



# SUSTAINABILITY WHITEPAPER BIOFUELS AS MARINE FUEL

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# ABS





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## OVERVIEW

### OBJECTIVE

The maritime industry faces challenges in adopting new technologies, alternative fuels and operational practices to comply with increasingly strict international, national and local regulations aimed at reducing sulfur oxides (SO<sub>x</sub>), nitrogen oxides (NO<sub>x</sub>), particulate matter (PM), carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO) and other emissions from ships that are considered greenhouse gases (GHGs). National and international regulations, such as those introduced by the International Maritime Organization (IMO), the European Union, the United States Environmental Protection Agency, the California Air Resources Board and others are designed to reduce these emissions to varying degrees. Some emissions, such as methane and black carbon in the Arctic and Antarctic regions, may be regulated by the IMO in the future.

Many technologies are being considered to specifically reduce carbon emissions from shipping. The American Bureau of Shipping (ABS) publication *Setting the Course to Low Carbon Shipping: Pathways to Sustainable Shipping* has categorized the available maritime fuel options for decarbonization. Among them, biofuels were identified as a potential low-carbon fuel that can enter the global market relatively quickly and help approach the IMO GHG reduction targets for 2050.

Through a series of sustainability whitepaper publications, ABS is providing additional information to highlight the fuels being considered by the marine industry to meet emissions reductions and the IMO GHG ambitions. This whitepaper provides information for the consideration of marine liquid biofuels as “drop-in” fuel options for replacing conventional marine diesel, marine gas oil (MGO), or residual fuel oils, such as heavy fuel oils (HFO), in both the near and long term.



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## INTRODUCTION

Biofuel is a general term encompassing a wide variety of liquids or gases derived from biomass or bio-waste. These include fatty-acid methyl ester (FAME) biodiesel, hydrotreated renewable diesel, Fischer-Tropsch (FT) diesel, dimethyl ether (DME) and bio-methanol. For this document, only the liquid drop-in biofuels are discussed that are most likely to be compatible with distillate and residual marine fuels such as marine gas oil (MGO) and heavy fuel oil (HFO). A drop-in fuel alternative is one that can blend with or fully replace an existing fuel with no required modifications to fuel storage, transfer systems or end consumer. Unblended fuel replacements can be known as ‘neat’ fuels, indicating a fuel sourced from 100 percent biomaterials. Drop-in biofuels are attractive for their non-toxic biodegradable properties and reduced GHG emissions profile when combusted, especially regarding sulfur oxides and particulates. The similar properties between drop-in biofuels and conventional petroleum fuels allow biofuel to take advantage of existing fuel transport and bunkering infrastructure. As such, they can provide logistically and economically attractive solutions for current and future marine vessels.

FUEL OIL REPLACED	FUEL
Distillate (e.g., MGO)	FAME biodiesel
	Hydrotreated renewable diesel (e.g., HVO)
	FT diesel
Residual (e.g., HFO)	Straight Vegetable Oil (SVO)
	Pyrolysis bio-oil
	Hydrothermal liquefaction (HTL) bio-crude

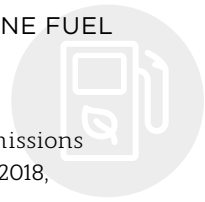
Table 1: Potential drop-in fuel options.

vegetable oils or animal fats, designated B100 and meeting requirements of ASTM D6751 or EN 14214. Alternatively, residual fuel oils can be substituted with heavier biofuels comprised primarily of hydrocarbon chains, designated by the prefix R for “residual”, for example, R100.

Drop-in biodiesels have a long history of use and regulation with land transportation, especially in road fuel distillates such as gasoline and diesel. For this reason, applicable fuel standards cover biofuel blends up to a certain percentage depending on regions, policies or governing bodies. These typically cover specifications to ensure biodiesels are compatible with the higher-quality petroleum fuels used for road applications. However, typical marine engines do not require high-quality fuels such as road gasoline or diesel, allowing for a variety of biofuel options that may not fall under existing standard specifications.

Due to the variety of globally available biofuel feedstocks and compatibility with existing fuel infrastructure, biofuels can potentially be widely available depending on production capability and capacity. Various production methods may be used to generate the various biofuels, which can affect fuel quality, cost and overall life-cycle emissions.

Biofuel options for MGO or HFO fuel replacement include Fatty Acid Methyl Esters (FAME) biodiesel, hydrotreated renewable diesel including hydrotreated vegetable oil (HVO), Fischer-Tropsch (FT) diesel, straight vegetable oil, pyrolysis bio-oil and hydrothermal liquefaction (HTL) bio-crude. The distillate and residual fossil fuels (i.e., MGO and HVO) can accept various types of drop-in biofuels, shown in Table 1. Distillates are typically replaced by biodiesels, which are specifically defined as a fuel comprised of mono-alkyl esters of long-chain fatty acids derived from



### IMO GOAL AND STRATEGY

The adoption of the Initial International Maritime Organization Strategy on Reduction of Greenhouse Gas Emissions from Ships by the IMO Marine Environment Protection Committee (MEPC) Resolution MEPC.304(72) in April 2018, demonstrates the IMO’s commitment to supporting the Paris Agreement. It includes measures to address the sustainability and availability of biofuel feedstocks.

The IMO strategy includes initial targets to reduce the average CO<sub>2</sub> emissions per transport work from 2008 levels by at least 40 percent by 2030 and 70 percent by 2050. These targets also seek to reduce the total annual GHG emissions from shipping by at least 50 percent by 2050. Technical operational approaches and alternative fuels may be used to achieve these goals. The near-term regulatory changes and the future impact of the IMO’s greenhouse gas targets for 2030 and 2050 should be considered when making decisions on fuel selection.

The IMO is investigating and setting requirements for GHG from a fuel life-cycle (well-to-wake) perspective. During this process, it is also expected that some sustainability criteria to produce biofuels will be implemented to avoid previously detrimental effects of land-use-change such as removing forests to produce biofuels. The expected increase in food demand may also stress the need for sustainable uses of land resources. To certify the sustainability of biofuel and feedstocks, verification schemes exist but are not yet mandated by the IMO.

### BIOFUEL AS FUEL FOR REDUCTION OF GREENHOUSE GAS

The various types of biofuels have different characteristic properties and qualities, including various emissions reduction benefits. The primary benefit of biofuels is low-sulfur emissions. Due to the nature of their feedstock and production, biofuels have naturally low sulfur content, which reduces SO<sub>x</sub> emissions as well as particulate matter during combustion. Biofuel blends may have emissions benefits proportional to the blend percentage.

The use of biofuel blends can meet the most stringent IMO SO<sub>x</sub> limits without any additional fuel additives or after-treatment systems. Lower particulate matter (PM) emissions can be attributed to reduced sulfur content and increased fuel oxygenation, which is also a naturally occurring characteristic of bio-derived fuels. Due to improved combustion and lubricity characteristics of certain types of biofuels or biofuel blends, the performance of some engine types may also increase, which in turn can improve fuel consumption. NO<sub>x</sub> emissions have more variable results when using biofuel or biofuel blends, and may depend on the biofuel type, engine type or engine load. Figure 1 shows the approximate SO<sub>x</sub> and GHG emissions of biofuels and typical marine petroleum fuels, showing potentially large SO<sub>x</sub> reduction when using biofuels compared to residual oil and other reductions of carbon emissions based on carbon uptake during the well-to-tank (WTT) production. Note that in the figure, the feedstock for hydrotreated renewable diesel and biodiesel is soybean, and the feedstock for the FT diesel is forest residue. The negative well-to-tank values of biofuels indicate the carbon uptake during feedstock growth, but can be offset by carbon emissions during production.

When produced from renewable biomass such as plant fibers and other materials, biofuels have the potential to offset the carbon footprint of a vessel due to the CO<sub>2</sub> absorption of the plant feedstock, which can help counterbalance the combustion emissions. However, the total carbon reduction potential of different biofuels clearly depends on their source feedstock, production pathways and fugitive emissions, such as GHG slip during production or transportation. Due to fugitive emissions, carbon emissions may not be zero from the well-to-tank (WTT) and tank-to-wake (TTW) phases.

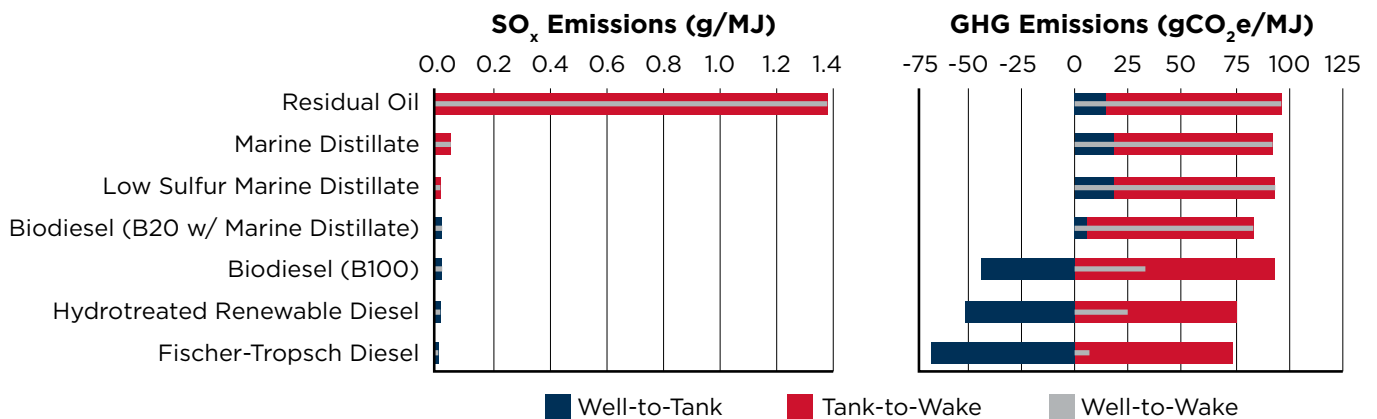
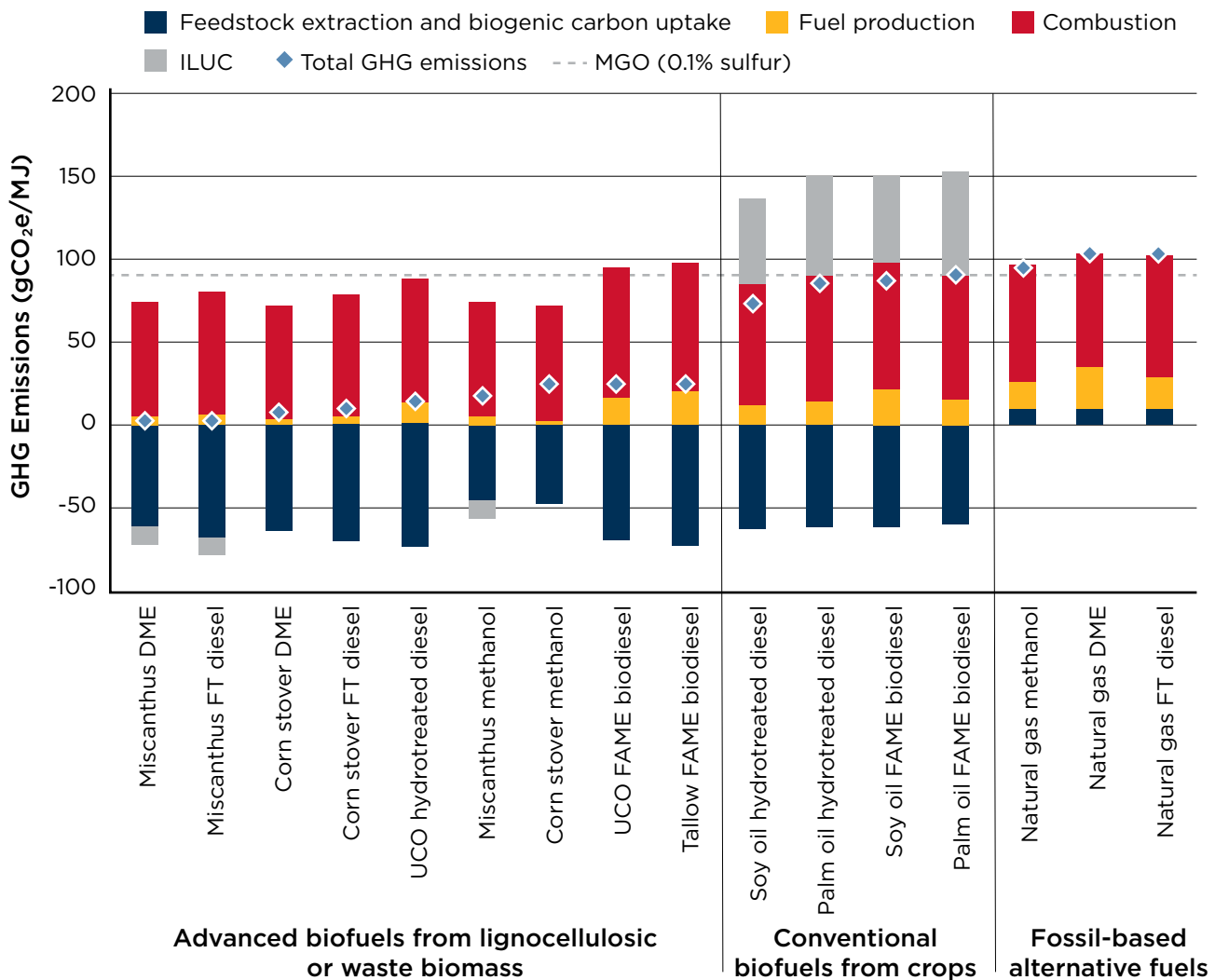


Figure credit: Troy Hawkins and Uisung Lee, Argonne National Laboratory

Figure 1: “Well-to-wake” life-cycle SO<sub>x</sub> and GHG emissions per megajoule of fuel combusted for marine applications.

The following Figure 2 shows the comparative total life-cycle carbon emissions of biofuels generated at feedstock extraction (carbon uptake), indirect land-use-change (ILUC), fuel production and combustion. The values are contrasted to MGO with 0.1 percent sulfur as a baseline. Depending on the biofuel, those which are produced from bio-waste feedstock may require little energy to produce and may have a positive impact on land use rather than degrade land resources. In this manner, biofuels could have a zero-net-carbon impact over the fuel's life-cycle.



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Figure 2: Life-cycle GHG emissions of the alternative liquid marine fuels and feedstocks analyzed by life-cycle stage. UCO: Used Cooking Oil.

To measure the overall net carbon impact of fuel, well-to-wake emissions should be considered because the concept encompasses the entire life-cycle of a fuel, including production, transportation and combustion. The IMO Initial Strategy MEPC.304(72) ambition recognizes this and includes short-term measures “...to develop robust life-cycle GHG/carbon intensity guidelines for all types of fuels”. The IMO data collection system (DCS) includes provisions that allow a fuel supplier to report in the bunker delivery note (BDN) zero or near-zero CO<sub>2</sub> emissions for biofuel by using the Energy Efficiency Design Index (EEDI) fuel conversion factor, which is calculated based on existing fuel carbon content and consumption. This method may currently be the simplest way for ships to meet the 2030 and 2050 requirements. However, it is not yet clear how guidelines for life-cycle emissions will be implemented by the IMO, so in the meantime, shipowners may emphasize using zero or low-carbon fuels with a focus on tank-to-wake (TTW) emissions, such as the significantly reduced SO<sub>x</sub> emissions when burning biofuels. TTW considers the emissions from burning or using an energy source but does not include the emissions produced during fuel production or transport to the ship.

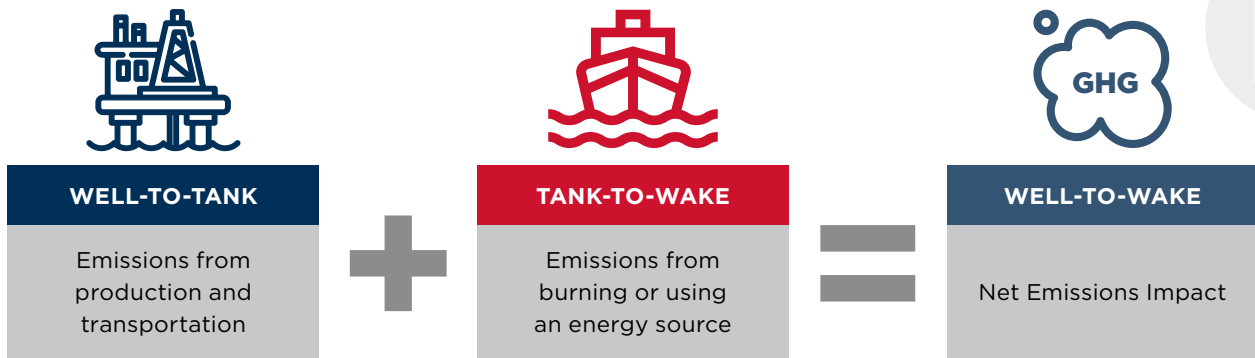


Figure 3: Life-cycle emissions.

To properly evaluate the overall GHG emission performance of biofuels, one important factor to consider is the source of the feedstock and various potential adverse effects that can result from the use of those feedstocks, including GHG emissions from agriculture. This concern is especially relevant to purpose-grown feedstock used to produce biofuels, which may be in direct competition with land dedicated to food crops or other biomaterial production. Conversely, the feedstock may be complementary to agricultural land use if unused or waste biomaterials are used to produce biofuel. This becomes more common as the industry focuses on relieving pressures on agriculture and other bio-resources. Adverse impacts from direct and indirect land-use change may also generate controversy when considering the sources of biofuel feedstock. For this reason, biofuels sourced from waste materials, for example, corn stover, residuals from wood biomass, manure and wastewater sludge will have lower emissions impact and less negative effects from land-use-changes. When feedstock is sustainably and responsibly sourced, carbon is extracted from a renewable (i.e., younger and more replenishable) carbon cycle. Biofuels produced from this feedstock can be a viable pathway to sustainable fuel production and displacement of fossil-derived sources, which release carbon that has been sequestered for millions of years.

## TYPES OF BIOFUELS

There are several categories of biofuels differing in their feedstock source, production process and fuel generated, each with various advantages and disadvantages. Marine liquid biofuels on the market can generally be produced using all platforms, but some earlier fuels, i.e., biodiesel, are most suited for marine applications.

Early biofuels remain the most common type of biofuel in production, often known as the first generation. These rely on a variety of common commodities such as sugarcane, starch, vegetable oil or food wastes. The most common first-generation biofuels are biogas, bioethanol (which is widely mixed with road gasoline), FAME and biodiesels, including those available for marine applications.

The next generation of biofuels is produced from the first-generation feedstock or lignocellulose biomass – dry plant matter composed of cellulose, hemicellulose and lignin – such as switchgrass, trees, bushes and corn stalks. Much of these feedstocks have traditionally been regarded as 'bio-waste' or crop byproducts that are difficult to break down and process. The increased use of low-value, excess biomass is important to increase biofuel supply.

These so-called second-generation biofuels often use improved processing technologies required to break down tough lignocellulose. These thermochemical and biochemical fuel processing treatments include gasification, pyrolysis and hydrothermal liquefaction. Thermochemical processes can yield a mixture of gases including hydrogen, carbon monoxide, carbon dioxide, methane and water, which can be used to produce renewable hydrocarbons. These processes produce a more stable biofuel; however, they require specialized technologies differing with each type of biomass.

More recent advancements in biofuel production use microbes and microalgae biomass, including algae and electro- and photobiological solar fuels. These types of biofuels are discussed in the future generation biofuels section.

## PRODUCTION

How biofuels are produced can play a large role in the fuel quality as well as the GHG impact the fuel will have. For the drop-in fuels that can potentially replace marine fuels, Table 2 lists the main production processes and associated biomaterial feedstocks. There are a few main types of biofuel productions: transesterification, thermochemical and biochemical, each having various specific sub-production processes. The production pathways for biomass feedstocks using established techniques are shown in Figure 4.

FUEL	PRODUCTION PROCESS	BIOMATERIAL FEEDSTOCKS
FAME biodiesel	Transesterification	Fats, oils and greases
		Vegetable oils (e.g., palm, soy)
Hydrotreated renewable diesel	Hydrotreating	Waste fats, oils and grease
		Vegetable oils (e.g., palm, soy)
FT diesel	Gasification then Fischer-Tropsch synthesis	Lignocellulosic biomass
Straight vegetable oil (SVO)	N/A	Vegetable oils (e.g., palm, soy)
Pyrolysis bio-oil	Catalytic fast pyrolysis	Lignocellulosic biomass
HTL bio-crude	Hydrothermal liquefaction (HTL)	Lignocellulosic biomass

Table 2: Drop-in biofuel production processes and feedstocks.

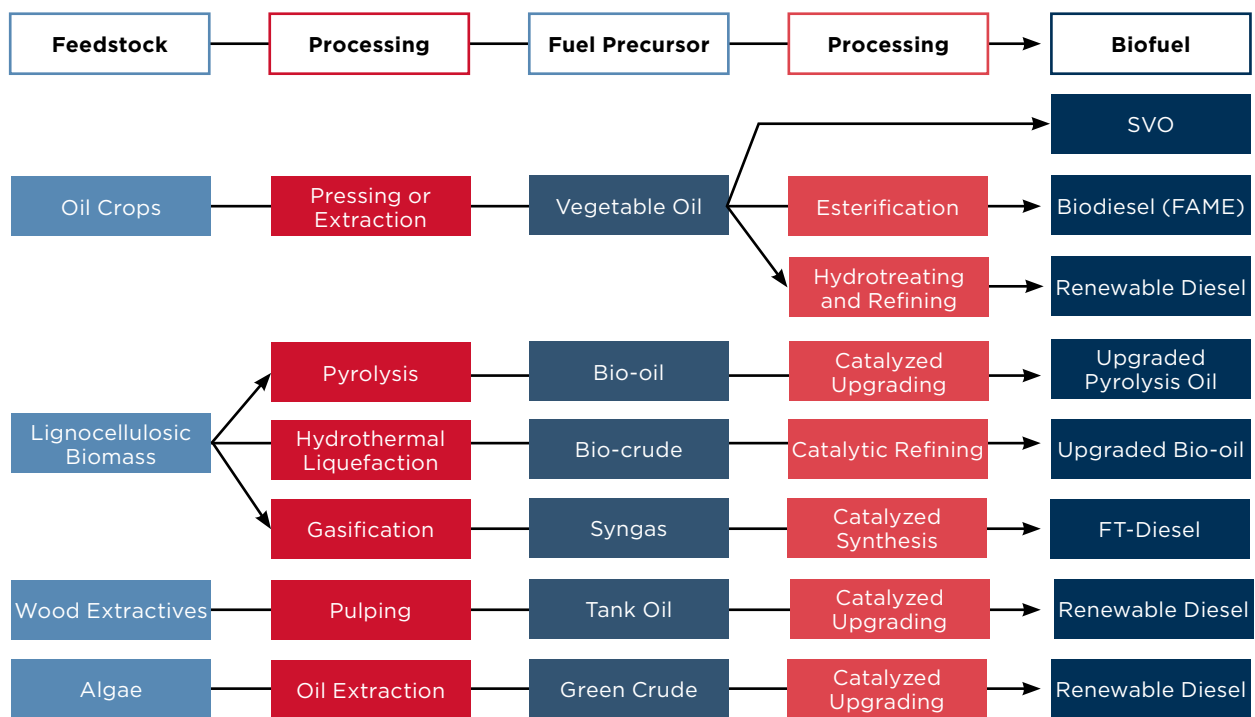


Figure 4: Overview of biofuel production pathways from different biomass feedstocks. (Source: Setting the Course to Low Carbon Shipping – Pathways to Sustainable Shipping)

Despite the diverse technologies suited for producing drop-in biomass, only a few of these techniques are active commercial operations. For example, GoodFuels and Biomass Technology Group (BTG) have partnered to develop production-scale biofuel using a thermochemical process to break down a variety of biomass feedstocks, including lignocellulose. The partnership has produced biofuel for several ongoing research projects to test the feasibility of blending biofuel oil (BFO) as a drop-in fuel with marine HFOs and recently has increased production to continue biofuel supply for normal operations. These projects are discussed in the ongoing research section.



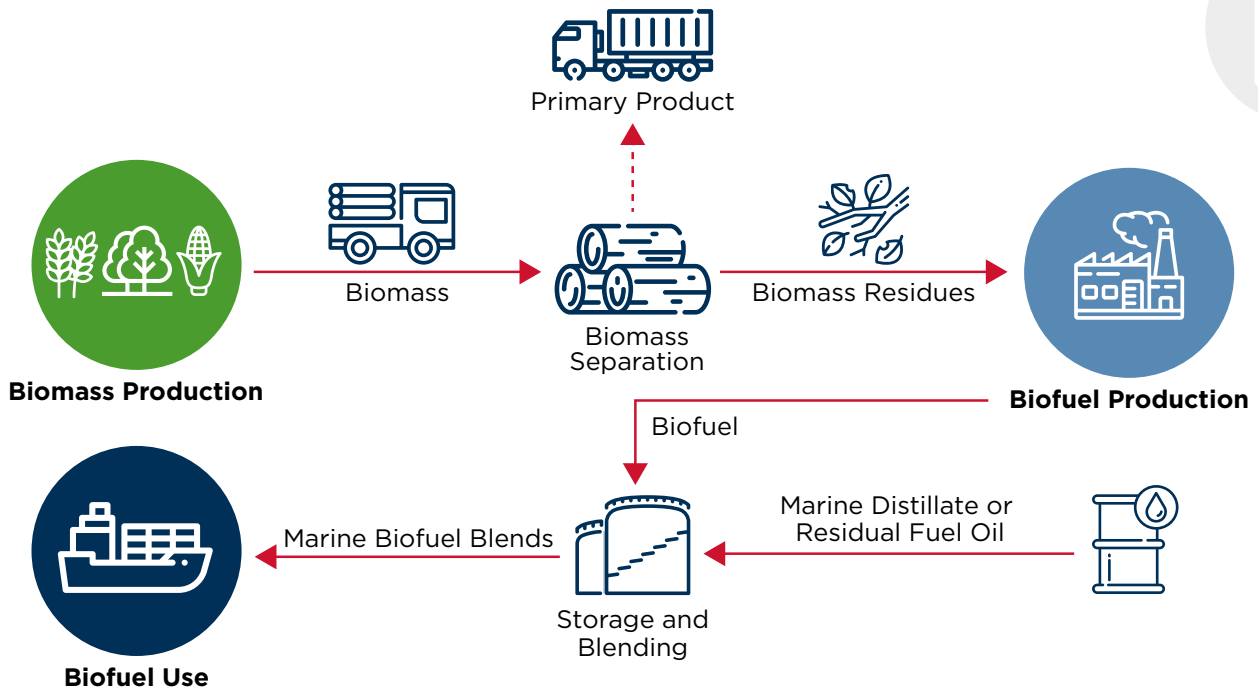


Figure 5: General production life-cycle of biofuels.

Transesterification is a technologically mature and reversible process that displaces alcohol from esters to generate a desired alcohol-ester solution, such as FAME. The process relies on vegetable oils and animal fats which produce free fatty acids when processed. Transesterification yields oxygenated long-chain fatty acid methyl esters, similar to those of petroleum diesel. FAME is currently covered by marine ISO standards in marine distillate blends up to seven percent. “Biodiesel synthesis” is chemically described as the transesterification of triglycerides (oil sources) into alkyl esters using alcohol, typically progressed under a catalyst. This chemical process is reversible, which accounts for biofuel deterioration due to hydrolytic and oxidative reactions.



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Thermochemical production has three common production pathways: (1) fast pyrolysis with hydrodeoxygenation (FPH); (2) gasification with Fischer-Tropsch synthesis (GFT); and (3) hydrothermal liquefaction (HTL) with hydrodeoxygenation. Raw lignocellulosic HTL biocrude is a heavier oil and can potentially be an acceptable direct replacement for petroleum HFO and bio-HFO blends in marine engines. Hydrotreated vegetable oil (HVO) and renewable diesel are advanced biofuels produced from plant oils or animal fat through hydrodeoxygenation and refining, typically in the presence of a catalyst.

Biochemical processing uses cellulase enzymes to hydrolyze polysaccharides into simple sugars, which are then fermented to ethanol by microbes. This conversion breaks down the hemicellulose which permits the enzymes to access the cellulose while the unreacted lignin can be recovered and used in subsequent thermochemical conversion processes. Biochemical processes also do not require any major pretreatment of the biomass, unlike thermochemical processes, which reduce the amount of energy required for biofuel production. While this process is proven technologically, the biofuels produced may not meet marine fuel standards.



## BIOFUEL SAFETY

### CHARACTERISTICS OF BIOFUEL

The physical properties of biofuels vary depending on the type of biomass and production method used. Some fuels, like the widely-used biodiesel, are produced according to a dedicated standard specification. For example, HVO may be produced to the diesel specification ASTM D975 but possess a more variable composition. When combusted, biofuels may affect engine performance due to the differences in characteristics between biofuel and fossil fuels. For example, biodiesel is typically more viscous than petroleum diesel, but drop-in biofuels for HFO are less viscous, which can result in less heating required and improved fuel lubricity.

The characteristics of biofuel may also impact materials used and storage practices. If allowed to oxidize, the higher acid values in biofuels have a greater potential to cause corrosion in fuel supply systems. Biofuels generally have higher cloud and pour points than Marine Diesel Oil (MDO). Specifically, biodiesel is more susceptible to oxidation degradation compared to MDO due to its higher content of organic compounds.

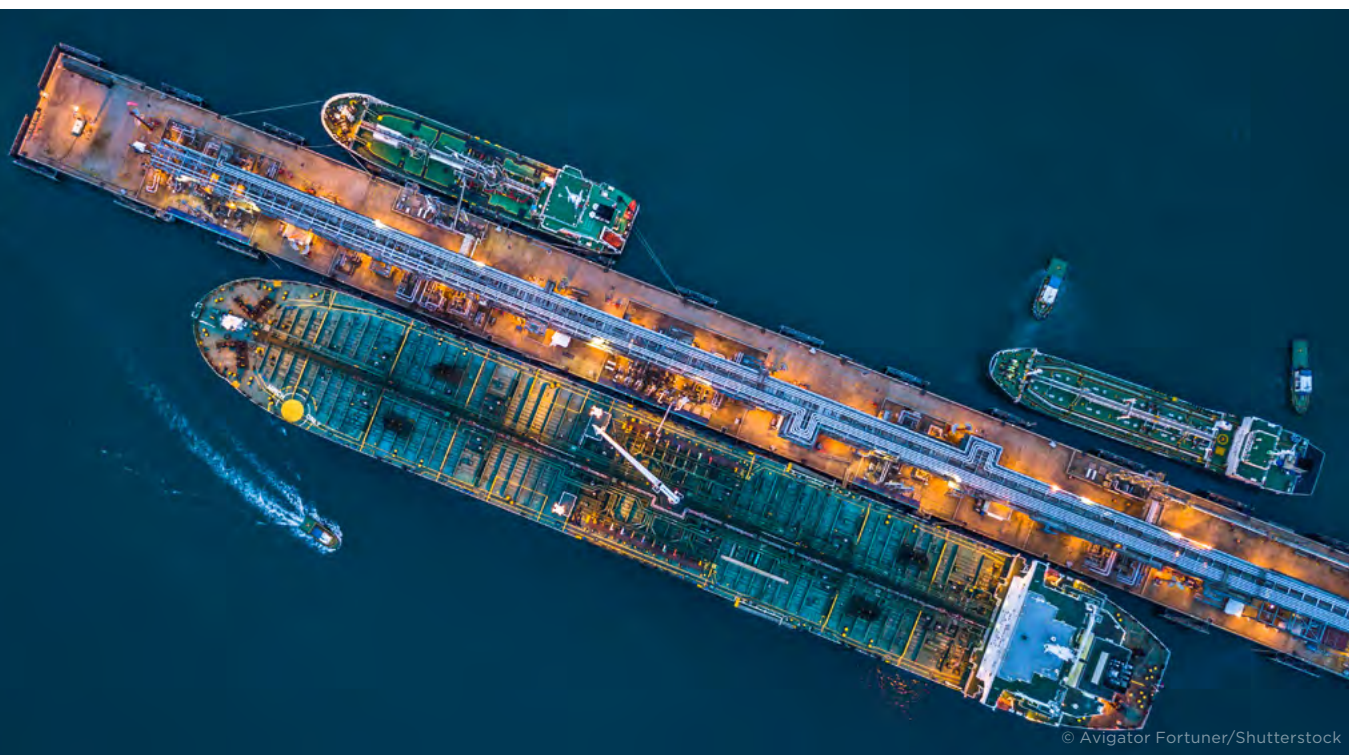
Biofuels, or biofuel blends, can be used as a drop-in fuel, which means certain biofuels are miscible with and directly blended with marine distillate or residual products. Biofuel blends are typically identified by the percent content of biofuel. For biodiesel, the percentage of biomass-sourced fuel is indicated with the prefix B, such as B7, B10, B20, and where B100 indicates an unblended pure biodiesel liquid which can provide the maximum pure carbon reduction option for users. Biodiesel blends, unlike most other biofuels, are regulated by American Society for Testing and Materials (ASTM) and European Standard (EN) regulatory bodies. Alternatively, drop-in biofuels intended for replacing residual fuel oils are indicated with the prefix R.

Diesel fuel is generally considered combustible with a flashpoint between 52° C to 96° C (126° F to 204° F). The flashpoint of biodiesel is greater than 93° C (200° F), so is considerably less hazardous. Biodiesel blends will therefore have flashpoints between those of diesel and pure biodiesel. The U.S. Department of Transportation considers any blend of biofuel with diesel with a flashpoint lower than 37.8° C (100° F) to be flammable, and blends with flashpoints between 37.8° C (100° F) and 93° C (200° F) are combustible. Table 3 compares typical fuel properties of FAME and HVO with diesel. Marine biofuels stored and used on vessels may be required to meet SOLAS flashpoint of less than 60° C (140° F).



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CHEMICAL COMPOSITION	FAME	HVO	DIESEL
Density at 20° C (kg/m <sup>3</sup> )	885	780	825
Lower Heating Value (LHV) (MJ/kg)	37.1	44.1	43.1
Viscosity at 20° C (mm <sup>2</sup> /s)	7.5	3.0 (at 40° C)	5.0
Surface Tension (N/m)	0.026	-	0.028
Cetane Number (CN)	56	80-99	40-50
Stoichiometric Air/Fuel Ratio	12.5	-	15
Oxygen Content (% vol.)	-11	0	0
Aromatics Content (% vol.)	-	0	-30
Sulfur Content (ppm)	-	0	< 3.5

Table 3: Properties of FAME and HVO.

(Source: Setting the Course to Low Carbon Shipping – Pathways to Sustainable Shipping)

## ENVIRONMENTAL SAFETY

Biofuels are biodegradable in nature and may have an advantage in the case of spills in the marine environment when compared to conventional marine fossil fuels. The organic biomass composed in biofuel reacts differently in the environment than conventional petroleum marine fuel. When biofuels come in contact with water, they quickly begin to degrade and disperse. Although considered non-toxic on land, biofuels spilled in a marine environment behave similarly to petroleum fuels until fully degraded. They may still cause oil sheen and water column toxicity. Specific impacts of biofuels vary by biofuel type and blend, but due to their similar properties to their petroleum counterpart, standard fuel spill recovery and clean-up practices should be followed in the case of a marine biofuel spill.

## FIRE SAFETY

Biofuels, biofuel blends and biodiesel may have very similar burning properties to their drop-in petroleum counterpart. Standard industry fire safety protocols and practices should be observed when transporting, handling and burning biodiesel blends. Neat (B100) biodiesel can be extinguished with dry chemical, foam, halon, CO<sub>2</sub> or water spray extinguishers. Some biofuels will burn if ignited, depending on the conditions, so it is best practice to isolate manifolds and ventilation arrangements from oxidizing agents, excessive heat and ignition sources.



## REGULATORY COMPLIANCE CONSIDERATIONS

### IMO REGULATIONS

The International Maritime Organization has an initial GHG strategy to reduce the carbon intensity of international shipping. The goal of the strategy is to cut the total annual GHG emissions by 50 percent in 2050 compared to the 2008 values. Biofuels can be used to meet IMO goals and reduce GHG emissions as a drop-in fuel to replace marine fossil fuels used in the existing fleet. The IMO states that to verify the carbon neutrality of biofuels, it is imperative to use biofuels that are sourced from sustainable feedstock and use sustainable energy sources in production. This can be achieved by following optional sustainability certification schemes, such as the International Sustainability and Carbon Certification (ISCC) scheme. However, current IMO mandates do not include life-cycle assessments for alternative fuels.

The International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI Regulation 13 outlines the requirements associated with nitrogen oxide (NO<sub>x</sub>) emissions from marine diesel engines. See the ABS Advisory on NO<sub>x</sub> Tier III Compliance for more information on Annex VI Regulation 13 certification and NO<sub>x</sub> reduction technologies.

MARPOL Annex VI Regulation 14 implemented the marine global fuel sulfur content limit of 0.50 percent or less from January 1, 2020, with the 0.10 percent limit in an emission control area (ECA) applicable since January 1, 2015. Biofuels tend to have inherently low sulfur content and can help shipowners meet these IMO requirements.

Vessels subject to compliance with the IMO Data Collection System (DCS) under Regulation 22 of MARPOL Annex VI shall give evidence of fuel consumption data for each type of fuel used on board. These should be in the annual report submitted for each reporting period. Vessels not subject to IMO DCS will give fuel type consumed through deck logbook abstract reports, bunker delivery notes (BDN) and bunker remaining on board reports. The DCS reporting system provides the ability for operators using biofuels to report the specific C<sub>f</sub> fuel conversion factor and specify a user-defined description from the fuel supplier BDN, effectively providing the route for reporting zero or low-carbon TTW emissions.



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MARPOL Annex VI Regulation 18 outlines the requirements for fuel oil quality for combustion delivered to and used on board ships. The IMO fuel quality requirements set several fuel quality criteria, including that they should not contain any inorganic acid, jeopardize the safety of the ship, reduce the efficiency of the machinery or harm personnel. The IMO fuel oil quality requirements are split between those blends of hydrocarbons derived largely from petroleum refining and those that are derived by methods other than petroleum refining. Biofuels may fall under either category, so there is an ongoing discussion within the industry on how this regulation should be applied. Regulation 18.3.2.2 indicates that a fuel derived from means other than petroleum refining is not to cause an engine to exceed the applicable  $\text{NO}_x$  emission limit.

Evidence from land-based testing of biodiesels suggests  $\text{NO}_x$  emissions may be higher in some cases. However, large marine diesel engines are typically equipped with the capability to adjust engine settings to account for variations

in fuel quality, including combustion characteristics, while remaining within the performance bounds of  $\text{NO}_x$  under Regulation 13.

The IMO  $\text{NO}_x$  certification regime is based on steady-state testbed testing on reference fuels and includes provisions for higher in-service  $\text{NO}_x$  emissions, depending on fuel type and higher fuel-bound nitrogen content that may be applicable to residual fuel oils. There are also mechanisms within MARPOL Annex VI to undertake trials for emission reduction purposes on board.

Therefore, the  $\text{NO}_x$  (and other Annex VI) implications of using any fuel, including biofuels, need to be assessed on a case-by-case basis with the flag Administration, but routes to the ready application of biofuels do exist in the provisions.

### EXISTING ABS RULES FOR BIOFUELS

Vessels using biofuels are effectively covered by the ABS Marine Vessel Rules (MVR) by compliance with the requirements for prime movers and fuel oil storage and transfer systems. For example, biofuels in fuel oil tanks should comply with MVR 4-6-4/13, which includes requirements for shipboard fuel oil storage, transfer, heating and purification. Since biofuels have various levels of flammability, those fuels and biofuel blends that are flammable in the tanks onboard a vessel should comply with the provisions of MVR 4-6-4/9, which includes the tank vents and overflow requirements. Furthermore, MVR 4-6-5/3 applies to fuel oil systems supplying internal combustion engines, together with MVR Sections 4-6-5/3.3 and 4-6-5/3.5 describing the rules related to the fuel oil service systems for propulsion and auxiliary engines.

As per MVR 4-6-4/13.5.1(d) and SOLAS requirements, for vessels of 500 gross tonnage and above, at least two fuel service tanks for each type of fuel used on board of at least eight hours capacity are to be provided.

Application of biofuels is not considered an engine type defining parameter (MVR 4-2-1 Table 4), and hence does not require a repeat of engine type tests. However, the suitability of any fuel, such as heavy fuel oil or biofuel, for which an engine is designed or can operate on should be agreed upon and/or validated by the engine designer. Most engine suppliers provide specific guidance on operation using biofuels and associated considerations that may be applicable for storage, filtration, fuel transfer equipment or operation. See also the ABS Marine Fuel Oil Advisory for more information on fuel oil standards, handling, stability and compatibility that should be considered for the application of any fuel oil or biofuel.



## EMISSION AND SUSTAINABILITY STANDARDS

The European Union has prepared to transition biofuels into more applications within the transport sector by adopting the Renewable Energy Directive 2018/2001 (EU RED) for the promotion of renewable energy sources. This directive is effective in the EU from June 30, 2021. The contribution of advanced biofuels in transportation in the EU is targeted by member states to be at least 3.5 percent of total energy generated by 2030. Most of the biofuels are expected to be used in the automotive sector, but the directive also applies to the aviation and marine transport sectors. However, the enforcement of the EU RED can differ from country to country within the European Union depending on how it becomes implemented into national legislation. Production of advanced biofuels is expected to minimize the overall direct and indirect land-use impacts from less sustainable sources of feedstock. EU countries are encouraged to limit the source of biomass from cereal, starch-rich crops, sugars and oil crops to seven percent in a RED mandate known as the Food Crop Cap. If implemented, these changes are expected to reduce the practice and consequences of land-use changes during first-generation biomass generation.

The International Sustainability and Carbon Certification (ISCC) is an independent global certifying body that verifies the environmentally, socially and economically sustainable production of biomass. ISCC is one of several voluntary certification schemes, which also include the Roundtable on Sustainable Biomaterials (RSB). These schemes intend to certify that covered aspects of the biofuel supply chain are sustainable, both environmentally and socially. Biofuels which are certified have verified sustainable supply chains which avoid land-use change and deforestation. The use of these systems is required for compliance with the EU RED. In practice, the use of this system allows biofuel producers to demonstrate the reduction of GHG emissions of the fuel by tracking its life-cycle.

The RSB is a voluntary standard that sets guidelines for certifying sustainably sourced biofuels through legal, social, environmental and managerial elements. Through their 12 elements, the production of biofuels can be certified as sustainable. Other than the marine fuels claiming RED credit in the EU, the RSB and other ISCC certifications do not specifically apply to marine biofuels but may encourage involvement from all industries to reduce the production emissions and overall carbon footprint of biofuels.

## BIODIESEL QUALITY REGULATIONS

Biofuels can have a varying range of properties depending on various feedstocks and production processes. The International Organization for Standardization (ISO) has implemented ISO 8217, Petroleum Products – Fuels (class F) – Specifications of marine fuels, which details the specifications for marine fuel to be used in different types and sizes of diesel engines and boilers. The standard covers marine fuels that are hydrocarbons derived from crude oil, oil sands and shale, together with hydrocarbons derived from synthetic or renewable sources and that are similar in composition to petroleum distillate fuels. Therefore, fuels covered by this standard include distillate (identified DFA, DFZ, DFB) grades with up to seven percent FAME together with hydrotreated vegetable oil (HVO), biomass-to-liquid (BTL) and any renewable feedstock similar in composition to petroleum distillates.

The most common standards for FAME biodiesels are ASTM D6751 “Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels” and EN 14214 “Liquid Petroleum Products – Fatty Acid Methyl Esters (FAME) for use in Diesel Engines and Heating Applications – Requirements and Test Methods”. When the limits of EN 14214 and ASTM D6751 are met for biodiesels, they can be used in most unmodified modern engines without impacting engine life.



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## DESIGN CONSIDERATIONS

### CONCEPT EVALUATION

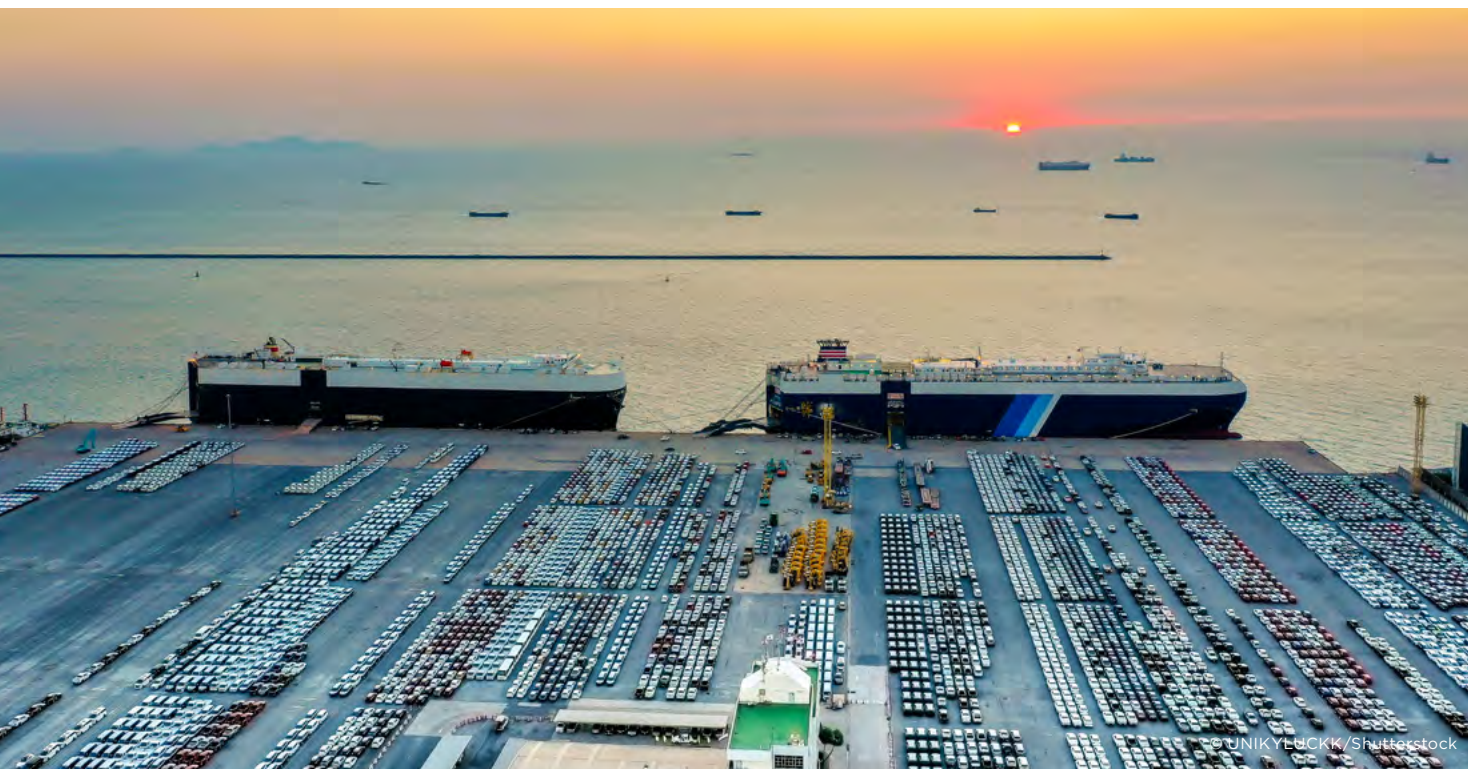
When using biofuels in vessels, all applicable vessel arrangements for the fuel should be evaluated including fuel storage, fuel treatment system, piping, centrifuges, etc. The following sections will discuss FAME and HVO (referred to as biomass-based diesel) but can be generally applied to other biofuels.

FAME has somewhat different chemical properties from diesel, which should be taken into consideration when used in engines. FAME has higher lubricity properties than diesel and thus results in less wear on the fuel pumps and injectors. However, it contains oxygen and therefore has lower energy content than diesel. This may increase the required tank volume when used in large amounts for long-distance travel. In areas of short-distance travel and where refueling is readily available, tank size may not necessarily need modification.

A 2008 Society of Automotive Engineers Journal of Engines article reported various engine studies with HVO that showed combustion generally resulted in fewer particulate emissions and lower filter smoke numbers than diesel, attributed to the lack of aromatic compounds in HVO, which form soot precursors. NO<sub>x</sub> formation can also be reduced due to the differences in peak cylinder temperature resulting from lower ignition delay with HVO. HVO may also produce less CO<sub>2</sub> due to its favorable hydrogen/carbon ratio compared to diesel. The higher gravimetric heating value of HVO may result in lower specific fuel consumption, thus higher engine efficiencies. However, the lower density of HVO can result in higher volumetric fuel consumption. Among all the studies performed, it was concluded that no changes to the hardware or control parameters were required for the diesel engines to use HVO, although, in its pure form, the lack of aromatics in HVO may have a corrosive impact on older elastomers. Note that study results may vary depending on the engine type and load. Other uses of HVO may not always produce the results listed here.

According to the Engine Manufacturers Association (EMA), biodiesels may be used as a drop-in fuel at any time for any modern diesel engine when using blends up to B5 with no consequences. When higher percentages are used, several challenges may occur in the fuel system and with the fuel itself. For example, while it is important to prove the feasibility of neat biofuel replacement, biofuel blends may exhibit preferred performance and maintainability for vessels or fleets. An initial concept evaluation of biofuels should account for operational and route considerations:

- Type of vessels, engine requirements and associated cargo operations
- Trade route of the vessel
- Bunker location, bunker frequencies and bunker providers
- Maintenance and repair locations







## DESIGN CHALLENGES AND SOLUTIONS

Biofuel feasibility tests and ongoing research show that many biofuel blends can be used without engine or fuel system modifications for short-term or test applications. The design challenges discussed in this section vary and may only occur when using high percentage biofuel blends or long-term applications. Owners or operators should contact their fuel supplier and engine manufacturer for specific recommendations for using biofuels.

Most of the challenges faced by biofuels can be addressed by fuel additives. Standard EN 14214 allows the use of additives without known harmful side effects.

Vessel owners have had compatibility issues with conventional fuels in the past due to the commingling of incompatible fuels onboard.

With multiple types of conventional fuels, different feedstock, different types of biofuels and blends available in the future, there will be a continuous need to manage fuels properly for use onboard. The fuel supplier should guarantee compliance with agreed fuel standards and commercial supply contracts, but as with conventional marine fuels, the responsibility is left to the vessel owner and the crew to ensure compatibility, stability and suitability of fuels matching the installed equipment and designers' recommendations. Some procedures are already made regarding the mixing of fuels or minimizing the mixing of fuels onboard. ISO PAS 23263 informs of additional test methods such as ASTM D4740, commonly known as the spot test, and other ASTM standards.

A main concern of biofuel use is system corrosion of certain materials due to fuel acidity. High concentration biodiesels have the largest effect, but corrosivity may also depend on feedstock, water contamination and microbial growth. Deterioration of rubber, copper, brass, lead, tin and zinc components can occur, impacting fuel system parts including gaskets, hoses, fuel filters and fuel injectors. Materials must be selected based on the interaction with the specific biodiesel blend used with the engine and tanks. Owners should verify all components of the applicable fuel system are compatible with their specific biodiesel blend.

The degeneration of some biofuels is also a concern. When water is present in a gasoil grade biofuel, bacterial and fungal growth can occur. This issue can be addressed by removing water from fuel tanks, regular sample testing, frequently draining the tanks or adding a high-quality fuel filter system. Fuel suppliers may add biocide or anti-microbial additives to the biofuel or biofuel blend to avoid microbial build-up.

Various studies and industry projects are examining the best practices to address challenges related to using biodiesels on marine vessels. Microbial growth may not be a difficulty due to available additives and modern filtering equipment. Tests done on Maersk Kalmar from April to November 2010 showed no microbial growth while using FAME because of proper fuel maintenance and handling which maintained a clean and water-free storage environment. Another study concluded that the costliest use of biofuels was regarding the preventative measures against corrosion in the storage tanks.

Biofuels with high oxygen content can also deteriorate naturally over time to form insoluble contaminants. Biofuels should be stored in a dark and dry environment to avoid deterioration, or antioxidant additives can be used to slow deterioration. Biofuels should be used in a timely and regular manner to avoid this degradation. Depending on the fuel properties, biofuels can be stored for up to three years or more if stored and maintained properly.

Low temperatures may also be a problem when using certain biofuels. At low ambient temperatures, biofuels tend to cloud and gel. If temperatures cannot be kept above the cloud point, cold flow and anti-gel additives may improve the cold-flow operability. These additives are common for conventional petroleum fuels with the same problem.

While compliance with marine fuel standards provides confidence in lubricity performance and hence should limit impacts on fuel injection equipment on all engine types, some biofuels could affect the properties of the lubricating oil. The use of biodiesel blends may therefore require reduced engine oil drain intervals.



## FUEL AVAILABILITY, COST AND STORAGE

### FUEL AVAILABILITY

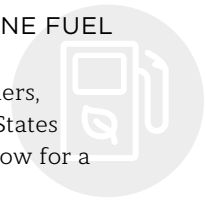
One of biofuel's main challenges is its availability to meet future potential demand. For the necessary substantial increase in production, high-level influence from policy and regulation may be required. Biofuel feedstock is limited due to competition with the agricultural, automotive and aviation industries and will need to be produced on an increasing scale to support uptake in the global maritime fleet. Overall, the feedstock and fuel availability may vary depending on the location, season, regulatory and environmental conditions.

Biomass-based diesel plant feedstocks include rapeseed oil (common in the EU), soybean oil (common in the U.S. and South America), palm oil (common in Southeast Asia), and distillers corn oil (common in the U.S.). Animal feedstocks include rendered beef, poultry litter and other animal fats. Used cooking oil can also be used to produce biomass-based diesel, often known as Used Cooking Oil Methyl Ester (UCOME).

Biomass-based diesels make up a growing share of the world's production of biofuel. According to the collaborative work by the Organization for Economic Co-operation and Development and the UN's Food and Agriculture Organization (OECD-FAO) Agricultural Outlook 2019-2029, the production of global biodiesel is expected to increase from 11 billion gallons in 2020 to 12.15 billion gallons in 2029. However, the production may depend on government policy support, which could impede or accelerate a biofuel agenda. The demand for biofuels in developing countries is expected to grow because of the development in transportation fleet and domestic policies. Table 4 below shows the five largest areas of production from 2020, with Europe leading production at 3.5 billion gallons. However, only a portion of these fuels will be available for shipping due to competition with the transportation sector. The table also shows each of the main distributing countries of biodiesel with their major feedstock source.

AREA	BIOFUEL VOLUME (BILLION GALLONS) IN 2020	COUNTRY	MAJOR BIOFUEL FEEDSTOCK
European	3.5	UK	Rapeseed and Waste Oil
		Germany	Rapeseed
		Italy	Rapeseed and Sunflower
		France	Rapeseed and Sunflower
		Turkey	Rapeseed and Sunflower
		Spain	Linseed and Sunflower
		Greece	Cottonseed
		Sweden	Rapeseed
North America	3.0	USA	Soybeans and Waste Oil
		Canada	Canola
		Mexico	Animal Fat and Waste Oil
South America	2.0	Brazil	Soybeans and Palm Oil
		Argentina	Soybeans
Indonesia/Malaysia	1.0	Malaysia	Palm Oil
		Indonesia	Palm Oil
		Thailand	Palm Oil and Coconut Oil
		Philippines	Coconut Oil
		China	Rapeseed and Waste Oil
India/Africa/Other	1.5	India	Jatropha and Pongamia
		South Africa	Jatropha and Castor
		Japan	Waste Oil
		Australia	Jatropha
		New Zealand	Waste Oil and Tallow

Table 4: Biofuel generation locations and feedstock.



The international biofuel market is heavily influenced by agricultural policy to support the economy of farmers, reduce GHG emissions and reduce energy dependency. The availability of biofuels is extensive in the United States for use in the automotive industry. Existing biofuel infrastructure and production methods therefore may allow for a relatively simple transition into the marine industry.

Production of HVO can potentially take place in oil refineries if they are equipped with hydrotreating facilities. However, modifications may be needed to develop scaled-up HVO-only production facilities. The production process is more expensive than for FAME biodiesel.

## FUEL COST

The cost of biofuels will vary depending on the feedstock, geography, regulations, taxes, variability, labor costs and rotation of crops by season. Specifically, the primary costs come from feedstock cultivation, transportation, densification (if applicable), storage and pretreatment processes. In general, biofuels are more expensive than MGO, MDO and HFO. However, certain policies such as the U.S. Renewable Fuel Standard and Low Carbon Fuel Standard are designed to make biofuels cost-competitive or cheaper than petroleum in qualifying end uses. Globally, various regulatory and legislative initiatives are designed to provide 'credits' to incentivize and reduce the costs of biofuel use. The biomass price is highly subject to market price supply, demand and economic policy, but it also fluctuates with the agricultural yield, which is impacted by locations, genetics, soil fertility levels and wide agricultural markets such as animal feed. If biofuels increase as an energy commodity, the competition of biomass feedstock with other sectors may result in an increase in the overall price. For this reason, the industry is encouraging the production of biofuels to lessen the competition with agricultural industries. Waste-based biofuels may be essential to lower the cost of fuel generation but is subject to policy. For example, biofuels generated from waste biomass in the EU may be more expensive because they count twice under the RED road mandates.

The future of biofuel prices is largely impacted by the market and considerations of supply and demand. As estimated by the International Renewable Energy Agency (IRENA), by about 2040, the price of biofuels is expected to become competitive.

Another aspect of the cost of biofuels is the conversion (if necessary) of vessels to suit biofuel storage, transfer and use. The cost of conversion may be lower for biofuels compared to other alternative fuels due to the nature of drop-in biofuels. Relatively minimal investments to modify the hoses (or pipes), filters, seals and other synthetic material components may be all the changes necessary. Owners should contact their fuel supplier for specific requirements based on their biofuel choice.

Minimal investment costs in fuel infrastructure may also affect fuel availability. Minor modifications to existing infrastructure such as fueling stations and bunkering infrastructure to handle specific requirements of biofuels can eliminate the need for expensive new infrastructure or bunkering procedures.



## FUEL STORAGE

Temperature control of biofuels is very important to maintain correct viscosity levels. This is crucial to improve flow characteristics, reduce clogging and optimize the fuel injection, atomization and combustion within engine cylinders. Biofuel storage temperatures should be kept 10-15° C above the cloud point, and hot spots should be cooled. The temperature required may vary depending on the type of biofuel, blend and feedstock. Many fuel storage tanks are already fitted with heating devices which would be adequate for heating biofuels. To protect against low-temperature behavior, biofuel blends of higher percentages that do not have acceptable cold properties are not recommended to be used when temperatures are unable to be controlled. Innovative additives to combat the effects of low temperatures are commonly used, and biofuels using the additives should be regularly tested and monitored for their temperature and cloud point properties.

B100 has about an 11 percent lower energy content than diesel fuel but this may be compensated by improved combustion performance. This can affect the frequency of bunkering or the storage space needed on board. The vessel may require larger tank space to accommodate a larger volume of oil. Biofuel tanks should be properly cleaned prior to every bunkering event.

Some biofuel's tendency to degrade over time due to poor oxidation stability can be addressed by antioxidant fuel additives. Biofuel storage for long periods (over six months) is possible with proper fuel handling and considerations; however, the interval may depend on the characteristics of the specific biofuel.

The storage of certain biofuels may need tanks with appropriate coatings and tank/pipe fittings to avoid corrosion if incompatible materials are used. Biofuel quality standards state that vessel owners should analyze the materials of the fuel supply system, such as the ship's storage, handling, treatment, service and machinery systems and other machinery components (such as oily-water separator systems). Some incompatible materials such as those listed in Table 5 may oxidize FAME and create sediment deposits. Note that this list is not all-inclusive, and for a full list of recommended materials, owners should contact the fuel supplier based on the specific characteristics of the biofuel used.

RECOMMENDED/COMPATIBLE MATERIALS WITH BIOFUELS	NOT RECOMMENDED/INCOMPATIBLE MATERIALS WITH BIOFUELS
Steel	Bronze
Aluminum	Brass
Fiberglass	Copper
Teflon	Lead
Fluorinated Polyethylene	Tin
Fluorinated Polypropylene	Zinc

Table 5: Typical material compatibility with biofuel.

Fuels should be protected from exposure to oxygen, light, metals and high humidity. Many engine manufacturers have demonstrated through tests the effects of corrosion and consider it to be one of the most important operational expenditures (OPEX). When not using an engine for long periods, the fuel system and tank should be purged of all biofuels and flushed with petroleum fuel. Biofuel storage requirements may vary by biofuel type; therefore, ship owners and operators should contact their fuel supplier, bunkering agency and engine manufacturer for specific fuel storage measures or other requirements.





## BUNKERING

The characteristics of biofuels may require a few changes to the bunkering process from comparable marine fossil fuels. Biofuel blending can be done at the refinery, by the bunkering parties, on the bunker ship or onboard the vessel. However, onboard blending can create additional operational risks and hazards for ship owners and operators. Therefore, blending biofuel by the bunkering organizations is recommended by industry and will most likely be the best option to allow for one Bunker Delivery Note per fuel supply. This can help confirm the properties of the blend as specified and protect against off-specification fuels damaging engines.

Bunkering of biofuels may see developing regulations and fuel test standards due to the degradation, oxygen stability and corrosion properties. Frequent tests using industry fuel standards should be conducted on the vessel to monitor the quality of the fuel and any degradation or corrosion occurring. While bunkering, safety guidance and protocols should be followed issued by the bunker party, flag States and other governing bodies.

## MAINTENANCE

Additional service to the fuel supply system, onboard fuel tanks and fuel filters may occur in vessels that use high-blend percentages of biofuels. Periodic testing of the fuel can provide details on potential moisture content and microbial growth entering from the air. The higher moisture content and microbial growth rates will result in an increased chance of filter clogging and fuel deposits. Biofuels have detergent properties and may loosen and suspend deposits left from marine petroleum fuel and clog the fuel system. Especially after its first use in an existing fuel system, fuel filters may need more frequent changes. The fuel system should be flushed when not in use and may require more fuel filter services depending on the blend percentage and feedstock used.

## ONGOING RESEARCH

### BIOFUEL VESSELS AND PROGRAMS

#### NOAA GREEN SHIP INITIATIVE

The National Oceanic and Atmospheric Administration (NOAA) has pivoted the Great Lakes Environmental Research Laboratory’s (GLERL) small research vessels to reduce emissions by using B100 soy biodiesel. Their entire marine diesel-powered, 10-vessel fleet in the Great Lakes is powered by biodiesel produced from soybean oil. The conversion to biodiesel has reduced air pollution and operational costs for GLERL since implementation in 2000. The operational and maintenance costs are reported to have been reduced by 20-40 percent compared to petroleum fuel due to improved engine performance and life and the reduction of maintenance due to the cleaning properties of biodiesel.

The emission reduction reported for the GLERL fleet since it was first converted is shown in Table 6.

<b>TOTAL UNBURNED HYDROCARBONS</b>	77%
<b>CARBON MONOXIDE</b>	48%
<b>PARTICULATE MATTER</b>	59%
<b>NO<sub>x</sub></b>	7%
<b>SULFATES</b>	74%
<b>PAH (POLYCYCLIC AROMATIC HYDROCARBON)</b>	66%

Table 6: GLERL fleet emission reduction B100 vs petroleum diesel.

#### GOODFUELS AND VOLKSWAGEN GROUP PARTNER FOR USE OF THEIR BIOFUEL

GoodFuels has partnered with Volkswagen Group in supplying GoodFuel’s advanced Bio-Fuel Oil (MR1-100 of BFO) at Vlissingen, Netherlands. The Depth Ltd. RoRo Carrier *Patara* was bunkered with 100 percent of GoodFuel’s BFO in November of 2020, which reported reduced CO<sub>2</sub> emissions by a minimum of 85 percent and all SO<sub>x</sub> on their voyage. The voyage test was between Emden, Germany, Setúbal, Portugal, Santander, Spain and Dublin, Ireland—a route expected to be traveled about 50 times every year. The vessel uses a MAN marine diesel, 14,222-kW engine and is expected to result in a reduction of CO<sub>2</sub> emissions of 52,000 tons per year while using biofuels. Since the successful test run, Volkswagen runs two vessels on the same route using MR1-100 to lower their emissions. GoodFuel’s BFO is a sustainably sourced biofuel produced from various certified waste or residue feedstocks, including waste oils from the food industry. The BFO acts as a drop-in fuel to normal MDO fuel tanks, which has not been reported to affect the hardware performance.



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### HOPPER DREDGER ALEXANDER VON HUMBOLDT USING 100% SUSTAINABLE MARINE BIOFUEL

Jan De Nul Group reports that they have completed 2,000 sailing hours using 100 percent renewable Biofuel Oil (BFO) on the vessel *Alexander Von Humboldt*. They have partnered with MAN Energy Solutions and GoodFuels to successfully show that BFO is ready to be used as a drop-in fuel to meet emission reduction targets. This project started in late 2019, and the vessel refueled several times during the first nine months, which resulted in a reported 85 percent reduced CO<sub>2</sub> emissions. The vessel operated on these biofuels during maintenance dredge work in Flemish seaports and the United Kingdom. After the successful performance of the *Alexander Von Humboldt*, Jan De Nul Group has increased the use of biofuel in their fleet.

### STENA BULK COMPLETES SUCCESSFUL TRIAL WITH EXXONMOBIL AND GOODFUELS MARINE BIOFUEL

Stena Bulk is a tanker shipping company with a fleet of approximately 115 tankers. In April 2020, Stena Bulk and GoodFuels completed a 10-day sea trial of their sustainable marine biofuel. GoodFuels bunkered the vessel with BFO at their location in Rotterdam. Stena Bulk's 49,646 deadweight ton Suezmax tanker *Stena Immortal* was used to test the GoodFuels BFO during its normal commercial cross-Atlantic operation, which reduced greenhouse emissions by 83 percent and reduced SO<sub>x</sub> emissions to meet the IMO 2020 sulfur cap. Stena Bulk is now introducing low-carbon shipping options for customers. Following the successful April operational test, a range of 20 percent to 100 percent biofuel will be offered as a carbon-offsetting program.



Figure 6: The suezmax tanker *Stena Immortal*.

In September 2020, Stena Bulk and ExxonMobil completed a successful sea trial of their first commercial biofuel oil. ExxonMobil's marine biofuel is a very low sulfur fuel oil (VLSFO) processed from FAME. The fuel can reduce CO<sub>2</sub> emissions up to 40 percent compared to fossil VLSFO. The fuel was evaluated based on onboard storage, handling and combustion in main and auxiliary engines. ExxonMobil's biofuel did not require any engine modifications or additional procedures to meet technical operational requirements. The fuel holds an International Sustainability and Carbon Certification (ISCC) which shows compliance with sustainable biofuel feedstock source practices.

### OCEAN NETWORK EXPRESS (ONE)

A successful biofuels trial completed in February 2021 with the M/V MOL Experience in collaboration with ONE, Mitsui O.S.K. Lines and fuel supplier GoodFuels. The trial used biofuels blended with conventional fossil fuel, bunkered in Rotterdam, and used along the containership's commercial route between Europe and the U.S. Project partners ONE and Mitsui O.S.K. expect to implement biofuels among other alternative fuels to achieve their decarbonization and sustainable business goals.



## MEDITERRANEAN SHIPPING COMPANY (MSC)

Geneva-based Mediterranean Shipping Company is a global company adopting drop-in biofuels for the future of container shipping. After successful trials in 2019, while using 10 percent biodiesel, MSC expects to continue bunkering sustainably sourced biofuels in Rotterdam, Netherlands. The 10 percent biodiesel used in testing was used cooking oil methyl ester (UCOME) in diesel engines. In November and December of 2019, the company bunkered 100,000 tonnes of fuel, which MSC estimates to have CO<sub>2</sub> savings of over 30,000 tonnes. Increasing the blend to 30 percent biodiesel (B30), MSC expects to further reduce absolute CO<sub>2</sub> vessel emissions by 15-20 percent.

## INDUSTRY PILOT PROJECTS

### MARAD RENEWABLE DIESEL FUEL

In 2013, the U.S. Maritime Administration (MARAD) evaluated the use of a biodiesel blend in the *T/S State of Michigan*, a retired Stalwart Class (T - AGOS 6) Modified Tactical General Ocean Surveillance Ship built by Tacoma Boat. The study compared the use of Ultra Low Sulfur Diesel (ULSD) and a blend of 67 percent ULSD and 33 percent Amyris Renewable Diesel (ARD), a synthetically derived biofuel. The vessel uses diesel-electric propulsion and four Caterpillar D-398 compression ignition engines, with one used as the test engine with ARD blend. The results showed that the emissions and fuel economy of the engines were the same for the ULSD as the blended fuel. The fuel analysis and biological contamination of the fuel were the same before and after the seven-month storage period. Overall, there were no significant differences in engine vibrations, performance, radiated noise or effect on the engine itself.



Figure 7: The *T/S State of Michigan*, MARAD-owned training ship for the Great Lakes Maritime Academy.

### MARINE BIOFUEL TESTING BY ALFA LAVAL

Alfa Laval Testing and Training Centre is a research and development group partnered with biofuel producer MASH Energy and shipowner DFDS that began testing biofuel in November 2020. Two 25 m<sup>3</sup> tanks (one stainless steel) were used to test and evaluate MASH Energy's Biofuel behavior in marine fuel systems of variable materials. MASH Energy's biofuel is made from the pyrolysis of waste biomass. The biofuel is first mixed with conventional fuel oil and combusted to examine flame characteristics and emissions such as NO<sub>x</sub> and particulate matter. Between the tanks and the boilers, the biofuel is treated with one of Alfa Laval's products, a high-speed impurity separator. Moving forward, Alfa Laval intends to test the biofuel in a four-stroke engine, and if successful, to bunker it on the *DFDS Pearl Seaways* for use producing hot water while in Danish ports.



Figure 8: The passenger ferry DFDS Pearl Seaways.

## ENGINE MANUFACTURERS

Caterpillar has approved their engines to comply with biodiesels that meet ASTM D6751 and EN 14214. B20 blends are accommodated in most CAT diesel engines. Higher biodiesel blends can be used but the OEM should be contacted before the use of B30 – B100 biodiesel

Cummins's engines are allowed up to five percent biodiesels on all engine models if the fuel meets ASTM D6751 and EN 14214 standards. B20 biodiesel blends can be used on limited engine models. MAN Diesel's large, medium-speed, four-stroke marine engines have experience running on B100 biodiesel, specifically those

produced from feedstocks such as soybean oil, palm oil, sunflower oil, waste edible oil and animal fat BFO.

Investigations have begun to use biofuels in Wärtsilä engines. The test requires the use of acid-resistant materials and careful temperature control. Rapeseed oil was found to be compatible with few alterations. In 2009, a Wärtsilä engine successfully tested operating on jatropha oil, fish oil and chicken oil. Fairbanks Morse allows biodiesel blends in one of their opposed-piston model engines. They have used fish oil biodiesel and soybean biodiesel.

Volvo Penta allows B7 biodiesel blends in their engines. Engines manufactured after January 1, 2012 are allowed B30 blends if the components meet standards EN 14214 and EN 590, respectively. Specific engine services can be used with B30 biodiesel blends.

Yanmar allows B5 biodiesel blends across their marine engines if the biodiesel met ASTM D6751 or EN 14214. B20 biodiesel blends are allowed on certain engine models.

## FUTURE GENERATION BIOFUELS

The future of biofuels is underway with the development of the next generation of biofuels, derived from microbes and microalgae. These are considered to be viable alternative energy resources devoid of the major drawbacks associated with first and second-generation biofuels. While next-generation biofuels are gaining momentum in research and development and proving to be technologically feasible, more production processing techniques may be necessary to cost-effectively produce biofuels in the quantities required for the shipping industry.

Next-generation biofuels use microalgae produced into a fuel, and with algal biomass, there is no competition with agricultural food and feed production. There are several advantages of these higher generations over first- or second-generation feedstocks including efficiencies and optimum growth with minimal resources. Algae can be grown continuously throughout the year when grown in isolated containment. However, to become commercially viable fuels, the technology and production process must become economically competitive.

The disadvantages of algae biofuels have slowed the production of these fuels. One of the main disadvantages is low biomass production. To process algae into biofuels, the algae must be harvested and separated from any lipids it may produce. Depending on the species of algae used, the amount of dried biomass that can be produced cost-efficiently is not currently able to sustain large vessel fuel requirements.

Production of low-cost microalgal biofuels requires better biomass harvesting methods, higher biomass production efficiencies and genetic modification research to improve the quality of the algae grown. However, genetically modified algae may have scaling challenges because they must be grown indoors due to concerns of escape and algal invasion into local ecologies. Beyond these technologies, biofuels focus on the advances in harvesting and processing techniques of algae by using photobioreactors and other downstream technologies to reduce the cost of these future generation biofuels.

**PROJECTED ROLE OF BIOFUELS AS MARINE FUEL**

Carbon neutral fuels such as biofuels have a great potential in assisting the transition to alternative fuels. Biodiesels can be used in increasingly higher percentage blends to lower the emissions of marine vessels with little change to the vessel's current operations. However, one of the current challenges of using drop-in fuels is their low availability and high cost of production. With proper regulation at a high level, biodiesels can be a beneficial contributor to lowering GHG emissions in short sea shipping or between ports where refueling may be readily available. The use of biofuels is expected to grow due to its potential similarities to marine petroleum, and ease of distribution, storage and bunkering. Figure 9 shows the currently projected marine fuel use until 2050 as the industry strives to meet the GHG emissions-reduction targets mandated by the IMO.

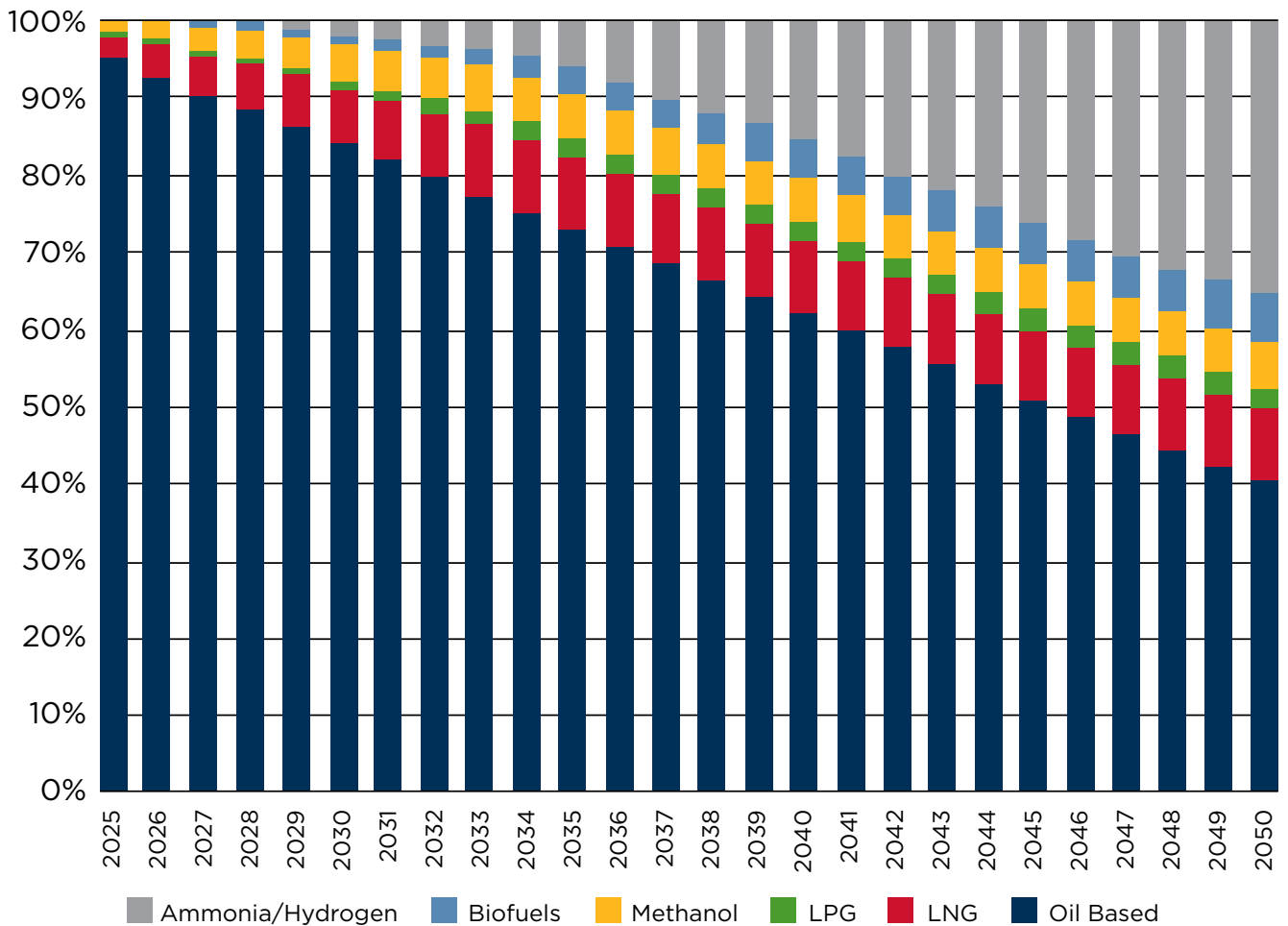


Figure 9: Projected Marine Fuel Use to 2050.  
 (Source: Setting the Course to Low Carbon Shipping – Pathways to Sustainable Shipping)





## ABS SUPPORT

It is to be noted that the information provided in this document is generic. For specific guidance on biofuel as a marine fuel, please contact your local ABS office.

ABS can assist owners, operators, shipbuilders and original equipment manufacturers as they consider the practical implications of the use of biofuel as a marine fuel. Services offered include:

- Risk assessment
- Regulatory and statutory compliance
- New technology qualifications
- Life-cycle and cost analysis of biofuel-fueled vessels
- Vessel/fleet benchmarking and identification of improvement options
- EEDI verification and identification of improvement options
  - Energy Efficiency Existing Ship Index (EEXI) verification and identification of improvement options
- Optimum voyage planning
- Alternative fuel adoption strategy
- Techno-economic studies
- Cyber safety notations and assessments
- Contingency arrangement planning and investigations



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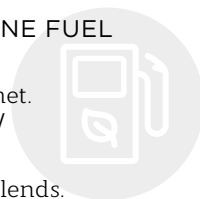
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## APPENDIX II: LIST OF ACRONYMS AND ABBREVIATIONS

<b>ABS</b>	American Bureau of Shipping	<b>LHV</b>	Lower Heating Value
<b>ARD</b>	Amyris Renewable Diesel	<b>MAN</b>	MAN Energy Solutions
<b>ASTM</b>	American Society for Testing and Materials	<b>MARAD</b>	US Maritime Administration
<b>BDN</b>	Bunker Delivery Note	<b>MARPOL</b>	The International Convention for the Prevention of Pollution from Ships
<b>BFO</b>	Biofuel Oil	<b>MDO</b>	Marine Diesel Oil
<b>BTG</b>	Biomass Technology Group	<b>MEPC</b>	Marine Environment Protection Committee (IMO)
<b>BTL</b>	Biomass-to-Liquid	<b>MGO</b>	Marine Gas Oil
<b>C<sub>F</sub></b>	Fuel Conversion Factor (EEDI)	<b>MSC</b>	Mediterranean Shipping Company
<b>CO</b>	Carbon Monoxide	<b>MVR</b>	Marine Vessel Rules (ABS)
<b>CO<sub>2</sub></b>	Carbon Dioxide	<b>NOAA</b>	National Oceanic and Atmospheric Administration
<b>DCS</b>	Data Collection System (IMO)	<b>NO<sub>x</sub></b>	Nitrogen Oxides
<b>DME</b>	Dimethyl Ether	<b>OECD</b>	Organisation for Economic Co-operation and Development
<b>ECA</b>	Emission Control Area	<b>ONE</b>	Ocean Network Express
<b>EEDI</b>	Energy Efficiency Design Index	<b>OPEX</b>	Operational Expenditures
<b>EMA</b>	Engine Manufacturing Association	<b>PAS</b>	Publicly Available Specification
<b>EN</b>	European Standards	<b>PM</b>	Particulate Matter
<b>EU</b>	European Union	<b>ppm</b>	parts per million
<b>FAME</b>	Fatty Acid Methyl Ester	<b>RED</b>	EU Renewable Energy Directive 2018/2001
<b>FAO</b>	Food and Agriculture Organization (EU)	<b>RSB</b>	Roundtable for Sustainable Biomaterials
<b>FPH</b>	Fast Pyrolysis with Hydrodeoxygenation	<b>SCR</b>	Selective Catalytic Reduction
<b>FT</b>	Fischer-Tropsch	<b>SO<sub>x</sub></b>	Sulfur Oxides
<b>GFT</b>	Gasification with Fischer-Tropsch synthesis	<b>SOLAS</b>	International Convention for the Safety of Life at Sea
<b>GHG</b>	Greenhouse Gas	<b>SVO</b>	Straight Vegetable Oil
<b>GLERL</b>	Great Lakes Environmental Research Laboratory	<b>TTW</b>	Tank-to-Wake
<b>HFO</b>	Heavy Fuel Oil	<b>UCOME</b>	Used Cooking Oil Methyl Ester
<b>HTL</b>	Hydrothermal Liquefaction	<b>ULSD</b>	Ultra Low Sulfur Diesel
<b>HVO</b>	Hydrotreated Vegetable Oil	<b>VLSFO</b>	Very Low Sulfur Fuel Oil
<b>ILUC</b>	Indirect Land-Use Change	<b>WTT</b>	Well-to-Tank
<b>IMO</b>	International Maritime Organization	<b>WTW</b>	Well-to-Wake
<b>IRENA</b>	International Renewable Energy Agency		
<b>ISCC</b>	International Sustainability and Carbon Certification		
<b>ISO</b>	International Organization for Standardization		





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