
| **Biomethane pilot and demonstration projects** | |
| Bio2Bunker<br><br>Timeline: July 2020 -<br><br>Type of project: demonstration in normal operations<br><br>Ship size: large | The project develops and expands a (Bio)-LNG (BLNG) bunkering supply chain by introducing three bunker barges in Zeebrugge, Rotterdam, and Lübeck. For the Amsterdam-Rotterdam-Antwerp region,<br>Titan LNG will construct a mothership, the "Titan Hyperion" that will resupply the smaller vessels. |
| Wes Amelie Ship Conversion<br><br>Timeline: 2019 -<br><br>Type of project: demonstration in normal operations | The 2017-retrofitted 'Wes Amelie', a 1,036-TEU feeder container ship operated by Unifeeder, will become the first vessel in the World to run on Synthetic Natural Gas (SNG) generated by wind energy. MAN Energy Services, Wessels Marine, Unifeeder and Nauticor are cooperating on the SNG project, which will see 'Wes Amelie' use liquefied SNG produced from renewable electrical energy as a drop-in fuel. |

## Appendix B – Overview of TCO

In the following sections of this annex, a list of the considered ship types and sizes is presented followed by the TCO of alternative-fuelled ships, by type of fuel. The TCO comprises all cost aspects in a minimum and maximum fuel cost case. CAPEX, bunkering and maintenance and repair costs are similar in both cases; only the fuel costs differ between lower and upper limits as found in different sources. Considering the different energy density of fuels, the figures include the cost for increased bunkering as a ratio of difference in energy content of the fuel considered. All TCO figures are rounded to the next thousand.

### List of considered ship types and sizes

| Ship type | Size category | Unit | Average Deadweight | Avg. installed power (kW) | Yearly total average fuel consumption (GJ) |
|---|---|---|---|---|---|
| Bulk carrier | 0-9999 | dwt | 4271 | 1,796 | 56,280 |
| Bulk carrier | 10000-34999 | dwt | 27303 | 5,941 | 128,640 |
| Bulk carrier | 35000-59999 | dwt | 49487 | 8,177 | 172,860 |
| Bulk carrier | 60000-99999 | dwt | 76147 | 9,748 | 237,180 |
| Bulk carrier | 100000-199999 | dwt | 169868 | 16,741 | 406,020 |
| Bulk carrier | 200000-+ | dwt | 251667 | 20,094 | 546,720 |
| Chemical tanker | 0-4999 | dwt | 4080 | 987 | 80,400 |
| Chemical tanker | 5000-9999 | dwt | 7276 | 3,109 | 124,620 |
| Chemical tanker | 10000-19999 | dwt | 15324 | 5,101 | 180,900 |
| Chemical tanker | 20000-39999 | dwt | 32492 | 8,107 | 281,400 |
| Chemical tanker | 40000-+ | dwt | 48796 | 8,929 | 285,420 |
| Container | 0-9999 | teu | 8438 | 5,077 | 148,740 |
| Container | 1000-1999 | teu | 19051 | 12,083 | 281,400 |
| Container | 2000-2999 | teu | 34894 | 20,630 | 402,000 |
| Container | 3000-4999 | teu | 52372 | 34,559 | 627,120 |
| Container | 5000-7999 | teu | 74661 | 52,566 | 932,640 |
| Container | 8000-11999 | teu | 110782 | 57,901 | 1,197,960 |
| Container | 12000-14499 | teu | 149023 | 61,231 | 1,250,220 |
| Container | 14500-19999 | teu | 179871 | 60,202 | 1,246,200 |
| Container | 20000-+ | teu | 195615 | 60,210 | 1,025,100 |
| General cargo | 0-4999 | dwt | 2104 | 1,454 | 28,140 |
| General cargo | 5000-9999 | dwt | 6985 | 3,150 | 76,380 |
| General cargo | 10000-19999 | dwt | 13423 | 5,280 | 152,760 |
| General cargo | 20000-+ | dwt | 36980 | 9,189 | 221,100 |
| Liquefied gas tanker | 0-49999 | cbm | 8603 | 2,236 | 156,780 |
| Liquefied gas tanker | 50000-99999 | cbm | 52974 | 12,832 | 510,540 |
| Liquefied gas tanker | 100000-199999 | cbm | 83661 | 30,996 | 1,109,520 |
| Liquefied gas tanker | 200000-+ | cbm | 121977 | 36,735 | 1,603,980 |
| Oil tanker | 0-4999 | dwt | 3158 | 966 | 64,320 |
| Oil tanker | 5000-9999 | dwt | 6789 | 2,761 | 96,480 |
| Oil tanker | 10000-19999 | dwt | 14733 | 4,417 | 148,740 |
| Oil tanker | 20000-59999 | dwt | 43750 | 8,975 | 289,440 |
| Oil tanker | 60000-79999 | dwt | 72826 | 11,837 | 361,800 |
| Oil tanker | 80000-119999 | dwt | 109262 | 13,319 | 389,940 |
| Oil tanker | 120000-199999 | dwt | 155878 | 17,446 | 534,660 |
| Oil tanker | 200000-+ | dwt | 307866 | 27,159 | 775,860 |
| Other liquids tankers | 0-999 | dwt | 3450 | 687 | 112,560 |
| Other liquids tankers | 1000-+ | dwt | 10813 | 2,034 | 277,380 |

| | | | | | |
|---|---|---|---|---|---|
| Ferry-pax only | 0-299 | gt | 4034 | 1,152 | 28,140 |
| Ferry-pax only | 300-999 | gt | 102 | 3,182 | 40,200 |
| Ferry-pax only | 1000-1999 | gt | 354 | 2,623 | 36,180 |
| Ferry-pax only | 2000-+ | gt | 1730 | 6,539 | 176,880 |
| Cruise | 0-1999 | gt | 3115 | 911 | 108,540 |
| Cruise | 2000-9999 | gt | 867 | 3,232 | 124,620 |
| Cruise | 10000-59999 | gt | 4018 | 19,378 | 514,560 |
| Cruise | 60000-99999 | gt | 8249 | 51,518 | 1,503,480 |
| Cruise | 100000-149999 | gt | 10935 | 67,456 | 1,825,080 |
| Cruise | 150000-+ | gt | 13499 | 73,442 | 1,776,840 |
| Ferry-RoPax | 0-1999 | gt | 2720 | 1,383 | 52,260 |
| Ferry-RoPax | 2000-4999 | gt | 832 | 5,668 | 112,560 |
| Ferry-RoPax | 5000-9999 | gt | 1891 | 12,024 | 196,980 |
| Ferry-RoPax | 10000-19999 | gt | 3952 | 15,780 | 418,080 |
| Ferry-RoPax | 20000-+ | gt | 6364 | 28,255 | 763,800 |
| Refrigerated bulk | 0-1999 | dwt | 2409 | 793 | 76,380 |
| Refrigerated bulk | 2000-5999 | dwt | 3986 | 3,223 | 152,760 |
| Refrigerated bulk | 6000-9999 | dwt | 7476 | 6,206 | 237,180 |
| Refrigerated bulk | 10000-+ | dwt | 12612 | 11,505 | 510,540 |
| Ro-Ro | 0-4999 | dwt | 1406 | 1,618 | 84,420 |
| Ro-Ro | 5000-9999 | dwt | 6955 | 9,909 | 317,580 |
| Ro-Ro | 10000-14999 | dwt | 12101 | 15,939 | 498,480 |
| Ro-Ro | 15000-+ | dwt | 27488 | 19,505 | 538,680 |
| Vehicle | 0-29999 | gt | 5151 | 7,264 | 237,180 |
| Vehicle | 30000-49999 | gt | 13571 | 11,831 | 337,680 |
| Vehicle | 50000-+ | gt | 20947 | 14,588 | 462,300 |
| Yacht | 0-+ | gt | 1077 | 1,116 | 16,080 |
| Service - tug | 0-+ | gt | 1218 | 1,086 | 20,100 |
| Miscellaneous - fishing | 0-+ | gt | 468 | 983 | 24,120 |
| Offshore | 0-+ | gt | 4765 | 2,010 | 44,220 |
| Service - other | 0-+ | gt | 2496 | 1,620 | 40,200 |
| Miscellaneous - other | 0-+ | gt | 11496 | 15,301 | 108,540 |

## Input variables

The fuel cost input is presented in the table below, based on (IEA Bioenergy, 2020), (E4Tech, 2018), (IEA, 2020). Cost figures are per GJ.

| NH3 production type | Year | Min | Max | NH3 production type | Year | Min | Max |
|---|---|---|---|---|---|---|---|
| VLSFO | 2021 | $ 6.60 | $ 19.80 | FAME (30%) | 2021 | $ 11.70 | $ 23.30 |
| | 2030 | $ 12.00 | $ 19.80 | | 2030 | $ 15.30 | $ 23.00 |
| | 2050 | $ 19.60 | $ 19.80 | | 2050 | $ 20.30 | $ 22.30 |
| Bio-methanol | 2021 | $ 23.00 | $ 52.00 | FT-diesel | 2021 | $ 17.00 | $ 46.00 |
| | 2030 | $ 22.00 | $ 49.00 | | 2030 | $ 10.00 | $ 36.00 |
| | 2050 | $ 18.00 | $ 43.00 | | 2050 | $ 10.00 | $ 36.00 |
| HVO | 2021 | $ 16.00 | $ 29.00 | Biomethane | 2021 | $ 12.00 | $ 35.00 |
| | 2030 | $ 16.00 | $ 28.00 | | 2030 | $ 10.00 | $ 27.00 |
| | 2050 | $ 15.00 | $ 26.00 | | 2050 | $ 8.00 | $ 22.00 |

Bunkering cost per GJ, based on CE Delft (CE Delft, 2021)

| Fuel type | Bunkering cost |
|---|---|
| VLSFO | $ 0.07 |
| Bio-methanol | $ 0.21 |
| HVO/FAME/FT | $ 0.07 |
| FAME | $ 0.07 |
| FT-diesel | $ 0.07 |
| Biomethane | $ 0.29 |

Increased bunkering factor of alternative fuels, based on DNV GL (DNV GL, 2019).

| Fuel type | MJ/L | Volumetric density % of VLSFO | Factor increased bunkering |
|---|---|---|---|
| VLSFO | 36 | 100.0% | 1.00 |
| Bio-methanol | 15 | 41.7% | 2.40 |
| HVO/FAME/FT | 32 | 88.9% | 1.13 |
| Biomethane (LNG) | 13 | 36.1% | 2.77 |

## Appendix C – Risk Matrix

| Category | Consequence Severity | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| Asset | No shutdown, costs less than $10,000 to repair | No shutdown, costs less than $100,000 to repair | Operations shutdown, loss of day rate for 1-7 days and/or repair costs of up to $1,000,000 | Operations shutdown, loss of day rate for 7-28 days and/or repair costs of up to $10,000,000 | Operations shutdown, loss of day rate for more than 28 days and/or repair more than $10,000,000 |
| Environmental Effects | No lasting effect. Low level impacts on biological or physical environment. Limited damage to minimal area of low significance. | Minor effects on biological or physical environment. Minor short-term damage to small area of limited significance. | Moderate effects on biological or physical environment but not affecting ecosystem function. Moderate short-medium term widespread impacts e.g. oil spill causing impacts on shoreline. | Serious environmental effects with some impairment of ecosystem function e.g. displacement of species. Relatively widespread medium-long term impacts. | Very serious effects with impairment of ecosystem function. Long term widespread effects on significant environment e.g., unique habitat, national park. |
| Community/ Government/ Media/ Reputation | Public concern restricted to local complaints. Ongoing scrutiny/ attention from regulator. | Minor, adverse local public or media attention and complaints. Significant hardship from regulator. Reputation is adversely affected, with a small number of site-focused people. | Attention from media and/or heightened concern by local community. Criticism by NGOs. Significant difficulties in gaining approvals. Environmental credentials moderately affected. | Significant adverse national media/public/ NGO attention. May lose license to operate or not gain approval. Environment/ management credentials are significantly tarnished. | Serious public or media outcry (international coverage). Damaging NGO campaign. License to operate threatened. Reputation severely tarnished. Share price may be affected. |
| Injury and Disease | Low level short-term subjective inconvenience or symptoms. No measurable physical effects. No medical treatment required. | Objective but reversible disability/impairment and/or medical treatment, injuries requiring hospitalization. | Moderate irreversible disability or impairment (<30%) to one or more persons. | Single fatality and/or severe irreversible disability or impairment (>30%) to one or more persons. | Short- or long-term health effects leading to multiple fatalities, or significant irreversible health effects to >50 persons. |
| | Low | Minor | Moderate | Major | Critical |
| Likelihood<br>Almost Certain (E) Occurs 1 or more times a year | High | High | Extreme | Extreme | Extreme |
| Likely (D) Occurs once every 1-10 years | Moderate | High | High | Extreme | Extreme |
| Possible (C) Occurs once every 10-100 years | Low | Moderate | High | Extreme | Extreme |
| Unlikely (B) Occurs once every 100-1000 years | Low | Low | Moderate | High | Extreme |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Rare (A) Occurs once every 1000-10000 years | **Low** | **Low** | **Moderate** | **High** | **High** |

| | | |
|---|---|---|
| Action Key | Low | No action is required, unless change in circumstances |
| | Moderate | No additional controls are required, monitoring is required to ensure no changes in circumstances |
| | High | Risk is high and additional control is required to manage risk |
| | Extreme | Intolerable risk, mitigation is required |

## Appendix D - HAZID Register: ROPAX (fueled with HVO)

| **No.:** 1 | Biofuel storage/tank (RoPax – HVO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 1.1 | Multiple Supplier/ Grade of Biofuel | Multiple Supplier- leads to quality issue for fuel | Engine slowdown/ Shutdown | Asset | 2 | C | Moderate | • Fuel Management Procedures (Fuel Implementation Plan)<br>• Sampling - Analysis of the Fuel - Compatibility Check before Bunkering | **1.** Request fuel analysis according to applicable standards |
| | | Different Grade | Engine slowdown/ Shutdown | Asset | 2 | C | Moderate | • Fuel Management Procedures (Fuel Implementation Plan)<br>• Proper Bunkering Procedures<br>• Crew Training | |
| | | | Mixing of Various Grade - Human Error | Asset | 2 | B | Low | | |
| | | | Impact on Machinery Equipment | Asset | 2 | B | Low | | |
| | | Kinematic Viscosity | Engine slowdown/ Shutdown | Asset | 2 | C | Moderate | • Sampling - Analysis of the Fuel - Compatibility Check before Bunkering<br>• Proper Control in the Fuel Viscosity in the Fuel Spec<br>• Limit the % of the Biofuel and use an appropriate blend<br>• System/equipment design per fuel specification requirements<br>• Sufficient cooling to increase viscosity | **2.** Use of fuel oil cooler to raise the viscosity sufficiently in order to bring the fuel within specification and to prevent the fuel from leaking out of injection equipment |
| | | | Damage to FO Pumps | Asset | 2 | B | Low | | |
| | | | Inadequate Pressure in the System | Asset | 2 | C | Moderate | | |
| | | | FO Pumps may not pressurise the fuel | Asset | 2 | B | Low | | |
| | | | Leakages from fuel system and fuel injection equipment (due to low viscosity - if below limits) (Kinematic Viscosity of HVO lower than that of FAME) | Asset | 3 | C | High | | |
| | | | Engine slowdown/ Shutdown | Asset | 2 | B | Low | • Fuel Management Procedures (Fuel Implementation Plan) | |
| | | | Impact on Machinery Equipment | Asset | 2 | B | Low | | |

| **No.:** 1 | Biofuel storage/tank (RoPax – HVO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | Degradation over time - Microbial Infestation - (if condensed water accumulates in biofuel) | Damage to FO Pumps | Asset | 2 | B | Low | • Additional Sampling during storage/operation condition - Frequent sampling<br>• Sampling Frequency - Monitor the Biofuel in Tank<br>• Biocides in the Fuel to prevent degradation<br>• Additive agents to prevent degradation | |
| | | | Inadequate Pressure in the System | Asset | 2 | B | Low | | |
| | | | Fuel Flow Issues due to Viscosity Increase | Asset | 2 | B | Low | | |
| | | | Bacteria and mould growth may lead to sludge formation, clogged filters and hoses/pipes | Asset | 2 | B | Low | | |
| | | Degradation - Detergent - Additive Agents | Deposits at Mechanical Parts - Clogging | Asset | 2 | B | Low | • Proper Inspection & Maintenance | |
| | | | Damage to Tank Coating - Corrosion | Asset | 2 | B | Low | | |
| | | pH value - (Acidic) | Impact on Machinery Equipment | Asset | 2 | B | Low | • Proper Material Selection - Proper System Design | |
| | | | Damage to FO Pumps | Asset | 2 | B | Low | | |
| | | | Material degradation, Seal - Filters - Gasket Degradation/ Premature Failure | Asset | 2 | B | Low | | |
| | | Low temperature flow properties (Cold Flow properties) | Engine slowdown/ Shutdown | Asset | 2 | B | Low | • Monitoring temperature/ Viscosity | **3.** Check biofuel specification (eg to include isomerisation in HVO's production process) |
| | | | Damage to FO Pumps | Asset | 2 | B | Low | | |
| | | | FO Pumps may not pressurise the fuel | Asset | 2 | B | Low | | |
| | | | Fuel Flow Issues due to Viscosity Increase | Asset | 2 | B | Low | | |

| **No.:** 1 | Biofuel storage/tank (RoPax – HVO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | | Fuel Instability | Asset | 2 | C | Moderate | | |
| | | Vapors from the Tank | Fume Venting to Open Deck - Hazardous Area | Asset | 2 | B | Low | • Meet Class & International Regulatory Requirements<br>• Proper Tank Design Specifications - Alarms - Detectors<br>• Continuous ventilation of ER per IMO/class requirement | |
| | | | Leak in E/R - Confined/ Enclosed Area | Asset | 2 | C | Moderate | | |
| | | | Crew Exposed to Vapors | Injury | 2 | B | Low | | |
| | | | Fire/ Explosion | Asset | 2 | C | Moderate | | |
| | | Human Exposure to Toxic Atmosphere - during tank entry | Crew Exposed to Vapors | Injury | 2 | B | Low | • Proper Tank Design Specifications - Alarms - Detectors<br>• Confined Space Entry Procedures - PPE | |
| | | Fuel Grade - Quality Issues | Engine slowdown/ Shutdown | Asset | 2 | C | Moderate | • Fuel Specification<br>• Fuel Management Procedures (Fuel Implementation Plan)<br>• Sampling - Analysis of the Fuel - Compatibility Check before Bunkering<br>• Proper Bunkering Procedures | **4.** Documentation of fuel before loading (BDN) or other fuel quality documentation |
| | | | Impact on Machinery Equipment | Asset | 2 | C | Moderate | | |
| | | | Damage to FO Pumps | Asset | 2 | B | Low | | |
| | | | Inadequate Pressure in the System | Asset | 2 | C | Moderate | | |
| | | | FO Pumps may not pressurise the fuel | Asset | 2 | B | Low | | |
| | | | Damage to Tank Coating - Corrosion | Asset | 2 | B | Low | | |
| | | Wax in Biofuels Content | Wax Buildup in the system blocking the filters | Asset | 2 | B | Low | • Fuel Specification<br>• Fuel Management Procedures (Fuel Implementation Plan) | |

| **No.:** 1 | Biofuel storage/tank (RoPax – HVO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | | | | | | | • Sampling - Analysis of the Fuel - Compatibility Check before Bunkering<br>• Monitoring temperature/ Viscosity | |
| | | Lubricity | Scuffing and wear of rotating/moving component in the fuel system (eg fuel system equipment, pumps, etc) | Asset | 3 | C | High | • Fuel Specification<br>• Fuel Management Procedures (Fuel Implementation Plan)<br>• Sampling - Analysis of the Fuel - Compatibility Check before Bunkering<br>• System/equipment design per fuel specification requirements<br>• Use of lubricating additive<br>• Extra spare parts | **5.** System and engine components are to be selected considering lubricity and change in property<br>**6.** Fuel analysis to ensure adequate lubricity of fuel<br>**7.** Evaluation of lubricity when biofuel is combined with additives |
| | | Elastomeric component compatibility with Biofuel | Seal swelling, deterioration, and damage of gaskets and hoses - may lead to seal failures, leakage of fuel | Asset | 2 | C | Moderate | | **8.** Material compatibility study and test to be conducted with all elastomeric material to verify swelling. absorption and degradation of seal material |
| | | Oxidative stability / Biodegradable nature | Loosening of foulants, such as water, sludge, cat fines, etc in fuel storage tanks | Asset | 2 | B | Low | • Regular Tank Cleaning | |
| | | Use of Biofuel - Engines (RoPAX) (linked to 8.1) | | | | | | | |

| **No.:** 2 | Bunkering Arrangement (RoPAX – HVO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 2.1 | No new risks identified | | No consequences of interest | | | | | | |

| **No.:** 3 | Biofuel system/arrangement/preparation room (RoPAX – HVO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 3.1 | Biofuel Grade | Biofuel Grade Changeover | Deposits in the piping system | Asset | 2 | B | Low | • System is designed to provide smooth changeover<br>• Fuel Changeover Procedure<br>• Proper Maintenance<br>• Sufficient Equipment (Purifiers)<br>• Bypass/redundant filter required by class in fuel system | |
| | | | Engine slowdown/ Shutdown | Asset | 2 | B | Low | | |
| | | | Filter Clogging | Asset | 2 | B | Low | | |
| | | | Loss of power - Grounding/ Collision | Overall | S3-Moderate | LB-Unlikely | Moderate | | |
| | | Exposure to High Temperature | Filter Clogging | Asset | 2 | B | Low | • Fuel Changeover Procedure<br>• Operational Control - Procedures - Monitoring\<br>• Bypass/redundant filter required by class in fuel system | |
| | | | Polymerization of the Biofuel - and clogging of the system | Asset | 2 | B | Low | | |

| **No.:** 4 | Machinery Space (RoPAX – HVO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 4.1 | No new risk identified | | No consequences of interest | | | | | | |
| **No.:** 5 | Ventilation (RoPAX – HVO) | | | | | | | | |
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 5.1 | No new risk identified | | No consequences of interest | | | | | | |
| **No.:** 6 | Safety System (RoPAX – HVO) | | | | | | | | |
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 6.1 | Firefighting system | | No consequence of interest | | | | | | |
| 6.2 | PPE | | No consequence of interest | | | | | | |
| 6.3 | Emergency Generator | | No consequence of interest. (Assumptions in section 4.3.7: Emergency gensets not running on biofuel) | | | | | | |
| 6.4 | Lifeboats and fast rescue craft | | No consequence of interest. (Assumptions in section 4.3.7: Lifeboats and fast rescue craft are not running on biofuel) | | | | | | |

| **No.:** 7 | Ship's Operation (RoPAX – HVO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 7.1 | Use of Biofuels | Human Error | Injury | Injury | 2 | B | Low | • Proper Training Procedures<br>• PPE | |
| | | | Fire | Asset | 3 | B | Moderate | | |
| | | | Loss of Life | Injury | 3 | A | Moderate | | |
| | | | Down time | Asset | 2 | B | Low | | |
| | | Long Idle Period | Down time | Asset | 2 | B | Low | • Preservation Procedures | |
| | | | Degradation of Biofuel | Asset | 2 | B | Low | | |
| | | Low usage of the fuel | Degradation of Biofuel | Asset | 2 | B | Low | • Proper Procedures are to be developed | |
| | | Biofuel Spill | Environmental Damage | Environmental | 3 | B | Moderate | | **9.** Spill response - Clean up - Equipment - Spill Net - Requirements to be studied and developed |

| **No.:** 8 | Engines (RoPAX – HVO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 8.1 | Use of Biofuel | Compatibility with Cylinder Lubricants | Impact on exhaust emissions | Environmental | 2 | B | Low | • Proper selection & testing of the lubricants - up to date with the Service Letters from the engine vendor | |
| | | | Increased wear of the Liners/piston, seizure, liner polishing, scuffing | Asset | 2 | B | Low | | |
| | | Fuel Grade - Quality Issue | Impact on exhaust emissions | Environmental | 2 | B | Low | • See 1.1 | |
| | | | Engine slowdown/ Shutdown | Asset | 2 | B | Low | | |
| | | | Damage to other components | Asset | 2 | B | Low | | |
| | | Low Calorific Value (LCV) | Possible Reduction in Power (Note: LCV of HVO could be higher than FAME and similar or lower to MGO) | Asset | 2 | C | Moderate | • Engine & System to be designed for a specific LHV<br>• Increased fuel consumption (in relation to diesel with higher LCV) Allowance for more bunkering quantities and fuel tank volume (storage quantities) | **10.** Consideration of possible increased fuel consumption with respect to vessel's operating profile (voyage) - May therefore require increased bunkered fuel quantities (in relation to diesel). Larger fuel tank, compared to tank designed for cruising range with conventional diesel<br>Input from Engine designer about Power output and fuel consumption for specific biofuel or blend |

| **No.:** 8 | Engines (RoPAX – HVO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | Combustion of Fuel | Possibility of no effect on NOx emissions or possible decrease in NOx by 10-15% | Environmental | 2 | C | Moderate | • Proper Maintenance<br>• After-Treatment Technology - SCR - NOx Traps | **11.** Engine manufacturer need to address emissions during engine testing and approval<br>**12.** Engine designers to provide confirmation that use of Biofuel (and relevant blend) does not increase NOx emissions above allowable limits |
| | | | Ash content of biofuel may lead to clogging of the T/C, deterioration of the exhaust gas aftertreatment system, clogging the economizer and the exhaust channel | Asset | 2 | C | Moderate | | |
| | | Cetane Number | Engine Performance and Emission | Asset | 2 | C | Moderate | • Engine require tuning adjustments to account for earlier ignition delay | **13.** Engine designer to confirm applicability of biofuel to specific engines |
| | | Corrosion | Degradation of on-engine components | Asset | 2 | B | Low | • Fuel system components that are compatible with specific biofuel (and blend) | |
| | | | Formation of deposits that can clog fuel system related components eg filters, injectors etc | Asset | 2 | B | Low | | |
| | | Kinematic Viscosity (linked from 1.1) | Leakages from fuel injection equipment (due to low viscosity - below limits) | Asset | 3 | C | High | • See 1.1 | **2.** Use of fuel oil cooler to raise the viscosity sufficiently in order to bring the fuel within specification and to prevent the fuel from leaking out of injection equipment |

| **No.:** 8 | Engines (RoPAX – HVO) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | Lubricity | Scuffing and wear of rotating/moving components in the fuel system (eg fuel injectors) (linked to 1.1) | Asset | 3 | C | High | • See 1.1 | **5.** System and engine components are to be selected considering lubricity and change in property<br>**6.** Fuel analysis to ensure adequate lubricity of fuel<br>**7.** Evaluation of lubricity when biofuel is combined with additives |

## Appendix E - HAZID Recommendations List: ROPAX (fueled with HVO)

| References | Recommendations |
|---|---|
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel storage/tank (RoPax – HVO) | **1.** Request fuel analysis according to applicable standards |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel storage/tank (RoPax – HVO)<br>8.1 Use of Biofuel – Engines (RoPAX - HVO) | **2.** Use of fuel oil cooler to raise the viscosity sufficiently in order to bring the fuel within specification and to prevent the fuel from leaking out of injection equipment |
| 1.1 Multiple Supplier/ Grade of Biofuel - Biofuel storage/tank (RoPax – HVO) | **3.** Check biofuel specification (eg to include isomerisation in HVO's production process) |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel storage/tank (RoPax – HVO) | **4**. Documentation of fuel before loading (BDN) or other fuel quality documentation |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel storage/tank (RoPax – HVO)<br>8.1 Use of Biofuel – Engines (RoPAX - HVO) | **5.** System and engine components are to be selected considering lubricity and change in property |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel storage/tank (RoPax – HVO)<br>8.1 Use of Biofuel – Engines (RoPAX - HVO) | **6.** Fuel analysis to ensure adequate lubricity of fuel |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel storage/tank (RoPax – HVO)<br>8.1 Use of Biofuel – Engines (RoPAX - HVO) | **7**. Evaluation of lubricity when biofuel is combined with additives |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel storage/tank (RoPax – HVO) | **8.** Material compatibility study and test to be conducted with all elastomeric material to verify swelling. absorption and degradation of seal material |
| 7.1 Use of Biofuels – Ship's Operation (RoPAX - HVO) | **9.** Spill response - Clean up - Equipment - Spill Net - Requirements to be studied and developed |
| 8.1 Use of Biofuel – Engines (RoPAX - HVO) | **10.** Consideration of possible increased fuel consumption with respect to vessel's operating profile (voyage) - May therefore require increased bunkered fuel quantities (in relation to diesel). Larger fuel tank, compared to tank designed for cruising range with conventional diesel Input from Engine designer about Power output and fuel consumption for specific biofuel or blend |
| 8.1 Use of Biofuel – Engines (RoPAX - HVO) | **11.** Engine manufacturers need to address emissions during engine testing and approval |
| 8.1 Use of Biofuel – Engines (RoPAX - HVO) | **12.** Engine designers to provide confirmation that use of Biofuel (and relevant blend) does not increase NOx emissions above allowable limits |
| 8.1 Use of Biofuel – Engines (RoPAX - HVO) | **13.** Engine designer to confirm applicability of biofuel to specific engines |

## Appendix F - HAZID Register: VLCC (fueled with FAME)

| **No.:** 1 | Biofuel Storage/Tank (VLCC – FAME) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 1.1 | Multiple Supplier/ Grade of Biofuel | Multiple Supplier- leads to quality issue for fuel | Engine slowdown / Shutdown | Asset | 2 | C | Moderate | • Fuel Management Procedures (Fuel Implementation Plan)<br>• Sampling - Analysis of the Fuel - Compatibility Check before Bunkering | Request fuel analysis according to applicable standards |
| | | Different Grade | Engine slowdown / Shutdown | Asset | 2 | C | Moderate | • Fuel Management Procedures (Fuel Implementation Plan)<br>• Proper Bunkering Procedures<br>• Crew Training | |
| | | | Mixing of Various Grade - Human Error | Asset | 2 | B | Low | | |
| | | | Impact on Machinery Equipment | Asset | 2 | B | Low | | |
| | | Kinematic Viscosity | Engine slowdown / Shutdown | Asset | 2 | C | Moderate | • Sampling - Analysis of the Fuel - Compatibility Check before Bunkering<br>• Proper Control in the Fuel Viscosity in the Fuel Spec<br>• Limit the % of the Biofuels and use an appropriate blend<br>• System/equipment design per fuel specification requirements<br>• Sufficient cooling to increase viscosity | **2.** Request sampling - analysis of biofuel for viscosity check. If too high, preheating may be required to bring viscosity within specification, to prevent operational problems and damages to systems/engine components. |
| | | | Damage to FO Pumps | Asset | 2 | B | Low | | |
| | | | Inadequate Fuel Pressure in the System | Asset | 3 | B | Moderate | | |
| | | | FO Pumps may not pressurise the fuel | Asset | 2 | B | Low | | |
| | | | Degraded operability, coking of fuel system components, maintenance issues (due to cold conditions leading to high viscosity - if above limits)<br>(Kinematic Viscosity of FAME higher than that of HVO) | Asset | 3 | B | Moderate | | |

| **No.:** 1 | Biofuel Storage/Tank (VLCC – FAME) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | Degradation over time - Microbial Infestation (if condensed water accumulates in biofuel) | Engine slowdown / Shutdown | Asset | 2 | C | Moderate | • Fuel Management Procedures (Fuel Implementation Plan)<br>• Additional Sampling during storage/operation condition - Frequent sampling<br>• Sampling Frequency - Monitor the Biofuel in Tank<br>• Additives Biocides in the fuel to prevent microbial growth and degradation | **3.** Draining of fuel tanks more often - Use of additives (biocides) in the fuel |
| | | | Impact on Machinery Equipment | Asset | 2 | C | Moderate | | |
| | | | Damage to FO Pumps | Asset | 2 | B | Low | | |
| | | | Inadequate Fuel Pressure in the System | Asset | 3 | B | Moderate | | |
| | | | Fuel flow issues due to possible viscosity increase | Asset | 2 | C | Moderate | | |
| | | | Bacteria and mould growth may lead to sludge formation, clogged filters and hoses/pipes | Asset | 2 | C | High | | |
| | | Degradation - Detergent - Additive Agents | Deposits at Mechanical Parts - Clogging | Asset | 2 | C | Moderate | • Proper Inspection & Maintenance<br>• Proper Material Selection - Proper System Design<br>• Proper Tank Design Specifications - Alarms - Detectors | **4.** Tank Coating to be evaluated and tested - Compatibility with Biofuels to be used & Additive Agents |
| | | | Damage to Tank Coating - Corrosion | Asset | 3 | C | High | | |
| | | pH value - (Acidic) | Impact on Machinery Equipment | Asset | 2 | C | Moderate | • Proper Material Selection - Proper System Design | |
| | | | Damage to FO Pumps | Asset | 2 | B | Low | | |
| | | | Material degradation, Seal - Filters - Gasket Degradation/ Premature Failure | Asset | 3 | B | Moderate | | |
| | | | Engine slowdown / Shutdown | Asset | 2 | C | Moderate | • Temperature/ Heating - Viscosity Monitoring/ Management/ Treatment | |
| | | | Damage to FO Pumps | Asset | 2 | B | Low | | |

**No.:** 1 | Biofuel Storage/Tank (VLCC – FAME)

| Item | Deviation | Causes | Consequences | Matrix | Severity | Likelihood | Risk | Safeguards | Recommendations |
|---|---|---|---|---|---|---|---|---|---|
| | | Low Temperature flow properties (Cold flow properties) | FO Pumps may not pressurize the fuel | Asset | 2 | B | Low | • Thermal management (fuel storage and transfer, above cloud point temperature) | **5.** Thermal management on board (fuel storage tanks, piping and filters). Maintaining fuel temperatures at least 10°C above the pour point (ref CIMAC). |
| | | | Fuel flow issues due to possible viscosity increase | Asset | 2 | C | Moderate | | |
| | | | Fuel instability | Asset | 3 | C | High | | |
| | | Vapors from the Tank | Fume Venting to Open Deck - Hazardous Area | Asset | 2 | B | Low | • Meet Class & International Regulatory Requirements<br>• Proper Tank Design Specifications - Alarms - Detectors<br>• Continuous ventilation of ER per IMO/class requirement | |
| | | | Leak in E/R - Confined/ Enclosed Area | Asset | 2 | C | Moderate | | |
| | | | Crew Exposed to Vapors | Injury | 2 | B | Low | | |
| | | | Fire/ Explosion | Asset | 3 | B | Moderate | | |
| | | Human Exposure to Toxic Atmosphere - during tank entry | Crew Exposed to Vapors | Injury | 2 | B | Low | • Proper Tank Design Specifications - Alarms - Detectors<br>• Confined Space Entry Procedures - PPE | |
| | | Fuel Grade - Quality Issue | Engine slowdown / Shutdown | Asset | 2 | C | Moderate | • Fuel Specification<br>• Fuel Management Procedures (Fuel Implementation Plan)<br>• Sampling - Analysis of the Fuel - Compatibility Check before Bunkering<br>• Proper Bunkering Procedures | **6.** Documentation of fuel before loading (BDN) or other fuel quality documentation |
| | | | Impact on Machinery Equipment | Asset | 2 | C | Moderate | | |
| | | | Damage to FO Pumps | Asset | 2 | B | Low | | |
| | | | Inadequate Fuel Pressure in the System | Asset | 3 | B | Moderate | | |
| | | | FO Pumps may not pressurise the fuel | Asset | 2 | B | Low | | |

| **No.:** 1 | Biofuel Storage/Tank (VLCC – FAME) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | Wax in Biofuels Content | Wax Buildup in the system blocking the filters | Asset | 3 | B | Moderate | • Fuel Specification<br>• Fuel Management Procedures (Fuel Implementation Plan)<br>• Sampling - Analysis of the Fuel - Compatibility Check before Bunkering<br>• Temperature/ Heating - Viscosity Monitoring/ Management/ Treatment | |
| | | Lubricity | Scuffing and wear of rotating/moving component in the fuel system (eg fuel injectors) | Asset | 2 | C | Moderate | • Fuel Specification<br>• Fuel Management Procedures (Fuel Implementation Plan)<br>• Sampling - Analysis of the Fuel - Compatibility Check before Bunkering<br>System/equipment design per fuel specification requirements | **7.** Fuel analysis to ensure adequate lubricity of fuel Evaluation of lubricity when biofuel is combined with additives |
| | | Elastomeric component compatibility with Biofuel | Seal swelling, deterioration, and damage of gaskets and hoses - may lead to seal failures, leakage of fuel | Asset | 3 | C | High | Compatibility check of fuel system components with subject biofuel and blending quantity | **8.** Material compatibility study and test to be conducted with all elastomeric material to verify swelling. absorption and degradation of seal, gasket and hose material |

| **No.:** 1 | Biofuel Storage/Tank (VLCC – FAME) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | Oxidative stability / Biodegradable nature | FAME can loosen foulants, such as water, sludge, cat fines, etc in fuel storage tanks and can increase the accumulation of deposits on engine equipment | Asset | 3 | C | High | • Proper tank coating<br>• Frequent tank cleaning<br>• Fuel treatment, and fuel supply equipment<br>• Main engine components design | **9.** Selection of Tank coating and thorough Tank cleaning prior to use of Biofuel<br>Frequent maintenance of fuel treatment, and fuel supply equipment<br>Frequent inspection of main engine components<br>System flushing when switching from diesel to biofuel (or blend)<br>Avoid bunkering the fuel for long-term storage prior to use<br>Possible use of antioxidants at an early stage can reduce possibility of degradation and allow for longer storage periods |
| | | | Fuel treatment equipment may become overloaded and lose its effectiveness of removing harmful contaminants from the fuel. Without proper removal and reduction to an acceptable level at the engine inlet, such contaminants can cause major engine damage | Asset | 2 | C | Moderate | | |
| | | Use of Biofuel - Engines (VLCC) (linked to 8.1) | | | | | | | |

| **No.:** 2 | Bunkering arrangement (VLCC – FAME) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 2.1 | No new risk identified | | No consequences of interest | | | | | | |

| **No.:** 3 | Biofuel system/arrangement/preparation room (VLCC – FAME) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 3.1 | Biofuel Grade | Biofuel Grade Changeover | Deposits in the piping system | Asset | 2 | C | Moderate | • System is design to provide smooth changeover<br>• Fuel Changeover Procedure<br>• Proper Maintenance<br>• Sufficient Equipment (Purifiers)<br>• Bypass/redundant filter required by class in fuel system | |
| | | | Engine slowdown/ Shutdown | Asset | 3 | B | Moderate | | |
| | | | Filter Clogging | Asset | 2 | B | Low | | |
| | | | Loss of power - Grounding/ Collision | Overall | S4-Major | LA-Rare | High | | |
| | | Exposure to High Temperature | Filter Clogging | Asset | 2 | B | Low | • Fuel Changeover Procedure<br>• Operational Control - Procedures - Monitoring\<br>• Bypass/redundant filter required by class in fuel system | |
| | | | Polymerization of the Biofuel - and clogging of the system | Asset | 3 | B | Moderate | | |

| **No.:** 4 | Machinery Space (VLCC – FAME) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 4.1 | No new risk identified | | No consequences of interest | | | | | | |
| **No.:** 5 | Ventilation (VLCC – FAME) | | | | | | | | |
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 5.1 | No new risk identified | | No consequences of interest | | | | | | |
| **No.:** 6 | Safety Systems (VLCC – FAME) | | | | | | | | |
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 6.1 | fire Fighting System | | No consequences of interest | | | | | | |
| 6.2 | PPE | | No consequences of interest | | | | | | |
| 6.3 | Emergency Generator | | No consequence of interest. (Assumptions in section 4.3.7: Emergency gensets not running on biofuel) | | | | | | |
| 6.4 | Lifeboats and fast rescue craft | | No consequence of interest. (Assumptions in section 4.3.7: Lifeboats and fast rescue craft are not running on biofuel) | | | | | | |

| **No.:** 7 | Ship's Operation (VLCC – FAME) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 7.1 | Use of Biofuel | Human Error | Injury | Injury | 2 | B | Low | • Proper Training Procedures<br>• PPE | |
| | | | Fire | Asset | 3 | B | Moderate | | |
| | | | Loss of Life | Injury | 3 | A | Moderate | | |
| | | | Down time | Asset | 2 | B | Low | | |
| | | Long Idle Period | Down time | Asset | 2 | B | Low | • Preservation Procedures | |
| | | | Degradation of Biofuel | Asset | 2 | C | Moderate | | |
| | | Low usage of the fuel | Degradation of Biofuel | Asset | 2 | C | Moderate | • Proper Procedures are to be developed | |
| | | Biofuel Spill | Environmental Damage | Environmental | 3 | B | Moderate | | **10.** Spill response - Clean up - Equipment - Spill Net - Requirements to be studied and developed |

| **No.:** 8 | Engines (VLCC – FAME) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 8.1 | Use of Biofuel | Compatibility with Cylinder Lubricants | Impact on exhaust emissions | Environmental | 2 | B | Low | • Proper selection & testing of the lubricants - up to date with the Service Letters from the engine vendor | |
| | | | Increased wear of the Liners - Piston seizure - Liner polishing - Scuffing | Asset | 2 | B | Low | | |
| | | Fuel Grade - Quality Issue | Impact on exhaust emissions | Environmental | 1 | B | Low | • See 1.1 | |
| | | | Engine Shutdown/ Trip | Asset | 2 | B | Low | | |
| | | | Damage to other components | Asset | 2 | B | Low | | |
| | | Lower Calorific Value (LCV) | Possible Reduced reduction in Power | Asset | 3 | C | High | • Engine & System to be designed for a specific LHV<br>• See 1.1<br>• Increased fuel consumption (in relation to diesel with higher LCV<br>Allowance for more bunkering quantities and fuel tank volume (storage quantities)<br>Engine & System to be designed for a specific LHV | **11.** Consideration of possible increased fuel consumption with respect to vessel's operating profile (voyage) - May therefore require increased bunkered fuel quantities (in relation to diesel)<br>Larger fuel tank, compared to tank designed for cruising range with conventional diesel<br>Input from Engine designer about Power output and fuel consumption for specific biofuel or blend |

| **No.:** 8 | Engines (VLCC – FAME) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | Combustion of fuel | Potential Possibility of higher NOx emissions | Environmental | 3 | C | High | • Engine performance tuning (by Engine designer)<br>• Exhaust gas after treatment technology e.g. SCR | **12.** Engine manufacturer designers to provide confirmation that use of Biofuel (and relevant blend) does not increase NOx emissions above allowable limits (need to address issue during engine testing and approval engine testing and emission measurements may be required) |
| | | | Ash content of biofuel may lead to clogging of the T/C, deterioration of the exhaust gas aftertreatment system, clogging the economizer and the exhaust channel | Asset | 2 | C | Moderate | | |
| | | Cetane Number | Engine Performance and Emissions | Asset | 2 | B | Low | • Engine may require tuning adjustments | |
| | | Corrosion | Degradation of on-engine components made of copper, brass, lead, tin, zinc, etc | Asset | 3 | C | High | • Fuel system components that are compatible with specific biofuel (and blend) | **13.** Engine manufacturer to advise on compatibility of existing engine components and changes/upgrades that may be needed for specific biofuel |
| | | | Formation of deposits that can clog fuel system related components eg filters, injectors etc | Asset | 3 | C | High | | |

| **No.:** 8 | Engines (VLCC – FAME) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | Kinematic Viscosity | Degraded operability, coking of fuel system components, maintenance issues (due to cold conditions leading to high viscosity - if above limits) | Asset | 3 | B | Moderate | • See 1.1 | **2.** Request sampling - analysis of biofuel for viscosity check. If too high, preheating may be required to bring viscosity within specification, to prevent operational problems and damages to systems/engine components. |
| | | Lubricity | Scuffing and wear of rotating/moving components in the fuel system (eg fuel injectors) | Asset | 2 | B | Low | • See 1.1 | **7.** Fuel analysis to ensure adequate lubricity of fuel Evaluation of lubricity when biofuel is combined with additives |

## Appendix G - HAZID Recommendations List: VLCC (fueled with FAME)

| References | Recommendations |
|---|---|
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel Storage Tank (VLCC – FAME) | **1**. Request fuel analysis according to applicable standards |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel Storage Tank (VLCC – FAME)<br>8.1 Use of Biofuel-Engines (VLCC-FAME) | **2.** Request sampling - analysis of biofuel for viscosity check. If too high, preheating may be required to bring viscosity within specification, to prevent operational problems and damages to systems/engine components. |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel Storage Tank (VLCC – FAME) | **3.** Draining of fuel tanks more often - Use of additives (biocides) in the fuel |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel Storage Tank (VLCC – FAME) | **4.** Tank Coating to be evaluated and tested - Compatibility with Biofuels to be used & Additive Agents |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel Storage Tank (VLCC – FAME) | **5.** Thermal management on board (fuel storage tanks, piping and filters). Maintaining fuel temperatures at least 10 degrees above the pour point (ref CIMAC). |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel Storage Tank (VLCC – FAME) | **6.** Documentation of fuel before loading (BDN) or other fuel quality documentation |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel Storage Tank (VLCC – FAME)<br>8.1 Use of Biofuel – Engines (VLCC-FAME) | **7.** Fuel analysis to ensure adequate lubricity of fuel<br>Evaluation of lubricity when biofuel is combined with additives |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel Storage Tank (VLCC – FAME) | **8.** Material compatibility study and test to be conducted with all elastomeric material to verify swelling. absorption and degradation of seal, gasket and hose material |
| 1.1 Multiple Supplier/ Grade of Biofuel – Biofuel Storage Tank (VLCC – FAME) | **9**. Selection of Tank coating and thorough Tank cleaning prior to use of Biofuel<br>Frequent maintenance of fuel treatment, and fuel supply equipment<br>Frequent inspection of main engine components<br>System flushing when switching from diesel to biofuel (or blend)<br>Avoid bunkering the fuel for long-term storage prior to use<br>Possible use of antioxidants at an early stage can reduce possibility of degradation and allow for longer storage periods |
| 7.1 Use of Biofuel – Ship's Operation (VLCC – FAME) | **10.** Spill response - Clean up - Equipment - Spill Net - Requirements to be studied and developed |
| 8.1 Use of Biofuel – Engines (VLCC – FAME) | **11.** Consideration of possible increased fuel consumption with respect to vessel's operating profile (voyage) - May therefore require increased bunkered fuel quantities (in relation to diesel)<br>Larger fuel tank, compared to tank designed for cruising range with conventional diesel<br>Input from Engine designer about Power output and fuel consumption for specific biofuel or blend |
| 8.1 Use of Biofuel – Engines (VLCC – FAME) | **12.** Engine manufacturer designers to provide confirmation that use of Biofuel (and relevant blend) does not increase NOx emissions above allowable limits (need to address issue during engine testing and approval engine testing and emission measurements may be required) |
| 8.1 Use of Biofuel – Engines (VLCC – FAME) | **13.** Engine manufacturer to advise on compatibility of existing engine components and changes/upgrades that may be needed for specific biofuel |

## Appendix H - HAZID Register: VLGC (fuelled with DME and LPG)

| **No.:** 1 | General Arrangement - LPG Carrier |
|---|---|

| Item | Deviation | Causes | Consequences | Matrix | Severity | Likelihood | Risk | Safeguards | Recommendations |
|---|---|---|---|---|---|---|---|---|---|
| 1.1 | DME storage tank located on deck | 1. Heavy weight (depending on tank sizing) | 1. Stability issue | Asset | 3 | B | Moderate | 1. Compliance with class stability requirements (consider new vs conversion) | 2. Investigate DME storage tank location and deck loading to comply with class requirements. |
| | | | 2. Structural damage due to high load on the deck and structure due to DME storage tank weight and dynamic loads | Asset | 3 | C | High | | |
| | | 2. Fluid movement inside DME storage tank (sloshing) | 3. Structural damage to DME storage tank | Asset | 2 | B | Low | 2. Bulkhead inside DME storage tank to minimize sloshing<br>3. Sloshing study for DME storage tank | |

**No.:** 2 DME storage tank

| Item | Deviation | Causes | Consequences | Matrix | Severity | Likelihood | Risk | Safeguards | Recommendations |
|---|---|---|---|---|---|---|---|---|---|
| 2.1 | Tank sizing | 1. Lower calorific value of DME | 1. Impact on tank size required (wrt Carbon Intensity Index (CII) and mixing) | Asset | 3 | C | High | 1. Tank sizing study will be conducted to determine appropriate DME storage tank capacity. Fuel oil is considered as back up fuel. | 1. Consider conducting feasibility study to determine how DME is stored on vessel (i.e. type and quantity of DME storage tanks), depending on 2030 Carbon Intensity Index (CII) regulations and maximum DME level of mixing allowed. |
| | | 2. Overfilling of DME storage tank | 2. PRV exposed to liquid and liquid DME into relief system | Asset | 2 | C | Moderate | 2. Tank filling limit will be designed considering all properties of DME and IGC requirements<br>3. Independent overfilling alarm system installed on DME storage tank (level HH alarm and shutdown)<br>4. DME storage tank design will follow IGC requirements for Type C tanks (including appropriate relieving capacity, 2 PRVs rated for fire case)<br>5. Bunkering of DME storage tank is manned operation<br>6. Fuel Management Systems procedures and monitoring (per IGC requirements for Type C tanks)<br>7. Pressure monitoring and pressure alarm installed on DME storage tank ( pressure H alarm and shutdown) | 8. Proper venting arrangement are to be provided for DME storage tank, at a later design stage (per IGC code requirements)<br>37. Fuel Management procedures for DME storage tank are to be developed to address operational and monitoring requirements (similar to IGF code requirements). |
| | | | 3. Over-pressurization of DME storage tank | Asset | 2 | B | Low | | |
| | | | 4. DME storage tank damage | Asset | 3 | B | Moderate | | |

| **No.:** 2 | DME storage tank | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 2.2 | Dropped object or interference with crane operations | 1. Dropped object | 1. Damage to the DME storage tank dome and connections | Asset | 3 | B | Moderate | 1. Material Handling Philosophy<br>2. Crane operator training and crane operational procedures<br>3. Appropriate PPE (given MSDS of DME)<br>4. Fire and Gas Detection<br>5. System can run on backup fuel and/or LPG | 3. IGC requires additional vapour detection and closed gauging for DME applications in the marine industry. Additionally, consider performing toxicity study to understand the impact of DME on personnel exposure and provide appropriate PPE for personnel onboard including masks, rubber and/or plastic gloves for organic vapors. Based on toxicity study, determine appropriate toxicity vapor detection such as detector type, alarm and shutdown detection setpoints per manufacturer recommendations.<br>38. Dropped object study to be conducted considering the material handling philosophy and general arrangements. |
| | | | 2. Uncontrolled release of DME from the storage tank | Asset | 4 | B | High | | |
| | | | 3. Vent mast damage | Asset | 3 | B | Moderate | | |
| | | | 4. Damage to the deck piping - release of DME | Overall | S3-Moderate | LB-Unlikely | Moderate | | |
| | | | 5. No fuel available for the system | Asset | 2 | B | Low | | |
| | | | 6. Potential personnel exposure to DME leak for crane operator and crew | Injury | 2 | B | Low | | |

| **No.:** 2 | DME storage tank | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | 2. Interference with crane operating radius | 1. Damage to the DME storage tank dome and connections | Asset | 3 | B | Moderate | 1. Material Handling Philosophy<br>2. Crane operator training and crane operational procedures | 3. IGC requires additional vapour detection and closed gauging for DME applications in the marine industry. Additionally, consider performing toxicity study to understand the impact of DME on personnel exposure and provide appropriate PPE for personnel onboard including masks, rubber and/or plastic gloves for organic vapors. Based on toxicity study, determine appropriate toxicity vapor detection such as detector type, alarm and shutdown detection setpoints per manufacturer recommendations.<br>9. Investigate vessel crane operating radius or potential interference issues between crane operations and DME storage tank location. |
| | | | 2. Uncontrolled release of DME from the storage tank | Asset | 4 | B | High | | |
| | | | 3. Vent mast damage | Asset | 3 | B | Moderate | | |

| **No.:** 2 | DME storage tank | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 2.3 | DME supply from DME deck storage tank to fuel preparation room | 1. High pressure DME supply piping on deck | 1. Fatigue and fracture of piping due to high pressure and structural movement, thermal stresses - release of DME | Overall | S3-Moderate | LB-Unlikely | Moderate | 1. Tank safety shutdown system (part of ESD system)<br>2. Inventory management (part of ESD system)<br>4. Fire and Gas Detection<br>5. Appropriate PPE (given MSDS of DME) | 3. IGC requires additional vapour detection and closed gauging for DME applications in the marine industry. Additionally, consider performing toxicity study to understand the impact of DME on personnel exposure and provide appropriate PPE for personnel onboard including masks, rubber and/or plastic gloves for organic vapors. Based on toxicity study, determine appropriate toxicity vapor detection such as detector type, alarm and shutdown detection setpoints per manufacturer recommendations.<br>31. Investigate integrity of DME supply piping from DME storage tank to fuel preparation room (e.g. dropped object, piping rupture scenarios).<br>32. Develop safety shutdown and isolation philosophy for DME storage tank and fuel preparation room. |
| | | | 2. No fuel available for the system | Asset | 2 | B | Low | | |
| | | | 3. Potential personnel exposure to DME leak | Injury | 2 | B | Low | | |

| **No.:** 2 | DME storage tank | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | 2. Trapped inventory (due to engine shutdown and isolation) | 3. Potential personnel exposure to DME leak | Injury | 2 | B | Low | 3. Trapped inventory will release from thermal safety relief valves (per IGC requirements)<br>4. Fire and Gas Detection<br>5. Appropriate PPE (given MSDS of DME) | 3. IGC requires additional vapour detection and closed gauging for DME applications in the marine industry. Additionally, consider performing toxicity study to understand the impact of DME on personnel exposure and provide appropriate PPE for personnel onboard including masks, rubber and/or plastic gloves for organic vapors. Based on toxicity study, determine appropriate toxicity vapor detection such as detector type, alarm and shutdown detection setpoints per manufacturer recommendations.<br>33. Include mechanisms to release inventory and draining in the design of DME storage deck tank, piping, and fuel preparation room. |
| | | 3. Dropped object or interference with crane operations (linked from 2.2) | | | | | | | |

| **No.:** 3 | Bunkering arrangement | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 3.1 | Bunkering under pressurized conditions | 1. Leakage at bunker manifold (DME) | 1. DME in the air (heavier than air) | Asset | 1 | D | Moderate | 1. Drip trays of low temperature steel<br>2. Bunker system is purged and tightness tested before operations with nitrogen<br>3. Appropriate Bunkering procedures<br>4. Fire and Gas Detection<br>5. Water curtain arrangements to provide side shell<br>6. Appropriate PPE (given MSDS of DME)<br>7. Fire fighting system (similar to LPG) | 3. IGC requires additional vapour detection and closed gauging for DME applications in the marine industry. Additionally, consider performing toxicity study to understand the impact of DME on personnel exposure and provide appropriate PPE for personnel onboard including masks, rubber and/or plastic gloves for organic vapors. Based on toxicity study, determine appropriate toxicity vapor detection such as detector type, alarm and shutdown detection setpoints per manufacturer recommendations.<br>5. Provide appropriate spray shields around all connections to minimize liquid sprays.<br>6. Select appropriate fire and gas detection system to detect LPG and DME gas leak or fire. Type of sensors and setpoints are to be determined per manufacturer recommendations. |
| | | | 2. Joule-Thompson (JT) effect on personnel handling DME (cold burn, frost bites) | Injury | 2 | B | Low | | |
| | | | 3. Exposure of DME release at high PPM level (toxic) to personnel handling DME | Injury | 3 | C | High | | |

| **No.:** 3 | Bunkering arrangement | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | | 4. Spraying of DME liquid on the deck or equipment leading to low temperature exposure to the hull, equipment, piping leading to damage | Asset | 2 | B | Low | | |
| | | | 5. Fire and explosion | Overall | S2-Minor | LB-Unlikely | Low | | |
| | | 2. Trapped HP fluid | 6. Unable to purge (no vapor return line for pressurized system) | Asset | 3 | C | High | 4. Fire and Gas Detection<br>6. Appropriate PPE (given MSDS of DME)<br>8. Trapped inventory will release from thermal safety relief valves (per IGC requirements) | 2. Investigate DME storage tank location and deck loading to comply with class requirements.<br>4. Bunkering system and all DME piping are to be designed such that system can be purged with inert media (handling of pressurized fluid initially) without any safety consequences.<br>5. Provide appropriate spray shields around all connections to minimize liquid sprays.<br>33. Include mechanisms to release inventory and draining in the design of DME storage deck tank, piping, and fuel preparation room. |

| **No.:** 4 | Fuel system/preparation - DME/LPG | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 4.1 | Low lubricity | 1. No additional concerns are identified compared to LPG. | | | | | | | |
| 4.2 | Low viscosity | 1. No additional concerns are identified compared to LPG. | | | | | | | |
| 4.3 | Compatibility with elastomer materials | 1. Elastomeric material degradation due to DME exposure (e.g. in valves, seals in rotating machines) | 1. Leakage (unable to seal) | Overall | S3-Moderate | LC-Possible | High | | 12. Conduct materials compatibility study to understand the impact of DME on elastomeric and other materials.<br>13. Consult engine systems and fuel supply systems manufacturers to understand materials compatibility requirements related to DME applications.<br>39. Determine the optimal DME/LPG blend for engine and equipment. |
| | | 2. Swelling of Elastomeric materials (expansion) | 1. Leakage (unable to seal) | Overall | S3-Moderate | LC-Possible | High | | 12. Conduct materials compatibility study to understand the impact of DME on elastomeric and other materials.<br>13. Consult engine systems and fuel supply systems manufacturers to understand materials compatibility requirements related to DME applications.<br>39. Determine the optimal DME/LPG blend for engine and equipment. |

| **No.:** 4 | Fuel system/preparation - DME/LPG | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 4.4 | DME leakage inside fuel preparation room (in compressor/motor room) | 1. DME leakage inside fuel preparation room | 1. Fire and Explosion | Asset | 3 | B | Moderate | 1. Room is designed for zone 1 (hazardous space)<br>2. Fire and Gas Detection System<br>3. Fire Fighting system (C02)<br>4. Liquid collection trays, deck drains<br>5. Ventilation Systems<br>6. Appropriate PPE (given MSDS of DME)<br>7. Appropriate operational procedures<br>8. Cargo compressor/motor room is normally unattended machinery space<br>9. Deck fire hydrants and foam system | 3. IGC requires additional vapour detection and closed gauging for DME applications in the marine industry. Additionally, consider performing toxicity study to understand the impact of DME on personnel exposure and provide appropriate PPE for personnel onboard including masks, rubber and/or plastic gloves for organic vapors. Based on toxicity study, determine appropriate toxicity vapor detection such as detector type, alarm and shutdown detection setpoints per manufacturer recommendations.<br>6. Select appropriate fire and gas detection system to detect LPG and DME gas leak or fire. Type of sensors and setpoints are to be determined per manufacturer recommendations.<br>40. Consider providing rescue stations (Any special space, i.e. eyewash stations, safety showers, treatment for personnel exposure due to toxicity) |
| | | | 2. Explosive atmosphere | Asset | 2 | C | Moderate | | |
| | | | 3. DME exposure to personnel | Injury | 2 | B | Low | | |

| **No.:** 4 | Fuel system/preparation - DME/LPG | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 4.5 | Mixing DME with LPG stream | 1. Wrong blend of DME to LPG | 1. Reduced engine output | Asset | 2 | D | High | 1. Engine monitoring system (Pressure Monitoring Indicators) will adjust fuel supply quantities accordingly | 15. Conduct detailed HAZOP study after the detailed systems design development.<br>16. Provide appropriate filters for DME system to eliminate contamination of fuel.<br>29. Depending on location of DME/LPG fuel mixing (e.g. mixing tank), study the impact of various DME/LPG fuel ratio on engine and develop engine safety systems accordingly. |
| | | 2. Different temperature and pressure of LPG and DME in storage conditions | 2. Final temperature supplied to main engine is out of spec | Asset | 2 | C | Moderate | 2. Temperature and pressure monitoring of supply fuel | 15. Conduct detailed HAZOP study after the detailed systems design development.<br>17. Provide appropriate heating/cooling, pressure and temperature management for the fuel system (after mixing DME and LPG)<br>41. Since fuel storage conditions are different, storage conditions in mixing tank are to be analyzed and proper systems are to be developed. |
| | | | 3. Excessive boil-off due to different temperature and/or pressure of DME and LPG supply to mixing tank | Asset | 3 | C | High | | |
| 4.6 | Return fuel (mixture of DME and LPG) | 1. Return fuel at different pressure and/or temperature compared to mixing temperature and/pressure | 1. High vaporization due to temperature difference between incoming stream and outgoing stream | Asset | 2 | D | High | | 15. Conduct detailed HAZOP study after the detailed systems design development. |

| **No.:** 4 | Fuel system/preparation - DME/LPG | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| | | | | | | | | | 18. Design system at detailed design level with consideration that the return fluid is a mixture of DME and LPG.<br>19. Investigate equipment for fuel system are appropriate to handle LPG, DME, or DME/LPG mixture. Upgrade equipment as necessary. |

| **No.:** 5 | Supply system/vapor handling - DME/LPG | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 5.1 | Mixture of DME and LPG vapor | 1. Engine return vapor is mixed with DME and LPG | 1. Unable to process/handle vapor (DME and LPG mixture) | Overall | S3-Moderate | LD-Likely | High | | 15. Conduct detailed HAZOP study after the detailed systems design development.<br>42. Fuel system is to be designed such that engine return fuel/vapor can be handled properly as it is a mixture of DME and LPG. |

| **No.:** 6 | Cargo Compressor/Motor Room | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 6.1 | DME Toxicity | 1. maintenance trapped fluid | 1. Human exposure to DME | Injury | 2 | D | High | 1. Gas Detection<br>2. Appropriate PPE (given MSDS of DME)<br>3. Monitoring of pressure and temperature | 3. IGC requires additional vapour detection and closed gauging for DME applications in the marine industry. Additionally, consider performing toxicity study to understand the impact of DME on personnel exposure and provide appropriate PPE for personnel onboard including masks, rubber and/or plastic gloves for organic vapors. Based on toxicity study, determine appropriate toxicity vapor detection such as detector type, alarm and shutdown detection setpoints per manufacturer recommendations.<br>6. Select appropriate fire and gas detection system to detect LPG and DME gas leak or fire. Type of sensors and setpoints are to be determined per manufacturer recommendations.<br>22. Develop maintenance procedures considering potential personnel exposure to DME during maintenance activities.<br>43. System is to be designed such that there is no trapped fluid and system has to be purged before maintenance. |

| **No.:** 7 | Engines - LPG Carrier | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 7.1 | Lower calorific value of DME | 1. Lower calorific value of DME | 1. Lower engine power output | Asset | 3 | C | High | | 14. Provide suitable sealing oil for engine injectors system for DME and LPG applications.<br>20. Conduct engine testing for DME suitability, including: selected DME % usage per manufacturer's recommendations, emissions testing (to verify NOx emissions are within limits), pump capability testing with selected DME % usage.<br>21. Considering the lower calorific value of DME, engine manufacturer to consider the use of pilot oil or higher pump capacity for selected DME percentage.<br>23. Conduct study to find the optimal DME/LPG mixture percentage, with considerations to changes on engine components and cost/benefit analysis.<br>27. Conduct engine type testing using DME/LPG mixture as a fuel with selected DME % usage per manufacturer's recommendations. |

| **No.:** 7 | Engines - LPG Carrier | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 7.2 | Emission | 1. Potential DME emissions | | | | | | | 24. Conduct engine testing and emissions testing to verify emissions due to DME (NOx, PM, CO, formaldehydes) and any other adverse emissions effects. Verify that DME emissions comply with Carbon Intensity Index requirements and compare with emissions from other fuels. Expectation is DME NOx emissions are comparable to LPG's, with some improvements. |
| 7.3 | Engine Safety Systems | 1. Potential unignited vapor (DME and LPG) | 1. Explosion due to vapor (DME and LPG) in the exhaust side of the engine | Asset | 3 | C | High | 1. Unburn fuel on exhaust side of engine is monitored via engine control system by monitoring cylinder pressures and other parameters (IGC requirement compliance) | 25. Verify Engine Safety Systems for use of DME and LPG mixture as a fuel. |
| | | 2. Unburned DME/LPG mixture into the exhaust drain | 1. Explosion due to vapor (DME and LPG) in the exhaust gas system of the engine | Asset | 3 | C | High | 1. Unburn fuel on exhaust side of engine is monitored via engine control system by monitoring cylinder pressures and other parameters (IGC requirement compliance) | 26. Conduct study to determine explosion potential of DME/LPG mixture in exhaust drains (engine manufacturers) |
| | | 3. Potential gas inside engine (crank case) and/or engine room | 2. DME and LPG mixture in crank case leading to explosion | Asset | 3 | C | High | 1. Unburn fuel on exhaust side of engine is monitored via engine control system by monitoring cylinder pressures and other parameters (IGC requirement compliance). Diesel combustion principle is used, which limit the risk of having fuel slip from incomplete combustion. | 28. Deviations to IGC code 16.7.3.3 are to be agreed with the flag and specified based on engine manufacturer studies. Gas detectors locations for engine and engine room safety are to be determined based on FMECA and other safety studies by manufacturer. (IGC 16.7.3.3: Crankcases, sumps, scavenge spaces and cooling system vents shall be provided with gas detection (see 13.6.17)) |

| **No.:** 7 | Engines - LPG Carrier | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 7.4 | Wrong DME/LPG blend | 1. Mixing DME with LPG stream - Fuel system/preparation - DME/LPG (linked from 4.5) | | | | | | | |
| **No.:** 8 | Ventilation and Venting System - DME/LPG | | | | | | | | |
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 8.1 | No additional hazards identified compare to LPG system. | 1. No additional hazards identified compared to LPG system. | | | | | | | |

| **No.:** 9 | Safety System | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 9.1 | DME leakage | 1. DME leakage | 1. Personnel exposure to DME (toxicity, frost bites) | Injury | 2 | C | Moderate | 1. Compliance with IGC requirements and LPG gas carrier requirements<br>2. Fire and Gas Detection<br>3. Firefighting System | 3. IGC requires additional vapour detection and closed gauging for DME applications in the marine industry. Additionally, consider performing toxicity study to understand the impact of DME on personnel exposure and provide appropriate PPE for personnel onboard including masks, rubber and/or plastic gloves for organic vapors. Based on toxicity study, determine appropriate toxicity vapor detection such as detector type, alarm and shutdown detection setpoints per manufacturer recommendations.<br>7. Provide sprinkler system on deck to protect DME storage tank in case of fire (IGC requirement).<br>30. Perform gas dispersion analysis and considering DME applications for all venting and leakage scenarios. |
| | | | 3. Fire and Explosion | Overall | S3-Moderate | LB-Unlikely | Moderate | | |

| **No.:** 10 | Ship's Operations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 10.1 | SIMOPS | 1. No significant consequences identified as there are no simultaneous operations allowed. | | | | | | | |
| 10.2 | Dry docking | 1. Gassing up of DME deck tank (linked from 10.3) | | | | | | | 11. Study the use of DME storage tank during dry docking to store cargo (LPG), the intention is to minimize venting of the cargo and provide capability of gassing operations once vessel is out of the ship yard.<br>34. Investigate purity requirements for inert gas (IG) and N2 for DME applications. |
| 10.3 | Gassing up of DME deck tank | 1. Purity of inert gas (IG) | 1. Contamination of DME | Asset | 2 | C | Moderate | | 10. Investigate operational requirements for tank design (e.g. isolation, removal spools, making tank safe, etc.).<br>34. Investigate purity requirements for inert gas (IG) and N2 for DME applications.<br>35. Investigate gassing up of DME deck tank with LPG before introduction of DME, and what is the change of atmosphere requirement.<br>36. Consider adding spool pieces for the connections in DME storage deck tank design, connections, and pipings. |

| **No.:** 11 | Emergency Escape, Evacuation, Rescue (EER) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | |
| **Item** | **Deviation** | **Causes** | **Consequences** | **Matrix** | **Severity** | **Likelihood** | **Risk** | **Safeguards** | **Recommendations** |
| 11.1 | No additional hazards identified related to DME applications, compared to typical concerns for LPG system. | 1. No additional concerns related to DME identified. | | | | | | | |

## Appendix I - HAZID Recommendations List: VLGC (fueled with DME and LPG)

| References | Recommendations |
|---|---|
| 2.1 Tank sizing – DME storage tank | 1. Consider conducting feasibility study to determine how DME is stored on vessel (i.e. type and quantity of DME storage tanks), depending on 2030 Carbon Intensity Index (CII) regulations and maximum DME level of mixing allowed. |
| 1.1 DME storage tank located on deck – General Arrangement - LPG Carrier<br>3.1 Bunkering under pressurized conditions – Bunkering arrangement | 2. Investigate DME storage tank location and deck loading to comply with class requirements. |
| 2.2 Dropped object or interference with crane operations – DME storage tank<br>2.3 DME supply from DME deck storage tank to fuel preparation room – DME storage tank<br>3.1 Bunkering under pressurized conditions – Bunkering arrangement<br>4.4 DME leakage inside fuel preparation room (in compressor/motor room) – Fuel system/preparation - DME/LPG<br>6.1 DME Toxicity – Cargo Compressor/Motor Room<br>9.1 DME leakage – Safety System | 3. IGC requires additional vapour detection and closed gauging for DME applications in the marine industry. Additionally, consider performing toxicity study to understand the impact of DME on personnel exposure and provide appropriate PPE for personnel onboard including masks, rubber and/or plastic gloves for organic vapors. Based on toxicity study, determine appropriate toxicity vapor detection such as detector type, alarm and shutdown detection setpoints per manufacturer recommendations. |
| 3.1 Bunkering under pressurized conditions – Bunkering arrangement | 4. Bunkering system and all DME piping are to be designed such that system can be purged with inert media (handling of pressurized fluid initially) without any safety consequences. |
| 3.1 Bunkering under pressurized conditions – Bunkering arrangement | 5. Provide appropriate spray shields around all connections to minimize liquid sprays. |
| 3.1 Bunkering under pressurized conditions – Bunkering arrangement<br>4.4 DME leakage inside fuel preparation room (in compressor/motor room) – Fuel system/preparation - DME/LPG<br>6.1 DME Toxicity – Cargo Compressor/Motor Room | 6. Select appropriate fire and gas detection system to detect LPG and DME gas leak or fire. Type of sensors and setpoints are to be determined per manufacturer recommendations. |
| 9.1 DME leakage – Safety System | 7. Provide sprinkler system on deck to protect DME storage tank in case of fire (IGC requirement). |
| 2.1 Tank sizing – DME storage tank | 8. Proper venting arrangement are to be provided for DME storage tank, at a later design stage (per IGC code requirements) |
| 2.2 Dropped object or interference with crane operations – DME storage tank | 9. Investigate vessel crane operating radius or potential interference issues between crane operations and DME storage tank location. |
| 10.3 Gassing up of DME deck tank Ship's Operations | 10. Investigate operational requirements for tank design (e.g. isolation, removal spools, making tank safe, etc.). |
| 10.2 Dry docking Ship's Operations | 11. Study the use of DME storage tank during dry docking to store cargo (LPG), the intention is to minimize venting of the cargo and provide capability of gassing operations once vessel is out of the shipyard. |
| 4.3 Compatibility with elastomer materials – Fuel system/preparation - DME/LPG | 12. Conduct materials compatibility study to understand the impact of DME on elastomeric and other materials. |

| References | Recommendations |
|---|---|
| 4.3 Compatibility with elastomer materials – Fuel system/preparation - DME/LPG | 13. Consult engine systems and fuel supply systems manufacturers to understand materials compatibility requirements related to DME applications. |
| 7.1 Lower calorific value of DME – Engines - LPG Carrier | 14. Provide suitable sealing oil for engine injectors system for DME and LPG applications. |
| 4.5 Mixing DME with LPG stream – Fuel system/preparation - DME/LPG<br>4.6 Return fuel (mixture of DME and LPG) – Fuel system/preparation - DME/LPG<br>5.1 Mixture of DME and LPG vapor – Supply system/vapor handling - DME/LPG | 15. Conduct detailed HAZOP study after the detailed systems design development. |
| 4.5 Mixing DME with LPG stream – Fuel system/preparation - DME/LPG | 16. Provide appropriate filters for DME system to eliminate contamination of fuel. |
| 4.5 Mixing DME with LPG stream – Fuel system/preparation - DME/LPG | 17. Provide appropriate heating/cooling, pressure and temperature management for the fuel system (after mixing DME and LPG) |
| 4.6 Return fuel (mixture of DME and LPG) – Fuel system/preparation - DME/LPG | 18. Design system at detailed design level with consideration that the return fluid is a mixture of DME and LPG. |
| 4.6 Return fuel (mixture of DME and LPG) – Fuel system/preparation - DME/LPG | 19. Investigate equipment for fuel system are appropriate to handle LPG, DME, or DME/LPG mixture. Upgrade equipment as necessary. |
| 7.1 Lower calorific value of DME – Engines - LPG Carrier | 20. Conduct engine testing for DME suitability, including: selected DME % usage per manufacturer's recommendations, emissions testing (to verify NOx emissions are within limits), pump capability testing with selected DME % usage. |
| 7.1 Lower calorific value of DME – Engines - LPG Carrier | 21. Considering the lower calorific value of DME, engine manufacturer to consider the use of pilot oil or higher pump capacity for selected DME percentage. |
| 6.1 DME Toxicity – Cargo Compressor/Motor Room | 22. Develop maintenance procedures considering potential personnel exposure to DME during maintenance activities. |
| 7.1 Lower calorific value of DME – Engines - LPG Carrier | 23. Conduct study to find the optimal DME/LPG mixture percentage, with considerations to changes on engine components and cost/benefit analysis. |
| 7.2 Emission – Engines - LPG Carrier | 24. Conduct engine testing and emissions testing to verify emissions due to DME (NOx, PM, CO, formaldehydes) and any other adverse emissions effects. Verify that DME emissions comply with Carbon Intensity Index requirements and compare with emissions from other fuels. Expectation is DME NOx emissions are comparable to LPG's, with some improvements. |
| 7.3 Engine Safety Systems – Engines - LPG Carrier | 25. Verify Engine Safety Systems for use of DME and LPG mixture as a fuel. |
| 7.3 Engine Safety Systems – Engines - LPG Carrier | 26. Conduct study to determine explosion potential of DME/LPG mixture in exhaust pipe and exhaust receiver (engine manufacturers) |
| 7.1 Lower calorific value of DME – Engines - LPG Carrier | 27. Conduct engine type testing using DME/LPG mixture as a fuel with selected DME % usage per manufacturer's recommendations. |
| 7.3 Engine Safety Systems – Engines - LPG Carrier | 28. Deviations to IGC code 16.7.3.3 are to be agreed with the flag and specified based on engine manufacturer studies. Gas detectors locations for engine and engine room safety are to be determined based on FMECA and other safety studies by manufacturer. (IGC 16.7.3.3: Crankcases, sumps, scavenge spaces and cooling system vents shall be provided with gas detection (see 13.6.17)) |

| References | Recommendations |
|---|---|
| 4.5 Mixing DME with LPG stream – Fuel system/preparation - DME/LPG | 29. Depending on location of DME/LPG fuel mixing (e.g. mixing tank), study the impact of various DME/LPG fuel ratio on engine and develop engine safety systems accordingly. |
| 9.1 DME leakage – Safety System | 30. Perform gas dispersion analysis and considering DME applications for all venting and leakage scenarios. |
| 2.3 DME supply from DME deck storage tank to fuel preparation room – DME storage tank | 31. Investigate integrity of DME supply piping from DME storage tank to fuel preparation room (e.g. dropped object, piping rupture scenarios). |
| 2.3 DME supply from DME deck storage tank to fuel preparation room – DME storage tank | 32. Develop safety shutdown and isolation philosophy for DME storage tank and fuel preparation room. |
| 2.3 DME supply from DME deck storage tank to fuel preparation room – DME storage tank<br>3.1 Bunkering under pressurized conditions – Bunkering arrangement | 33. Include mechanisms to release inventory and draining in the design of DME storage deck tank, piping, and fuel preparation room. |
| 10.2 Dry docking – Ship's Operations<br>10.3 Gassing up of DME deck tank – Ship's Operations | 34. Investigate purity requirements for inert gas (IG) and N2 for DME applications. |
| 10.3 Gassing up of DME deck tank – Ship's Operations | 35. Investigate gassing up of DME deck tank with LPG before introduction of DME, and what is the change of atmosphere requirement. |
| 10.3 Gassing up of DME deck tank – Ship's Operations | 36. Consider adding spool pieces for the connections in DME storage deck tank design, connections, and piping. |
| 2.1 Tank sizing – DME storage tank | 37. Fuel Management procedures for DME storage tank are to be developed to address operational and monitoring requirements (similar to IGF code requirements). |
| 2.2 Dropped object or interference with crane operations – DME storage tank | 38. Dropped object study to be conducted considering the material handling philosophy and general arrangements. |
| 4.3 Compatibility with elastomer materials – Fuel system/preparation - DME/LPG | 39. Determine the optimal DME/LPG blend for engine and equipment. |
| 4.4 DME leakage inside fuel preparation room (in compressor/motor room) – Fuel system/preparation - DME/LPG | 40. Consider providing rescue stations (Any special space, i.e. eyewash stations, safety showers, treatment for personnel exposure due to toxicity) |
| 4.5 Mixing DME with LPG stream – Fuel system/preparation - DME/LPG | 41. Since fuel storage conditions are different, storage conditions in mixing tank are to be analyzed and proper systems are to be developed. |
| 5.1 Mixture of DME and LPG vapor – Supply system/vapor handling - DME/LPG | 42. Fuel system is to be designed such that engine return fuel/vapor can be handled properly as it is a mixture of DME and LPG. |
| 6.1 DME Toxicity – Cargo Compressor/Motor Room | 43. System is to be designed such that there is no trapped fluid and system has to be purged before maintenance. |

## Appendix J – Detailed Regulatory Gap Analysis with Comments

Biofuels EMSA Report Gap Analysis

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| No Gap or Changes needed to address biofuels |
| Small Gap or Minor Change to address biofuels |
| Medium Gap or Some Challenging Change to address biofuels |
| Large Gap or Many Challenging Changes to address biofuels |

| Subject | Rule/Guidance | Comment on Code/Standard - Benefits | Comment on Code/Standard - Gaps | Discussion and Recommendations |
|---|---|---|---|---|
| Sustainability and Emissions Regulations | IMO Prevention of Pollution from Ships (MARPOL) Convention Regulation 13 - Nitrogen Oxides (NOx) and Regulation 18 - Fuel Oil Availability and Quality | Applies the NOx Technical Code (NTC) to reference testing and certification of all subject marine diesel engines | There are variations in NOx emissions from the use of biofuels and biofuel blends (depends on the engine, load and specific fuel). The NOx Technical Code is limited on provisions for certification of NOx with biofuels. While there are 'trials' or 'equivalent' regulations within Annex VI to enable the use of biofuels, application of the NOx obligations under regulation 18.3.2.2 is unclear. Amendment of Annex VI and the NTC will contribute to the uptake of biofuels within the global marine industry. | Further discussion and encouragement to amend Annex VI and the NOx Technical Code to account for biofuels will encourage the uptake of biofuels. |
| | IMO Prevention of Pollution from Ships (MARPOL) Convention Regulation 14 - Sulphur Oxides (SOx) and Particulate matter | Restricts the amount of SOx and (sulphate) particulate matter emitted by all fuel oil-consuming equipment onboard ships by limiting the sulphur content in the fuel. | The IMO's ECA fuel sulphur limit of 0.1% (1,000 ppm) is less stringent than land-based regulations, where limits may be as low as 0.001% (10 ppm). Biofuels significantly exceed this standard but are not encouraged for adoption by the IMO fuel sulphur limits. | Timely update of international IMO MARPOL emissions and air pollution limits, to accommodate industry needs and development, is a strong driver to support adopting of alternative fuels such as biofuels. Supporting international technical and regional/national standards and requirements can continue to support the prevention of pollution from ships and contribute to the adoption of sustainable biofuels as marine fuel. |
| | IMO Prevention of Pollution from Ships (MARPOL) Convention Regulation 21 - Required EEDI Chapter 4 – Regulations on the Carbon Intensity of International Shipping | Required calculations for ships energy efficiency and carbon intensity using various methods, including EEDI, EEXI or CII are based on limited current fuel carbon factors. Ability to certify ships with alternative (certified) fuel carbon factors, at design and during operation, may encourage the uptake of biofuels as shipowners look for ways to reduce their | Required calculations for ships energy efficiency and carbon intensity using various methods, including EEDI, EEXI or CII are based on limited current fuel carbon factors. Clarification of how to incorporate biofuels into calculations to meet EEDI, EEXI, or CII values and DCS reporting is needed, taking into account the sustainability of the fuel over its lifecycle of production to use. | |

| Subject | Rule/Guidance | Comment on Code/Standard - Benefits | Comment on Code/Standard - Gaps | Discussion and Recommendations |
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| | | carbon footprint and increase efficiency. | The ability to certify ships with alternative (certified) fuel carbon factors, at design and during operation, may encourage the uptake of biofuels as shipowners look for ways to reduce their carbon footprint and increase efficiency. | |
| | EU Renewable Energy Directive (RED) 2009/28/EC | This European Commission Directive directly contributes to the uptake of biofuels in EU Member states, specifically requiring the integration of at least 32% biofuels in energy by 2030. | Due to the regional nature of this directive, issues may arise when biofuels are traded across non-member borders.<br>This directive could be more effective if its provisions within the directive were officgnised, adopted, or incorporated in non-member states and international reporting schemes for sustainable energy sources. | The EU is taking the initiative with the EU RED to require the uptake of biofuels through policy and economic principles, including the qualification of biofuel sustainability through supply chain validation. |
| | EU Fuel Quality Directive (FQD) 2009/30/EC | European Commission directives such as the FQD provide ship owners guidance and instruction of how to implement and account for decarbonisation and reduced emissions initiatives through alternative marine fuel schemes. | The FQD may be more useful in contributing to the uptake of biofuels if reporting requirements included provisions for more types of biofuels and aligned with other regional, national and international reporting schemes. | Due to the wide variety of biofuels based on feedstock sources and production methods, sustainability accounting is not clearly established. |
| Storage | American Petroleum Institute API RP 1640 *Product Quality in Light Product Storage* | This Recommended Practice provides guidance for light liquid biofuel (biodiesel/FAME) handling and storage for bunkering and ship facilities. Guidance documents that cover various applications, uses, and processes for biofuels can contribute to its uptake. | Similar to other guidance documents and fuel quality rules, this RP covers only ethanol, butane and FAME light product biofuel.<br>Modifications to this or the creation of further guidance covering other commonly used liquid or gaseous biofuel types may be more useful | Guidelines such as these can contribute to the uptake of biofuels as it is used by ship designers, owners, regulators, and operators as an informational resource when addressing alternative or new types of fuels. |
| Transportation & Handling | IMO Code for Construction and Equipment of Ships Carrying Liquefied Gases (IGC Code) | Adequately deals with the transport in bulk of liquefied gases. Gas carrier fleet is focused on transport of LNG, LPG, ethane, ethylene and ammonia with bulk of experience with burning LNG | Could benefit from clarifying current Code covering transport of bio equivalents such as bio-LNG or updated as necessary | As bio-derived gaseous and liquid fuels continue to grow in the industry, addressing their specific needs as a cargo (if any) is equally as important as addressing provisions in use. Further experience and developments |

| Subject | Rule/Guidance | Comment on Code/Standard - Benefits | Comment on Code/Standard - Gaps | Discussion and Recommendations |
|---|---|---|---|---|
| | | as cargo and evolving trend to burn other cargoes such as ethane and LPG. | | regarding the trade and transport of gaseous and liquid biofuels can contribute to the uptake of those types of alternative fuels. |
| | International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code) | Adequately deals with the transport in bulk of chemicals. Methanol carrying fleet emerged as early adopters of methanol as fuel. | Considered covers carriage of biofuel equivalents such as bio-methanol in association with other IMO instruments covering energy-rich fuels and application of MARPOL Annexes I and II | |
| | Guidelines for the Carriage of Energy-Rich Fuels and their Blends (MEPC.1/Circ.879) and Guidelines for the Carriage of Blends of Biofuels and MARPOL Annex I Cargoes (MSC MEPC.2/Circ17) | Provides important information to the marine industry about the handling and carriage of biofuels and energy-rich fuels. | Considered covers carriage in bulk of biofuel blends and energy-rich fuels in bulk | Internationally published guidelines such as these can contribute to the uptake of biofuels as it is used by ship designers, owners, regulators, and operators as an informational resource when addressing alternative or new types of fuels. |
| | IBIA, IMPCA, Methanol Institute | IMPCA and Methanol Institute are active in developing methanol specifications and methanol handling guidance, including bunkering. IBIA are undertaking future fuels assessments, including biofuels. | Dedicated marine bunkering guidance for biofuels currently missing. | Development of industry best practice and guidance publications for biofuel handling, specifically bunkering and transfers, should be supported. |
| Use & Consumption | IMO International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels (IGF Code) | Provides requirements for ships using fuels with low-flashpoint (i.e., below 60°C), prescriptively covers LNG but can apply to other low flashpoint or gaseous fuels, including bio-methanol (applies MSC.21/Circ.1621) or bio-LNG. | Long term objective is to amend to include detailed prescriptive requirements for gaseous and low flashpoint fuels other than LNG as experience develops, including the bio-derived variants. Prior to amendments, the development of interim guidelines similar to the methyl/ethyl alcohol precedent can support take-up. From a safety perspective, with no | The origin of the IGF Code was initially to support the adoption of LNG as marine fuel, but contains provisions to approve other low flashpoint fuels and gases under the 'Alternative Design' process. In the absence of amendments, publication of interim guidelines (as already implemented for methyl/ethyl alcohol fuels with MSC.1/Circ.1621) would facilitate |

| Subject | Rule/Guidance | Comment on Code/Standard - Benefits | Comment on Code/Standard - Gaps | Discussion and Recommendations |
|---|---|---|---|---|
| | | | significant differences between methane and biomethane, or methanol and biomethanol, there are no specific barriers to adoption of biofuels under this IMO Instrument. | take up of those fuels, and their biofuel equivalents. |
| | IMO International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) | 2014 Update introduced the option to burn non-toxic cargoes as fuel other than natrual gas (methane). These can include biofuel cargo variants, such as biomethane. | The 2014 update facilitates burning of other cargoes such as ethane and LPG. On basis of no significant differences between bio variants of IGC Code cargoes to their biofuel equivalents, the Code adequately covers potential burning of those cargoes as fuel. Some differences between IGC Code and IGF Code hamper harmonized requirements for effectively the same equipment and systems. | Future work at the IMO Sub-Committee on Carriage of Cargoes and Containers (CCC) plans to undertake a complete review of the IGC Code. These changes seek to fix implementation problems with the 2014 Code, harmonize further with the IGF Code where practicable and to consider widening the range of allowed cargoes to be burnt. Earliest implementation is expected to enter into force 1 January 2028. |
| | IMO MSC.1/Circ.1621 - Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel | Applicable to methyl/ethyl alcohol fuels and supports application under the IGF Code. Landmark publication supporting application of methanol as a marine fuel beyond the early adopters. | No significant gaps for supporting application of biomethanol as a marine fuel. | Further updates expected based on industry experience. |
| | SOLAS and IMO International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels (IGF Code) | Historically, SOLAS has prohibited the use of fuel oils with less than a 60˚C flashpoint, except for use in emergency generators (where the flashpoint limit is 43˚C) and subject to other requirements detailed in SOLAS Chapter II-2 Regulation 4.2.1. Currently this work item being considered by CCC to develop requirements for fuel oils with a flashpoint between 52˚ and 60˚C. | Fuel oils (which may include biofuels) with lower than 60˚C flashpoint currently not covered within SOLAS or IGF Code. | The lack of current regulation for fuel oils with a flashpoint between 52˚ and 60˚C is not seen as a significant barrier to biofuel take-up (since many have flashpoints above 60˚C), however this is a gap in the current IMO instruments. |

| Subject | Rule/Guidance | Comment on Code/Standard - Benefits | Comment on Code/Standard - Gaps | Discussion and Recommendations |
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| | SOLAS ISM Code, SOLAS II-1/Regulation 3-1 and classification society requirements | SOLAS ISM Code requires operators to assess all risks to a company's ships. SOLAS also requires equipment compliance with classification society rules. Liquid biofuels (biodiesels) are not an engine type defining parameter, but onboard demonstration of suitability typically required. | IMO guidance similar to MEPC.1/Circ.878 for biodiesels and clarification on application via IACS UR missing. | IMO guidance similar to MEPC.1/Circ.878 for biodiesels would facilitate owners and operators' obligations under the ISM Code. Together with clarification on application of classification society requirements via IACS URs or similar instruments would support harmonized application of class society requirements, as called out by SOLAS II-1/Regulation 3-1. |
| | CIMAC *Guideline for Ship Owners and Operators on Managing Distillate Fuels up to 7.0% v/v FAME (biodiesel) (2013)* | Guidelines from international parties such as CIMAC can contribute to the uptake of biofuels from a global audience of engine manufacturers and users in addition to those in the maritime industry. Detailed CIMAC guidelines can validate experience and understanding of alternative fuels | Additional publications such as these from CIMAC can further encourage and validate other blend percentages or other types of biofuels in industrial and marine engine systems. Publication of specific engine type guidance from CIMAC engine designers should be encouraged. | Encourage regular updates to cover the broader range of biofuels being considered and applied by the marine industry through generic CIMAC publications and engine type specific guidance through the engine designers. |
| Quality | ISO 8217:2017 Petroleum products – Fuels (class F) – Specifications of marine fuels | Limits allow liquid biofuel blends to de minimis or 7%, depending on the grade of marine fuel. | Working group ISO/TC28/SC4/WG6 is to develop requirements for marine fuel grade performance, which may allow for up to 50% blend FAME, meeting other quality standards. Allowing higher blend percentages of qualified biofuels in marine fuels can contribute to more uptake. Currently limiting application only to 7% FAME biofuels. Specific energy calculator not accurate for all biofuels being trialed Standard could be revised to allow higher blend percentages of qualified biofuels in marine fuels | Additional types of liquid biofuels other than FAME have been used in marine fuel blends to meet sulphur limit regulations, but do not exactly conform to the fuel grades defined in this or other biofuel quality standards. Future updates of this standard intend to cover other fuels as industry experience grows. Including the 0.50% S fuel guidance, additional liquid biofuels, higher % of FAME fuels and updating the specific energy calculator in the next ISO 8217 revision can contribute to the uptake of biofuels. |

| Subject | Rule/Guidance | Comment on Code/Standard - Benefits | Comment on Code/Standard - Gaps | Discussion and Recommendations |
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| | ISO/PAS 23263 Petroleum Products - Fuels (class F) - Considerations for fuel suppliers and users regarding marine fuel quality in view of the implementation of maximum 0,50% sulfur in 2020 | Addresses quality considerations that apply to marine fuels, defining general requirements that apply to all 0,50 mass% sulfur fuels and confirms the applicability of ISO 8217 for those fuels. | Incorporation of these considerations to the next ISO 8217 revision would consolidate the requirements and explicitly apply to liquid biofuels to be blended with petroleum fuels. | |
| | IMO Prevention of Pollution from Ships (MARPOL) Convention - Regulation 18 - Fuel Oil Availability and Quality | Provides recognised MARPOL fuel quality and availability regulations for marine fuel supply. | There is uncertainty on application of regulation 18.3.2.2 for NOx. Annex VI Should add required clarifications for suppliers of liquid biofuels regarding the NOx emissions resulting from the biofuel and other relevant biofuel specific requirements such as BDNs and CF factors that may be applicable. | While a workaround exists by application of regulation 3.2 for trials onboard or regulation 4 for 'equivalents', there is an urgent need to update Annex VI and the NOx Technical Code to provide clarity and harmonized application for burning biofuels. |
| | ISO 23306:2020 Specification of liquefied natural gas as a fuel for marine applications | The standard applies to LNG derived from sources other than fossil petroleum, including shale gas, coalbed methane, biomethane or synthetic methane. | The limiting facet of this standard is the method to calculate the Methane Number (MN) of the fuel and the potential for particles or debris, which is based on the fuel composition.<br>Standard does not set quality limits or defines a minimum MN value (requires the minimum to be agreed between supplier and user). It could benefit from including limits for those characteristics. | The inclusion of biomethane in this standard, and therefore bio-LNG, encourages the uptake of these fuels derived from biomaterials. |
| | ISO/AWI 6583 *Specification of methanol as a fuel for marine applications* | While this standard is not yet beyond the preparatory stage, it is expected to follow the ISO 23306 approach to cover fuels derived from both fossil and renewable sources. | Ongoing standard development should ensure coverage of fuels derived from renewable sources (i.e., bio-methanol) | The adoption of this standard into international marine regimes can contribute to the uptake of bio-derived methanol (and possibly bio-derived ethanol). |
| | ASTM D6751-20a *Standard Specification for* | Applies to biofuel drop-in for middle distillate fuels.<br>In addition to quality | No significant gaps for supporting application of FAME biofuel as a marine fuel. | Other biofuels should be covered in similar standards depending on characteristics derived from |

| Subject | Rule/Guidance | Comment on Code/Standard - Benefits | Comment on Code/Standard - Gaps | Discussion and Recommendations |
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| | *Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels* | parameters, this standard also provides guidance on handling liquid biofuels. | | biomass feedstock and production process. Future standards in place for a variety of biofuel types can encourage further uptake of bio-derived fuels in the industry. |
| | ASTM D7544-12:2017 *Standard Specification for Pyrolysis Liquid Biofuel* | | Limited land-use application of this standard restrains the marine industry from adopting pyrolysis liquid biofuels. | The revision of standards such as this for land-based applications to include marine applications could contribute to the adoption of pyrolysis liquid biofuels. Provisions for handling, compatible materials and safety recommendations based on the characteristics of the fuel are useful for the industry to adopt a new type of biofuel. |
| | ASTM D7467-20a *Standard Specification for Diesel Fuel Oil, Biodiesel Blend (B6 to B20)* | Applies to biofuel drop-in for middle distillate fuels, including the quality of biofuel blend stock for blending with diesel fuel oil, where biofuels are between 6% and 20% of the fuel mix. | No significant gaps for supporting application of FAME biofuel as a marine fuel. | Other standards like this covering specific blend percentages for biofuel in diesel, as well as other standards that cover biofuels blended with other types of fuel, such as light or heavy distillate or residual fuels, can provide the industry with further guidance on the use of a variety of biofuel types in a variety of conventional fuel grades. |
| Bunkering | ISO/TS 18683:2015 *Guidelines for systems and installations for supply of LNG as fuel to ships* | Where LNG is derived from biomethane, this guideline applies to fuel supply systems to ships | This is applicable to LNG (and therefore to bio-LNG), but could be revised to include specific provisions or guidance for other bio-derived alternative fuels if the characteristics of the biofuel require specific consideration. Alternatively, this could be used as a basis for the development of new standard(s) | Existing standards that cover equipment requirements and bunkering procedures for a qualified type of fuel such as LNG as per ISO 23306 or other quality standard can ease the adoption of fuel alternatives using the existing infrastructure, such as bio-LNG. |
| | ISO 20519:2017 *Ships and marine technology – Specifications for bunkering of liquefied natural gas fuelled vessels.* | Where LNG is derived from biomethane, this guideline applies to fuel bunkering | This is applicable to LNG (and therefore to bio-LNG), but could be revised to include specific provisions or guidance for other bio-derived alternative fuels if the characteristics of the biofuel require specific consideration. Alternatively, this could be used as | |

| Subject | Rule/Guidance | Comment on Code/Standard - Benefits | Comment on Code/Standard - Gaps | Discussion and Recommendations |
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| | | | a basis for the development of new standard(s) | |
| | ISO 28460:2010 *Petroleum and natural gas industries – Installation and equipment for liquefied natural gas – Ship-to-shore interface and port operations* | Where LNG is derived from biomethane, this guideline applies to fuel supply systems to ships | This is applicable to LNG (and therefore to bio-LNG), but could be revised to include specific provisions or guidance for other bio-derived alternative fuels if the characteristics of the biofuel require specific consideration. Alternatively, this could be used as a basis for the development of new standard(s) | |
| | ISO 21593:2019 *Ships and marine technology. Technical requirements for dry-disconnect/connect couplings for bunkering liquefied natural gas.* | Where LNG is derived from biomethane, this guideline applies to fuel bunkering | This is applicable to LNG (and therefore to bio-LNG), but could be revised to include specific provisions or guidance for other bio-derived alternative fuels if the characteristics of the biofuel require specific consideration. Alternatively, this could be used as a basis for the development of new standard(s) | |
| | ISO 20519:2021 *Ships and marine technology - Specification for bunkering of liquefied natural gas fuelled vessels* | Where LNG is derived from biomethane, this guideline applies to fuel bunkering | This is applicable to LNG (and therefore to bio-LNG), but could be revised to include specific provisions or guidance for other bio-derived alternative fuels if the characteristics of the biofuel require specific consideration. Alternatively, this could be used as a basis for the development of new standard(s) | |
| | MI/LR Introduction to Methanol Bunkering Technical Reference | MI/LR: publication provides a checklist and process flow approach to safely handle methanol bunkering transfers. | Supports take up of methanol and biomethanol as a marine fuel. | |

| Subject | Rule/Guidance | Comment on Code/Standard - Benefits | Comment on Code/Standard - Gaps | Discussion and Recommendations |
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| IACS Classification Societies Rules, Guides and Guidance | | Classification Societies participate in international committees and regulatory bodies regarding ship design, construction, and safety requirements. IACS collectively make a unique contribution to maritime safety and regulation by providing technical support, compliance verification (of statutory instruments in their role as Recognised Organizations) and research and development. The collaborative effort of multiple class societies in IACS leads to the implementation of common rules, unified requirements (UR) for typical Class Rules, unified interpretations (UI) of statutory instruments and other recommendations that are applied consistently by IACS members. They are participating with ship owners and engine manufacturers to guide safety practices, as well as to gain experience on the use of biofuels as marine fuel. | While Class Societies are engaging with biofuel stakeholders to contribute to the safe uptake of biofuels, more could be done to encourage industry adoption of biofuels. Where IACS have adopted URs, these must be uniformly applied by IACS members in their rules. Similarly, where IACS UIs exist to statutory requirements, these are, by purpose, to facilitate harmonized application of the regulations. Currently no such IACS publications related to biofuels exist. | Considering the challenges in developing and implementing changes to regulations in a timely manner, industry stakeholders such as IACS can facilitate biofuel take up and harmonized application by the development of Unified Requirements, Unified Interpretations and Recommendations, this should be encouraged. |
| Regional and National Rules for Marine Fuel, including Biofuels as Marine Fuel | | In general, when regions, nations, and local authorities adopt rules, standards, or regulations regarding the decarbonisation and reduced emission limits of marine fuels, they are contributing to the uptake of biofuels as marine fuels. Specific authorities that contribute to the uptake of biofuels include:<br>- The United States | Regional and national regulations can lead developments at IMO level.<br>Wider adoption of IMO (or regional or national regulations) in those locations laking all such instruments could uniformly support the adoption of biofuels. When local marine authorities do not implement emissions reductions limits similar to those of IMO MARPOL Annex VI, the uptake of biofuels for marine fuel | The selection of regional or national authorities in the sections above was made due to those countries having higher vessel traffic and port calls. They can be seen by the industry as the leaders in regional maritime authority, and therefore the policy and regulations put in place regarding alternative fuels may or may not lead others to implement similar measures.<br>When these authorities |

| Subject | Rule/Guidance | Comment on Code/Standard - Benefits | Comment on Code/Standard - Gaps | Discussion and Recommendations |
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| | | - Canada<br>- China<br>- Japan<br>- South Korea<br>- Panama Canal Authority | is generally restrained. Specifically, without the required emissions limits (or economic incentive), shipowners and operators will continue to purchase and use the less costly options for fuel, which are typically the conventional petroleum heavy fuel oils. | incorporate emission limits on emissions from local, domestic and international shipping, contributions to the uptake of alternative fuels including biofuels are being made. |

## Appendix K – Symbols, Abbreviations and Acronyms

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| **ABS** | American Bureau of Shipping |
| **AER** | Annual Efficiency Ratio (IMO) |
| **AFC** | Alkaline Fuel Cell |
| **AIP** | Approval In Principle |
| **ALARP** | As Low As Reasonably Practical |
| **ANSI** | American National Standards Institute |
| **API** | American Petroleum Institute |
| **ASME** | American Society of Mechanical Engineers |
| **ASTM** | American Society for Testing of Materials |
| **ATR** | AutoThermal Reforming |
| **BC** | Black Carbon |
| **BDN** | Bunker Delivery Note |
| **BLEVE** | Boiling Liquid Expanding Vapor Explosion |
| **BMEP** | Brake Mean Effective Pressure |
| **BOG** | Boil Off Gas |
| **nBOG** | Natural Boil Off Gas |
| **CAPEX** | Capital Expenditure |
| **CARB** | California Air Resources Board |
| **CC** | Carbon Chains |
| **CCC** | Carriage of Cargoes and Containers Sub-Committee (IMO) |
| **CCR** | California Code of Regulation |
| **CCUS** | Carbon Capture Utilization Storage |
| **$C_F$** | Fuel-Conversion Factor (IMO - EEDI) |
| **CFR** | Code of Federal Regulations |
| **CHP** | Combined Heat and Power |
| **CII** | Carbon Intensity Indicator (IMO) |
| **CIMAC** | International Council on Combustion Engines |
| **CNG** | Compressed Natural Gas |
| **CO** | Carbon Monoxide |
| **$CO_2$** | Carbon Dioxide |
| **$CO_2e$** | Carbon Dioxide Equivalent |
| **DBB** | Double Block Bleed |
| **DCS** | Data Collection System (IMO) |
| **DF** | Dual Fuel |
| **DFDE** | Dual Fuel Diesel Electric |
| **DOT** | Department of Transport |
| **DPF** | Diesel Particulate Filter |
| **DWT** | Deadweight Tonnage |

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| **ECA** | Emission Control Area |
| **EEA** | Exhaust Emission Abatement |
| **EEBD** | Emergency Escape Breathing Devices |
| **EEDI** | Energy Efficiency Design Index (IMO) |
| **EEOI** | Energy Efficiency Operational Index (IMO) |
| **EEXI** | Energy Efficiency Existing Ship Index (IMO) |
| **EEZ** | Exclusive Economic Zone |
| **EGR** | Exhaust Gas Recirculation |
| **EIAPPC** | Engine International Air Pollution Prevention Certificate (IMO) |
| **EMSA** | European Maritime Safety Agency |
| **EN** | European Standards (European Norm) |
| **EPA** | Environmental Protection Agency |
| **ESD** | Emergency Shutdown |
| **EU** | European Union |
| **FAME** | Fatty Acid Methyl Esters |
| **FAT** | Factory Acceptance Test |
| **FGSS** | Fuel Gas Supply System |
| **FMEA** | Failure Mode and Effects Analysis |
| **FOC** | Fuel Oil Consumption |
| **FOG** | Fat Oil and Greases |
| **FSS** | Fuel Supply System |
| **FT** | Fischer-Tropsch |
| **GESAMP** | Group of Experts on the Scientific Aspect of Marine Environmental Protection |
| **GFS** | Gas-Fuelled Ship |
| **GHG** | Green House Gas |
| **GISIS** | Global Integrated Ship Information System (IMO) |
| **GNSS** | Global Navigational Satellite System |
| **GVT** | Gas Valve Train |
| **GVU** | Gas Valve Unit |
| **GWP** | Global Warming Potential |
| **HAZID** | Hazard Identification Studies |
| **HAZOP** | Hazard and Operability Study |
| **HB** | Haber-Bosch |
| **HC** | Hydrocarbon |
| **HFO** | Heavy Fuel Oil |
| **HP** | High Pressure |
| **HVO** | Hydrotreated Vegetable Oil |

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|---|---|
| **HTL** | Hydrothermal Liquefaction |
| **IACS** | International Association of Classification Societies |
| **IAPPC** | International Air Pollution Prevention Certificate (IMO) |
| **IBIA** | International Bunker Industry Association |
| **IC** | Internal Combustion |
| **ICE** | Internal Combustion Engine |
| **IDLH** | Immediately Dangerous to Life or Health |
| **IEA** | International Energy Agency |
| **IEC** | International Electrotechnical Commission |
| **IEEC** | International Energy Efficiency Certificate |
| **IGC** | International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IMO) |
| **IGF** | International Code of Safety for Ships Using Gases or other Low-Flashpoint Fuels (IMO) |
| **IMO** | International Maritime Organization |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IRENA** | International Renewable Energy Agency |
| **ISO** | International Organization for Standardization |
| **IFO** | Intermediate Fuel Oil |
| **ISSC** | International Sustainability and Carbon Certification |
| **LBM** | Liquified Biomethane |
| **LCV** | Lower calorific value |
| **LFO** | Light Fuel Oil |
| **LFL** | Lower Flammability Limit |
| **LHV** | Lower Heating Value |
| **LL** | Loading Limit |
| **LNG** | Liquified Natural Gas |
| **LNGC** | Liquified Natural Gas Carrier |
| **LP** | Low Pressure |
| **LPG** | Liquified Petroleum Gas |
| **MAN ES** | MAN Energy Solutions |
| **MARPOL** | Marine Pollution (IMO) |
| **MCFC** | Molten Carbonate Fuel Cell |
| **MCR** | Maximum Continuous Rating |
| **MDO** | Marine Diesel Oil |
| **MFV** | Master Fuel Valve |
| **ME-GI** | MAN engine identifier – M series Electronic Gas Injection |

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| **ME-LGI** | MAN engine identifier – M series Electronic Liquid Gas Injection |
| **ME-LGIA** | MAN engine identifier – M series Electronic Liquid Gas Injection Ammonia |
| **ME-LGIM** | MAN engine identifier – M series Electronic Liquid Gas Injection Methanol |
| **ME-LGIP** | MAN engine identifier – M series Electronic Liquid Gas Injection LPG |
| **MEPC** | Marine Environment Protection Committee (IMO) |
| **MGO** | Marine Gas Oil |
| **MGV** | Master Gas Valve |
| **MRV** | Monitoring Reporting Verification (EU) |
| **MSC** | Maritime Safety Committee (IMO) |
| **MSDS** | Material Safety Data Sheet |
| **Mtoe** | Million Tonnes Oil Equivalent |
| **NACE** | National Association of Corrosion Engineers |
| **NGO** | Non-Governmental Organisation |
| **$NH_3$** | Ammonia |
| **NIOSH** | National Institute for Occupational Safety and Health (U.S.) |
| **NMHC** | Non-methane Hydrocarbon |
| **NOAA** | National Oceanic and Atmospheric Administration |
| **NO** | Nitrogen Oxide |
| **$NO_2$** | Nitrogen Dioxide |
| **NOx** | Nitrogen Oxides |
| **$N_2O$** | Nitrous Oxide |
| **NRMM** | Non-Road Mobile Machinery |
| **NTC** | NOx Technical Code |
| **NTE** | Not To Exceed |
| **OECD** | Organization for Economic Co-operation and Development |
| **OEM** | Original Equipment Manufacturer |
| **OPEX** | Operating Expenditure |
| **PAH** | Polycyclic Aromatic Hydrocarbons |
| **PAS** | Publicly Available Specification |
| **PEM** | Proton Exchange Membrane |
| **PEL** | Permitted Exposure Limit |
| **PAFC** | Phosphoric Acid Fuel Cell |
| **PM** | Particulate Matter |
| **PN** | Particle Number |
| **PPM** | Parts Per Million |
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| **PPR** | Pollution Prevention and Response Sub-Committee (IMO) |
| **PRV** | Pressure Relief Valve |
| **PSC** | Port State Control |
| **PTO** | Power Take Off |
| **RA** | Risk Assessment |
| **RED** | Renewable Energy Directive (EU) |
| **REL** | Recommended Exposure Limit |
| **RLF** | Renewable and Low-carbon Fuel |
| **RO** | Recognised Organization |
| **SCC** | Stress Corrosion Cracking |
| **SCR** | Selective Catalytic Reduction |
| **SDS** | Safety Data Sheet |
| **SECA** | SOx Emission Control Area |
| **SFOC** | Specific Fuel Oil Consumption |
| **SGC** | Specific Gas Consumption |
| **SGMF** | Society for Gas as a Marine Fuel |
| **SIGTTO** | Society of International Tanker and Terminal Operators |
| **SIMOPS** | Simultaneous Operations |
| **SMR** | Steam Methane Reforming |
| **SOFC** | Solid Oxide Fuel Cell |
| **SOLAS** | International Convention for the Safety of Life at Sea, 1974, as amended (IMO) |
| **SOEC** | Solid Oxide Electrolyser Cell |
| **SOFC** | Solid Oxide Fuel Cell |
| **$SO_2$** | Sulphur Dioxide |
| **$SO_3$** | Sulphur Trioxide |
| **SOx** | Sulphur Oxides |
| **SPOC** | Specific Pilot Oil Consumption |
| **SSAS** | Solid State Ammonia Synthesis |
| **STCW** | Standards of Training, Certification and Watchkeeping for seafarers |
| **SVO** | Straight Vegetable Oil |
| **TAN** | Total Ammonia Nitrogen |
| **TCO** | Total Cost of Ownership |
| **TCS** | Tank Connection Space |
| **TEU** | Twenty Foot Equivalent (Container) |
| **THC** | Total Hydrocarbon |
| **ToR** | Terms of Reference |
| **TRL** | Technology Readiness Level |
| **TTW** | Tank To Wake |

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| **UI** | Unified Interpretation |
| **ULSFO** | Ultra Low Sulphur Fuel Oil |
| **UNECE** | United Nations Economic Commission for Europe |
| **UNFCCC** | United Nations Framework Convention on Climate Change |
| **UR** | Unified Requirement |
| **USCG** | United States Coast Guard |
| **VOC** | Volatile Organic Compound |
| **VLSFO** | Very Low Sulphur Fuel Oil |
| **WinGD** | Winterthur Gas & Diesel |
| **WTT** | Well To Tank |
| **WTW** | Well To Wake |

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