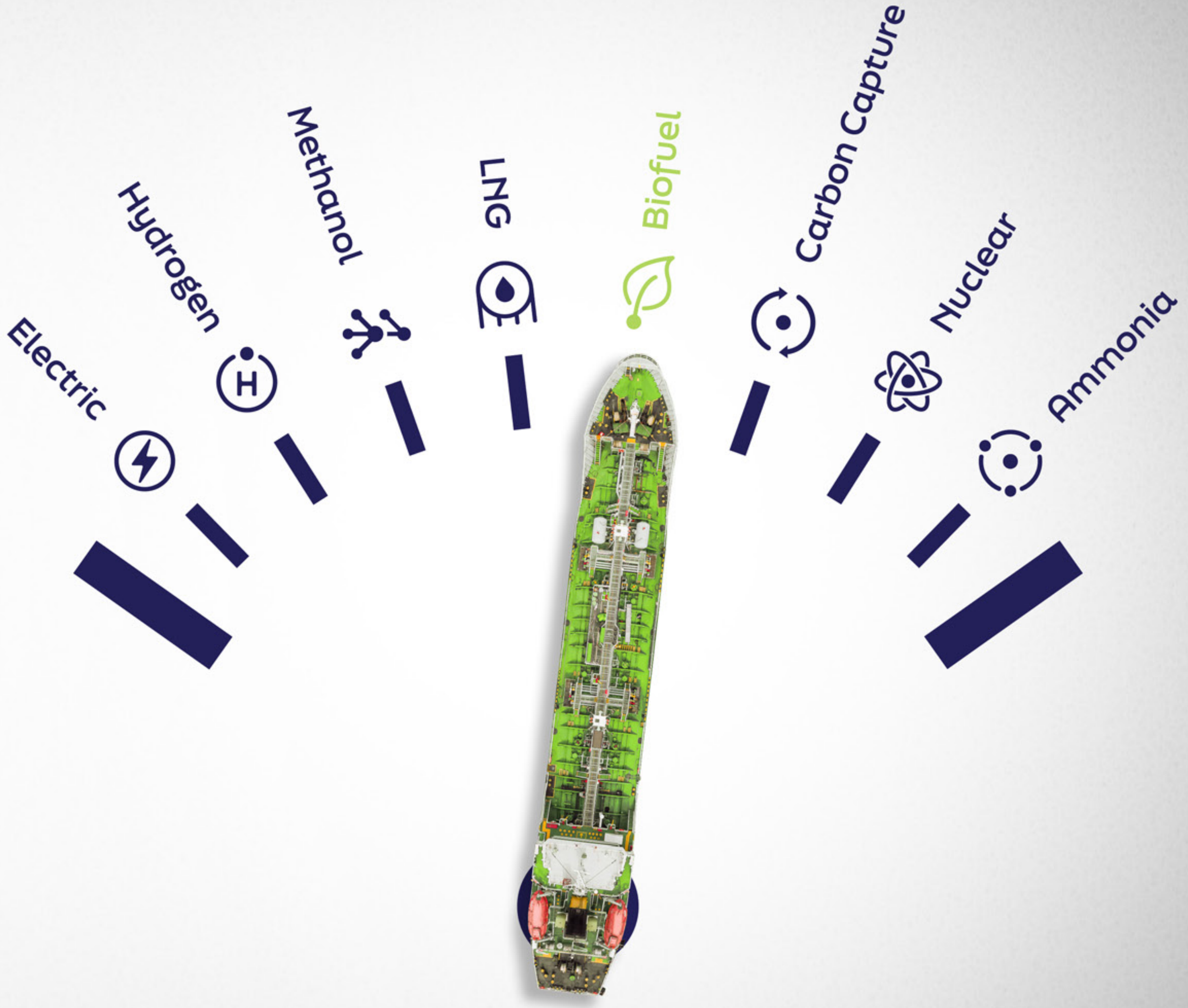
Fuel for thought

Biofuel

Expert insights into the future of alternative fuels

Your trusted adviser in alternative and low carbon maritime fuel



Contents

Preface

1 Introduction

2 Safety

3 Drivers for biofuels

4 Biofuel production and supply

5 Technology readiness

6 Summary and conclusion

7 Other resources and annexes

Preface

The challenge of maritime decarbonisation is not that it is happening, but that it needs to happen so quickly.

The evolution of sail to its heyday of the great tea clippers took centuries, and the transition to coal-powered steam ships was driven by greater supply chain mobility and speed. The arrival of diesel-fuelled engines led to a new type of ship propulsion and power generation, but this has taken close to one hundred years to evolve to where they are today.

Each shift had a dramatic impact on the cost, speed and efficiency of shipping. The energy transition that the maritime industry faces today is distinct from those earlier evolutions. It is not driven solely by technological advances or economics, but by an environmental imperative, increasingly underscored by social pressure, policy, and regulatory demands to reduce emissions.

Decisions are being made today with some commercial uncertainty, but in the knowledge that regulations, rather than economics, will push forward change. In this context, shipowners, charterers, insurers, financial markets and technology suppliers are seeking a better understanding of where the industry is heading.

Lloyd’s Register (LR) is committed to providing trusted advice and to leading the maritime industry safely and sustainably through the energy transition. Our new Fuel for Thought series puts decarbonisation options under the spotlight, analysing policy developments, market trends, supply and demand mechanics and safety implications. Each edition focuses on a specific fuel or technology, creating a reference point for the industry to overcome upcoming challenges as it faces the next great shift in ship propulsion.

This edition of Fuel for Thought focuses on biofuels which are drop-in replacements for fossil fuels produced from biomass. The compatibility of most biofuels with existing engine technologies and their improved well-to-wake greenhouse gas (GHG) emissions make biofuels a valuable tool for decarbonising the shipping industry.

Other editions of Fuel for Thought, dedicated to methanol, ammonia, and other alternative fuels, can be found on the Fuel for Thought hub: www.lr.org/fuelforthought

1.1

Chapter 1: Introduction

Similar to other sectors, the shipping industry is on a journey toward decarbonisation. As we advance, it becomes increasingly clear that this endeavor is complex, presenting a tapestry of challenges: economic implications, technological uncertainties, and regulatory hurdles.

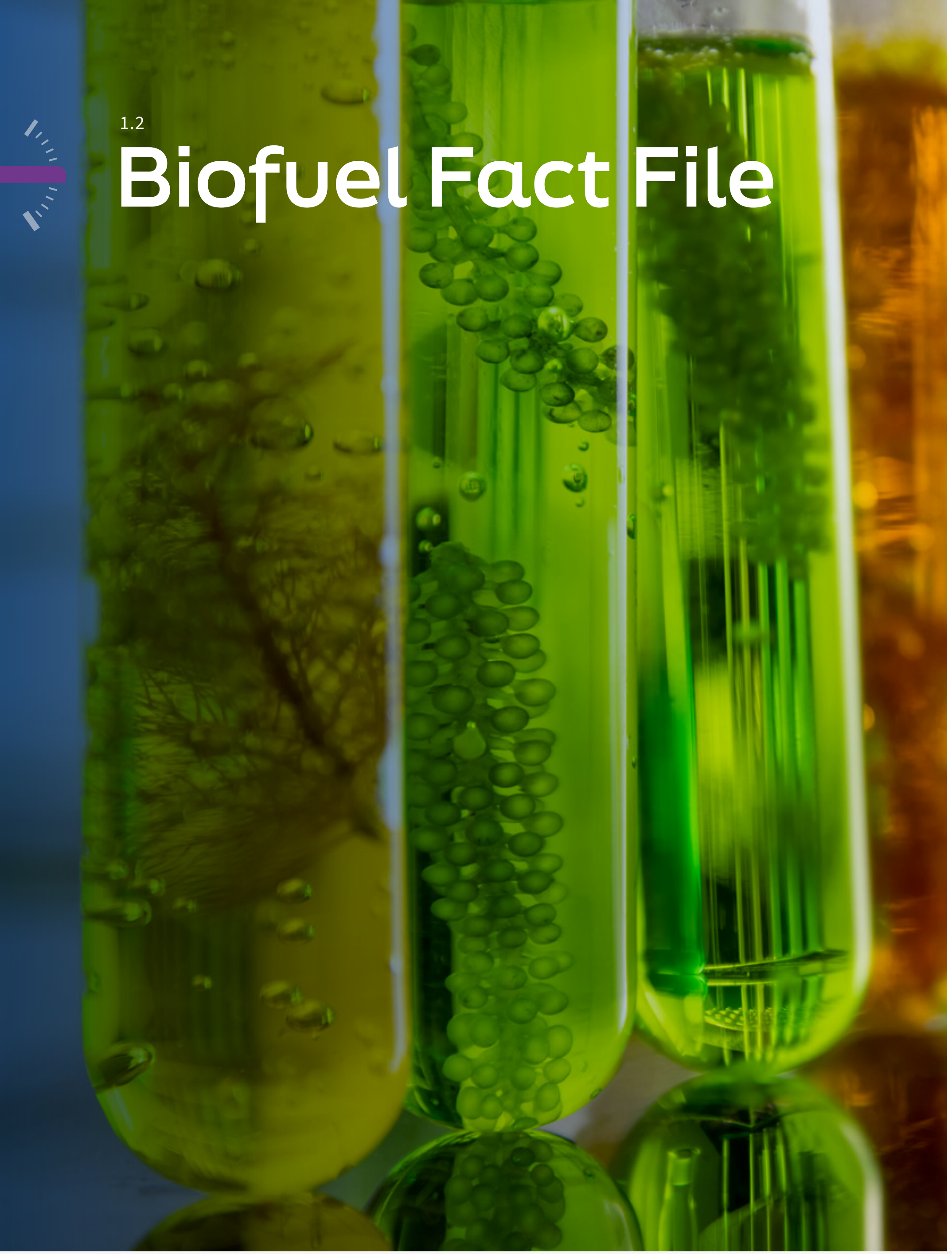
Yet, there are also significant opportunities: harnessing human creativity to pioneer clean technologies, enhancing operational efficiencies, and fostering exciting investments. These efforts are crucial to reduce the sector's impact on the planet and preserve it for current and future generations.

I am confident that the shipping industry is informed, mindful, and collectively prepared to contribute to this global effort.

Lloyd's Register (LR) with their 'Fuel for Thought®' series is a perfect example of this spirit of collaboration, sharing, and education. LR aids in steering us through the intricacies of decarbonisation by offering comprehensive insights and highlighting the current pain points that hinder the wider adoption of existing solutions.

The biofuel analysis provided is thorough and well-researched. I strongly urge my peers in the shipping industry, along with regulators and policymakers, who are not yet acquainted with the topic, to invest time in reading this document and the forthcoming publications.

Olivier Josse
Marine Fuels Lead, Ocean Transportation
Cargill International SA



1.2

Biofuel Fact File

Biofuel is a generic term for energy sources created from the processing of recently created organic material, in other words non- fossil sources. Biofuels can be solid, liquid or gaseous, and are derived from feedstock biomass such as plant material, algae, vegetable oils and fats from animal waste. Feedstocks are typically also sourced from industrial and municipal waste streams.

Biofuels 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.

Created from a wide range of feedstocks including processed cooking oils and fats, FAME and HVO can both be used as a standalone fuel, but FAME is more commonly blended with their fossil-derived marine fuel equivalents, and HVO less so due its premium price.

A drop-in fuel as supplied, with a flash point not less than 60°C, is one that replaces a fuel oil previously used in a ship's fuel oil systems and combustion machinery without the need for either alterations or adjustments outside those already available onboard.

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.

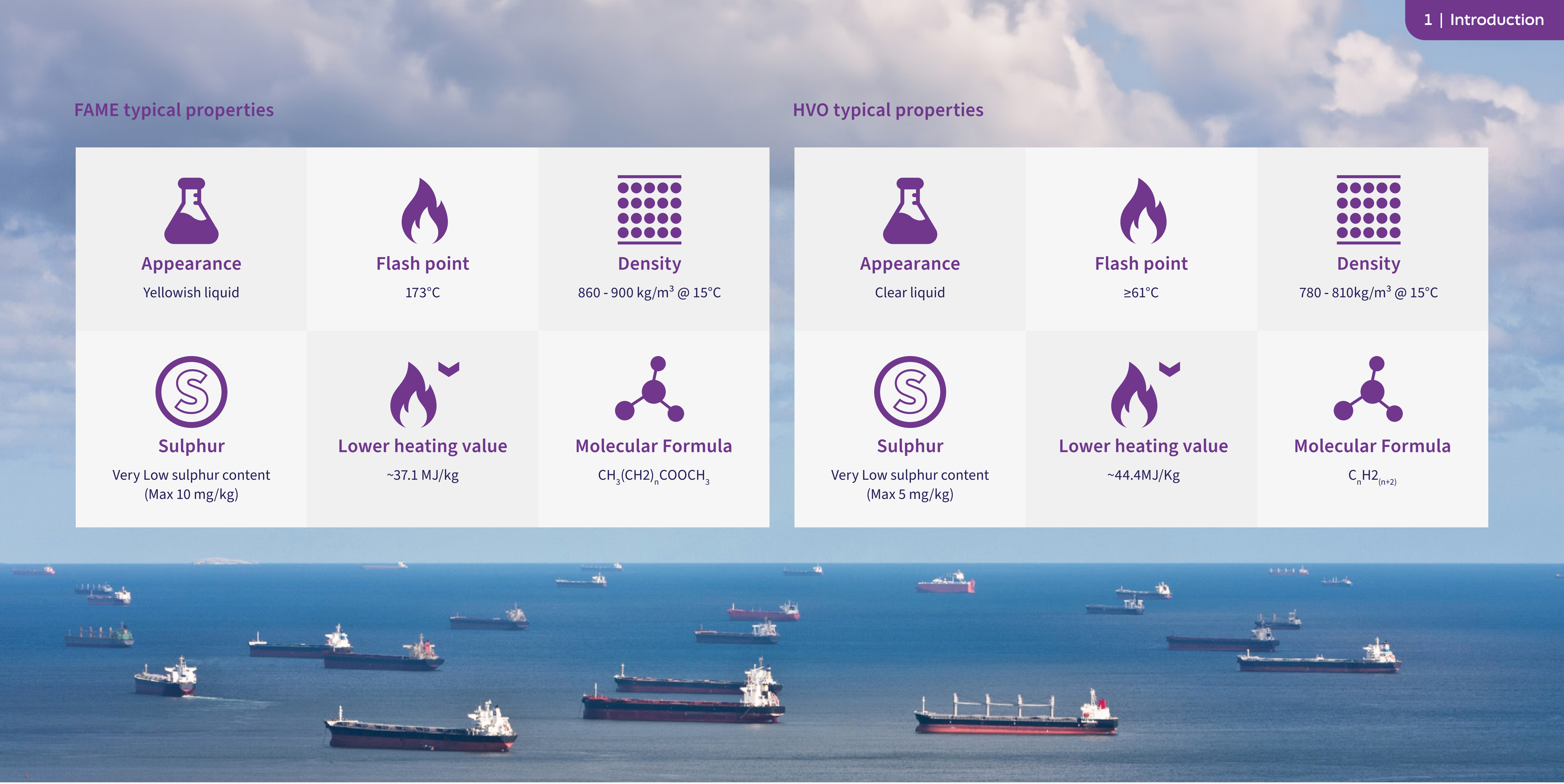
Clarksons predicts that around two-thirds of existing ships are unlikely to be retrofitted for future fuels due to economic factors. For conventionally fuelled ships too old and uneconomic for investment in the retrofits required to adopt fuels like LNG, methanol, and ammonia, biofuels provide an opportunity 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 report 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. For more relevant information on the use of bio-methanol in shipping, please refer to Fuel for Thought Methanol. The main application of bio-methane in the maritime industry will be for liquefaction to create bio-LNG and will be explored in the future Fuel for Thought LNG publication.



FAME typical properties

Property	Value
Appearance	Yellowish liquid
Flash point	173°C
Density	860 - 900 kg/m^3 @ 15°C
Sulphur	Very Low sulphur content (Max 10 mg/kg)
Lower heating value	~37.1 MJ/kg
Molecular Formula	$CH_3(CH2)_nCOOCH_3$

HVO typical properties

Property	Value
Appearance	Clear liquid
Flash point	≥61°C
Density	780 - 810kg/m^3 @ 15°C
Sulphur	Very Low sulphur content (Max 5 mg/kg)
Lower heating value	~44.4MJ/Kg
Molecular Formula	$C_nH2_{(n+2)}$

Advantages and disadvantages of biofuels

The following table gives brief insight into the more general benefits of FAME and HVO biofuels as a marine fuel and the challenges.

FAME advantages and potential
Immediate GHG emissions savings potential
Drop-In replacement for conventional petroleum derived marine liquid fuels. making it available for use for most of the global fleet, without large capital investment
Easily applied to ships marine combustion machinery due to: • enhanced combustion properties • good lubricity characteristic • compatibility with both distillate and residual fuel oils
Safety aspects for transport and handling are broadly similar to that of the petroleum derived fuels in use.
Lower SOx, PM, and lifecycle CO_2 emissions
Biodegradable, reducing environmental contamination risk
Extensive positive experience using functionally similar fuels and engines

FAME challenges and issues
Onboard combustion creates GHG, mitigated under life cycle assessment criteria
Increased potential for microbial contamination risk
Increased NOx emissions in some cases. (IMO produced its unified interpretation guidance on this in way of the MARPOL Annex VI Regulations 18.3.2. (MEPC .1 – Circ.795 Rev9) to address approach to this regulation)
Wide spectrum of biofuels - one biofuel cannot be used as a reference for all – each type needs to have its performance and suitability assessed prior to any attempt to carry out a sea trial
Concern for persistent floaters if FAME spilled in the ocean, a particular issue with IBC Code Annex II tankers which carry FAME as a cargo. Like petroleum fuels, FAME should not be washed overboard
Lack of availability as a result of competing demand from other transport and industrial sectors and the increased demand from shipping
Competing demand from other transport and industrial sectors
Inferior cold flow properties and probable metal and sealing material compatibility issues need to be managed
Lower energy than petroleum fuel by around 10%
More expensive than fossil equivalents

HVO advantages and potential
Most preferred alternative to fossil diesel due to higher combustion performance, reduced emission of black carbon
Indistinguishable to distillate marine fuels – hence easily blended and handled
Energy density for HVO is on par with petroleum fuel
Immediate GHG emissions savings potential
Drop-In replacement for conventional petroleum derived marine liquid fuels
Extended storage stability characteristics make HVO attractive for ships requiring longer term storage properties
Lower SOx, PM, and lifecycle CO_2 emissions
Biodegradable, reducing environmental contamination risk
Extensive cross-industry experience using functionally similar fuels and engines

HVO challenges and issues
Limited availability
Onboard combustion creates GHG, mitigated under life cycle assessment criteria
Any increase in NOx emissions is insignificant, but less so than FAME due to very low oxygen content compared to FAME. (IMO produced its unified interpretation guidance on this in way of the MARPOL Annex VI Regulations 18.3.2. (MEPC .1 – Circ.795 Rev9) to address approach to this regulation)
Competing demand from other transport and industrial sectors, in particular from sustainable aviation fuels
More expensive than fossil equivalents
Sustainability LCA calculations are complex in view of the diversity of feedstock, location and processing methods

1.3

Readiness of biofuel 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.

The main production methods for future biofuel for the maritime industry are described in Chapter 4, while Chapter 5 details the onboard considerations for using biofuel and biofuel blends on board a ship. The Lloyd's Register Maritime Decarbonisation Hub has already developed a framework to measure the current readiness of several fuels in the Zero Carbon Fuel Monitor.

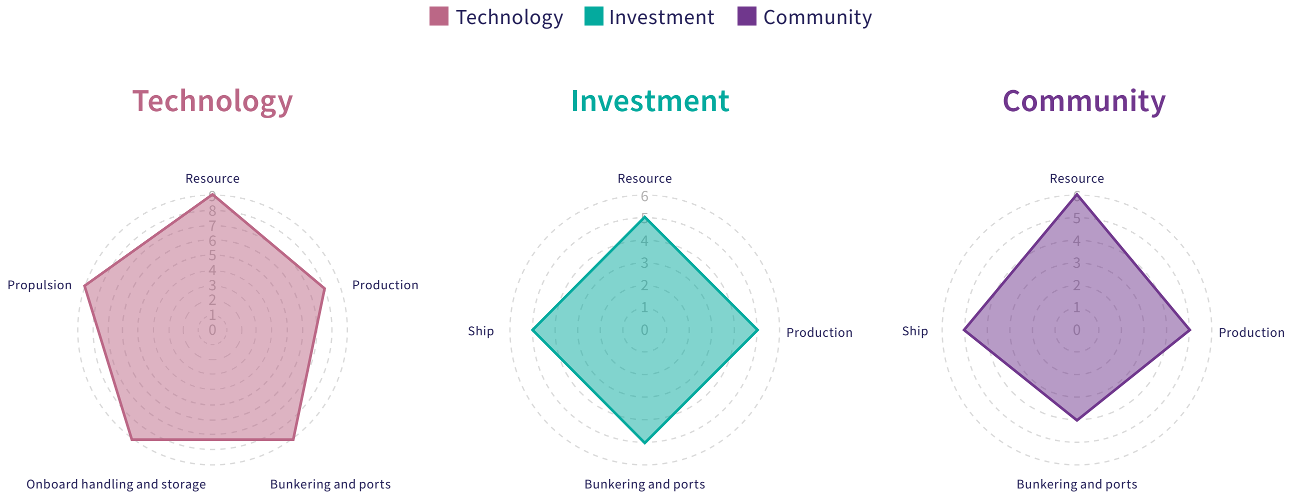
A lot of focus is often put on technology readiness level (TRL) of new technology, which assesses the maturity of solutions to becoming marine application ready, however this is just one element of readiness.

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.

TRL is assessed on a scale of one to nine, whilst IRL and CRL are on a scale of one to six. LR uses the outputs of the monitor to identify research, development and deployment projects that will advance solution readiness and accelerate a safe and sustainable transition to net zero GHG emissions. The detailed information in Zero Carbon Fuel Monitor Biofuel shows biofuels as among the most ready 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. Definitions of the IRL, TRL and CRL levels can be found in Annex 1.

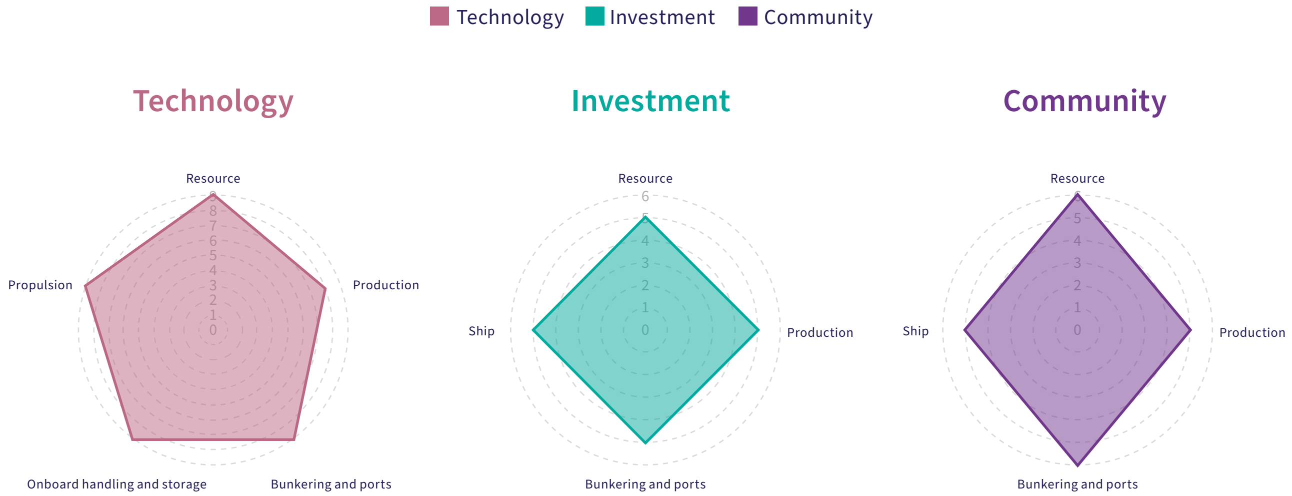
Biodiesel (FAME) Technology, Investment and Community Readiness



Technology Readiness Levels (1–9), Investment and Community Readiness Levels (1–6)

Source: [Biodiesel - Compare zero carbon fuels | LR]

Biodiesel (HVO) Technology, Investment and Community Readiness



Technology Readiness Levels (1–9), Investment and Community Readiness Levels (1–6)

Source: [Biodiesel - Compare zero carbon fuels | LR]

2.1

Chapter 2:
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.

As for all fuels supplied to a ship, a marine Safety Data Sheet should be supplied, to which extent the ship's crew should take note of and apply any safety considerations given.

2.2

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”.

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%.

2.3

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. For a sea-trial to proceed it will be subject to evidence being gathered to demonstrate the suitability of the novel fuel to be used on board ship. See Chapter 5 for more detail. 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.

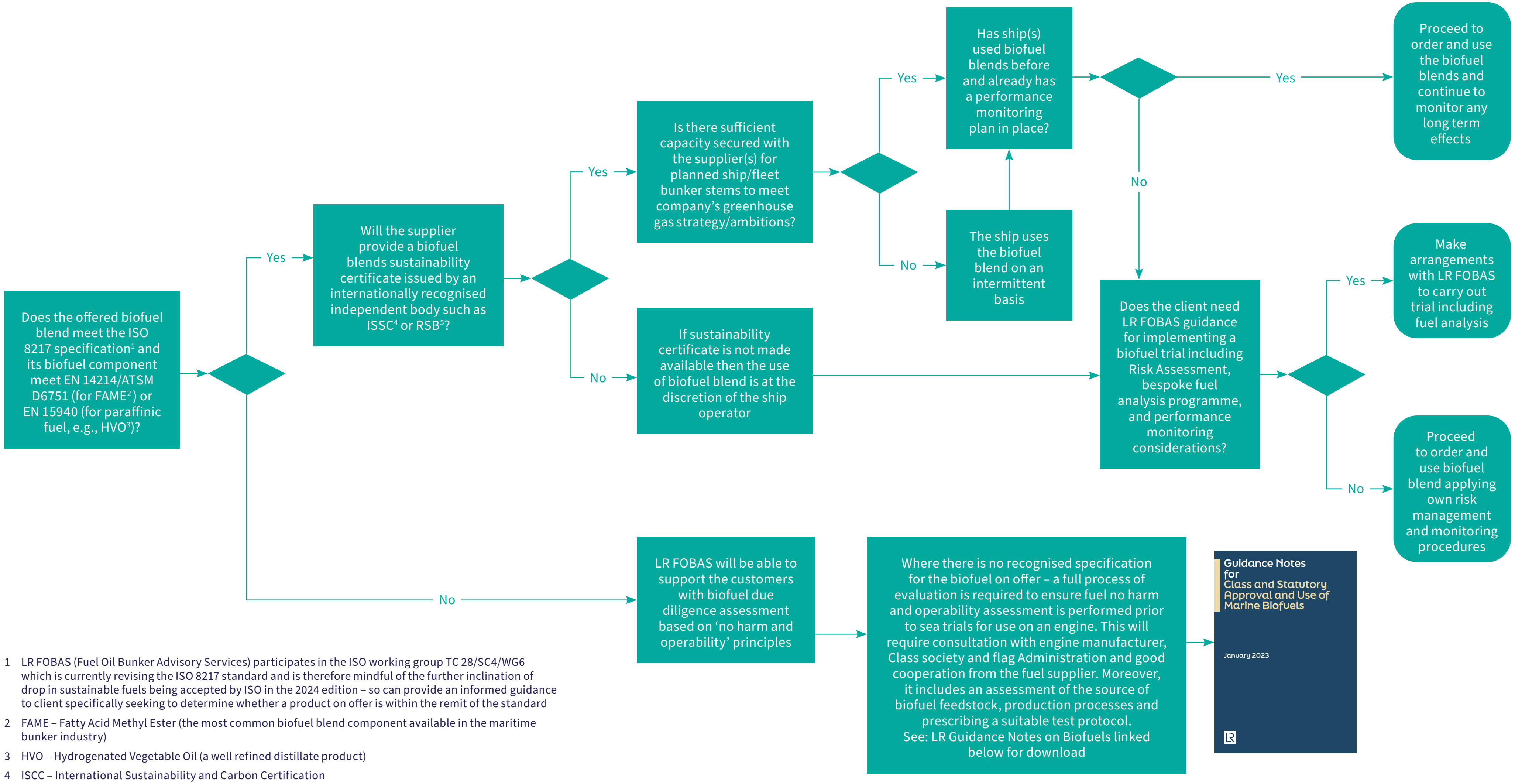
For HVO biofuels — which are indistinguishable to distillates marine fuels — and HVO blends, it is required by ISO 8217 that the fuel is compliant with the EN 15940 Automotive fuels – Paraffinic diesel from synthesis or hydrotreatment – Requirements and test methods standard.

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).

Biofuel testing

LR’s fuel oil bunker analysis service FOBAS has developed a bespoke testing programme for biofuels to support trouble free use in ship fuel systems and engines. FOBAS also supports customers with the onboard operational risk assessment before using biofuels and has developed a training programme for technical teams to support the use of renewable fuels.

FOBAS has created a ship operators decision pathway for biofuel procurement in 2023, reproduced below:



Does the offered biofuel blend meet the ISO 8217 specification[1] and its biofuel component meet EN 14214/ATSM D6751 (for FAME[2]) or EN 15940 (for paraffinic fuel, e.g., HVO[3])?

Yes → Will the supplier provide a biofuel blends sustainability certificate issued by an internationally recognised independent body such as ISSC[4] or RSB[5]?

Yes → Is there sufficient capacity secured with the supplier(s) for planned ship/fleet bunker stems to meet company’s greenhouse gas strategy/ambitions?

Yes → Has ship(s) used biofuel blends before and already has a performance monitoring plan in place?

No → The ship uses the biofuel blend on an intermittent basis

Yes → Proceed to order and use the biofuel blends and continue to monitor any long term effects

No → Does the client need LR FOBAS guidance for implementing a biofuel trial including Risk Assessment, bespoke fuel analysis programme, and performance monitoring considerations?

No → If sustainability certificate is not made available then the use of biofuel blend is at the discretion of the ship operator

Yes → Make arrangements with LR FOBAS to carry out trial including fuel analysis

No → Proceed to order and use biofuel blend applying own risk management and monitoring procedures

No → LR FOBAS will be able to support the customers with biofuel due diligence assessment based on ‘no harm and operability’ principles

Where there is no recognised specification for the biofuel on offer – a full process of evaluation is required to ensure fuel no harm and operability assessment is performed prior to sea trials for use on an engine. This will require consultation with engine manufacturer, Class society and flag Administration and good cooperation from the fuel supplier. Moreover, it includes an assessment of the source of biofuel feedstock, production processes and prescribing a suitable test protocol.
See: LR Guidance Notes on Biofuels linked below for download

Guidance Notes for
Class and Statutory Approval and Use of Marine Biofuels

January 2023

[1] LR FOBAS (Fuel Oil Bunker Advisory Services) participates in the ISO working group TC 28/SC4/WG6 which is currently revising the ISO 8217 standard and is therefore mindful of the further inclination of drop in sustainable fuels being accepted by ISO in the 2024 edition – so can provide an informed guidance to client specifically seeking to determine whether a product on offer is within the remit of the standard

[2] FAME – Fatty Acid Methyl Ester (the most common biofuel blend component available in the maritime bunker industry)

[3] HVO – Hydrogenated Vegetable Oil (a well refined distillate product)

[4] ISCC – International Sustainability and Carbon Certification

[5] RSB – The Roundtable on Sustainable Biomaterials

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/m^3	800-910 (15°C)	765 – 800	878-895
Kinematic viscosity (40°C)	mm^2/s	≥ 1.4 (40°C)	2.6	3.8 – 5.0
Oxidation stability*	[g/m^3] or [h]	Max 25 g/m^3	Max 25 g/m^3	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)

3.1

Chapter 3: Drivers for Biofuels

Regulations and lifecycle analysis

The following discussion focuses on various regulatory drivers behind the interest in the use of biofuels in shipping. For safety regulations, see Chapter 2 of this report. The regulatory drivers for biofuels are goal-based decarbonisation initiatives and not specific to biofuels. They do however 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
- Revised Alternative Fuels Infrastructure Regulation (AFIR)
- A revised Renewable Energy Directive (RED III)

Initial analysis highlights how these interlocking requirements will drive ship owners to adopt more stringent ship efficiency strategies, as well as low-carbon fuels such as biofuels.

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.

There are no free allowances as there were for other sectors in early stages of the EU ETS, but for shipping there will be a phase-in period where shipping companies will have to surrender allowances that cover only a percentage of the verified emissions for a particular year:

40%

of verified emissions reported for 2024

70%

of verified emissions reported for 2025

100%

of verified emissions reported for 2025 (and each year thereafter)

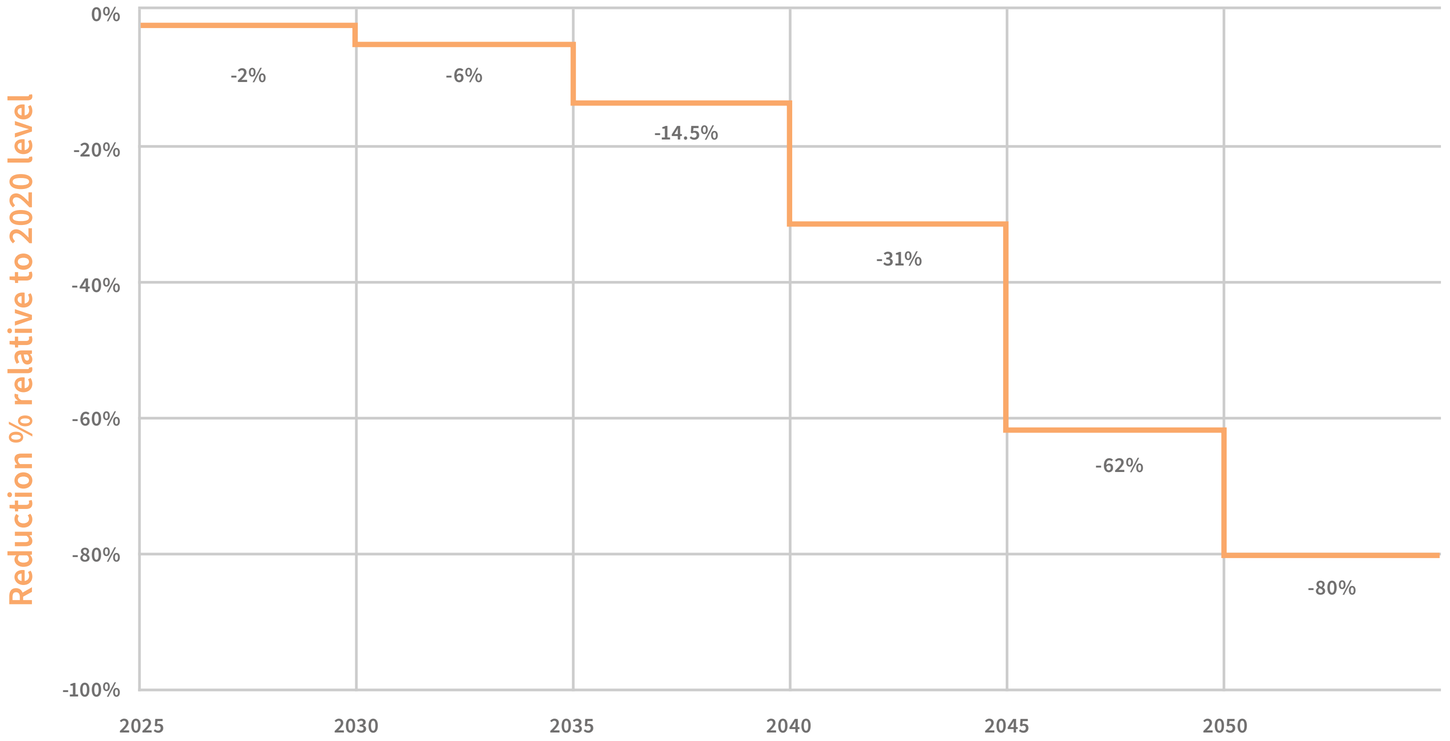
Surrender of allowances for each reported year will be required by 30 September of the following year.

Fuel EU Maritime

This regulation will operate alongside EU ETS and promotes the use of alternative low or zero carbon fuels. FuelEU creates demand for these fuels, noting that the carbon pricing policies in EU ETS (that in part, support improvements in energy efficiency) alone will not be sufficient to meet the EU's target to be a carbon neutral continent by 2050. From 1 January 2025, shipping companies, operating ships of over 5,000 GT calling at EEA ports, are required to meet stepped reductions in the GHG intensity of energy used onboard as shown in the table here, with an additional requirement to have zero at-berth emissions (for container and passenger ships) coming into effect from 2030.

The FuelEU Maritime Regulation requires submission of a monitoring plan, separate to the MRV monitoring plan. Assessment for each ship should indicate the chosen method used to monitor and report the amount, type and emission 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.

FuelEU Maritime Reduction Factor



Above: Reduction in GHG intensity of energy used on board from 2020 levels (%).

Pooling

Included in the provision of each ship's FuelEU data is the optional notification of the decision to pool ships. Pooling allows the responsible owners and managers to bring together ships that have been operated within a fleet, within a company or among companies. The objective is to encourage the deployment of new ships using low- or zero-GHG-emission solutions, instead of focusing only on improving the performance of existing ships. Pooling allows the benefits of one ship to be shared among a fleet to reduce the GHG intensity of the individual ships. The purpose of pooling is to incentivise the use of and investment in other alternative fuels, including biofuels.

As noted in this LR article, the ability to pool emissions surpluses has far-reaching significance. For example, a pool of ten boxships could avoid around €277 million in FuelEU Maritime penalties in five years (2030–2034) if they are joined by a single ship fuelled with e-methanol. That saving far outweighs the likely cost of building the methanol-fuelled containership.

GHG emission factors for fuels under Fuel EU Maritime

FuelEU Maritime provides a methodology for establishing the GHG intensity of the energy used on board, with well-to-tank and tank-to-wake calculations. Biofuels produced using feed and food crops are not eligible under FuelEU Maritime. Emissions factors for biofuels and biogas not produced from food or feed crops can be determined using the methodologies set out in Renewable Energy Directive (RED). GHG emissions savings from the use of biofuels must be at least 65% for fuels used in the transport sector (i.e. a baseline of 94 g CO_2eq/MJ).

RED contains default CO_2eq emissions values (without combustion) which can be used for all fuels whose pathways are included in RED, alternatively a RED-approved certification scheme can be used.

Table: Default emissions factors for biofuels under FuelEU Maritime

(source- FuelEU Maritime)

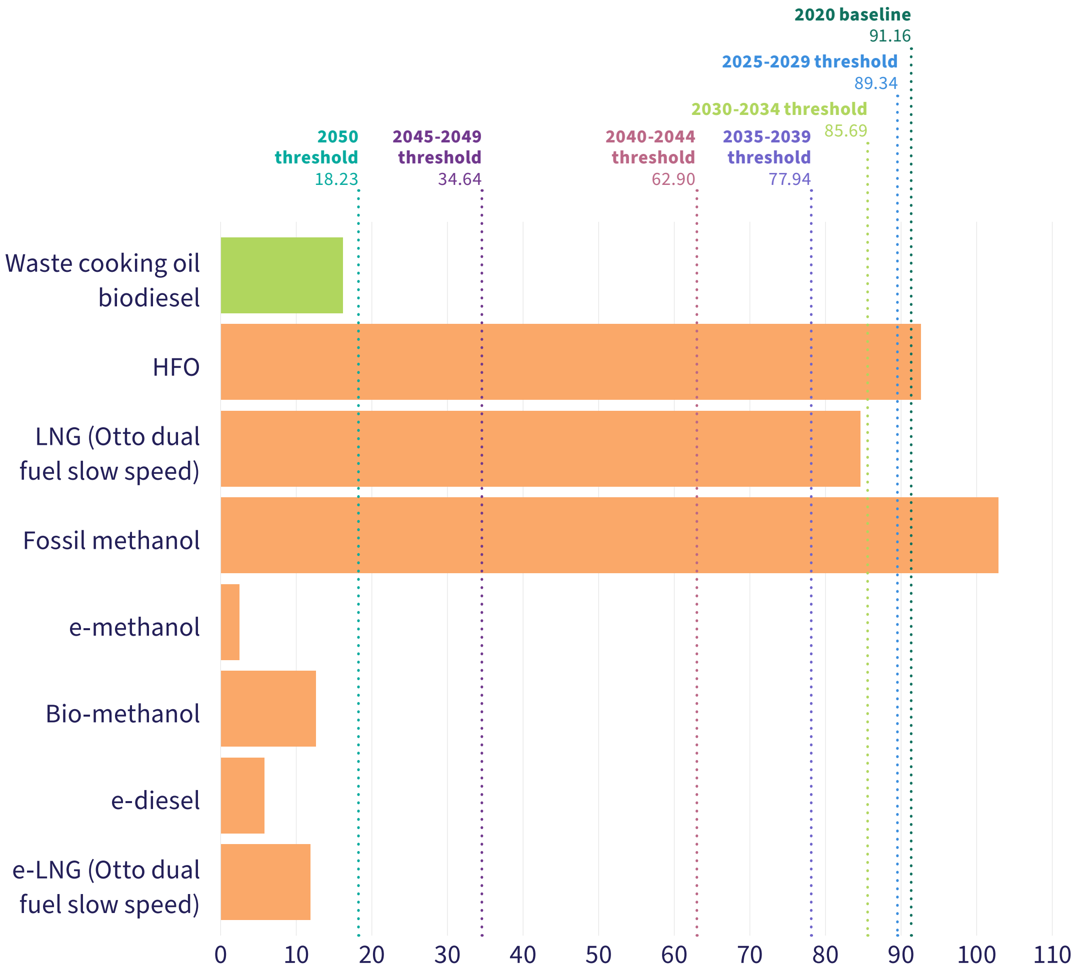
	Lower Calorific Value (MJ/g) WtT	CO_2eq emissions (gCO_2eq/MJ) WtT	Emission factor Cf for CO_2 ($gCO_2/gfuel$) TtW	Cf for methane in [$gCH_4/gfuel$] TtW	Cf for nitrous oxide in [$gN_2O/gfuel$] TtW
Biodiesel (FAME)	0,0372	Ref. to Directive (EU) 2018/2001	2,834	0,00005	0,00018
HVO (EN15940)	0,044	Ref. to Directive (EU) 2018/2001	3,115	0,00005	0,00018

The following chart compares the well-to-wake carbon intensity of marine fuels against the emissions thresholds under FuelEU and shows the potential ability of waste cooking oil FAME biofuels to meet those thresholds through until 2050 on a B100 basis. Through blending, cost and regulatory compliance can be balanced in the coming decades. Further information on this topic can be found in LR's research report Fit for 55: Managing compliance and optimising operations under the EU's new regime.

It is important to note the wide range in the GHG intensity of biofuels, depending on the feedstock used, travel distance from source to refinery, production process, and more. RED contains typical and default values for the GHG emissions savings from a range of biofuels by feedstock against a fossil comparator of 94 g CO_2eq/MJ, assuming no net carbon emissions from land-use change.

Biofuel production pathway	Greenhouse gas emissions saving against fossil comparator (94 g CO_2eq/MJ)
rape seed biodiesel	47%
sunflower biodiesel	52%
soybean biodiesel	50%
palm oil biodiesel (open effluent pond)	20%
palm oil biodiesel (process with methane capture at oil mill)	45%
waste cooking oil biodiesel	84%
HVO from rape seed	47%
HVO from sunflower	54%
HVO from soybean	51%
HVO from palm oil (open effluent pond)	22%
HVO from palm oil (process with methane capture at oil mill)	49%

Source: EU Directive 2018/2001



Sources: CE Delft, Mærsk Mc-Kinney Møller Centre for Zero Carbon Shipping.

The chart above is for illustration purposes only. WTT GHG intensity of fuels vary significantly based on factors including production method and feedstock, while TTW emissions vary factors including engine technology.

International regulations (International Maritime Organization)

In 2018, following the 2015 Paris Climate Agreement, the IMO agreed an initial GHG strategy to outline a pathway to reduce shipping emissions by focusing on CO_2 reductions from ships, to keep global warming to within 1.5 degrees. The initial strategy led to the development of short-term measures including the Energy Efficiency Existing Ship Index (EEXI) and the Operational Carbon Intensity Indicator (CII).

At the 80th meeting of its Marine Environment Protection Committee (MEPC80), IMO adopted a revised GHG reduction strategy. This aims to achieve net-zero CO_2 equivalent emissions by, or around, 2050. There are indicative checkpoints along the way for shipping to aim for, including:

- Total GHG emissions to reduce by 20–30% by 2030
- Total GHG emissions to reduce by 70–80% by 2040

Both compared to 2008 levels. There is also a target for low- or zero-carbon fuel uptake of at least 5%, striving for 10%, as well as a reduction of carbon intensity of international shipping compared to 2008 levels by at least 40%, by 2030.

The revised GHG reduction strategy sets a timeline for the adoption of mid- and long-term measures to reduce emissions from shipping, requiring an agreement on mid-term measures at MEPC 83 in spring 2025 in order for those measures to enter into force in 2027.

The measures will include both a technical, and an economic, element. The IMO has adopted fuel lifecycle analysis guidelines and continues to review them. These will support the technical and economic measures by enabling calculations of well-to-tank emissions (the emissions associated with the production and supply of a marine fuel) as well as well-to-wake emissions (also adding in emissions as a result of the fuel's use on the ship).

Lifecycle Assessment

The lifecycle analysis of biofuels is critical to proving their GHG emissions reduction. Burning biofuels produces CO_2; unlike fossil fuels, however, biofuels are produced from renewable sources which reuse carbon as an input, creating a carbon cycle which reduces net GHG emissions across the lifecycle of the fuel. Emissions must be measured on a well-to-wake basis rather than a tank-to-wake basis to capture the GHG emissions reductions of biofuel use.

In a well-to-wake calculation, the GHG intensity of the feedstock, fuel production process and associated transport and distribution – the so-called "fuel pathway" – are all accounted for. Tank-to-wake emissions evaluate the intensity of CO_2, CH_4, and N_2O emitted onboard a ship related to use of the fuel and all relevant fugitive emissions.

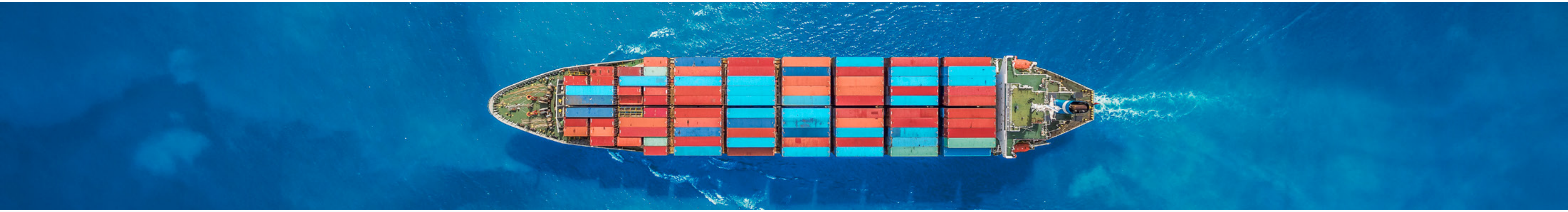
The IMO adopted the guidelines on the life-cycle analysis of marine fuels (LCA Guidelines) at MEPC 81. The well-to-wake and tank-to-wake emissions factors attributed to each fuel pathway and energy converter in the guidelines are expected to be used in future IMO regulations for the reduction of GHG emissions in shipping. The guidelines contain initial default emissions factors for FAME and HVO.

IMO initial default emission factors by fuel

Fuel type	Fuel Pathway	WtT GHG intensity (gCO_2eq/ MJ)	LCV (MJ/g)
Diesel (FAME)	Transesterification from second-generation feedstocks using grid mix electricity	20.8	0.0372
Renewable Diesel (HVO)	Hydrogenation of first-generation feedstocks using grid mix electricity	14.9	0.044

Lifecycle analysis guidelines, and how they are applied by regulators, determine the viability of a fuel under any market-based measure, and therefore have a crucial influence on shipowner investment decisions. For biofuels in particular, the various feedstocks and production methods will lead to a range of carbon intensity figures for individual fuels depending on their pathway. These variations will have a direct impact on the commercial value of biofuels under global and regional emissions regulations.

Biofuels will be required to have certification of sustainability from a recognised international standard such as the International Sustainability and Carbon Certification (ISCC) and Roundtable on Sustainable Biomaterials (RSB).



Biofuels and CII

A simplified interim method for calculating the emission conversion factor for biofuels under the IMO Data Collection System (DCS) and CII are set out in *Interim guidance on the use of biofuels under regulations 26, 27 and 28 of MARPOL Annex VI (DCS and CII)* (MEPC.1/Circ.905).

Certified fuels with well-to-wake emissions reduction of at least 65% compared to the 94 gCO_2e/MJ level for MGO may be assigned an emission conversion factor equal to the value of the well-to-wake GHG emissions of the fuel according to the certificate, multiplied by its lower calorific value for the purpose of regulations 26, 27 and 28 of MARPOL Annex VI for the corresponding amount of fuels consumed by the ship.

Biofuels not certified as sustainable or that fail to meet the 65% reduction in well-to-wake emissions compared to MGO, 33 gCO_2e/MJ, are treated as the equivalent fossil fuel type.

Renewable Fuel for Ocean-Going Vessels Act

In the United States, a bipartisan bill has been introduced to support the use of biofuels in ocean going ships. The bill will enable Renewable Identification Number (RINs) to be preserved by producers of biodiesel and renewable diesel under the Renewable Fuel Standard (RFS) programme. RFS currently excludes fuel used in ocean-going ships from its definition of transport fuels, and so RINs – credits under RFS – must be retired for fuel volumes used by ships operating in international waters. If the bill is successful, it will support the use of biofuels in ocean-going ships in the US.

3.2

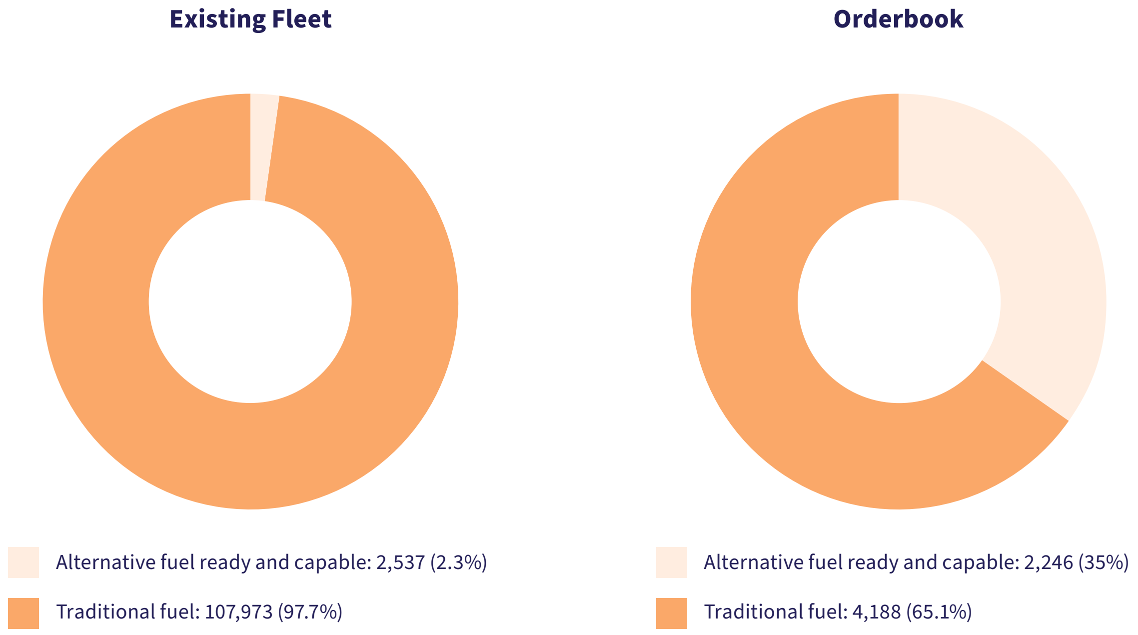
Ship operator demand and interest

There is significant evidence of heightened interest in biofuels as a means of reducing ship emissions and improving regulatory compliance. Demand for biofuels in shipping has risen from negligible levels in 2020 to over 1m tonnes in key shipping hubs in 2023, according to the Global Centre for Maritime Decarbonisation. Despite the increase, this still represents just 1.7% of global bunker sales in those hubs.

There are many ongoing and completed trials of various blends of biofuel in shipping for multiple shipowners and ship types. The blends range from the B7 level seen in distillate fuels to higher blends of B20 through B50 in new VLSFOs. LR has received enquiries for 100% pure FAME or B100 fuel, and some ships are sailing with 100% other bio-derived fuels, claiming up to 90% carbon reduction benefits.

Biofuels offer a route to lower GHG emissions for many ships where retrofitting of other alternative fuel capabilities would be uneconomical. Due to the drop-in nature of many biofuels, the intention of a ship operator to use biofuels cannot be gauged from the orderbook alone. While biofuel ready notations exist, most marine engines are capable of using biofuels without modification, and so their biofuel capability is not reflected in the orderbook in the same way as for example, LNG-capable or ammonia-capable vessels.

The charts below show the number of ships in the world fleet and orderbook capable only of using traditional fuels, compared with the size of the entire fleet and orderbook. The data demonstrates the large share of the fleet and orderbook for which biofuels are a route to reduced GHG emissions.



Source: Clarksons, August 2024.

Biofuel trials

The range of biofuel trials across ship segments and biofuel types (see annexes) reflect a strong level of interest from shipowners in the use of biofuels. LR has been involved in biofuel verification and trials since as far back as 2011, when a trial of FAME biodiesel with A.P. Moller-Maersk measured fuel consumption, emissions, and lube oil performance of an auxiliary engine running on biofuel blends up to B100.

The Global Centre for Maritime Decarbonization has embarked on a six-month study into the prolonged use of biofuels on large ships. Partnering with NYK, the study will explore potential challenges in the use of a FAME VLSFO blend on the systems of large vehicle carriers. Its findings will be used to support guidelines on engine monitoring while using biofuels onboard.

LR FOBAS recently collaborated with United European Car Carriers (UECC), Wartsila and biofuel supplier ACT Group on a trial of Cashew Nut Shell Liquid (CNSL)-feedstock based biofuel known as FSI.100. The collaboration resulted in the provisional acceptance of CNSL- based FSI.100 as a 30% blend component in a distillate DMA marine fuel oil, cleared by OEM, class, and flag Administrations, for sea-trial stages, this trial phase remains ongoing.

3.3

Techno-economic drivers

The main challenges for the widespread deployment of biofuels in shipping are availability of the fuel and scaling of production to meet the significant fuel quantities required to replace conventional fuels. Production volumes are constrained by feedstock availability, and the pricing of biofuels is sensitive to availability of feedstocks and demand from competing fuel users.

The existence of an established supply chain for traditional fuels is beneficial to biofuel adoption as biofuel production processes are co-located with fossil fuel processing in some refineries and can use existing supply chains to reach markets. The specific carriage requirements of biofuels have a minimal impact on delivered cost.

Biofuel currently trades at a premium to traditional equivalents, a premium which varies regionally depending on the feedstock and production method used to create the fuel, as well as regional supply and demand. The IEA expects the price of biodiesel blends to rise alongside blending levels as feedstock prices are driven higher by demand.

Techno-economic modelling examples

While biofuel prices are sensitive to multiple market variables, their ability to be transported in existing supply chains and used in traditional engines without modification makes price forecasting simpler than for many other alternative fuels. Future fuel price uncertainty is a commercial variable for fossil fuels just as it is for biofuels.

Fuel comparisons to VLSFO and MGO in the following pages can be made without the need to consider costly retrofits, lost revenue from time out of service, or increased capital costs from ordering ships with new engine technologies. The ‘drop-in’ nature of the fuels makes cost comparisons valid for vessels on the water, as well as the majority of ships in the orderbook which have no specific alternative fuel capability.

LR carries out more detailed techno-economic analysis on a case-by-case basis.

Biofuel cost development

Fuel	Feedstocks	Cost 2030 compared to 2020	Cost trend 2030 - 2050
FAME	FOGs (fats, oils and grease)	Lower	Falling
FAME	Vegetable oils	Lower	Falling
HVO	FOGs	Similar	Stable
HVO	Vegetable oils	Similar	Stable
FT diesel	Lignocellulosic biomass	Similar	Falling
DME	Lignocellulosic biomass	Similar	Falling
Methanol	Lignocellulosic biomass	Lower	Falling
Ethanol	Sugar & starch crops	Lower	Falling
Ethanol	Lignocellulosic biomass	Similar	Falling
SVO	Vegetable oils	Lower	Stable
Pyrolysis bio-oil	Lignocellulosic biomass	-	Stable
HTL biocrude	Lignocellulosic biomass	Similar	-
Liquefied Bio Methane (LBM)	Waste and residues (digestion)	Higher	Increasing
Liquefied Bio Methane (LBM)	Lignocellulosic biomass	Similar	Stable

Source: EMSA Potential use of biofuels for shipping 2023

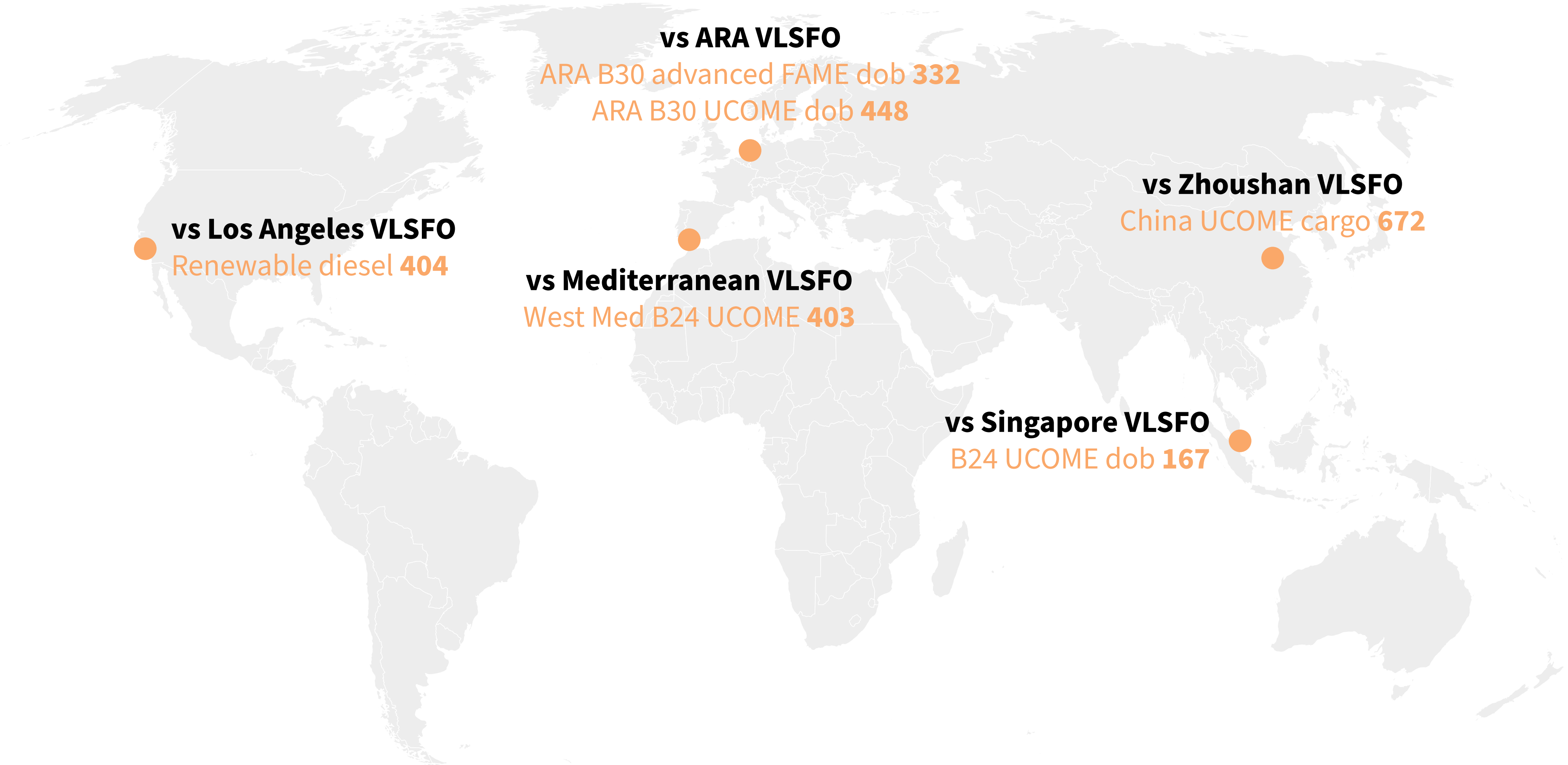
3.4

Fuel cost comparisons

Biofuel blends are available on the market, and so immediate cost comparisons can be made between the use of biofuels and traditional fossil fuels.

The IMO provides a reference on prices on alternative fuels which shows the premium for various fuels in different regions. The map displays the price premium for biofuel blends on a US dollar per tonne of VLSFO equivalent.

Argus Alternative marine fuels less VLSFO ($/t VLSFO-equivalent)



vs ARA VLSFO
ARA B30 advanced FAME dob **332**
ARA B30 UCOME dob **448**

vs Los Angeles VLSFO
Renewable diesel **404**

vs Mediterranean VLSFO
West Med B24 UCOME **403**

vs Zhoushan VLSFO
China UCOME cargo **672**

vs Singapore VLSFO
B24 UCOME dob **167**

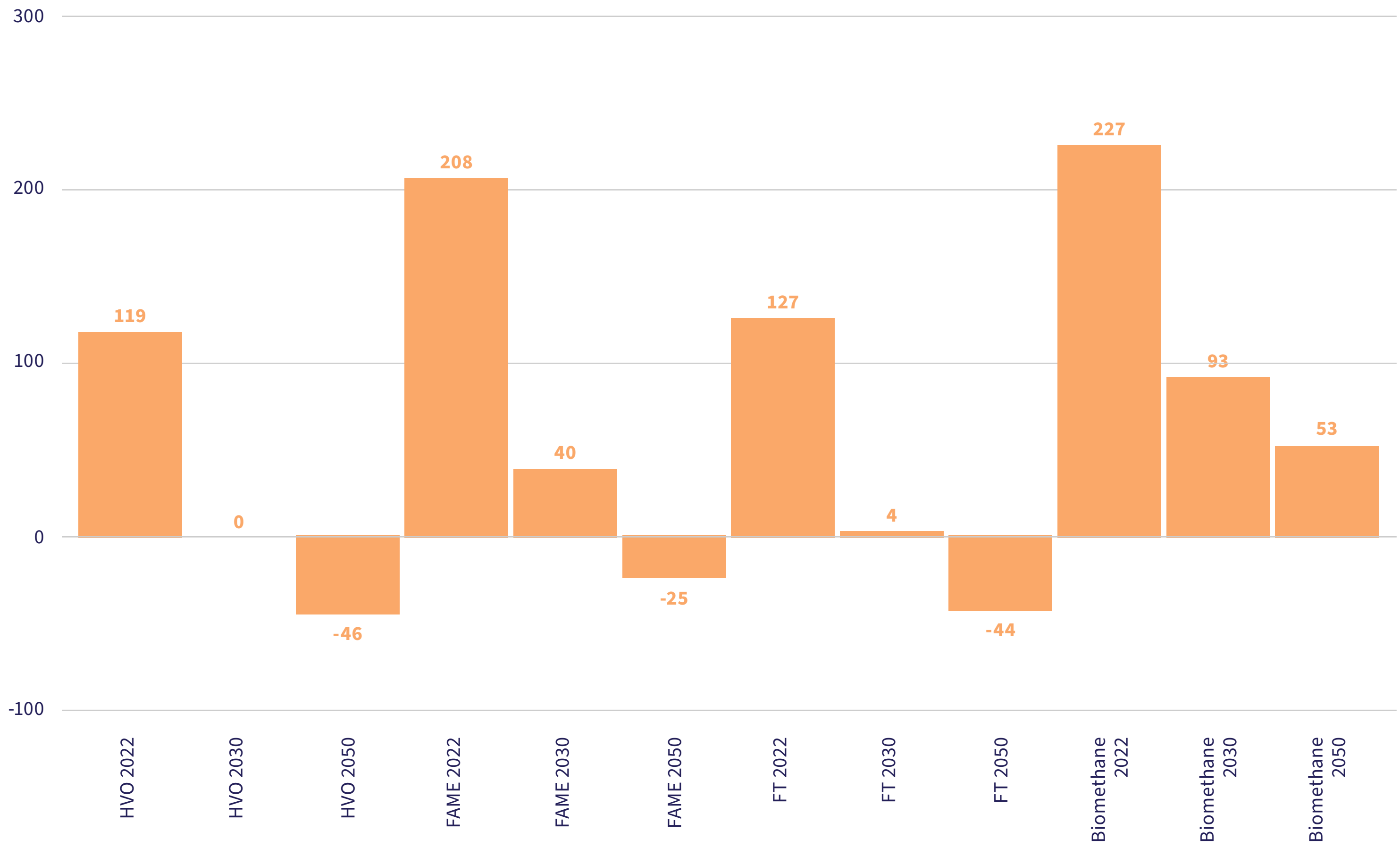
The future competitiveness of biofuels will depend on, among other variables, carbon pricing and the carbon emissions factors assigned to biofuels under global and regional regulations.

The following charts from EMSA use an ETS price of €46 per tonne CO_2 in 2030, and €150 per tonne CO_2 in 2050. Fuel costs are derived from projected production costs, are averaged across regions, and do not reflect future market prices.

EMSA's figures consider fuel costs, including bunkering and carbon costs, as well as CAPEX and non-fuel OPEX which are materially significant only for Biomethane, owing to its engine and fuel storage requirements. Higher bunkering frequencies to offset the lower energy density of the fuels were also factored into the analysis.

The chart shows similar operation costs for HVO and FT biofuels compared to VLSFO by 2030, and a narrowing of the fuel premium for other fuels over the same period. By 2050, the liquid fuels all show a lower total cost of ownership (TCO) compared to VLSFO as the penalties for using carbon intensive fuels increase over time.

Containership biofuels TCO (% delta to VLSFO)



4.1

Chapter 4:
Biofuel production and supply

Introduction

The availability of biofuels for marine use is limited by production volumes and competition from other transport sectors. Scalability of production is an issue and availability of supply is limited compared to the conventional fuel quantities consumed by the marine sector today. Although biofuels are readily produced in most countries from wide-ranging oil seed crops, with waste cooking oil being derived from their use, the scale of production is more appropriate for a percentage blend in marine fuel to meet conventional fuelled diesel ships rather than complete replacement of fossil fuels.

Competition for feedstock from aviation is forecast to rise sharply over the next five years as the sector increases Sustainable Aviation Fuel (SAF) use to meet policy targets. Electric vehicles and other alternative fuel such as Hydrogen are expected in the medium to longer term to erode biofuel demand for road transportation, currently the dominant biofuel user (IEA Renewables 2023).

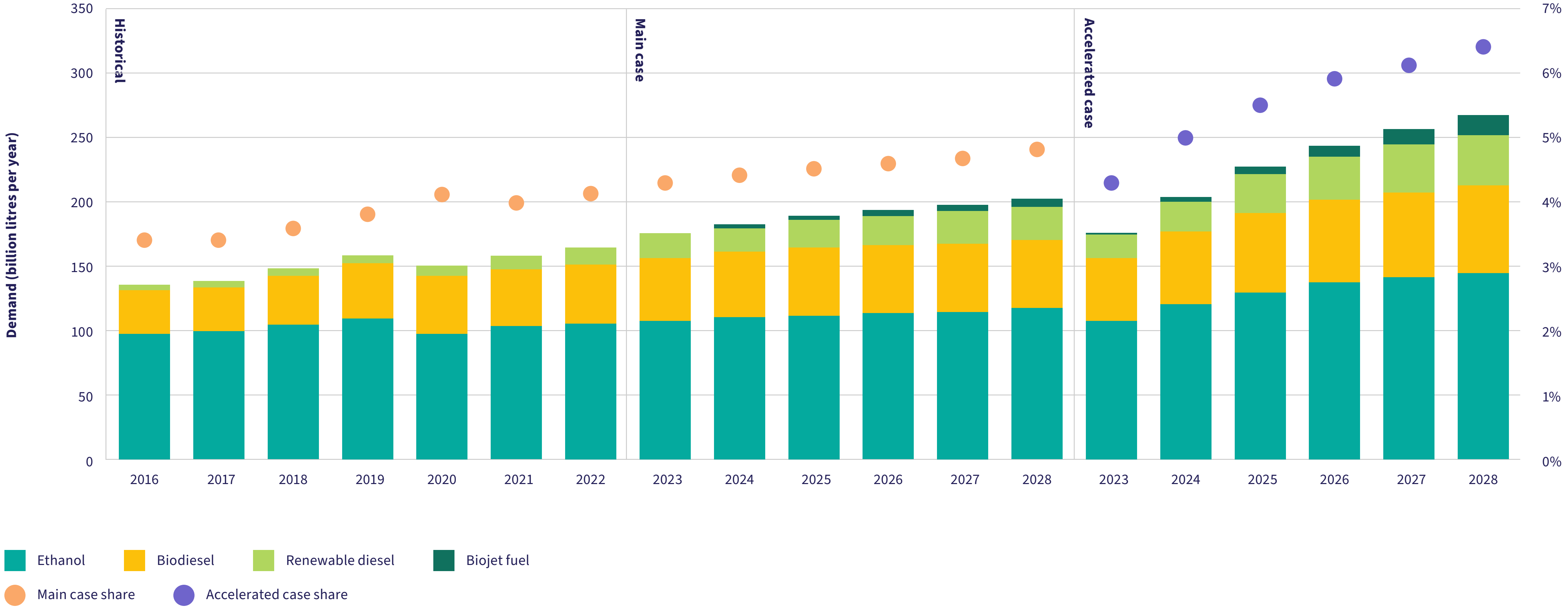
An analysis of available biomass sources showed high variability in the outlook for future biofuel supply to the maritime industry (OGCI, 2023), with sensitivity to feedstock production levels, biomass collection rates, and competition from other industrial sectors. By 2050, marine biofuel will be available to meet 13% of global marine fuel demand in the base scenario, assuming total marine fuel demand of 280Mtoe, however the low scenario gave no available biomass for marine use, and the high scenario 60% of total fuel requirements.

IEA forecasts show strong growth in biofuel production in emerging economies in the 2023-2028 period, especially Brazil, Indonesia and India. S&P Global Commodity Insights forecast global biodiesel demand to reach more than 1.4 million barrels per day (b/d) in 2025, up from around 1 million b/d in 2022. Road transport blending is expected to account for most of this increased demand.

In the longer term, S&P Global estimates biofuels will account for almost a quarter of transport fuel demand by 2050.

Other alternative fuel such as methane, methanol and ammonia require pilot diesel fuel, a factor which will drive demand for biofuel as a less carbon intensive source of pilot fuel than diesel.

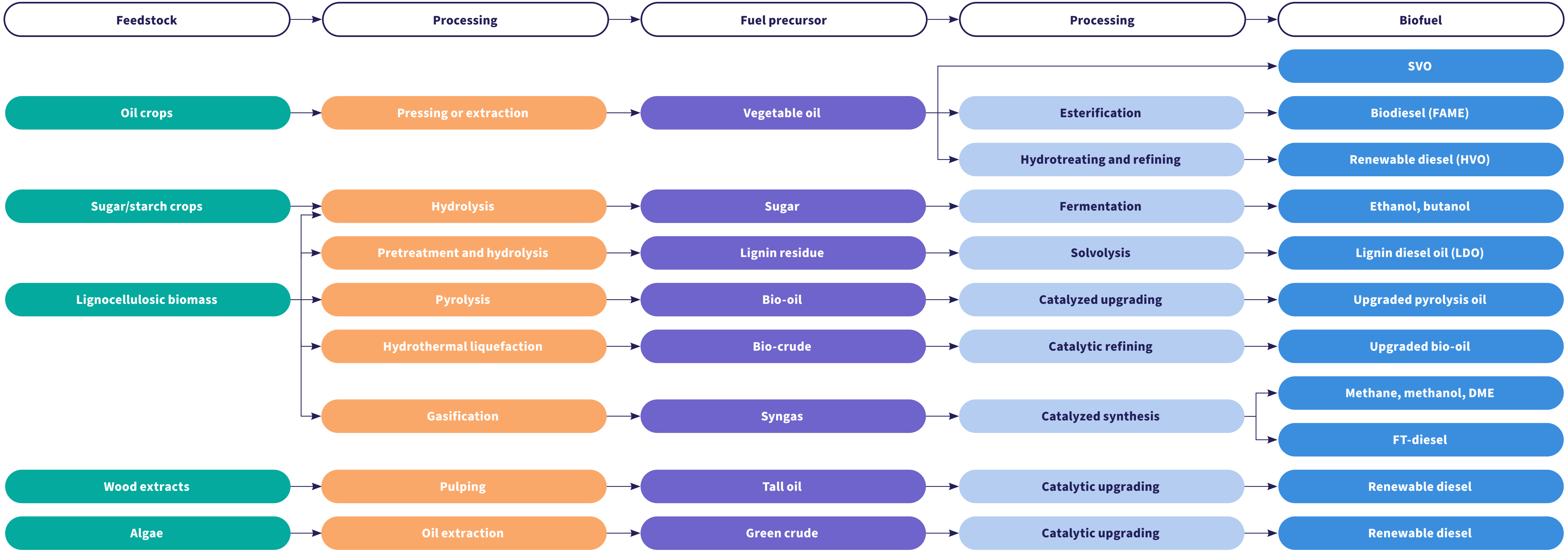
Global biofuel demand, historical, main and accelerated case, 2016-2028 (IEA)



4.2

Production methods

There are a wide range of biofuel production methods using various biomass feedstocks resulting in many distinct biofuel products. New methods of turning biomass into fuel continue to be developed. The following chart from the International Energy Agency gives an overview of the production process for some biofuels. Production of the most common biofuels for marine use are explored in more detail below.



Feedstock	Processing	Fuel precursor	Processing	Biofuel
Oil crops	Pressing or extraction	Vegetable oil		SVO
			Esterification	Biodiesel (FAME)
			Hydrotreating and refining	Renewable diesel (HVO)
Sugar/starch crops	Hydrolysis	Sugar	Fermentation	Ethanol, butanol
Lignocellulosic biomass	Hydrolysis			
	Pretreatment and hydrolysis	Lignin residue	Solvolysis	Lignin diesel oil (LDO)
	Pyrolysis	Bio-oil	Catalyzed upgrading	Upgraded pyrolysis oil
	Hydrothermal liquefaction	Bio-crude	Catalytic refining	Upgraded bio-oil
	Gasification	Syngas	Catalyzed synthesis	Methane, methanol, DME
				FT-diesel
Wood extracts	Pulping	Tall oil	Catalytic upgrading	Renewable diesel
Algae	Oil extraction	Green crude	Catalytic upgrading	Renewable diesel

FAME

FAME is produced by a process called transesterification. In this process, plant oils or animal fats are chemically reacted with an alcohol, usually methanol, in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide. This reaction converts the triglycerides present in the oils or fats into FAME biodiesel and glycerine as a byproduct.

HVO

HVO is produced by hydrotreatment and hydrocracking of feedstocks such as vegetable oil, animal fats, used cooking oils and tall oil byproducts. Hydrotreatment saturates the feedstock with hydrogen before conversion into fatty acids and the removal of propane. The fatty acids are then converted to hydrocarbons which can be cracked to the desired specification.

Biofuel feedstock sources are commonly divided by generation, which relates to the feedstock used.

	First generation	Second generation	Third generation	Fourth generation
	Food crops	**Non-food crops**	**Algae and other microbes**	**Advanced third generation**
Biomass source	Food and feed crops- wheat, sugarcane, rapeseed, sunflower, soyabeans, etc. Straight vegetable oils (SVO)	Waste Based, ligno-cellulosic, Animal fats Sped bleaching oil, POME, nut shells, rubber seed oils, husks, corn cobs etc.	Direct CO_2 capture from algae and microbes.	Genetically modified (GM) Algae for higher yield and greater CO_2 capture ability
Production method	Biochemical methods like fermentation or hydrolysis for alcohols/ethanol. Transesterification for FAME and glycerine	Fisher Tropsch (FT) - Biomass to liquid (BTL) Biochemical or thermo-chemical and fermentation	Fisher Tropsch (FT) – Biomass to liquid (BTL) Biochemical or thermochemical and fermentation	Biochemical conversion, thermochemical conversion
EU Life Cycle GHG saving (RED)	65%-70%	80%-88%	70% - 92%	

Novel biofuels

There are a number of novel and special biofuels beyond HVO and FAME, which do not have any specific standards to define their properties. Shipping is a prime candidate for the use of certain lower grade biofuels due to the higher tolerances of large marine engines compared to road engines. Feedstocks for novel biofuels include cashew nut shell liquids (CNSL), rubber seed oils (RSO) , and non-bio feedstocks from other renewable or waste sources which undergo similar treatment to biofuels, such as processing used tyres by pyrolysis.

Demonstrating the value of a cautionary approach to the adoption of novel feedstocks and fuels, there was an influx in 2022 of VLSFO/bio blends from cashew nut seed liquid (CSNL) feedstock and refining processes which was unfamiliar to the maritime industry. The blended fuel met ISO 8217 Table 2 tested parameter requirements, but parts of the General Requirements of Clause 5 had seemingly not been met. Operational problems were reported on over 22 ships, according to LR FOBAS records, during a space of approximately 6-12 months and intermittently since, while other ships reportedly having loaded similar fuels did not report any problems.

LR FOBAS analysis revealed the unusual presence of ginkgol, cardonal, monoene and cardol in the fuel pointing to the presence of CNSL. However, a number of producers and suppliers, seeing a market opportunity for the need to meet the increasing demand for biofuels, have been initiating in-depth investigations into how best to process and refine this CNSL feedstock for blending in marine fuels. Trials are also ongoing in determining the nature of marine fuel that is best suited to be blended into to avoid the earlier reported issues.

The main reported issues from the use of the CSNL blends were of fuel pump wear and failure, injector nozzle deposits, and T/C fouling.

The initial experience and results from the use of CNSL use onboard do not preclude the use of CNSL in marine biofuels, but to use CNSL as a blend component, particular precautions have to be taken. Suitable grades of CNSL bends are still being developed and better understood, with some marine fuel blend options now in the early stages of being offered to market for acceptance in sea trials in a controlled manner.

LR FOBAS recently collaborated with United European Car Carriers (UECC), Wartsila and biofuel supplier ACT Group on a trial of their FSi100- ACT grade product, a refined CNSL feedstock. This collaboration resulted in the provisional acceptance of CNSL- based FSi100 as a 30% blend component in a distillate DMA marine fuel oil, by Class, OEM, and flag Administrations, for sea-trial stages. This was only achieved following a comprehensive pre–sea trial fuel characterisation, compatibility and engine bench performance testing and a sustainability assessment programme.

For all novel biofuels and blends with petroleum derived fuels, where the biofuel components do not meet FAME nor HVO paraffinic fuel standards, as required by ISO 8217 standard, LR recommends fuel-and ship-specific no harm and operability assessment. The process is detailed in Guidance Notes for Class and Statutory Approval and Use of Marine Biofuels (January 2023), and includes:

Bunker supplier/source

Supplier to provide a specific fuel blend grade identifier, production process, and feedstock used, along with details of production controls for consistent delivery. This should include the approach taken to ensure that the three key operational criteria's have been met – as defined under the ISO 8217 General Requirements Clause 5 – No Harm to machinery or personnel, operability, and regulatory compliance, as well as the final delivered product having met the limits set against the ordered DM or RM Table's categories in ISO 8217:2024.

OEM guidance

Seek guidance and support for the trial of a novel unestablished product; for a novel fuel it is unlikely 'no objection' will be issued by an OEM, due to their own lack of experience of the product. Engage OEMs in a full risk assessment programme and consider any specific recommendations

Engine considerations

Detailed fuel properties analysis and compositional assessment

Test Bench lab trials preferred and may be required to determine combustion, stability, material compatibility, corrosivity, solvency affect etc.

Cylinder lube oils, ring/liner, time between overhaul (TBO)

Material compatibility

Lubricating oil, exhaust emission control equipment, sensors etc.

Submissions to Class to include:

A full supplier biofuel product suitability assessment report independently validated

OEM pre-trial engagement and support or no-objection letter

Ship and machinery details

Details on proposed fuel oil and or machinery modifications if any

Fuel tank arrangements

Material compatibility information including tank coatings

Information on MARPOL compliance aspects (check flag Administration)

Risk assessment

Ship implementation plans

Shipboard trials

Short-, medium-, and long-term monitoring programmes should be in place to confirm in service performance and machinery equipment endurance

Final evaluation report by all stakeholders for the specific biofuel named grade, linked to supplier production process and quality control suitability, for general use on named machinery types

5.1

Chapter 5:
Technology readiness

Introduction

Technology readiness for the use of biofuel in shipping is more advanced than for any other alternative fuel. FAME and HVO are functionally very similar to their petroleum equivalents and generally compatible with existing machinery and infrastructure. Their use is broadly supported by OEMs. Many of the characteristics of biofuels which can present issues with machinery can be mitigated through adherence to fuel specifications for FAME and HVO. Other characteristics of certain biofuels can improve engine and machinery performance such as lubricity, lower black carbon emissions and lower sulphur emissions.

A risk assessment is recommended when switching to a new fuel for the first time. It is important to understand the characteristics of biofuel, monitor its impact on ship machinery performance and handling characteristics and on-board fuel management processes may be then duly amended.

The broader range of biofuel types and blends that may be offered to the marine market creates potential hazards and considerations for owners, operators and equipment manufacturers. The hazards are similar to those relating to the design and operational considerations for the use of low and very low sulphur fuel oils. Certain biofuels may require some modifications to fuel systems or engine components depending on the biofuel type and blend ratio. The use of such biofuels will therefore require assessment of the fuel and ship specific operational considerations for satisfactory implementation on a case-by-case basis.

LR's Guidance Notes for Class and Statutory Approval and Use of Marine Biofuels (January 2023) provides extensive guidance on the class and statutory requirements for use of drop-in liquid biofuels for marine and offshore installations, including a checklist of the requirements and recommendations for the use of biofuels.

Factors to consider for the use of FAME biodiesel and FAME blends include:

- Lower Energy Value 37 MJ/kg (RM fuels 39- 42 MJ/kg)
- Oxidation stability
- Hygroscopic
- Material compatibility
- Cold flow properties
- Microbial Activity
- NOx emissions

Cold flow properties

The cold flow characteristics of FAME and FAME blends can be improved with cold flow improver in a similar way as fossil marine fuels. This is most relevant for use of FAME in distillates where heated systems may not be installed or of sufficient capacity .

Risk assessments carried out by Canada Steamship Lines (CSL) on the use of biofuels in its fleet found that additives were required to lower the pour point, and cold filter plug point (CFPP) of biodiesel and that a heating medium may be necessary for storage during winter months. Due to the complexity of treating biofuels with such additives, this is best performed by the fuel supplier before delivery.

Biofuels material compatibility

The solvent property of FAME affects some materials used in ship machinery. The following table shows recommended materials for use with biofuels. Areas for attention include sensors, paints, filters and coalescers, joints, seals, and gaskets.

Material	Recommended	Not Recommended
Metals	Carbon steel Stainless steel Aluminium	Brass Bronze Copper Lead Tin Zinc
Elastomers	Fluorocarbon Nylon Teflon® Viton®	Nitrite rubber Neoprene Chloroprene Natural rubber Hypalon Styrene-Butadiene rubber Butadiene rubber
Polymers	Carbon filled acetal	Polyethylene Polypropylene Polyurethane Polyvinylchloride
Others	Fibreglass	

Source: CONCAWE

Solvent properties

Due to the solvent properties of FAME biofuels, effective tank cleaning is recommended prior to repurposing for biofuel storage. The use of biofuels can cause filter clogging if tanks are not properly cleaned, as residual remnants are dislodged from the tank and flushed through the system to the fuel filter.

Microbial Activity

FAME is hygroscopic which means FAME and its blends absorb water more than conventional diesel. To prevent contamination, FAME and FAME blends should be protected from exposure to water, including atmospheric water. Water absorption can lead to exceeding fuel moisture specifications, and conditions for microbial growth leading to contamination. Water contamination and microbial growth can lead to filter clogging and tank corrosion.

Due to the risk of extensive microbial growth during longer term storage, it is recommended that emergency generators, lifeboat engines, fire pumps etc. that may store fuel in individual fuel tanks should be kept free of FAME biofuels.

5.2

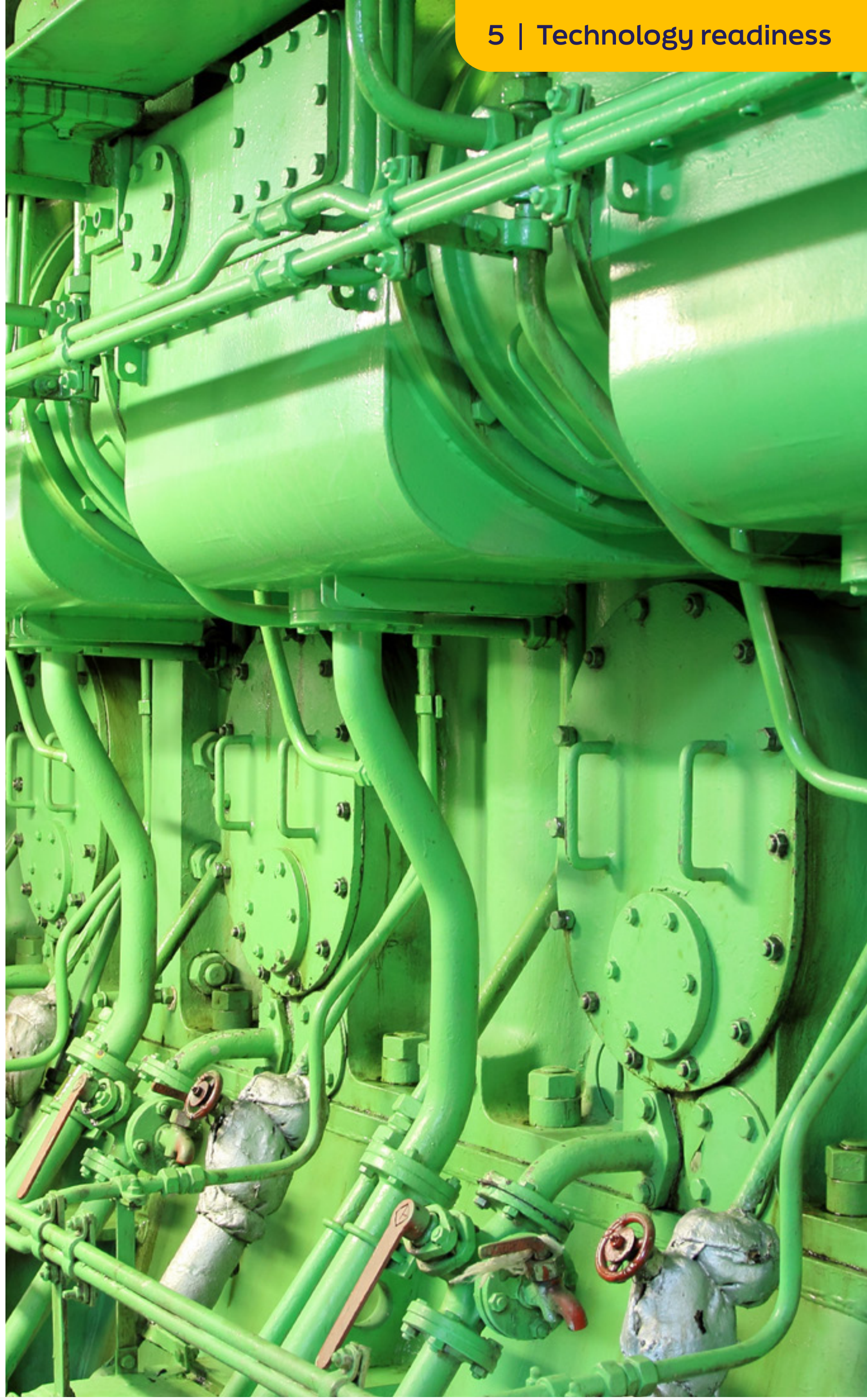
Marine engines

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.

The International Council on Combustion Engines (CIMAC) is the forum for the global large engine industry and has a specific working group focused on guidelines and position papers for fuels and fuel systems, including recommendations for fuel quality and operation, combustion properties and biofuel considerations. Its publications are a useful source of fuel-specific information to support engine OEM publications, notably its 2024 guideline Marine-fuels containing FAME; A guideline for shipowners & operators further relevant CIMAC publications are linked in the annexes.



5.3

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)

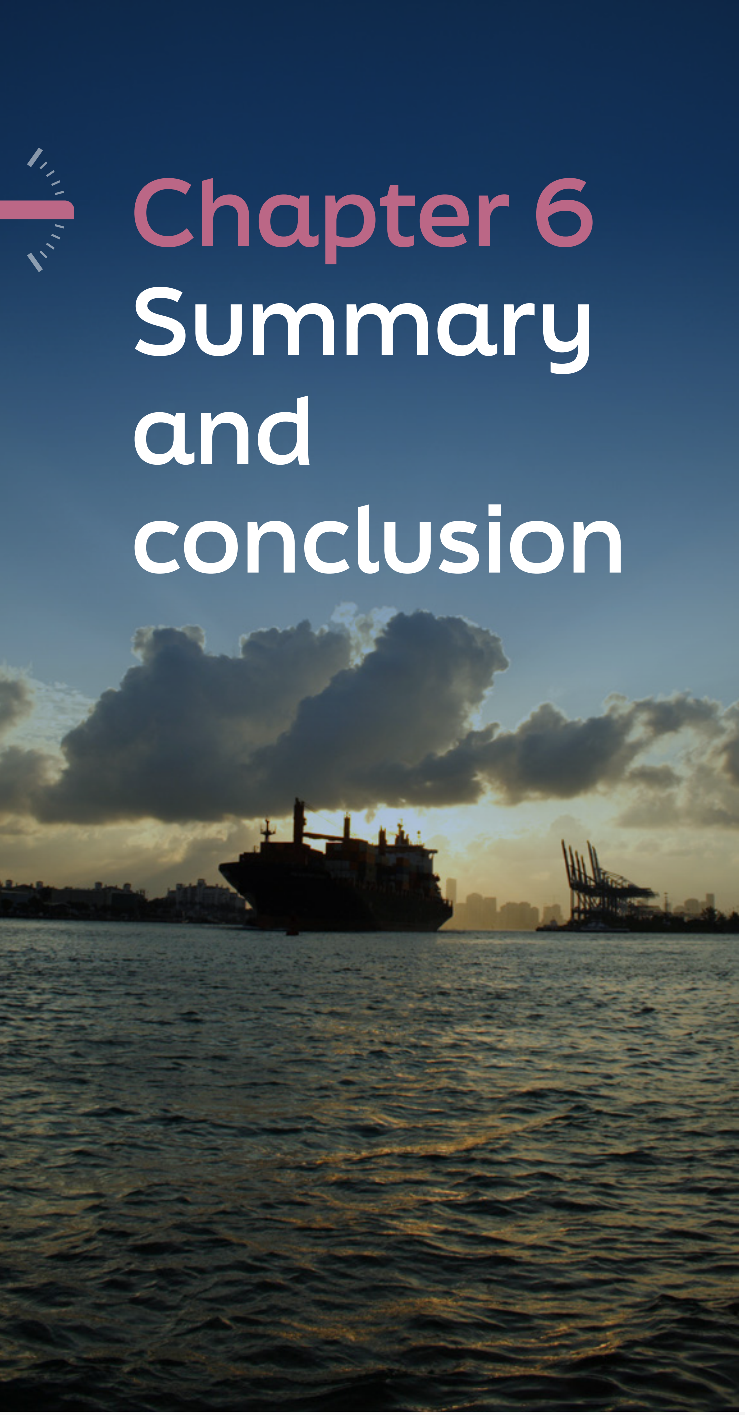
LR's technical report on NOx from marine diesel engines using biofuels consolidates LR's experiences with its shipping clients and industry feedback with sea trial findings on NOx emissions when using biofuels. It addresses the requirement that fuel oil derived by methods other than petroleum refining 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.

Chapter 6

Summary and conclusion



Biofuels are unique among the future fuels for shipping as the vast majority of the world fleet is equipped with engines that can make use of them. As a ‘drop-in’ replacement for fossil fuels, biofuels are an available and affordable method of reducing carbon emissions in the short term without large capital investment. Biofuels also offer a marked reduction in hydrocarbons, particulate matter and carbon monoxide emissions.

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The similarities between biofuels and their fossil fuel counterparts bring further benefits to an industry with decades of experience operating using petroleum distillates and residual fuel oils (MGO and HFO). Safety requirements for the transportation, handling and bunkering of biofuels are broadly similar to those for their fossil counterparts, albeit with the need for the development of specific guidance in some areas. Extensive research and experience in the use of biofuels at sea and on land has demonstrated their safety and suitability for use in internal combustion engines, and training requirements for crew are minimal compared to other future fuels.

The volume of biofuels used in shipping is growing rapidly as shipowners commit to larger-scale trials and accept the higher fuel price in exchange for lower environmental impact and the regulatory and reputational benefits brought by biofuels. The volume growth of biofuels in shipping will soon encounter its main near-term challenge, and one that may follow it in the longer term: lack of availability.

Studies show a large divergence and uncertainty in forecasts of available biomass and biofuel for shipping in the coming decades. Biofuels of FAME and subsets of FAME and HVO are produced the world over, but in current volumes they are only suitable as a blend component for marine fuel. The regular use of biofuels and biofuel blends by shipping companies will require more widespread availability of the fuels in key bunkering locations. As no one biofuel product can be used as a reference fuel for all biofuels, unestablished and non-standardised biofuels such as those from feedstocks of CNSL, other organic liquid oils, and car tyres, will need to be demonstrated as bunker safe for use on board a ship’s machinery plant

Trusted certification programmes will be essential in building buyer confidence in biofuels. The sustainability credentials of biofuels are contentious, and, from a lifecycle perspective, some could have worse carbon credentials than the fuels they are replacing, depending on the biomass feedstock used. The success of biofuels will depend on the ability of producers to demonstrate their zero or near-zero GHG emissions. Certification schemes like those offered by the RSB and ISCC will provide the data necessary to calculate the carbon intensity of a given biofuel and reassure the buyer of a fuel’s provenance.

As with the other fuels explored in the Fuel for Thought series, 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.

Lloyd’s Register will continue to closely follow the development of biofuels in shipping and cover it in future updates to this guide.

7.1

Chapter 7
Links and resources

Guidelines for handling and blending FAME - Concawe

FuelEU Maritime - EU

Guidelines on the life-cycle analysis of marine fuels (LCA Guidelines) - IMO

Zero Carbon Fuel Monitor Biodiesel - LR

MEPC.1/Circ.795/Rev.8 (July 2023) - IMO

Guidance Notes for Class and Statutory Approval and Use of Marine Biofuels (January 2023) - LR

LR Technical Report on NOx from marine diesel engines using biofuels - LR

CIMAC

CIMAC Guideline 04 2024. Marine-fuels containing FAME; A guideline for shipowners & operators

CIMAC Guideline 02 2024. ISO 8217:2024 - FAQ

CIMAC Guideline 03 2024. Overview and interpretation of total sediment test results in the context of ISO 8217:2024

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.

CIMAC Guideline 01 2015. Cold flow properties of marine fuel oils.

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

7.2

Annexes

Annex 1: Technology, Investment and Community readiness levels (TRL, IRL, CRL) and definitions

There are three readiness levels used in this report: technology, investment and community. All are on a scale, with TRL on a scale of one to nine, and CRL and IRL on a scale of one to six.

Technology readiness (TRL)

The technology readiness level indicates the maturity of a solution within the research spectrum from the conceptual stage to being marine application ready. It is based on the established model used by NASA and other agencies and institutes, using a nine-level scale.

Level	Technology Readiness Level (TRL)	
1	Idea	Basic principle observed
2	Concept	Technology concept formulated
3	Feasibility	First assessment feasibility concept and technologies
4	Validation	Validation of integrated prototype in test environment
5	Prototype	Testing prototype in user environment
6	Product	Pre-production product
7	Pilot	Low-scale pilot production demonstrated
8	Market introduction	Manufacturing fully tested, validated and qualified
9	Market growth	Production and product fully operational

Investment readiness level (IRL)

The investment readiness level indicates the commercial maturity of a marine solution on the spectrum from the initial business idea through to reliable financial investment. It addresses all the parameters required for commercial success, based on work by the Australian Renewable Energy Agency (ARENA). The six-level scale used summarises the commercial status of the solution and is determined by the available evidence in the market.

	INVESTMENT READINESS LEVEL (IRL)	
1	Idea	Hypothetical commercial proposition
2	Trial	Small-scale commercial trial
3	Scale up	Commercial scale up
4	Adoption	Multiple commercial applications
5	Growth	Market competition driving widespread development
6	Bankable asset	Bankable asset class

More details on the readiness levels adopted by Lloyd's Register can be found on the LR Maritime Decarbonisation Hub zero carbon fuel monitor.

Community readiness level (CRL)

The community readiness level indicates the societal maturity of a marine solution in terms of acceptability and adoption by both people and organisations. It is gauged on the spectrum from societal challenge through to widespread adoption. CRL is based on the work by ARENA and Innovation Fund Denmark adapted to a six-level scale.

	COMMUNITY READINESS LEVEL (CRL)	
1	Challenge	Identifying problems and expected societal readiness, formulation of possible solution(s) and potential impact
2	Testing	Initial testing of proposed solution(s) together with relevant stakeholders
3	Validation	Proposed solution(s) validated, now by relevant stakeholders in the area
4	Piloting	Solution(s) demonstrated in relevant environment and in cooperation with relevant stakeholders to gain initial feedback on potential impact
5	Planning	Proposed solution(s) as well as a plan for societal adaptation completed and qualified
6	Proven solution	Actual project solution(s) proven in relevant environment

Annex 2: Recent marine biofuel trials

Owner/Operator	Trial Date	Trial Details
Mitsui OSK	Feb-24	Mitsui OSK trialled blockchain technology for carbon insets, allowing it to monitor and tokenise its reduction in carbon emissions when using biofuels.
NYK	Jan-24	NYK will conduct full-scale trials of long-term use of biofuels starting in 2024, with biofuels being used continuously for three months on multiple ship types.
PIL, DP World	Dec-23	Pacific International Lines and DP World signed a Memorandum of Understanding agreeing to collabo-rate on trial shipments using biofuels between Jebel Ali and destinations within Singapore-based PIL's network.
EPS	Dec-23	The Global Centre for Maritime Decarbonisation partnered with Eastern Pacific Shipping to successfully complete a bunkering supply chain trial using B30 biofuel blend of HVO (HVO) and marine gas oil (MGO) involving the 'KAUPANG', a mid-sized gas carrier equipped with an LPG dual-fuel engine. The GCMD found that net carbon emissions fell 20% using the B30 blend compared to VLSFO.
Wallenius Wilhelmsen	Nov-23	Vehicle carrier 'M/V TORRENS' became the first Wallenius Wilhelmsen ship to trial HSFO biofuel.
Mitsui OSK	Oct-23	Mitsui OSK revealed that the 499 GT RoRo Ship 'TETSUUN MARU' trialled a B30 biofuel blend, marking the first Japanese initiative to use this type of biofuel on a ship.
GS Caltex, POSCO, HLine Shipping	Oct-23	The South Korean companies H-Line Shipping, POSCO and GS Caltex signed a Memorandum of Understanding signalling the commencement of a B30 biofuel blend trial aboard bulk carriers.
HMM	Sep-23	HMM announced the usage of a B30 biodiesel blend in a trial run aboard its 6,400 TEU containership 'HMM TACOMA', reportedly resulting in a 24% reduction in GHG emissions as compared to traditional fuels.
KPI OceanConnect	Sep-23	KPI Ocean completed the successful two-day trial of a custom B30 biofuel mix aboard the 5,700 dwt chemical tanker 'M/T ALSIA SWAN', in which the trial found that switching from LSMGO gasoline to B30 lowered particulate matter emissions by up to 42%, whilst carbon emissions also fell by 18%..
Royal Caribbean Group	Sep-23	Royal Caribbean Group completed a successful 3-month biofuel trial, becoming the first cruise company to effectively test and deploy a biofuel blend.
COSCO Shipping	Sep-23	COSCO Shipping completed a trial run using B24 biofuel on the company's MPP 'DA CHUNG'.
NYK	Jul-23	The wood-chip carrier 'DAIO AUSTRAL' was the first oceangoing ship operated by NYK to bunker bio-diesel in Japan, making a test voyage to Cai Lan in Vietnam

(source: Clarksons Research)

FUEL FOR THOUGHT

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