Availability of sustainable biofuels

A follow up to SSI's 2019 inquiry into the sustainability and availability of biofuels for shipping

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SSI Sustainable Shipping Initiative

GREENFUELHUB

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About the authors

The Sustainable Shipping Initiative (SSI)

The Sustainable Shipping Initiative (SSI) is a multi-stakeholder collective of ambitious and like-minded leaders, driving change through cross-sectoral collaboration to contribute to – and thrive in – a more sustainable maritime industry. Spanning the entire shipping value chain, SSI members are shipowners and charterers; ports; shipyards, marine product, equipment and service providers; banks, ship finance and insurance providers; classification societies; and sustainability non-profits.

www.sustainableshipping.org

GreenFuelHub

GreenFuelHub is an independent platform and consultancy specialised in exploring sustainable marine fuels to help the shipping industry eliminate their greenhouse gas emissions. GreenFuelHub offers consultancy services, including, e.g., expertise in biofuels and biofuel conversion technologies, fuel supply chain, project management, and development.

The marine biofuel platform connects sustainable fuel producers, cargo companies, ship manufacturers and ports, policymakers, research organisations, and corporations worldwide.

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About this report

This report is a follow up to SSI's 2019 inquiry into the role of sustainable biofuels in the decarbonisation of shipping, and aims to dive deeper into the availability of sustainable biofuels for shipping, highlight the complexity of the challenge and the factors that need to be considered when exploring this. Commissioned by SSI and authored by GreenFuelHub, the report draws on a view of current research in the field of biofuels, the bioeconomy, and industry reports, as well as publicly available data on trials, and discusses a number of elements that need to be considered in the debate surrounding biofuels as a potential emissions reduction option for shipping.

This concludes SSI's current work on biofuels, which began in 2018 with the report *Zero Emission Vessels: What needs to be done?* that found that "advanced biofuels may represent the most economically feasible zero-emission alternative for the shipping industry", while noting two important issues: sustainability and availability.

The question of sustainability and availability led to a 2019 inquiry into the potential role (if any) of sustainable biofuels for shipping, drawing on consultations with over 100 stakeholders across and beyond the shipping industry and culminating in the report *The role of sustainable biofuels in the decarbonisation of shipping* The inquiry indicated that sustainable biofuels are currently available and are starting to be used within shipping, though production remains small compared to their potential. The inquiry also suggested that in the short-term, biofuels could have a significant role to play to accelerate early decarbonisation action, with a potential window of opportunity for shipping to use sustainable biofuels whilst sustainable biomass feedstocks are underutilised. However, this supply may be limited in the medium- and longer-term – particularly given the ratcheting up of climate ambition and thus potential demand pressure across all sectors.

Acronyms and abbreviations

B45	Blend that contains 45% biofuel (volume basis)
B50	Blend that contains 50% biofuel (volume basis)
B100	100 % biofuel
BFO	Bio Fuel Oil
CAPEX	Capital Expenditure
DME	Dimethyl Ether
FAME	Fatty Acid Methyl Esther
FT	Fischer Tropsch
GFH	GreenFuelHub
GHG	Greenhouse Gas
HFO	Heavy Fuel Oil
HTL	Hydrothermal Liquefaction
HVO	Hydrotreated Vegetable Oil
IEA	International Energy Agency
ICCT	International Council on Clean Transportation
IMO	International Maritime Organisation
IRENA	International Renewable Energy Agency
LNG	Liquified Natural Gas
LPG	Liquid Petroleum Gas
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
MUC	Marginal, Underutilised and Contaminated
OPEX	Operational Expenditure
RSB	Roundtable on Sustainable Biomaterials
SSI	Sustainable Shipping Initiative
TRL	Technology Readiness Level
UCO	Used Cooking Oil
UCOME	Used Cooking Oil Methyl Esther
WWF	World Wide Fund for Nature

Introduction

The shipping industry is currently responsible for approximately 3% of global greenhouse gas (GHG) emissions (IMO, 2020), as well as 2.3 mega tonnes (Mt) of sulphur dioxide and 3.2 Mt nitrogen oxides per year (Balcombe, et al., 2019). As the industry is projected to continue growing, both in terms of number of ships and activity (Lloyd's Register, n.d.), ambitious decarbonisation and emission reduction efforts need to be undertaken now to mitigate current emissions and counteract future emissions as a result of increased activity.

The International Maritime Organization (IMO) has a current ambition to reduce total GHG emissions from shipping by at least 50% by 2050, and to reduce carbon intensity by 70% by 2050 compared to 2008 levels (IMO, 2018). Many companies and other actors in the sector, including SSI, support zero emission shipping by 2050.

As ships can be operated for 20 years or more, vessels entering the world fleet by 2030 need to already contribute to achieving these targets. In 2020, the Fourth IMO GHG study predicted that more than 60% of emissions reduction efforts by 2050 will be achieved by zero and low carbon alternatives (IMO, 2020).

Shipping's decarbonisation demands exploring a range of options for emissions reduction, including technical and operational energy efficiency measures, improvements to resource use, and the widespread adoption of sustainable, zero and low carbon fuels and technologies. Consequently, there is a growing interest in which alternative fuel sources are likely to impact shipping, as well as awareness in understanding both the lifecycle emissions and sustainability considerations associated with these fuels (IMarEST, 2020).

This report focuses on sustainable biofuels for shipping, drawing on current academic research, industry reports, and publicly available data to outline the current industry landscape, covering production processes, available biofuels, recent and ongoing trials, the challenges around estimating current and future available quantities, as well as shipping's role in the broader bioeconomy.

Considerations for adoption of zero and low carbon marine fuels

Many factors influence the range of zero and low carbon fuels that may be adopted by shipping to achieve its emissions reduction targets. There is no 'silver bullet' fuel, and it is likely that a range of zero and low carbon options (including both fuels and technologies) will need to be adopted by the industry to differing degrees. A number of factors will influence the range of fuels to be used, as outlined in figure 1 below, including availability and sustainability, infrastructure, well-to-wake emissions, and regulation. One of the significant challenges will be the development at scale of sustainably sourced fuels.

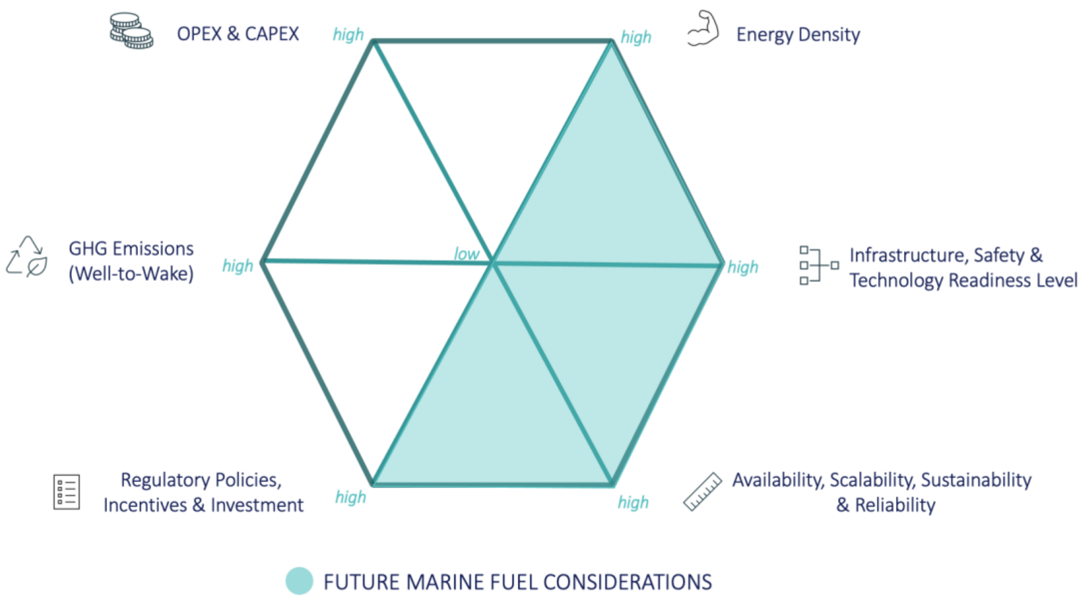

Figure 1: 'Magical hexagon' for the factors that influence the adoption of low and zero carbon marine fuels by the shipping industry (Hofmann, 2020).

Why is the sustainability of marine fuels important?

As the industry transitions to zero emission shipping, stakeholders across the shipping value chain are increasingly aware of the need to better understand the sustainability issues surrounding the zero and low carbon marine fuels under consideration.

Managing supply chain risks of marine fuels requires an understanding of the sustainability issues from a full lifecycle perspective – i.e., 'well-to-wake'. Defining the sustainability principles and criteria for these fuels provides supply chain assurance and helps narrow down the choices for investment, purchase and consumption. The Sustainable Shipping Initiative (SSI) is working to identify sustainability principles and criteria for zero and low carbon marine fuels. Read more.

Biofuels

Biofuels are generally recognised[1] as one option for lowering GHG emissions in sectors with high energy density fuel demand, such as shipping and aviation. A distinction is typically made between 'conventional' (1st generation) biofuels, which can be produced from crops that may also be used for food and animal feed production (such as sugar, starch and vegetable oils) and comprise the vast majority of currently used biofuels, and 'advanced' (2nd and 3rd generation) biofuels (SSI, 2019).

The IEA defines advanced biofuels as those "produced from non-food crop feedstocks, which are capable of delivering significant life-cycle GHG emissions savings compared with fossil fuel alternatives, and which do not directly compete with food and feed crops for agricultural land or cause adverse sustainability impacts" (IEA Bioenergy, 2017). Advanced biofuels may be produced from:

- lignocellulosic material e.g. agricultural and forestry residues,
- industrial waste and residue streams,
- animal manure and sewage sludge,
- energy-specific non-food crops grown on less-productive and degraded land, or in aquatic environments (i.e., grasses miscanthus, algae).

Sustainability considerations of biofuels for shipping

SSI's 2019 inquiry into the role of sustainable biofuels in shipping's decarbonisation highlighted that "the most contentious concerns surrounding biofuels relate to their full life-cycle carbon credentials and how their use might have indirect impacts across global land management and food production systems" (SSI, 2019). Dedicated crop-based biofuels potentially raise sustainability concerns, as production of biofuels for industry should not compete with basic societal objectives such as food production for a growing population (Lloyd's Register; UMAS, 2018).

Many sustainability considerations of biofuels relate to land use, e.g., indirect land-use change (ILUC), which can release considerable GHG emissions into the atmosphere (Transport&Environment , n.d.), land-grabbing, monocultures, displacement of traditional population and land uses, foregone carbon sink potential, etc. (IRENA, 2019). Additionally, GHG emissions for biofuels should be considered on a well-to-wake basis, from the cultivation of biomass feedstock through harvest and transportation and upstream and downstream processing.

Biomass-related sustainability regulations, standards and certification schemes, based on robust sustainability criteria, currently exist and are being used. Certification schemes can help ensure the sustainability of biofuels and transparency throughout the production process. Nevertheless, the different regulations, standards, and certifications can differ in terms of criteria and there is a need for harmonised rules and certification schemes, "along with consistent assessment methods for emissions and land-use impact" (IRENA, 2019), which ensure the sustainability of biofuels and their carbon benefits over fossil alternatives (WWF, 2017).

[1] E.g by DNV, 2020; IRENA, 2020a; IEA 2020; IRENA 2020c.

Advanced biofuel options for shipping

A number of advanced biofuels options exist with potential marine applications. A selection of these, based on a review of academic literature and existing use and trialling by shipping companies, is presented below and considers the biomass feedstock (and its availability), production process, use, and market availability.

BIO-METHANOL/BIO-DIMETHYL ETHER (BIO-DME)

Biomass feedstocks and availability: Potential biomass feedstocks to produce bio-methanol/bio-DME include municipal solid waste (MSW), sewage sludge, black liquor, biogas from landfill and forestry and agricultural residues. There is a wide variety of biomass feedstocks with potentially high availability.

Production process: Bio-methanol can be produced through the gasification of biomass or reformation of biogas to a syngas (synthesis gas). The syngas is then conditioned with hydrogen, which is followed by bio-methanol synthesis. Bio-methanol can be further dehydrated to bio-dimethyl ether (Bio-DME).

Use: Bio-methanol is chemically identical to fossil fuel-derived methanol and e-methanol. The properties of Bio-DME are similar to liquid petroleum gas (LPG). According to a 2020 white paper by International Council on Clean Transportation (ICCT) (Zhou et al., 2020), the use of (fossil-derived) methanol was demonstrated on nine vessels in 2019, while Bio-DME has been demonstrated on ships with smaller engines.

Technology maturity and market availability: The technology readiness level (TLR)[2] of the production process is approximatively 8-9, while the infrastructure for bio-methanol/bio-DME is still under development (Thepsithar, 2020). However, methanol bunkering is readily available in several ports. A dual-fuel engine or minor diesel engine modifications are necessary for implementing bio-methanol/bio-DME on vessels. Bio-methanol and Bio-DME do not auto ignite. In dual fuel engines it requires a pilot-fuel (diesel quality) to start the ignition process.

Currently, bio-methanol based on mass balance with biogas certificates is available and volumes are already being sold into the automotive industry. 0.2 Mt of renewable methanol is currently produced annually, mostly as bio-methanol (IRENA & Methanol Institute, 2021).

Other considerations: In comparison to other fuels, methanol has a relatively low volumetric energy density compared to some fuels and would require more storage capacity on board of the vessel. It has a high storage stability. Methanol is considered highly toxic.

BIOMASS-TO-LIQUID FUEL (BTL FUEL) / SYNTHETIC FUEL VIA FISCHER-TROPSCH

Biomass feedstocks and availability: Agricultural and forestry residues and lignocellulosic biomass. There is a wide variety of biomass feedstocks with potentially high availability.

Production process: BTL-fuel/synthetic fuel can be produced via gasification of dried biomass in an oxygen-controlled environment with subsequent gas conditioning and fuel synthesis through the Fischer-Tropsch process. The oxygen-rich fuel can then be upgraded to transportation fuels.

[2] TRL 1-3: Research state; TRL 4-5: Pilot state; TRL 6-7: Demonstration state; TRL 8: First-of-a-kind commercial demo; TRL 9: Fully commercial.

Use: BTL-fuels/Synthetic fuels have similar chemical and physical properties to conventional diesel. They can be used pure or in blends without major engine or delivery system modification.

Technology maturity and market availability: The technology is in demonstration stage with a technology readiness level of 6-7.

Other considerations: Additives are required to improve lubricity properties.

BIOMASS-TO-LIQUID FUEL (BTL FUEL) VIA FAST PYROLYSIS BIO-OIL

Biomass feedstocks and availability: Waste and residue streams as well as lignocellulosic materials like straw**.** Limited biomass feedstock variety with potentially medium availability.

Production process: Bio-oil from fast pyrolysis is produced through the decomposition of biomass in an oxygen-free environment. The gas is subsequently condensed, and the product is an oxygen-rich bio-oil which needs further upgrading before being used as a drop-in transportation fuel.

Use: Some studies (e.g., Kass *et al.*, 2020) state that blending heavy fuel oil (HFO) with bio-oil (in the case of this study case, 15 mass %) can result in a product of acceptable combustion quality.

Technology maturity and market availability: The process is commercially available, and production plants with a TRL of 9 are operational.

Other considerations: Due to the high oxygen content, non-upgraded pyrolysis bio-oil is corrosive and therefore can be difficult to store. This fuel also has a lower volumetric energy density compared to fossil fuel oils, requiring more storage capacity on board.

FATTY ACID METHYL ESTERS (FAME) BIODIESEL

Biomass feedstocks and availability: FAME biodiesel is typically produced from oil crops such as soy and palm oil. Producing biofuels from these biomass feedstocks presents significant sustainability concerns such as direct deforestation and peatland dewatering. FAME biodiesel produced in this way is not considered an advanced biofuel.

Potentially advanced biomass feedstocks to produce FAME biodiesel, such as waste cooking oil and animal fats, as well as energy crops that can be grown on marginal, underutilized, and contaminated (MUC) lands are now being used. Lipids from microalgae can also serve as a biomass feedstock for FAME biodiesel production. FAME biodiesel produced from advanced feedstocks may be considered an advanced biofuel.

The availability of potentially sustainable biomass feedstock, like used cooking oil (UCO) is currently limited (Zhou *et al.,* 2020; Jørgensen & Felby, 2018).

Production process: FAME biodiesel is produced through transesterification of the oil with an alcohol. This produces biodiesel and glycerol, which are separated into their final products through a purification step.

Use: FAME biodiesel is used as a blend in the transport sector. FAME biodiesel is miscible with marine diesel oil (MDO).

Technology maturity and market availability: FAME biodiesel production is a mature technology, and biodiesel is commercially available (TRL 9).

Other considerations: There are existing concerns regarding FAME biodiesel are its storage stability due to oxidation and microbial growth, its relatively high cold flow plugging point as well as corrosion and softening of fuel supply systems and storage materials.

HYDROTHERMAL BIOCRUDE

Biomass feedstocks and availability: Waste streams, such as sewage sludge and manure, as well as lignocellulosic feedstocks and tall oil. A potential future biomass feedstock is algae. There is a wide variety of biomass feedstocks with potentially high availability.

Production process: The hydrothermal liquefaction of wet biomasses produces a fossil crude-like product. The process converts the biomass under the presence of a catalyst at high pressure and medium temperature.

Use: HTL bio-crude could be used as drop-in fuels in heavy engines or further upgraded and fractionated.

Technology maturity and market availability: Demonstration plants are currently being built. The technology readiness level is 6-7. Furthermore, the existing infrastructure supply chain from fossil fuels can be used.

Other considerations: There are currently no marine engine performance test results available.

HYDROTREATED VEGETABLE OIL (HVO)
(Also called renewable diesel)

Biomass feedstocks and availability: Produced from waste streams, such as used vegetable cooking oil (UCO). There is limited availability of biomass feedstock (tall oil, rapeseed oil, waste cooking oil, and animal fats).

Production process: HVO can be produced through processes such as hydrotreating.

Use: Renewable diesel can result in GHG emissions savings of up to 80% compared to fossil alternatives when using pure renewable diesel (B100) (Zhou *et al.,* 2020), and it has better storage stability, handling and combustion properties compared to biodiesel (Jørgensen & Felby, 2018). Renewable diesel based on HVO can be used as a drop-in fuel for ship engines. Several pilot runs have been carried out by different companies (see *Biofuel trials and use in the shipping sector* section).

Technology maturity and market availability: Renewable diesel based on HVO is readily available on the market (TRL 9) and renewable diesel production is a mature technology that is commercially available and has existing infrastructure.

Other considerations: The physical and chemical properties of renewable diesel are similar to marine gas oil (MGO), making it suitable for modern engines and fuel supply systems.

LIGNIN FUELS

Biomass feedstocks and availability: Lignin is a by-product of ethanol production and a waste stream from pulp and paper mills (craft lignin). A variety of lignocellulosic waste biomass can potentially be used to produce lignin fuel, which has potentially high availability.

Production process: Biofuel from lignin is produced through lignin depolymerisation. To produce lignin fuel, lignin is dissolved in either ethanol or methanol (renewable) in a ratio of 50 to 50 in the presence of a catalyst. The process is called solvolysis.

Use: Lignin fuel is a low flash point fuel and can be used in methanol type dual fuel engines (Jørgensen & Felby, 2018).

Technology maturity and market availability: So far one company exists that converts lignin to a liquid intermediate (so called lignol) that could be upgraded in a refinery. The technology readiness level is 6-7.

Other considerations: There are currently no marine engine performance test results available.

LIQUEFIED BIOMETHANE (BIO-LNG)

Biomass feedstock and availability: The biomass feedstocks used to produce biomethane can include waste and residue streams (e.g., sewage sludge, organic waste and agricultural residues) and wastewater via landfill degradation. There is a wide variety of biomass feedstocks with potentially high availability.

Production process: Bio-LNG is liquefied biomethane. Biomethane is purified biogas and can be produced from several biomass feedstocks through anaerobic digestion with upgrading or gasification with consequent catalytic methanation. Currently, the majority is produced through anaerobic digestion.

Use: Bio-LNG can be treated just like fossil LNG, its use having been widely demonstrated, and it is readily available on the market. Dual-fuel engines, fuel gas supply and storage on board of LNG vessels can be used for Bio-LNG. GHG emissions savings of up to 80% are possible (Edel *et al.,* 2019; EBA *et al*., 2020).

Technology maturity and market availability: LNG infrastructure in some ports has TRL of 9 and is therefore ready to be used. Biomethane is commercially available on the market, however the use by shipping stands in competition with heavy land transport and heat production.

Other considerations: Anaerobic digestion, the process through which biogas is produced, is difficult to scale up. Gasification provides an alternative pathway, but so far it is not widespread for biogas production. Furthermore, the process to liquify the biomethane (the purified biogas resulting from anaerobic digestion and gasification) usually takes place in centralised, large scale conventional liquefaction plants which are not located near biogas plants. Scaling up production of Bio-LNG would thus require decentralisation and downscaling for smaller, local anaerobic digestion plants, which can be technically and economically challenging**.**

A further consideration in producing Bio-DME is the potential methane slip from the production process. Methane is a potent greenhouse gas, and methane emissions should be avoided.

Energy density of biofuels

Energy density of marine fuels plays an important role since the storage capacity on a vessel, despite being more flexible than on e.g., an aircraft, is still limited. The energy density of most biofuels is comparable to the energy density of conventional fossil-based marine fuels. Figures 2 and 3 show the energy densities of several biofuels, other potential zero and low carbon marine fuels, and conventional fuels.

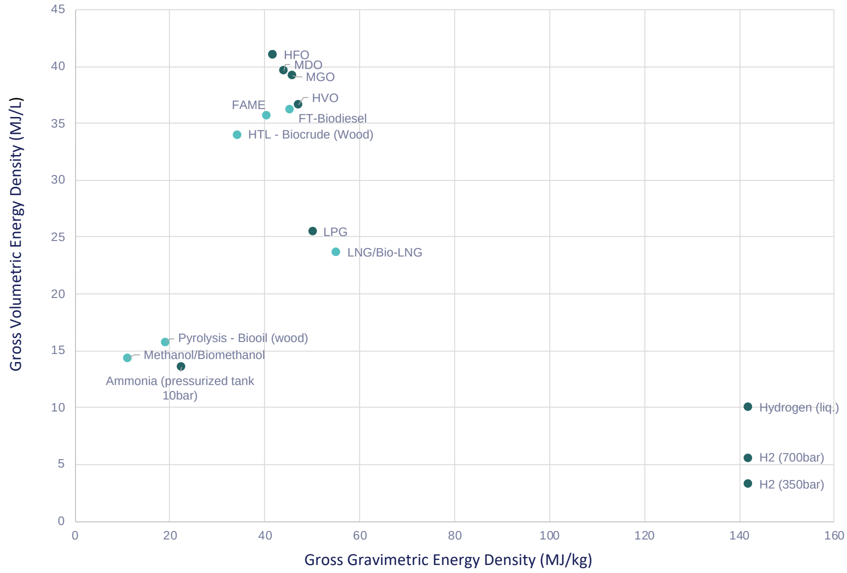

Figure 2: Gross gravimetric and volumetric energy densities of biofuels (light blue) and other existing and potential marine fuels (dark green). Calculations are based on values from Pedersen et al., 2016; Mohan et al., 2006; Zamfirescu & Dincer, 2009; NIST, n.d. The values for compressed hydrogen and ammonia have been calculated under ambient temperature conditions. N.B. Lignin fuels are not included as data on energy densities are not currently publicly available.

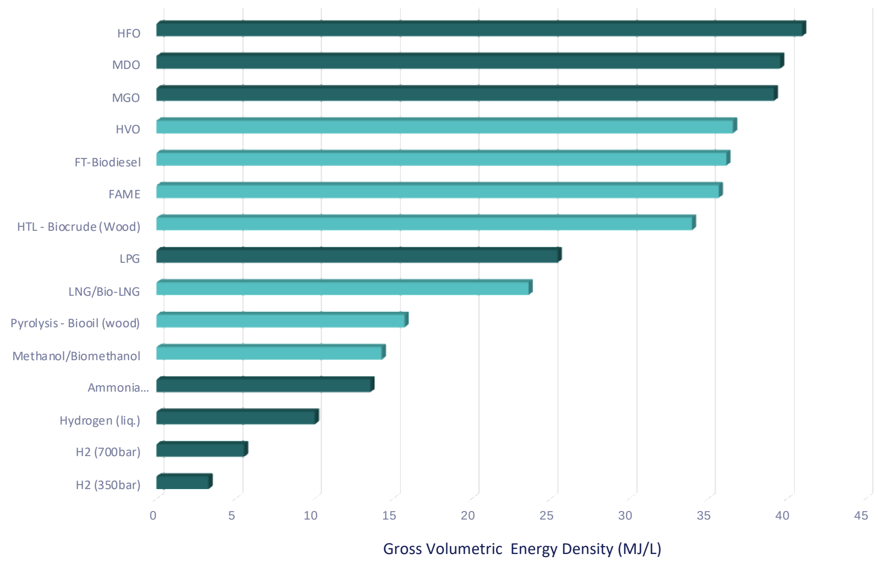

Figure 3: Gross volumetric energy densities of biofuels (light blue) and other existing and potential marine fuels (dark green). Calculations are based on values from Pedersen et al., 2016; Mohan et al., 2006; Zamfirescu & Dincer, 2009; NIST, n.d. The values for compressed hydrogen and ammonia have been calculated under ambient temperature conditions. N.B. Lignin fuels are not included as data on energy densities are not currently publicly available.

Production processes

Each biofuel production process has different requirements regarding the quality of the biomass feedstock used. The properties and characteristics of the resulting biofuel can vary depending on the production method and biomass feedstock used. Furthermore, the production processes differ in their biofuel yield, production economics, scalability, overall process sustainability, and by- or co-products.

Several biofuel production processes are ready for commercialisation and large-scale deployment (IRENA, 2019), and operational refineries are currently demonstrating innovative production concepts. A selection of advanced biofuel production processes is shown in Figure 4. These processes are able to convert biomass feedstocks (e.g., waste and residue streams) into a biofuel that could potentially be used in the shipping sector.

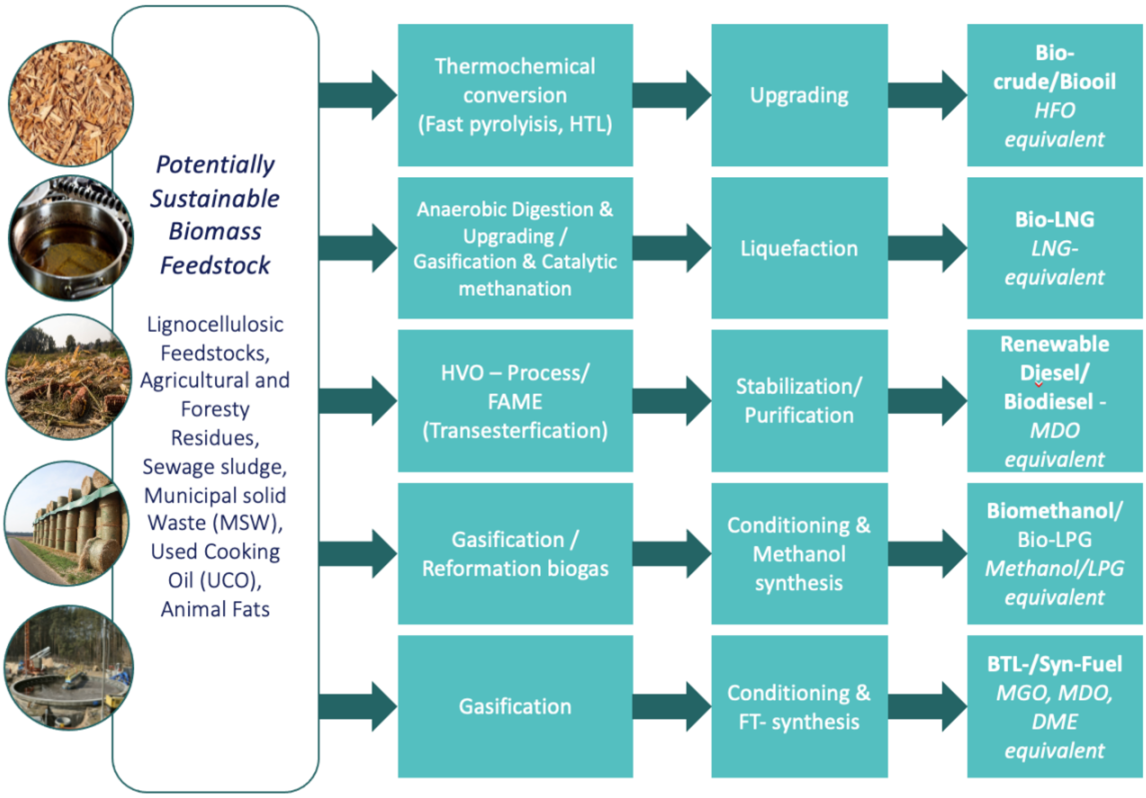

Figure 4: From potential biomass feedstock to marine biofuel. Abbreviations can be found at the beginning of this paper.

Availability of sustainable biomass feedstock

Sustainable biofuels production requires a sustainable biomass feedstock. The availability of these feedstocks is difficult to estimate, and although various sources provide estimates, data on current production and land productivity is not comprehensive. This leads to ambiguous forecasts and varying methods to estimate future biomass production and availability[3], which make it difficult to calculate a specific and reliable figure.

Figure 5 shows the potential availability of different advanced biomass feedstocks in the short, medium and long term. Final potential biofuel yield depends on the energy conversion efficiency for each production process and biomass feedstock used. In this diagram the energy conversion efficiency has been estimated at 50%. However, for a more in-depth study the efficiency from biomass feedstock to well would have been taken into consideration for each process and biomass feedstock.

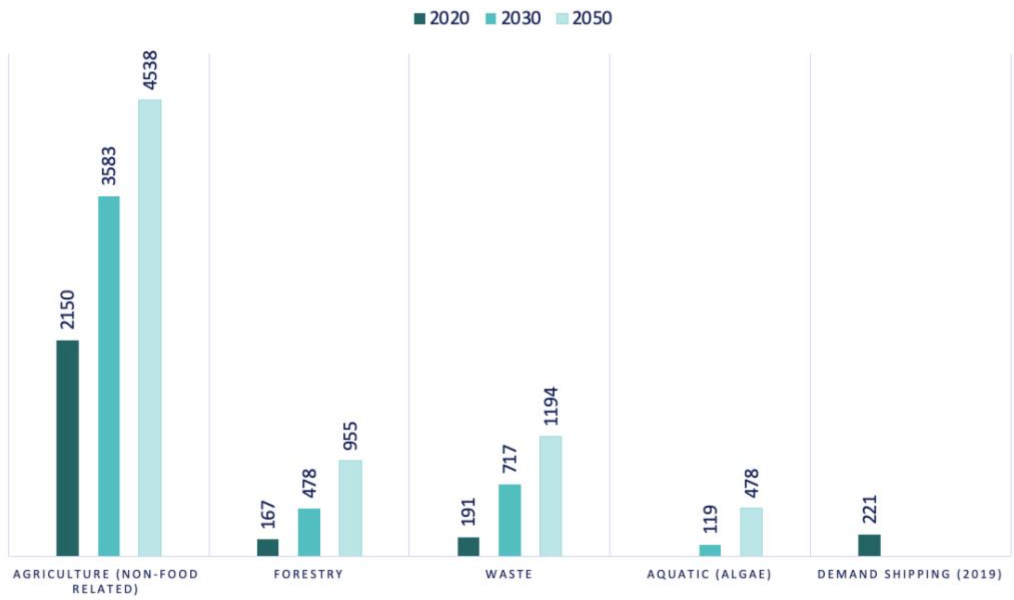

Figure 5: Global advanced biomass feedstock availability in Mtoe. Values from Concawe, (2019). UCO values are included under 'waste', the current global availability of UCO is estimated 13.1 Mtoe (Sarno & Iuliano, 2019).

The current production of biofuels from advanced biomass feedstocks has been recently investigated by Bokinge & Nyström (2020) and calculated to be 6.83 Mtoe/year in 2019, with planned and idle plants totalling a capacity of 15 Mtoe/year. The estimations show that advanced biomass feedstock is available for the production of biofuels, but commercialisation of production plants would have to be financed and harvesting methods for newer biomass feedstocks (e.g., algae) need to be developed.

[3] SSI's 2019 inquiry found that the International Energy Agency (IEA), the United Kingdom Climate Change Committee (UK CCC) and the Energy Transitions Commission (ETC) have all produced projections for future availability of sustainable biofuels; although the results are not directly cross-comparable. The UK CCC focuses on the availability of globally tradeable biomass feedstock; whereas the IEA quantifies total availability. UK CCC data looks forward to 2050, whereas IEA numbers are for 2060. The ETC embraces the IEA's analysis, but then applies additional screens.

Influencing factors for sustainable biomass feedstock availability

The availability of potentially sustainable biomass feedstocks depends on several factors (IRENA, 2020b; ETIP Bioenergy, n.d) including, among others:

- The theoretical biomass feedstock production potential on marginal, underutilised and contaminated (MUC)[4] lands;
- Climate change affecting the areas of usable MUC lands for biomass production;
- Population growth and geopolitics;
- How much MUC land can be exploited while keeping economic, logistic and environmental concerns in mind.

Calculating biomass feedstock availability is therefore dependent on the factors included in the methodology from the outset. When calculating biomass feedstock availability, the resulting figure, estimated as biomass feedstock availability 'potential' can reflect a theoretical potential, a technical potential, an economic potential, or a sustainable implementation potential i.e., the potentially available biomass when all these dimensions are included in the methodology.

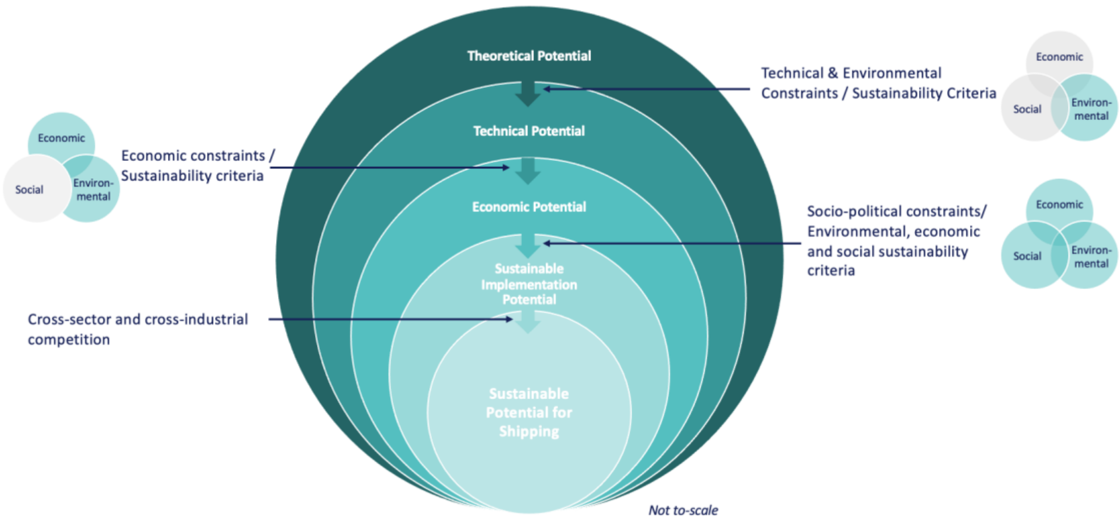

Figure 6: From theoretical biomass feedstock potential to sustainable biomass feedstock implementation potential for shipping. Adapted from (Torén, 2011), (Hoefnagels, 2018).

The *theoretical potential* contains all available biomass theoretically available for bioenergy production, only considering limitations such as rainfall, solar radiation, soil and temperature and assuming optimal management and maximum productivity. The *technical potential* only considers the biomass feedstock which can be harvested and processed after technical factors, such as accessibility, infrastructure and land use, have been applied to the theoretical potential. The *economic potential* is the biomass feedstock share of the technical potential which meets the requirements of financial profitability regarding the production processes used. Finally, the *sustainable implementation potential* is the available biomass feedstock resulting after environment, social, and governance criteria have been taken into consideration.

[4] MUC lands are not suitable for agricultural food production anymore.

Further to technical, economic, socio-political constraints and sustainability criteria, the potential availability of biomass for marine biofuels production depends on the demand by competing cross-sectors and industries. The *sustainable potential for shipping* is the share that includes all these parameters. It becomes clear that many factors need to be taken into account in order to determine the real potential availability of biomass feedstocks for shipping, presenting a challenge for correctly calculate and scale all influencing factors.

Sustainable biomass feedstock potential for shipping

In the 2019 *The role of sustainable biofuels in the decarbonisation of shipping* report (SSI, 2019), the current shipping energy demand is stated as 10 exajoules (EJ) per year, projected to grow to 13 EJ per year by 2050. However, various scenarios indicate a total marine fuel demand of 16 to 25 EJ in 2050, which is equal to a biomass demand of around 32 to 50 EJ/a[5]. In order to meet this energy demand with biofuels, sufficient bio resources must be available for its production.

Figure 7 illustrates a potential methodology to estimate the current available biomass feedstocks for the shipping industry, using biomethane as an example. The methodology, contributed by Nanyang Technological University (NTU), assumes an unlimited amount of investment and that all theoretical biomass feedstock potential goes to only one specific production process.

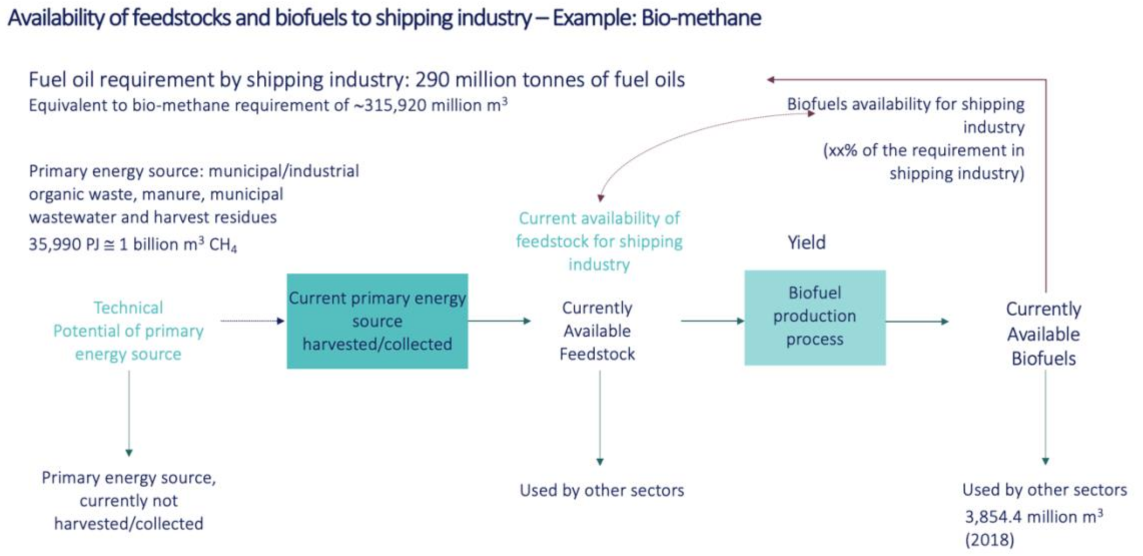

Figure 7: Availability of biomass feedstock and biofuels to the shipping industry - Example: Bio-methane. Values taken from: (WBA, 2013; IEA, 2020a). Figure provided by the Marine Energy and Sustainable Development Centre of Excellence (MESD CoE) at Nanyang Technological University (NTU)[6]

The resulting estimate is influenced by many factors which are difficult to predict, including those outlined overall biomass feedstock availability. However, additional factors need to be considered for use by the shipping sector, including:

[5] Assuming all of shipping's energy demand to be met by biofuels and an average biomass-to-fuel efficiency of 50% for all production processes

[6] This figure was developed as part of an ongoing preliminary study conducted by MESD CoE at NTU and partners.

- Competing demand for direct heat production and bioproducts (e.g., bulk chemicals);
- Competing demand between industries (e.g., cement production) that need sustainable carbon for their production
- Biomass feedstock needed for the production of biofuels for other hard to abate sectors like, e.g., aviation;
- Competition between decarbonisation options including electrification and other zero and low carbon fuels which may influence the biofuel market.

Considerations for large-scale uptake of biofuels

One of the main barriers holding back large-scale use of biofuels in the shipping sector is the lack of certainty about scaling and sufficient availability of sustainable biomass feedstocks to produce these sustainable biofuels. It is important to only look at biomass feedstock that can produce a fuel that is sustainable on a lifecycle basis: well-to-wake. Potential sustainable biomass feedstock, such as wastes and residues, as well as crops grown on marginal, underutilised and contaminated (MUC) lands, are a limited resource that needs to be used efficiently and shared with other sectors. Policies are needed in order to ensure that the available sustainable biomass feedstock is adequately directed towards the sectors that require it.

Future biofuel production technologies, that are biomass feedstock flexible, may enable the conversion of other advanced biomass feedstocks, such as algae, into biofuel. Investment is needed to move commercialisation forward and bring technologies from pilot to market at scale. Furthermore, certain advanced technologies offer the possibility to produce a crude oil-like product that covers a full range of fuel-fraction and thereby minimises the competing demand of different sectors, e.g. produces a jet-fuel as well as a marine fuel fraction.

Shipping’s role in the bioeconomy

The bioeconomy can be defined as “the production, utilization, conservation, and regeneration of biological resources, including related knowledge, science, technology, and innovation, to provide sustainable solutions (information, products, processes and services) within and across all economic sectors and enable a transformation to a sustainable economy” (Global Bieconomy Summit, 2020 as cited in FAO,2021).

A sustainable bioeconomy fulfils two main criteria. Firstly, the world's population’s need for sufficient high-quality food is being met. Secondly, the remaining bio-based resources are distributed in the most ecological, social, and economic beneficial way possible (Lewandowski, 2018).

As the bioeconomy expands, the world’s dependence on bio-based products to generate energy and materials, in addition to food, will continue to grow. Aside from agriculture, there will be an increase in demand for biomass feedstocks from the transportation and energy industries and other sectors seeking to move away from fossil-based production. Those sectors include the chemical industry (e.g., bioplastics- and rubbers production), consumer products and specialty chemicals production, steel and cement, as well as the heating/cooling industry and electricity production, to mention a few (IRENA, 2020c). Some of these sectors can be electrified, or sustainable non-biomass alternatives can be used; others depend on a carbon source.

For the transport sector, aviation, marine and road transport fuels have competing demand as they all seek to decarbonise. These sectors and industries have diverse needs in terms of fuel volume and available sustainable and technically feasible zero and low carbon fuel alternatives.

The availability of sustainable biofuels for the shipping sector must therefore be seen in the context of the overall bioeconomy. As a result, the amount of biomass available for marine biofuels is heavily influenced by consumer and market demand. Furthermore, various factors such as biomass feedstock and processing costs, as well as government subsidies and incentives, determine the final price of the biomass feedstock and, consequently, the price of marine biofuels.

These considerations only add to the complexities around the availability of sustainable biofuels for shipping. Although new processes can optimise biomass utilisation, and biotechnology has accelerated the development of new biomass value chains, financial support structures as well as government subsidies and incentives are needed to move these innovations forward (IRENA, 2020b).

Biofuel trials and use in the shipping sector

Despite the questions around biofuel availability raised throughout this report, a number of companies in the shipping and marine fuel sectors are currently investigating biofuels as part of their decarbonisation research and strategies. Below are several examples of companies using or trialling biofuels. This list has been developed based on public information and therefore information on specific biofuels used was only partially available.

A.P. Moller-Maersk and **Wallenius Wilhelmsen**; retailers such as H&M Group, BMW Group, Levi Strauss & Co. and Marks & Spencer; and Copenhagen University established the LEO coalition (a collaboration between researchers, customers, and shipowners) and are currently developing lignin fuels for the shipping sector, which are being trialled in the near future (A.P. Moller-Maersk, 2019a).

A.P. Moller-Maersk has also been extensively testing 20% (B20) biofuel blend in long-distance shipping (A.P. Moller-Maersk, 2019b). Furthermore, A.P. Moller-Maersk is continuously trialling/using (Maersk ECO Delivery) biofuels blends with up to 45% (B45) biodiesel from UCO and tall oil at time.

CMA CGM partnered with **Royal Dutch Shell** to test 20% UCO biodiesel blends (CMA CGM, 2019).

DS Norden was the first to trial biofuels on ocean-going vessels and is currently undergoing its third test voyage using sustainably sourced biofuels (Norden, 2020). They are furthermore involved in a research project developing lignin-based biofuels for shipping (Biofuels International, 2019).

Eastern Pacific Shipping (EPS) bunkered GoodFuels Bio Fuel Oil (BFO), a residual-fuel equivalent derived from forest residues and waste oil products on their medium range tanker (EPS, 2020).

Hapag-Lloyd has conducted trial runs with 20 v/v -% FAME biodiesel blends from UCO (Hapag-Lloyd, 2020).

Mediterranean Shipping Company (MSC) has gained experience in operations with biofuels through several biofuel trials and is now using biofuels on a large scale. They are currently bunkering 45% biofuel (B45) blends on a routine basis in the Port of Rotterdam (Darr, 2020; MSC, 2019).

A bulk carrier owned by **Nippon Yūsen Kabushiki Kaisha (NYK) Line** and chartered by a mining company was fuelled with 30 v/v-% biofuel and 70 v/v-% conventional MDO (GoodFuels, 2020).

Ocean Network Express (ONE), in cooperation with shipowner **Mitsui O.S.K.** successfully completed a trial during M7V MOL Experience's Atlantic Ocean crossing between Europe and the USA. During the first trial GoodFuels's waste UCO biodiesel was blended with conventional fossil fuel (ONE, 2020).

Oldendorff Carriers, together with global resources company BHP, GoodFuels and with the support of the Maritime and Port Authority of Singapore, has successfully conducted the first marine biofuel trial involving an ocean-going vessel bunkered in Singapore in 2021. The trial was conducted with advanced biofuel blends (Oldendorff, 2021).

Royal Boskalis Westminster N.V. (Boskalis) started the "Boskalis on Bio" program in 2015 together with engine manufacturer Wärtsilä and biofuel supplier GoodFuels and is since then testing biofuel blends with MGO on their dredging and offshore installation vessels. In 2019 they successfully trialled 100% bio-fuel oil from waste cooking oil. (Boskalis, 2019)

Stena Bulk completed a successful 10-day sea trial using a 100% biofuel oil, which is the only trial of this kind thus far. The biofuel was derived from forest residues and waste oil (Stena Bulk, 2020).

Short-sea shipowner **United European Car Carriers (UECC)** trialled biofuels from GoodFuels for 3 months on M/V Autosky in 2020 using biodiesel from UCO. Together with BMW Group they are continuing testing Bio Fuel Oil (BFO) on one of their car carriers (UECC, 2020)

Van Oord, a Dutch marine contractor is currently testing a blend with 50 v/v -% (B50) biodiesel from UCO on one of their hoppers (Van Oord, 2019).

Wallenius Wilhelmsen conducted a trial on 0.50% VLSFO with 45 v% waste-based FAME. 2000 Mt have been bunkered on the vessel MV Figaro in Amsterdam. (WW, 2021).

Lessons from Lloyd's Register on NOx compliance: early findings from biodiesel trials

Biofuels typically have higher emissions of nitrogen oxides (NOx) when compared to conventional marine fuels. NOx are a significant pollutant, impacting both public health and the environment.

Marine use of biofuels requires in-service testing to determine whether established NOx emissions limits are exceeded. From projects and trials, Lloyd's Register has drawn tentative findings for blends of up to 50% biodiesel with conventional diesel. They have found that NOx emissions are generally within allowable limits. They also found that operational (tank-to-wake) CO_2 emissions are decreased, relative to conventional diesel. Engine settings do not require adjustment and there are no significant operational problems. Whilst too early to generalise, initial findings are promising.

However, questions remain. There is uncertainty over whether biodiesel could be available in the scale needed for the shipping industry and other hard-to abate sectors. Full lifecycle assessment is required to establish the complete emissions picture. Read more.

Conclusion

Shipowners, charterers, and their customers are developing strategies and taking action toward decarbonising the shipping sector and thereby their supply chains. Among these, several companies are trialling biofuels as a potential alternative fuel. Several biofuel types are available and offer GHG emission reductions at the operational stage (tank-to-wake). However, the sustainability of the biomass feedstocks used to make these biofuels needs to be carefully scrutinised, alongside the full lifecycle (well-to-wake) carbon credentials of the biofuel, in order to ensure that GHG emissions are not shifted upstream (well-to-tank). Biofuels are one fuel where it is difficult to discern between sustainable and non-sustainable alternatives, which is why their sustainability should be verified through widely accepted standards and associated certification schemes. As shipping has a global nature it is important to ensure that the same sustainability criteria are applied regardless of geography in order to truly ensure GHG benefits of biofuels over fossil alternatives.

There is still much uncertainty around whether sustainable biofuels are a mass market, scalable and long-term solution to decarbonise the shipping sector or if they will only have niche applications. Data from SSI's 2019 inquiry anticipated that biofuel use by the shipping sector would be higher in 2030 than 2050, implying that biofuels are more of a short- rather than long-term solution.

Whilst the demand for energy by the shipping sector may perhaps, and theoretically, be met with biofuels, in reality the amount of biofuels available globally will need to be shared, and competed for, with other industries such as aviation and bioplastics. As mentioned early in this report, shipping's future energy needs will likely be met by a range of solutions and low and zero carbon fuels and technologies.

Summing up:

- Biofuels are generally recognised as one option for lowering GHG emissions for shipping;
- Sustainable biomass feedstock availability is hard to foresee and calculations vary depending on the factors taken into account from the onset;
- The current data on sustainable biomass availability presents disparities between the different sources;
- There is a need for better understating the cross-sector and cross-industrial demand for sustainable biofuels;
- Some biofuel production technologies offer the possibility to produce biofuels for several markets;
- Innovation and investment can lead to the development and eventual commercialisation of more advanced, feedstock flexible, biofuel production technologies;
- Policies are needed to direct the sustainable biomass resources into the various industrial sectors that would require what is available;
- The application and verification of robust sustainability criteria is needed to ensure the sustainability of biofuels across the shipping sector and beyond.

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About the Sustainable Shipping Initiative
The Sustainable Shipping Initiative (SSI) is a multi-stakeholder collective of ambitious and like-minded leaders, driving change through cross-sectoral collaboration to contribute to – and thrive in – a more sustainable maritime industry. Spanning the entire shipping value chain, SSI members are shipowners and charterers; shipyards, marine product, equipment and service providers; banks, ship finance and insurance providers; classification societies; and sustainability non-profits.

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