Analysis of readiness of FAME and HVO biofuels as energy sources for the shipping industry – including safety, bunkering, regulatory and NOx considerations.

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Abstract

The document provides an in-depth analysis of the readiness of FAME and HVO biofuels as energy sources for the shipping industry. It covers various aspects including safety, bunkering, regulatory considerations, and NOx emissions. Biofuels, derived from organic materials, are seen as a key driver for decarbonizing transport in the short to medium term. The document highlights the drop-in nature of biofuels, allowing their use in existing fleets without significant modifications. However, challenges such as scalability, global availability, and sustainability concerns are noted. The document also discusses the regulatory landscape, including EU regulations and the IMO's guidelines. Safety considerations for handling and bunkering biofuels are detailed, along with the chemical and physical characteristics of FAME and HVO. The conclusion emphasizes the potential of biofuels to reduce carbon emissions and the need for effective regulation to make them commercially viable.

Introduction

Biofuels - energy sources created from the processing of recently created organic material, such as plant material, algae, vegetable oils and fats from animal waste, have applications in multiple modes of transport, including road, aviation and more recently, marine. Demand for biofuels is expected to be a key driver of decarbonisation in transport at least in the short to medium term whilst new technologies and alternative fuel options become more established in the marine market, with global biofuel demand forecast to rise by almost 30% in 2023-2028, compared to the 2017-2022 period (IEA, 2023).

There are many types of biofuels produced through different processes using wide range feedstocks. The most established products, suitable for shipping, are:

- Fatty Acid Methyl Ester (FAME), (defined by the specifications of EN 14214 and ASTM D 6754), often referred to by some as biodiesel, and
- Hydrotreated Vegetable Oil (HVO) (defined by the paraffinic fuel specification EN 15940), a synthetic diesel very often referred also to as green or renewable diesel.

The drop-in nature of most liquid biofuels enables their use in the majority of the existing conventional petroleum fuel world fleet, providing GHG emissions reduction without significant modifications to engines and equipment. Biofuels are mostly similar in characteristics to their equivalent oil-based fuels, and require similar safety mitigations for transportation, bunkering, and handling.

Clarksons predicts that around two-thirds of existing ships are unlikely to be retrofitted for future fuels due to economic factors. For conventionally fuelled ships too old and uneconomic for investment in the retrofits required to adopt fuels like LNG, methanol, and ammonia, biofuels provide an opportunity to meet their carbon reduction targets with minimal capex requirements.

The main challenge to the adoption of biofuels is their scalability and global availability in the long term, in conjunction with the diverse nature of the feedstocks and processing methods used in their creation. Demand competition from other transport and industrial sectors is expected to increase in the coming decades, for both FAME and paraffinic products. Sustainability concerns over land and water use in the production of feedstocks must be addressed through certification schemes in order to increase buyer confidence and release more feedstock for production purposes.

The chemical composition and physical characteristics of biofuels vary depending on feedstock and production process; it should be understood therefore that 'no one biofuel product can be used as a reference fuel for all biofuels.

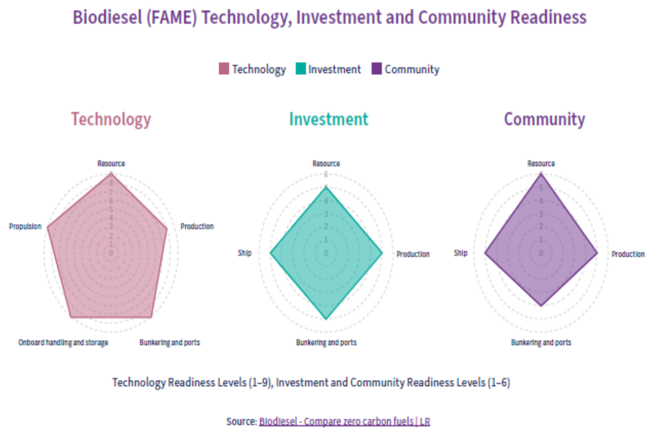
Bio-methanol and bio-methane

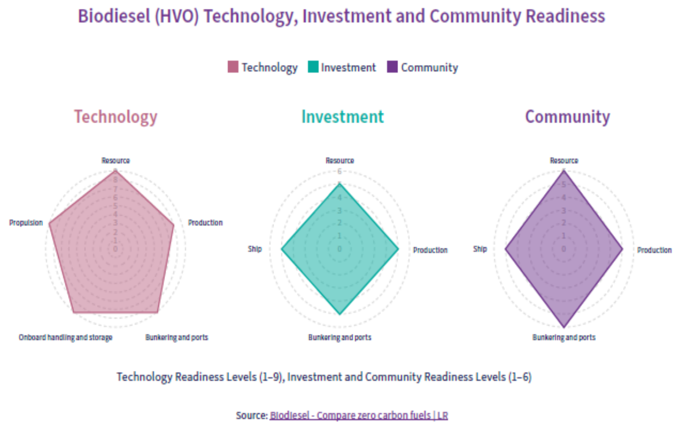
This technical paper focuses on liquid biofuels of FAME and HVO, which serve as tried and tested 'drop-in' replacements for conventional fuels. There are other bio-derived fuels with applications in the maritime industry, such as bio-methanol and bio-methane, which share an origin in biomass but differ significantly in regulatory, technology, and operational considerations. The main application of bio-methane in the maritime industry will be for liquefaction to create bio-LNG.

Readiness of Biofuels as a Marine Fuel

LR has collaborated with industry stakeholders to build a comprehensive assessment of different aspects of the fuel supply chain from production to delivery onboard, and the technologies for use as a fuel onboard for power generation.
A lot of focus is often put on technology readiness level (TRL) of new technology, which assesses the maturity of solutions to becoming marine application ready, however this is just one element of readiness. The industry's willingness to adopt a technology is also based on its investment readiness level (IRL), which signifies whether the business case is hypothetical or well proven.

Community readiness level (CRL) is also crucial, identifying whether the frameworks for safe and publicly acceptable use of a technology and fuel are in place. Biofuels are shown as among the readiest alternative fuels across TRL, IRL and CRL, with the most mature supply chains. The main readiness challenges identified for biofuels in shipping include feedstock availability, scaling global production and supply chains, completion of LCA guidelines at the IMO, and the need for long term studies into biofuel storage and use. More details on the ratings and comparison to other alternative fuels is available at www.lr.org/ZCFM





Safety

General Safety and Toxicity Issues

FAME

FAME is not acutely toxic, is biodegradable, and is classified as not hazardous according to regulation (EC) 1272/2008 and by

CONCAWE Guidelines for handling and blending FAME (2009). It is combustible but considered not readily flammable. It may cause minor eye irritation, and fine mists or vapours created by heating FAME may irritate mucous membranes, and cause dizziness and nausea. Combustion of FAME emits toxic fumes and particulates. Eye protection must be worn when handling FAME, along with chemical resistant gloves.

HVO

Repeated exposure to HVO may cause skin dryness or cracking. Spray/mists may cause respiratory tract irritation. Entry into the lungs following ingestion or vomiting may cause chemical pneumonitis, which can be fatal. HVO is flammable in liquid and vapour forms and will burn readily if ignited or exposed to sufficient heat. Risks related to fire and explosion including electrical and static ignition sources are similar to those for diesel. HVO vapour is heavier than air and could potentially flash back in flammable concentrations. Combustion of HVO emits toxic fumes and particulates. Eye protection must be worn when handling FAME, along with chemical resistant gloves.

Specific Bunkering Considerations

Liquid biofuels are generally similar in hazard profile to common fossil-derived marine fuels. The European Maritime Safety Agency (EMSA) released its Safe Bunkering of Biofuels report in 2023, which details regulatory and safety considerations in the bunkering of bio-methanol, HVO, FAME, bio-dimethyl ether (bio-DME) and Bio-Fischer-Tropsch-diesel (bio-FT-diesel).

The report found no specific standards or guidelines for bunkering HVO or FAME, owing to their similar properties to fossil-derived diesel. The report suggests a risk-based approach to bunkering biofuels as most appropriate until their use matures, and specific guidance is developed.

For FAME, for which a number of subsets of grades are currently being developed for marine purposes, quality monitoring should be employed to ensure the product remains within specification over periods of prolonged storage, as the fuel may deteriorate more rapidly over time, being more easily oxidised (See Chap 2.3 on fuel quality). Care should be taken to avoid water contamination in FAME and FAME blends to avoid the absorption of water which can lead to microbial growth in the fuel.

The Port of Singapore gives no specific bunkering instructions for biofuels, referring instead to its general bunkering rules SS 660. The port considers both HVO and FAME to fall under MSC-MEPC.2/Circ.17 when blended, and Chapter 17 of the IBC code when not blended, requiring an IBC Code compliant ship for bunkering. It also states that the bunker supplier: “shall ensure that the Flag Administration, and Class Society of the bunker craft approve or have no objection to the loading, carriage, and delivery of the biofuel onboard the bunker barge”.

Comparison table of key properties liquid biofuel with marine gas oil:

Fuel property	Unit	MGO	HVO	FAME
Flashpoint	°C	≥ 60	≥61	≥120 - <180
LFL and UFL	% v/v	0.5-7.5	0.8 – 5.4	-
Auto-ignition temperature	°C	240-350	204	≥256 - ≤266
Normal Boiling point	°C	160-400	180 – 390	≥302.5-≤570
Specific gravity (Air = 1)	-	> 1	> 1 (V)	> 1 (V)
Specific gravity (Water = 1)	-	< 1	0.77– 0.79	0.87-0.89
Vapour pressure	mbar	<0.4 (20°C)	0.4 (20°C)	2 to 6
Density (15°C)	kg/m³	800-910 (15°C)	765 – 800	878-895
Kinematic viscosity (40°C)	mm²/s	≥ 1.4 (40°C)	2.6	3.8 – 5.0
Oxidation stability*	[g/m³] or [h]	Max 25 g/m³	Max 25 g/m³	Min 8 h
Water solubility	g/litre	Negligible	Non-soluble	Negligible
Typical Net Calorific Values	MJ/Kg	43	44	37

Source: EMSA Safe Bunkering of Biofuels, 2023

*Test methods differ for HVO (ISO 12205) and FAME (EN 15751)

IBC Code

As detailed in MSC-MEPC.2/Circ.17, biofuel blends containing more than 25% FAME fall under MARPOL Annex II - Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk, and the IBC Code, which lists such blends as Category X – “Noxious Liquid Substances”. Bunker tankers carrying more than B25 fuel blends are therefore subject to the IBC Code requirements, while those carrying blends of less than or equal to 25% FAME are subject to the requirements of MARPOL Annex I - Prevention of Pollution by Oil.

While these regulations do not specify bunkering procedures, they do currently create a barrier to the wider provision of biofuels by effectively preventing the carriage of more than B25 biofuel blends by the conventional bunker tankers, which are designed for the carriage of petroleum-derived hydrocarbon fuels. A particular challenge with this B25 limit is that it is lower than the commonly sought after biofuel blend B30, which therefore cannot be carried by Annex I bunker tankers.

Upgrading tankers to meet the full IBC Code requirements would, for the most part, not be economically viable. Alternatively, an Annex II bunker tanker would be more expensive than Annex I equivalent, and it could take two to three years for such a ship to be built and delivered, potentially delaying the general provision of biofuels.

Addressing biofuel blend limits to enable the carriage and supply of biofuel on Annex I bunker tankers would be one way to remove an operational barrier to their wider adoption. In a submission to MEPC81 in March 2024, India and the Republic of Korea called for the urgent provision of an MEPC circular "for tentatively allowing the conventional bunkering vessels certified for carriage of oil fuels under MARPOL Annex I to transport up to B30 biofuels which are mostly preferred in the market." The International Bunker Industry Association (IBIA) noted the Annex II blend limit issue in its own submission, and the matter was referred to the IMO Working Group on Evaluation of Safety and Pollution Hazards, ESPH30. The meeting will be held in October 2024, with a view to advising MEPC on the way forward.

However, dual certification of an Annex I bunker tanker for the additional carriage of FAME blends up to B100 under the IBC Code could be much more readily achieved with less downtime. For the liquids it lists, the IBC Code's standards covering the bulk carriage of a wide range of diverse products, whereas a bunker tanker carries only a very limited range of products and does not require tank cleaning between loadings. Furthermore, a bunker tanker by the nature of its trade will have particular manoeuvring and cargo arrangements suitable for its trade sector.

In order to obtain a limited product range dual (Petroleum / FAME) certification, a gap-analysis would need to be carried out on an Annex I bunker tanker to assess what would be required for Flag and Coastal State Administrations to consider certifying and accepting the ship as being able to carry Annex II FAME blends up to B100. LR offers such a gap analysis through its Marine Advisory Services, whereby many existing Annex I bunker tankers could have greater versatility by being also certified to carry FAME up to 100%.

Biofuel Bunker Quality

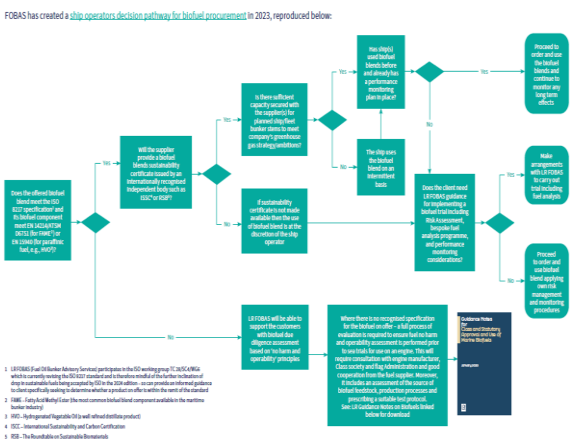
Quality standards are in place for the most common and established biofuels and blend inputs such as FAME and HVO. Processes are still being developed to account for special and novel biofuel types. Quality controls for biofuel blends rely on suppliers using quality blending inputs, which they have determined as suitable for blending into a marine fuel, in the same manner as applied for conventional petroleum derived fuels.

Other alternative biomass-based products with unestablished and defined specifications.

Under Class requirements, engines are to undergo shipboard trials to demonstrate their suitability for burning unestablished/untested special liquid biofuels and other renewable waste-based products such as rubber tyres processed through pyrolysis. To attain acceptance for a sea-trial, a pretrial on shore assessment of the fuel's suitability for on board ship use is to be established. Further to this, the ship is advised to prepare an implementation plan to include a risk assessment and performance monitoring programme.

LR recommends that biofuel for marine use meets a declared standard and that the technical and operational parameters of the biofuel or biofuel blend as supplied comply with the ISO 8217:2024 Petroleum products from petroleum, synthetic and renewable sources — Fuels (class F) — Specifications of marine fuels standard as far as possible, and that any deviations are declared, understood, and are part of the agreed specification between purchaser and supplier. The updated ISO 8217:2024 provides the operational and technical specifications to be met by drop-in fuels – allowing FAME blends ranging from de minimis to B100. For FAME biofuels supplied under the ISO 8217 marine fuel standard as a B100 or blend, it is required that the FAME product is compliant with the EN 14214 Liquid petroleum products – Fatty acid methyl esters (FAME) for use in diesel engines and heating applications – Requirements and test methods, or ASTM D6751 Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels standard. For HVO biofuels — which are indistinguishable to distillates marine fuels — and HVO blends, it is required by ISO 8217 that the fuel is compliant with the EN 15940 Automotive fuels – Paraffinic diesel from synthesis or hydrotreatment – Requirements and test methods standard. The sustainability certification schemes for biofuels approved by ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), as referenced in IMO MEPC.1/Circ.905, are the International Sustainability and Carbon Certification (ISCC) and Roundtable on Sustainable Biomaterials (RSB).

For a ship operators decision pathway for biofuel procurement see figure below



Drivers for Biofuels - Regulations and Lifecycle Assessment

The regulatory drivers for biofuels are goal-based decarbonisation initiatives and not specific to biofuels. They encourage owners and operators to switch their ships to less carbon-intensive operations; the compatibility of biofuels with most of the current world fleet make them a leading candidate for decarbonising shipping operations in the near term.

EU Regulations

Some of the most advanced regulations are from the European Union (EU). Shipping companies need to be aware of five elements of the EU Fit for 55 package that impact shipping. The Fit for 55 package is the bloc's overarching decarbonisation strategy across society and business. It includes:

- A revised Monitoring, reporting, and verification of greenhouse gas emissions from maritime transport regulation (EU MRV)
- A revised Directive on the EU emissions trading system (EU ETS)
- A new FuelEU Maritime Regulation

EU Emissions Trading System

As of 1 January 2024, passenger and cargo ships of 5,000GT and over calling at EEA ports became subject to the region's emission trading scheme. (Additional ship types and sizes will fall into scope of the scheme in future years). Shipping companies with responsibility for such ships will need to buy allowances to cover greenhouse gas (GHG) emissions (CO_2, CH_4 and N_2O) reported under EU MRV, for intra-EEA (EU plus Norway and Iceland), in EEA ports and for half of the GHG emissions created during voyages to and from the EEA. From 1 January 2024, EU allowances for CO_2 emissions will have to be surrendered under EU ETS, with CH_4 and N_2O emissions falling into scope of ETS from 2026.

The FuelEU Maritime Regulation requires submission of a monitoring plan, separate to the MRV monitoring plan. Assessment for each ship should indicate factor of energy used on board. From 1 January 2025, each ship must implement the FuelEU monitoring plan to collect the required data. The full year's data will then be submitted for verification by 30 March of the following year.

Marine engines

Under class requirements, engines are to undergo shipboard trials to demonstrate their suitability for burning residual fuels or 'other special fuels', which is interpreted as also being applicable to liquid biofuels. The process is detailed in LR's Guidance Notes for Class and Statutory Approval and Use of Marine Biofuels (January 2023).

For ships engines, the guidance recommends the following issues be considered through confirmation with the engine OEM, fuel supplier, or long- term testing and condition monitoring:

- Base Number (BN) specification of the cylinder lubricating oil and feed rate suitable for the fuel sulphur content.
- Monitoring of cylinder liner and ring pack condition and wear rates, e.g. visual inspection, oil drain down analyses, measurement, verification of Time Between Overhauls (TBO).
- Fuel lubricity, acid number and biofuel properties for potential impacts on fuel system components, fuel injection equipment, common rail systems and control units, as applicable.
- Suitability and potential impacts of the use of low viscosity biofuels.
- Thermal management of the biofuel including required biofuel heating (or cooling) and fuel drain arrangements.
- Materials of fuel system components including seals exposed to biofuel.
- Solvent effect of biofuels on fuel system deposits and coatings.
- Compatibility and deposit impacts on sensors, instrumentation or monitoring and control systems.
- Impact on trunk piston engine lubricating oil from biofuel combustion.
- Influence on exhaust emission abatement plant operation, e.g. Selective Catalytic Reduction (SCR) catalysts and monitoring and control systems.

NOX emissions

The use of biofuels in certain engines and conditions can lead to higher NOx emissions when compared to its petroleum-based distillate fuels. (Refer to 2.3 for regulatory guidance)

LR's technical report on NOx from marine diesel engines using biofuels consolidates LR's experiences with its shipping clients and industry feedback with sea trial findings on NOx emissions when using biofuels. It addresses the requirement that fuel oil derived by methods other than petroleum refining shall not cause an engine to exceed the applicable NOx emissions limit set forth in regulation 13 of MARPOL Annex VI (MARPOL Annex VI Regulation 18.3.2.2).

The main findings on NOx emissions in the report are:

1. In terms of magnitude, NOx emissions were not significantly increased across the load range, in any instances by the use of any of the biofuels trialled.
2. In terms of range, the majority of the NOx emission changes resulting from the use of those biofuels were no more than that level of trial repeatability.
3. Each combination of biofuel and engine has its own particular NOx emission characteristics.
4. For all the biofuel trials undertaken, there were no specific engine adjustments; the

NOx critical settings or operating values were retained, as given in the respective Technical Files, as they would be for the use of the petroleum derived fuels.

Conclusion

Biofuels stand out among future shipping fuels because most of the world's fleet can already use them. As a ‘drop-in’ replacement for fossil fuels, they provide an immediate, cost-effective way to cut carbon emissions without major investments. They also significantly reduce emissions of hydrocarbons, particulate matter, and carbon monoxide.

Their similarity to fossil fuels also brings operational benefits, as existing safety protocols for handling petroleum products can be applied with minor adjustments. Extensive research has shown biofuels are safe for use in internal combustion engines, requiring minimal crew training compared to other future fuels.

The usage of biofuels in shipping is growing rapidly, driven by their lower environmental impact and regulatory advantages, despite higher costs. However, their availability remains a major challenge in both the near and long term. Studies show mixed forecasts for biomass and biofuel supply in the coming decades. Currently, biofuels are used mainly as blend components due to limited production volumes.

For regular use, biofuels must become more widely available at key bunkering locations. Moreover, emerging biofuels, such as those from unconventional feedstocks like CNSL or organic oils, need certification to be deemed safe for ship machinery. Trusted certification programs will be crucial in building buyer confidence and proving the sustainability of biofuels. Schemes like RSB and ISCC will help assess the carbon intensity and verify the origins of biofuels, ensuring they meet zero or near-zero GHG emission standards. The adoption of biofuels will depend on effective regulation to reduce emissions from ships. For biofuels to make commercial sense, the price premium for biofuels will need to be narrowed through mechanisms such as a carbon tax to incentivise the adoption of greener fuels. Depending on future carbon pricing, biofuels could become cost competitive with traditional fuels within a decade.

References

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CIMAC Guideline 05 2024. Design and operation of fuel cleaning systems for diesel engines
CIMAC Guideline 01 2024. The Interpretation of Marine Fuel Analysis Test Results
CIMAC Guideline 01 2019. Marine fuel handling in connection to stability and compatibility.
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Standards
ISO 8217:2024 Products from petroleum, synthetic and renewable sources — Fuels (class F) — Specifications of marine fuels - ISO
EN 14214 Liquid petroleum products – Fatty acid methyl esters (FAME) for use in diesel engines and heating applications – Requirements and test methods
ASTM D6751 Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels
EN 15940 Automotive fuels – Paraffinic diesel from synthesis or hydrotreatment – Requirements and test methods.
EN 590 Automotive fuels – Diesel – Requirements and test methods