WHITE PAPER

Marine biofuels

What to expect in the 2020s

April 2021

Contents

Introduction

The international shipping industry emitted an estimated 1,056 million tonnes of CO_2 in 2018, equivalent to one fourth of the total greenhouse gas emissions in the European Union during the same year. It is expected that the international shipping industry's share (in %) of total CO_2 emissions will increase in the coming years, due to both increased shipping activities, i.e. world trade demand, and to increased emission mitigation in other industries (as a consequence of public opinion and regulations).

In support of the United Nations Sustainable Development Goal 13, which is to take urgent action to combat climate change and its impacts, the International Maritime Organization (IMO) has agreed to adopt a strategy to reduce CO_2 emissions related to shipping by 40% before 2030 and to reduce all greenhouse gas (GHG) emissions by 50% before 2050, when compared with figures from 2008. A more detailed strategy and the implementation requirements are expected to be formalized by the IMO GHG group in 2023 (International Maritime Organization [IMO], 2020).

Transitioning to alternative fuels is necessary to limit GHG emissions from international shipping as soon as possible and to reach IMO's CO_2 reduction goals. A number of different fuel types are being discussed as potential replacements for fossil fuels, including green and blue hydrogen, ammonia, methanol and biogas. However, the supply infrastructure and technological readiness for these fuels remain to be developed. Several biofuel alternatives are already available today, and more are expected to become available in the near future.

Some alternative fuels are very similar to petroleum fuels and are consequently spoken of as drop-in fuels. However, most alternative fuels, including drop-in fuels, behave differently and require adaptation of the fuel handling and treatment systems, as well as operational procedures. Biofuels, which include biodiesels and renewable diesels, differ from fossil fuels in both chemical and physical properties.

Biodiesels are fuels comprising mono-alkyl esters of long chains of fatty acids derived from lipids. They are produced by transesterification, a process that introduces oxygen into the fuel, which may cause issues with freezing temperature, microbial growth, separation during storage and emissions.

Renewable diesels, just like petroleum fuels, consist of hydrocarbons. However, the hydrocarbons in renewable diesels are mainly paraffins, whereas petroleum fuels comprise a mix of several types of hydrocarbons, including paraffins and aromatics. Thus, renewable diesels present new challenges. Renewable diesels have low density, for example, which puts additional requirements on the fuel treatment system.

Alfa Laval recommends making it a routine to take fuel samples of each bunker and send them for laboratory analysis. The new bunker should not be used before receiving the laboratory report. Recent fuel contamination investigations have shown that fuel composition differs even among blends with the same notation, and that a proper quality surveillance program can help avoid undesired events (International Council on Combustion Engines [CIMAC], 2013).

This paper covers FAME and HVO, two of the favourable biofuel options available to the marine industry. The paper focuses on the advantages and challenges connected to treatment and operation, but it also touches upon the production process and the problematization of sustainability. The UN World Commission on Environment and Development has defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs", which is the definition applied here.

What are biofuels?

Biofuels are liquid fuels converted from biologically renewable resources, most commonly crops but also animal fats and biodegradable waste. Biofuels are considered renewable and have received increasing attention due to their potential for carbon neutrality, i.e. net zero CO_2 emissions achieved through a balance with offsetting. However, the well-to-wake (WTW) emissions savings are strongly correlated to the biomass origin and therefore vary significantly (Organisation for Economic Co-operation and Development [OECD], 2019).

Biofuels may be denominated first or second generation depending on the biomass used. First-generation biofuels utilize food crops such as oil seeds, sugar beets, grains and animal fats. Second-generation biofuels are produced from non-food biomass such as crop residues, wood crops and municipal solid waste (European Commission [EC], 2018).

The sustainability of first-generation biofuels has been problematized because of the competing use of food sources, the potential negative net impact on GHG emissions and the overall effect on biodiversity due to biomass production and transportation. The second-generation biofuels were developed to combat the first generation's drawbacks. Second-generation biofuels enable more efficient biomass use, being produced from the residual non-food parts of crops and industry waste (EC, 2018).

The land used to grow biomass for both generations, but especially for first-generation biofuels, is cause for concern. Biomass generally grows on cropland that was previously used for other agriculture. This is problematic, because the need for food and animal feed has not decreased as the demand for biofuels has increased. Instead, biomass production has caused agriculture to push into non-cropland, including areas with high carbon stock, e.g. forests, wetlands and peatlands.

The shift in land use due to biomass production is called indirect land use change (ILUC). Because ILUC may cause the release of CO_2 stored in trees and soil, it risks negating the GHG savings from increased market share of biofuels (EC, 2018). Therefore, biomass origin is controlled through the European Commission's Renewable Energy Directive (RED II), which is part of the European Union agreement on energy policy framework: Clean energy for all Europeans package.

Today there is a wide range of biofuels, including FAME, HVO, pyrolysis oils, e-fuels and alcohols such as ethanol and methanol. Many of these, such as ethanol, FAME and HVO, have already been adopted by the automotive industry.

This paper will discuss FAME and HVO fuels for marine application. Based on the automotive industry's experience, FAME and HVO, are believed to have the greatest potential for application in marine diesel engines.

The following chapters will examine and elaborate on the characteristics of both fuels, their main differences and the issues connected to their handling on board with respect to fuel line equipment, which includes tanks, pumps, separators, fuel conditioning systems and filters. It will also look at the fuels' effects on engine performance.

Biofuels and their impact on the fuel line

FAME – fatty acid methyl ester

General characteristics

Fatty acid methyl ester (FAME) is a so-called biodiesel oil. Biodiesels are derived exclusively from lipids such as vegetable oils (e.g. palm oil, soybean oil, rapeseed oil), animal fats (e.g. tallow oil) and used cooking oil. FAME is a mono-alkyl ester produced through a transesterification process, in which triglyceride from the feedstock reacts with methanol in the presence of a catalyst, forming the mixture of fatty acid esters and glycerol (European Biofuels – Technology Platform, 2011).

FAME has the benefit of a much smaller WTW carbon footprint compared to MGO – only 38–48 g CO_2e/MJ compared to 85–87 g CO_2e/MJ (Fridell et al., 2019).

Biodiesel can, in theory, replace MDO and MGO in low- to medium-speed diesel engines. However, it is more commonly used as a blending component, as biodiesel in neat form can be compromised by cold weather and cause problems in older engine systems. FAME's physical and chemical characteristics depend on the length (number of carbons) and unsaturation level of the fatty acid.

Under current supply logistics, the practice of blending FAME into distillate fuels is relatively common; this nearly guarantees that some distillate fuels supplied in the marine market contain FAME. In response, the International Organization for Standardization (ISO), based on available experience from the use of biodiesel in conventional automotive diesel fuel and the use of marine distillate fuels containing biodiesel, has revised the ISO 8217 standard to provide a wider tolerance and additional specifications for FAME content.

The international standard for marine fuels specifies distillate (DF grades) containing up to 7.0 v/v % FAME and DM grades and residual RM grades containing less than the de minimis level of 0.5 v/v % FAME. DMX grade must be FAME-free. The FAME used for blending shall fulfil the specification of the European Committee for Standardization (CEN) standard EN 14214 or the American Society for Testing and Materials (ASTM) standard ASTM D6751. However, blends containing up to 30% v/v FAME are used in Indonesia.

The automotive fuel standards allow higher FAME content: up to 10 (B10) v/v % FAME specified in EN16734:2016+A1:2018 and up to 20 (B20) and 30 (B30) v/v % FAME specified in EN16709:2015+A1:2018. Marine bio-blends containing 20–50 v/v % FAME are under development for more widespread application, and ISO is currently evaluating whether to allow higher FAME ratios in residual fuels in the upcoming revision of ISO 8217.

Given that FAME is already allowed in several MGO grades, and considering the complex fuel supply chain of MGO, there is a likelihood that FAME will end up in DMA and DMZ grades as well. A survey performed by ECHA Microbiology Ltd. Guardian Marine Testing and Lloyds Register Marine, FOBAS, yielded the following results from 2346 globally taken MGO DMA grade samples:

- 1 in 20 samples showed FAME concentrations higher than 0.5 v/v %
- ~ 45% of FAME-contaminated samples displayed evidence of microbial growth
- 2.2% of samples tested positive for FAME and microbial growth
- The FAME-contaminated samples contained concentrations in the range 0.5–7.0 v/v % (one sample contained as much as 57% FAME)

Storage and treatment on board

FAME's chemical composition and hygroscopic properties (dissolves 1000–1500 ppm water) cause it to form stable emulsions and make it prone to microbial contamination (Kalligeros et al., 2013). However, bacteria and fungi (single-cell yeasts and filamentous moulds) require moisture to grow and reproduce. Consequently, microbial contamination can be controlled through the water content.

Water risks entering the bunker tank by means of inadequate ventilation or leaking coils, for example. Pockets of water within a tank create the perfect conditions for uncontrollable growth of bacteria and fungi, which can be devastating for the fuel. Water should continuously and actively be removed from the storage system, and frequent water level checks are recommended. Note that microbes grow over time, which means that using the fuel as soon as possible is more critical for FAME than for fossil fuels. Reducing microbial growth with biocides is generally not recommended, due to environmental and health concerns. Instead, overall housekeeping of the fuel system is key. Clean tanks, continuous dewatering and control over the separation process allow ship operators to process FAME just like any petroleum fuel.

The fuel's oxidation stability must also be managed. FAME has a lower oxidation stability, meaning it is more prone to degrade over time and form hydroperoxides, aldehydes, carboxylic acids, alcohols and insoluble material. Increased water content accelerates the formation of acidic products, because water facilitates the hydrolysis of esters into carboxylic acids when acids (low pH) or bases (high pH) are present (Felby and Hsieh, 2017).

The formation of acid groups leads to polarity changes that can affect the fuel's compatibility with polymer materials. The degradation products also increase sludge build-up, potentially clogging filters, separators and injectors. Water's accelerating effect on the degradation process further underlines the importance of maintaining good fuel system housekeeping, removing water and using the fuel as soon as possible.

In order to control the degradation of biodiesels, ISO and CEN have specified oxidation stability in ISO 8217 and EN 14214, respectively. However, the degradation of FAME is inevitable. The acidic products may corrode the fuel system's components, damaging fuel pumps, piston rings and injectors. To avoid irreversible damages, corrosion must be monitored continuously, preferably by means of frequent visual inspections.

Relevant Alfa Laval equipment offered today, including separators and fuel conditioning systems, can withstand the acidity of all fuel grades specified in ISO 8217. For older equipment of any brand, however, Alfa Laval recommends verifying compatibility with the supplier.

FAME's high solvency may also cause deposits within fuel tanks and treatment systems to dislodge, thereby clogging filters. Furthermore, it can degrade rubber parts as well as attacking certain metals (CIMAC, 2013).

For fuel blends containing FAME concentrations of 0/30/50 v/v %, Alfa Laval has investigated fuel compatibility and the degradative effect on various wetted components made of polymeric materials and steel, such as discs, O-rings and seal rings. Tested fuel blends were shown to be compatible, with no noteworthy forms of degradation evident. However, fuel blends containing higher concentrations of FAME may degrade the components' materials.

FAME's high flashpoint in combination with a high oxygen content increases both fuel consumption and NO_x formation. This leads to quicker accumulation of unspent biofuel, soot in the lubrication oil and NO_x in the exhaust. The peak combustion temperature, which affects NO_x formation, can be lowered by reducing the injection pressure and retarding injection times. Alfa Laval recommends confirming the specifics with the engine maker.

Because FAME contains almost no sulphur, SO_x emissions are drastically reduced, as are particulate matter (PM) emissions.

As with other fuels, FAME's viscosity is highly dependent on temperature. Because cold conditions may cause wax precipitation, both the storage and separation temperatures should always exceed the cloud point. In the event that wax crystals appear, FAME must be heated to above the wax melting point in order to regain liquid properties. Both the cloud point (wax appearance temperature [WAT]) and the wax melting point (wax disappearance temperature [WDT]) are dependent on the specific fuel blend and may differ greatly between blends.

Note that while a high enough temperature is required, temperatures that are too high may cause the fuel to polymerize, meaning that it becomes a gum-like material. It is therefore important to avoid concentrated spots of higher temperature, i.e. hotspots.

HVO – hydrotreated vegetable oil

General characteristics

Hydrotreated vegetable oil (HVO) is a hydrogenation-derived renewable diesel, also known as renewable diesel, hydrotreated esters and fatty acids (HEFA) or hydrotreated renewable oil (HRO).

HVO is produced from the same biomass as FAME, but it may also be produced from residual crops and industrial waste like wood spill. HVO is produced through hydrocracking, which forms paraffinic hydrocarbons similar to those found in petroleum-based diesel. A diesel engine can run on neat HVO, which is why HVO is considered a drop-in fuel in the automotive industry. However, the fuel treatment system on a marine vessel may require adjustments due to the low fuel density. HVO quality is not specified in any marine fuel standard, but it is defined in the standard for automotive paraffinic diesel fuels: EN 590 B7 and EN 15940:2016 class A. Its density, 765–800 kg/m^3, is specified in EN 15940:2016+A1:2018 +AC:2019 class A.

HVO can be considered a first-generation or second-generation biofuel, depending on the biomass used. HVO made from biomass such as vegetable oils, e.g. palm oil, soybean oil, or rapeseed oil, is a first-generation biofuel. HVO made from biomass such as residual crops and industrial waste, e.g. wood spill, is a second-generation biofuel. As a second-generation biofuel, HVO has a much smaller WTW carbon footprint compared to MGO – only 8–48 CO_2e/MJ compared to 85–87 g CO_2e/MJ (Fridell et al., 2019).

Storage and treatment on board

HVO can be stored and treated in much the same way as marine petroleum distillate. In contrast to FAME, it is not more prone to microbial growth than fossil diesel oils. Nevertheless, the low fuel density may require adjustment of the separator for efficient removal of water.

Engine ancillary system and combustion

HVO contains neither aromatics nor sulphur. It therefore burns cleaner than fossil diesel oil, resulting in only minor soot formation when efficiently combusted. Hence the ash content remains limited and lubrication oil quality lasts longer.

However, the great density difference between HVO and residual fuels increases the risk of soot formation and asphaltene precipitation during a fuel changeover.

What to expect in the next decade

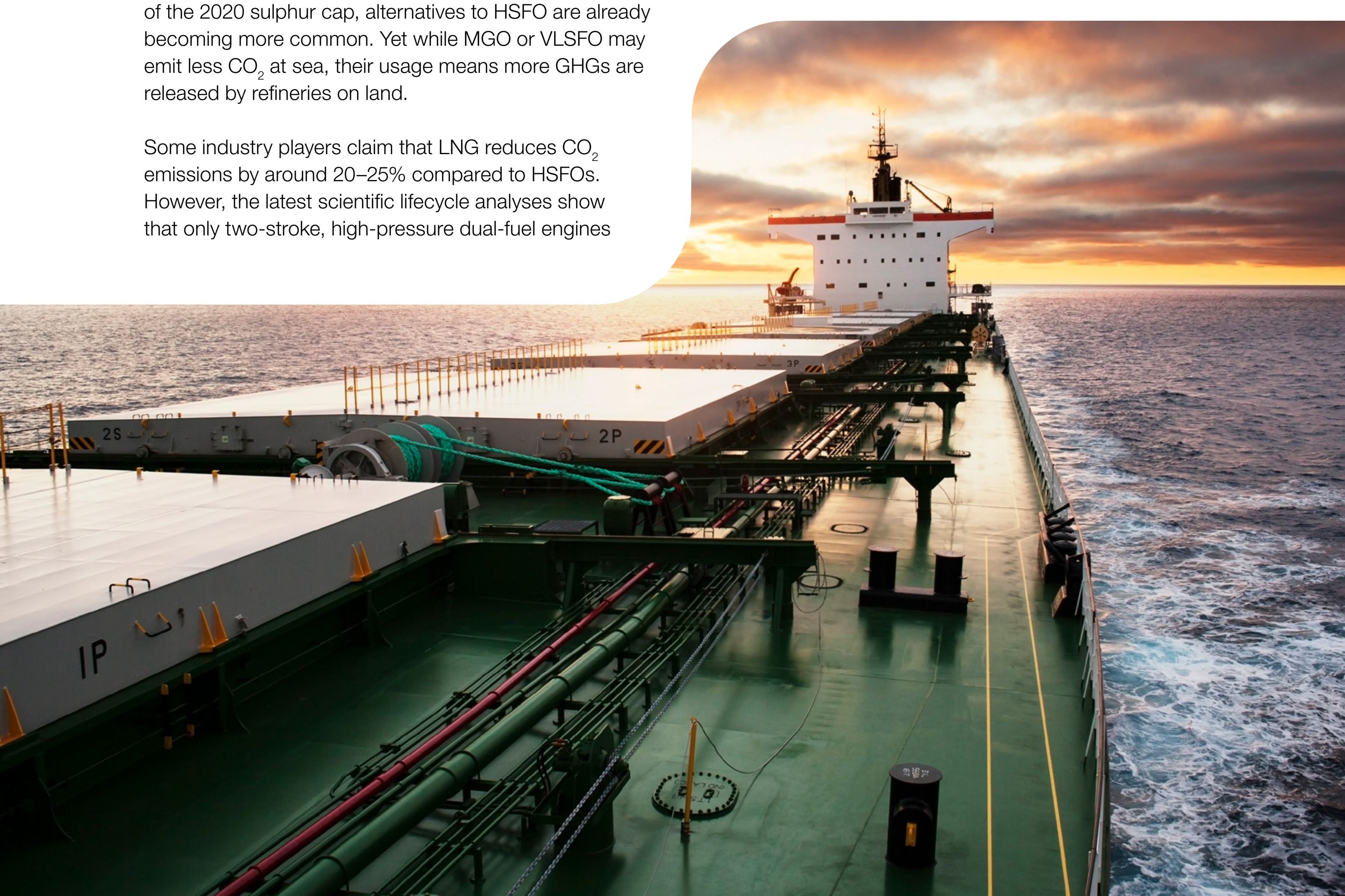
The introduction of the 0.50% sulphur limit on 1 January 2020 brought about a major change in fuel handling on board. The announced step to decarbonize the shipping industry by 2050, with the first major milestone in 2030, has changed the shipping industry.

In the short term, there are already steps fleets can take to reduce GHG emissions. Slow steaming is the easiest option today, and it is very possible that that the near future will see speed limits imposed on certain vessels or in certain regions. However, this approach will naturally mean longer voyage times and, eventually, more vessels sailing on each route.

Ultimately, decarbonizing the shipping industry will require switching to clean and sustainable fuels. As a result of the 2020 sulphur cap, alternatives to HSFO are already becoming more common. Yet while MGO or VLSFO may emit less CO_2 at sea, their usage means more GHGs are released by refineries on land.

Some industry players claim that LNG reduces CO_2 emissions by around 20–25% compared to HSFOs. However, the latest scientific lifecycle analyses show that only two-stroke, high-pressure dual-fuel engines contribute to slightly reduced GHG emissions. This is due to the methane slip from low-pressure engines, whereby uncombusted fuel escapes from the engine cylinders when the exhaust gases are released. The continued use of HSFO with a scrubber may make a bigger contribution towards global CO_2 reduction.

Simply put, meeting the IMO targets will require continued innovation and the introduction of alternative fuel sources. Development and testing are well underway in both the automotive and marine industries, but there are still many challenges left to solve. Infrastructures will need to be laid out and renewable production set up, just as vessels will need to be designed for running on alternative fuels.



Biofuels like FAME and HVO are viable alternatives in terms of having significantly lower emission levels than traditional marine fuel oils. However, global biofuel production remains far below the levels needed to support today's growing shipping industry, with the aviation and automotive industries also requiring a very large portion of the current supply. Furthermore, depending on the type of biomass resources used, the production of these fuels can create further environmental challenges due to deforestation and heavy water consumption. Moreover, much of the vegetable oil supply around the world will still be needed as a critical food source.

If biofuels are the way forward, lubrication oil producers will have to adapt. The absence of sulphur in FAME (even though the TAN may be high) and HVO requires marine engine lubrication oils with low TBN and high detergency in order to provide efficient engine lubrication and prevent scuffing. Evidence also suggests that the use of a centrifugal separator to remove contaminants (insoluble content and water) from the lubrication oil will continue to promote engine longevity and efficiency, regardless of the biofuel oil used.

Biofuels are likely to dominate in the coming years, due to their existing supply chain and the ease of integrating them into existing fuel infrastructure and onboard treatment plants. However, the future marine fuel landscape promises to be even more complicated than it is today. No matter what fuels become dominant, treatment of the fuel will remain a necessity, pilot fuels will still need to be cleaned, and lubrication and control oil must remain in good condition.

Financial considerations

A cost comparison between biofuels and fossil fuel oils shows that biofuels are significantly more expensive (Figure 1). However, FAME and HVO prices are volatile and highly dependent on the price of the feed stock, which is largely independent from the crude oil price.

To drive the use of biofuels in the marine market, strict legislation is needed – either in the form of regulation or in the form of CO_2 taxation.

The required tank volume plays a very important part in the evaluation of future fuels. This is especially true for alternative fuels such as LNG and ammonia, which cannot be used with traditional fuel treatment equipment. Even though HVO is a low-density fuel, it has a relatively high volumetric energy content (55 GJ/m^3) and hence requires less storage space (Figure 2).

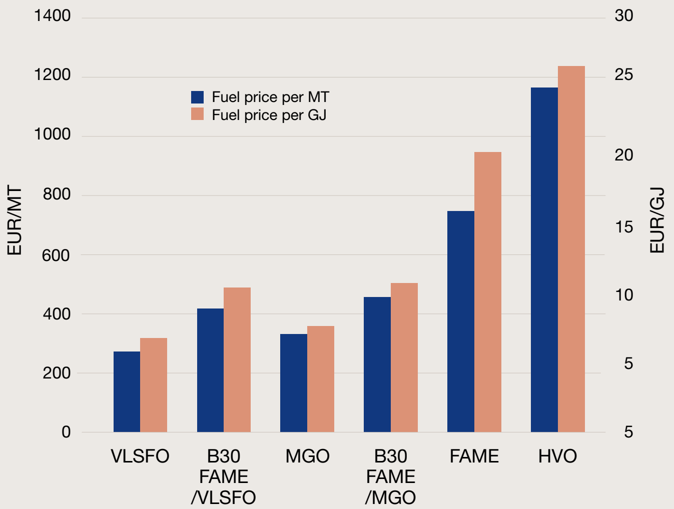


Figure 1: Cost comparison according to March 2021 fuel price level expressed as euro per mass in metric tonnes and energy content in gigajoules (Cision PR Newswire, 2020; Neste, 2021; Ship & Bunker, 2021).

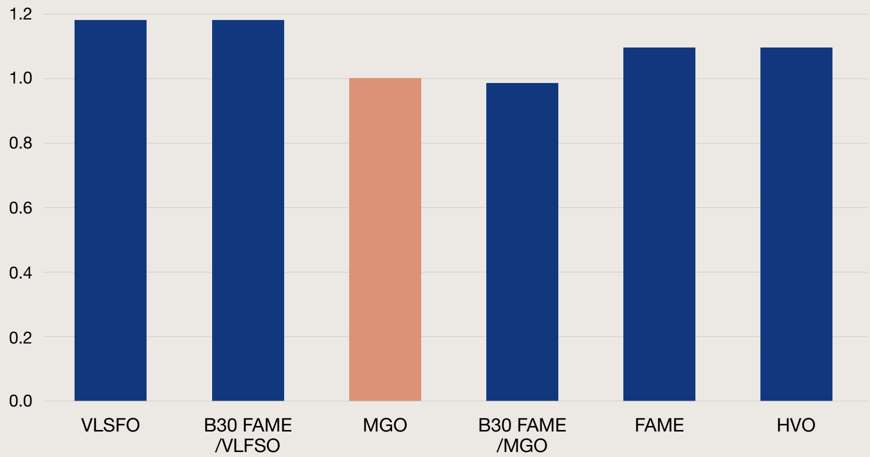


Figure 2: Volumetric comparison of fuels expressed per equivalent energy content of MGO (=1) (Neste, 2020; Ship & Bunker, 2020)

Summary

The Alfa Laval Test & Training Centre in Aalborg, Denmark, includes facilities for testing both gas-related solutions and biofuels. It is the world's most advanced test centre for environmental and combustion technology for the marine industry.

The marine fuel market must change for the sector to reach the goals of the Paris Agreement and to cut global GHG emissions. Biofuels, such as FAME and HVO, will contribute to decarbonizing the global shipping industry, but not without placing new requirements on both equipment and operator.

FAME and HVO are often considered drop-in fuels. However, special attention should be paid to operation on board, including fuel storage and treatment.

The properties of each bunker of biofuels should be analysed on a case-by-case basis. Due to the lack of biofuel quality specifications for marine applications, fuel quality varies significantly. This creates, in itself, a great risk of equipment breakdown, as well as a risk of incompatibility when mixing with both residual and distillate fuels.

The most common problems when running on biofuels are related to energy content and low, very temperature-dependent viscosity. To avoid problems, frequent and careful temperature checks are required.

Additionally, microbial growth and oxidation need to be kept under control. Both tank and equipment cleanliness and storage time play key roles here.

Sludge build-up from biofuels may require more frequent discharges, but it can be treated in the same way as that of petroleum fuels.

The solvent properties of biofuels are also reason for additional control and maintenance, as they may degrade rubber and attack certain metals.

Finally, the flashpoint of both biofuels must be considered, as it affects both lubrication oil quality and emissions.

To conclude, based on all the above, FAME and HVO require thought-through solutions before uptake. It is of utmost importance to make sure the fuel treatment equipment is adapted, and that the crew is prepared before putting these fuels to use. Alfa Laval encourages you discuss your fuel treatment equipment needs.

Discuss your needs with Alfa Laval

Flexibility will continue to grow more important, and the design for any new vessel in the coming years should consider how it can switch to low- and zero-emission fuels later on. This is where we at Alfa Laval can help. We exist to accelerate success for our customers, with solutions that keep people and the planet in focus.

Our development is heavily focused on new solutions for improving energy efficiency and adapting to emerging fuels, and we have years of expertise in working with both liquid and gaseous fluids. We already offer a fuel conditioning system for methanol, and we have recently introduced one for LPG that can even be modified to work with ammonia. We enjoy creating solutions to technical challenges, and we invite you to discuss your biofuel integration with our experts.

No matter what your fuel plans currently are, you will no doubt have many new questions in the coming years. Rest assured that we will be here to keep you updated with the latest developments and news when you need it. Everyone in the marine industry is preparing for a dramatic – but exciting – journey into a new world of fuels. Alfa Laval is ready to be your partner in this process, so you can be confident of not having to make that journey alone.

Property	FAME			HVO		
	Min	Max	Standard	Min	Max	Standard
Cetane number	51	–	EN 14214	70	–	EN 15940
Density @ 15°C [kg/m³]	860	900	EN 14214	765	800	EN 15940
Flashpoint [°C]	101	–	EN 14214	55.1	–	EN 15940
Viscosity @ 40°C [mm²/s]	3.5	5.0	EN 14214	2.0	4.5	EN 15940
Lubricity [µm]				–	400	EN 15940
Aromatics [% (m/m)]				–	1.1	EN 15940
Sulphur content [mg/kg]				–	5.0	EN 15940
Carbon residue on 10% distillation residue [% (m/m)]				–	0.1	EN 15940
Sulphated ash content [% (m/m)]	–	0.02	EN 14214	–	0.001	EN 15940
Water content [% m/m]	–	0.05	EN 14214	–	0.02	EN 15940
Total contamination [mg/kg]	–	24	EN 14214	–	24	EN 15940
Oxidation stability @ 110°C [h]	8.0	–	EN 14214	–	25	EN 15940
Acid value [mg KOH/g]	–	0.5	EN 14214	–	0.01	EN 15940
Cloud point [°C]				–	-10 summer -32 winter	EN 15940
Cold filter plugging point (CFPP) [°C]	–	Grade A +5 Grade B 0 Grade C -5 Grade D -10 Grade E -15 Grade F -20 Grade G -26			-10 summer -32 winter	EN 15940
Appearance @ 25°C		–		Clear and bright		EN 15940

Table 1: Fuel properties for FAME and HVO (CEN, 2019a; CEN, 2019b)

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This is Alfa Laval

Alfa Laval is active in the areas of Energy, Marine, and Food & Water, offering its expertise, products, and service to a wide range of industries in some 100 countries. The company is committed to optimizing processes, creating responsible growth, and driving progress – always going the extra mile to support customers in achieving their business goals and sustainability targets.

Alfa Laval's innovative technologies are dedicated to purifying, refining, and reusing materials, promoting more responsible use of natural resources. They contribute to improved energy efficiency and heat recovery, better water treatment, and reduced emissions. Thereby, Alfa Laval is not only accelerating success for its customers, but also for people and the planet. Making the world better, every day. It's all about *Advancing better*™.

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