The UUPO project – New fuels for maritime logistics as drivers of green transition and blue growth

Fuel Info Package: Bio- and Renewable Diesel

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Satakunta University of Applied Sciences

SATAKUNTALIITTO

Regional Council of Satakunta

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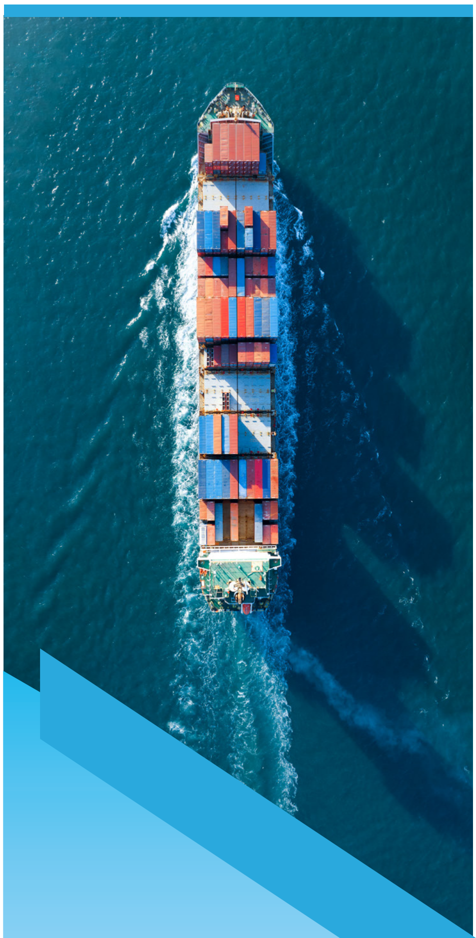
Basic information



Bio- ja renewable diesel
Bio- and renewable diesels are carbon-based fuels, produced from a variety of feedstocks using different methods, resulting in significant variations in their properties. The most common bio- and renewable diesels are FAME (Fatty Acid Methyl Ester), HVO (Hydrotreated Vegetable Oil), and FT diesel (Fischer-Tropsch Diesel). Among these three types of diesel, HVO and FT diesel particularly resemble conventional diesel in terms of their properties. [1] [2]

Like other carbon-based fuels, these diesels produce CO_2 during combustion, contributing to greenhouse gas emissions and climate change. However, the lifecycle emissions of FAME, HVO, and FT diesels are generally lower than those of conventional fossil fuels, making them a more environmentally friendly option. [3] This reduction in lifecycle emissions has significantly increased their use in the shipping industry, where reducing environmental impacts and CO_2 emissions has become a top priority amid growing concerns about climate change and regulatory pressures.

The flexibility of bio- and renewable diesels is also notable and adds to their appeal. Some of these diesels can be used as “drop-in” fuels, meaning they can be directly utilized in existing diesel engines or easily blended with some conventional marine fuels in various ratios. This adaptability makes them particularly attractive to ship operators, as it allows for a smoother transition to lower-emission alternatives without necessitating significant investments in new engines. Consequently, bio- and renewable diesels represent a significant step toward more sustainable shipping and have garnered considerable interest among industry stakeholders.

Important notes:

1. HVO and FT diesels are “drop-in” fuels, meaning they can be used in existing ship diesel engines

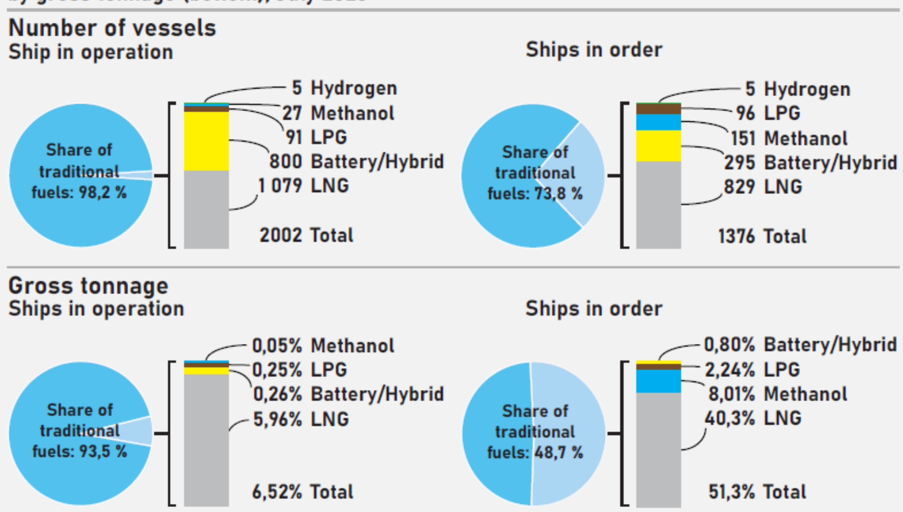
2. The properties of FAME diesel can vary, depending on the feedstock used in its production

3. The availability of bio- and renewable diesel is influenced by the availability of feedstocks

4. The lifecycle emissions of first-generation bio- and renewable diesels can, in some cases, be comparable to those of fossil fuels

5. Bio- and renewable diesels are carbon-based fuels, so their use results in CO_2 emissions

Figure 1. Adoption of alternative fuels in the global fleet by the number of vessels (top) and by gross tonnage (bottom), July 2023



Citations: [1], [2], [3], [Figure 1]

Production methods

In practice, bio and renewable diesels can be categorized into three different types based on their raw materials and production methods. These three categories are FAME, HVO, and FT diesel. The latter two are classified as “drop-in” fuels, meaning they can be used with minor modifications or even, in some cases, without any changes in existing diesel engines. [4] [5]

Biodiesel (FAME)

Biodiesel typically refers to FAME (Fatty Acid Methyl Ester), which is produced from various triglycerides, such as vegetable oils or animal fats. The production of FAME begins with the pretreatment of raw materials, during which impurities are removed. After pretreatment, the oil and fat mixture is heated and transferred to a transesterification reactor, where it reacts with methanol, forming FAME diesel and glycerol as a byproduct. After transesterification, the produced diesel and glycerol are separated, and the diesel undergoes further processing, such as washing with water, resulting in purified biodiesel. [6]

Common raw materials used in the production of FAME diesel include rapeseed oil, palm oil, corn, coconut, animal fats, and used cooking oils, such as those from fast-food restaurants. [7]

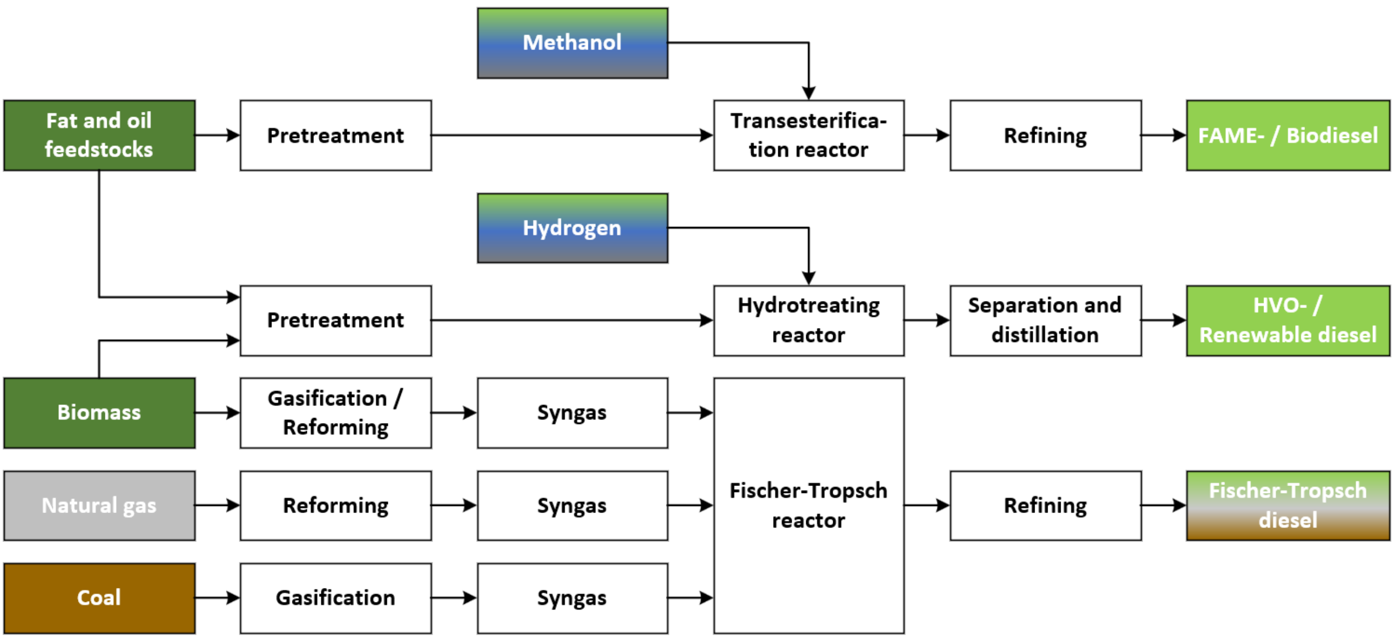
The physical and chemical properties of biodiesel, such as cold-flow characteristics, depend on the raw material used in its production. [8]

Hydrotreated vegetable oil (HVO)

Hydrotreated renewable diesel, typically referred to as HVO (Hydrotreated Vegetable Oil), can be produced from the same raw materials as biodiesel. Additionally, HVO can be made from lignocellulosic biomass, which is generated from agriculture and forestry industries. [9]

The production of HVO begins similarly to biodiesel, with the pretreatment of raw materials to remove impurities. The raw

Figure 2. The main methods for producing bio- and renewable diesels



Citations: [4], [5], [6], [7], [8], [9], [Figure 2]

Production methods

materials are then fed into a hydrotreating reactor, where hydrogen is also introduced. In the reactor, the raw materials react with hydrogen under pressure and heat, forming liquid hydrocarbons and some gases. The liquid-gas mixture is then transferred to a separator, where the gas is removed, and the remaining liquid continues to distillation. The distillation process yields renewable diesel, as well as some byproducts such as liquefied petroleum gas (LPG) and naphtha. [10]

The properties of HVO diesel are less dependent on the raw material used in its production compared to biodiesel, resulting in more consistent performance and quality. [11]

Fischer-Tropsch renewable diesel

FT diesel is produced through the Fischer-Tropsch process, and like HVO, it can be made from various biomass sources, such as agricultural and forestry residues. The production of FT diesel begins with the pretreatment of biomass, which helps to enhance the efficiency of subsequent processes. After pretreatment, the biomass is gasified. In gasification, the biomass is heated to high temperatures, and oxygen or steam is injected, resulting in syngas, which mainly consists of carbon monoxide and hydrogen. This syngas undergoes a purification process to remove various impurities, ensuring that it meets the necessary specifications for the next step. Once purified, the syngas is transferred to the FT reactor, where it undergoes a chemical transformation. The product from the FT reactor is then further refined, ultimately resulting in FT diesel. [12]

Syngas can also be produced from coal or natural gas, but the lifecycle emissions of the resulting diesel are significantly higher in these cases. The name of FT diesel can also vary depending on the raw material used. For example, diesel produced from biomass may be called BtL (Biomass to Liquid) diesel. Diesel produced from coal is sometimes referred to as CtL (Coal to Liquid) diesel, and diesel from natural gas as GtL (Gas to Liquid) diesel. [13]

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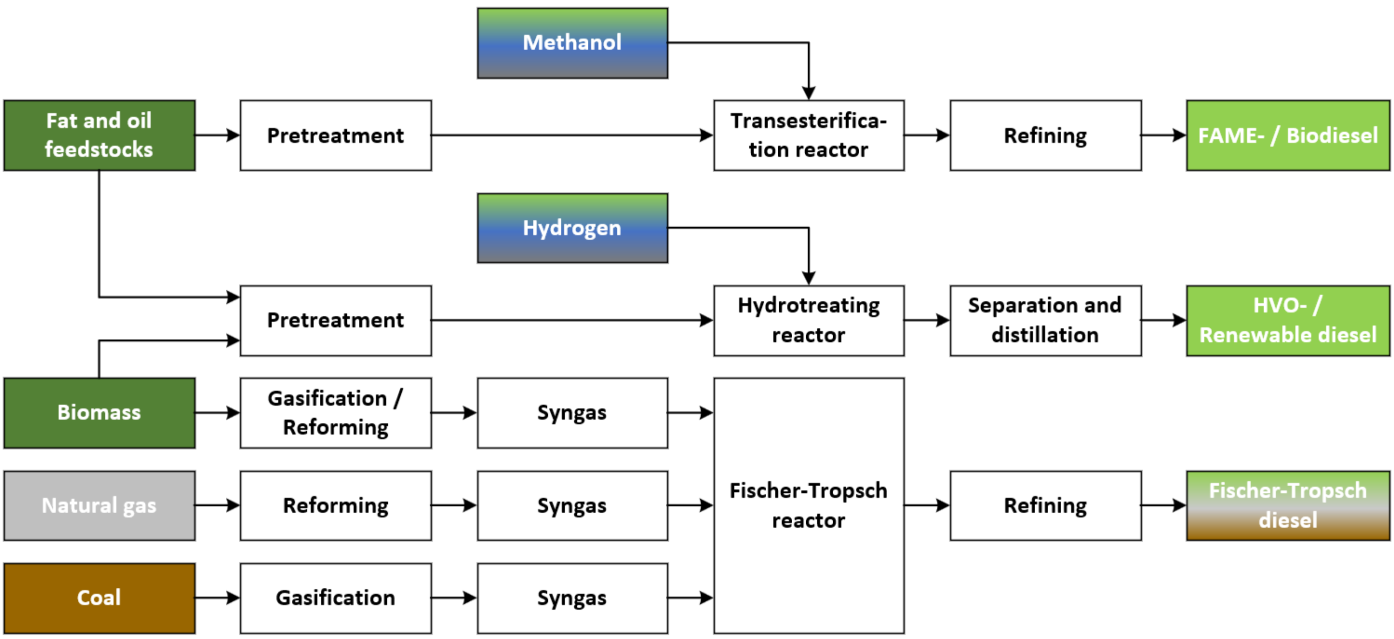

Citations: [10], [11], [12], [13], [Figure 2]

Properties and safety aspects

Fuel properties

As fuels, FAME, HVO, and FT diesels are quite similar and closely resemble traditional maritime fuels such as heavy fuel oil (HFO). For instance, their ignition properties are largely comparable to those of marine diesel oil (MDO) and HFO. Additionally, when comparing the energy density of heavy fuel oil to that of the alternative fuels, the energy densities of bio and renewable diesels are the closest to that of HFO.

Bio and renewable diesels can also be blended with traditional fuels, significantly reducing the lifecycle emissions of the vessel. [14]

It is important to note that the properties of bio and renewable diesels can vary depending on the raw material and production method. Therefore, specific standards have been established for FAME and HVO (FAME: EN 14214, HVO: EN 15940) to set limits and requirements, and to define testing methods to ensure the quality of these fuels. [15]

The quality of FT diesel is typically defined according to the EN 15940 fuel standard as well. [16]

Safety aspects

Bio and renewable diesels do not pose a significant danger to humans. For example, short-term skin contact with these fuels is generally not harmful. However, prolonged or repeated exposure may cause skin irritation, dryness, and cracking. [17] [18]

Bio and renewable diesels are also relatively easy and safe to handle since they are always in liquid form, making them practical for everyday operations and transport. This means that in case of spills, personnel do not need to worry about vapor or gas emissions, which in cases like ammonia or hydrogen leaks, could pose serious health or fire safety risks. Additionally, bio and renewable diesels are less flammable than many other fuels, enhancing their safety in both use and storage. [19] In practice, many of the safety protocols and precautions that apply to traditional diesel also apply to the safe handling of bio and renewable diesels, ensuring consistency in safety measures and procedures. [20]

	Energy and storage					Flammability		
Fuel	Density [kg/m^3]	Lower heating value [MJ/kg]	Energy density [MJ/m^3]	Boiling point [°C]	Fuel volume requirement vs. LSHFO	Autoignition temperature in air [°C]	Flashpoint [°C]	Flammability limits in air [%]
LSHFO	993	40,5	40 217	> 180	-	230	> 60	0,6 - 7,5
MDO	819	40,5	33 170	> 180	1,21	210	> 60	0,6 - 7,5
LNG	450	49,1	22 095	-162	1,82	540	-188	5,0 - 15,0
MeOH	792	19,9	15 761	65	2,55	464	12	6,7 - 36,0
EtOH	789	26,8	21 145	78	1,90	365	17	3,3 - 19,0
L NH_3	680	18,6	12 648	-33	3,18	651	132	15,0 - 28,0
L H_2	70	120	8 400	-253	4,79	585	-	4,0 - 75,0
FAME	**880**	**37,2**	**32 736**	**> 180**	**1,23**	**261**	**> 61**	**0,6 - 7,5**
HVO	**780**	**44**	**34 320**	**> 180**	**1,17**	**204**	**> 61**	**0,6 - 7,5**
FT-Diesel	**785**	**43,2**	**33 912**	**> 180**	**1,19**	**204**	**89**	**0,6 - 7,5**

Citations: [14], [15], [16], [17], [18], [19], [20], [Table]

Production

Global production

In 2022, there were slightly over 500 bio and renewable diesel production facilities worldwide, with an annual production capacity of around 84 billion liters. [21]

The majority of these production plants produce FAME diesel, which accounted for approximately 59 billion liters in 2022. However, FAME diesel production has seen little growth over the past five years. In contrast, HVO diesel production has significantly increased during the same period. In 2019, around 6 million tons of HVO diesel were produced, while by 2022, production had risen to nearly 9,5 million tons, or about 12 billion liters. [22] [23]

Compared to these production volumes, FT diesel production is still very limited, though it holds great potential for future growth. Several FT diesel plants are currently under construction, and production is expected to grow rapidly in the coming years. One advantage of FT diesel production facilities is their flexibility to produce other fuels from syngas, such as methanol or dimethyl ether, which broadens the potential applications of these facilities and increases their adaptability in a diverse fuel market. [24]

Future outlooks in Finland and Satakunta

Finland has a long history of producing HVO diesel, with Neste playing a crucial role in this development. In 2007, Neste began producing HVO diesel at the world's first large-scale production facility in Porvoo. The company has continued its development work and investments in its production facilities, which has been central to advancing HVO diesel production. In addition to Porvoo, Neste also produces its HVO diesel, known as Neste MY, in Rotterdam and Singapore. [25] [26] These facilities make Neste the world's largest producer of HVO diesel. [27]

Neste has plans to further increase its renewable diesel production capacity. In December 2023, the company announced investments to gradually transform its Porvoo refinery into a facility focused on renewable and circular economy solutions. In addition to renewable diesel, the revamped refinery will produce renewable aviation fuel and various products for the chemical industry. [28]

In addition to Neste, UPM also produces a type of HVO-like diesel in Lappeenranta, made from pulp production residues. [29]

Citations: [21], [22], [23], [24], [25], [26], [27], [28], [29]

Technical aspects

Infrastructure, transportation and storage
Renewable diesels largely behave similarly to conventional maritime fuels, allowing the existing fuel infrastructure to be utilized for the transportation, storage, and bunkering of renewable diesels. This significantly eases their adoption in the maritime industry. [30]

However, the characteristics of bio-based FAME diesel differ somewhat from traditional fuels, requiring specific considerations during transportation, storage, and usage.

FAME diesel is prone to microbial growth, which can lead to various corrosion issues in storage tanks and fuel supply systems. FAME is also highly hygroscopic, meaning it readily absorbs moisture from the air, further promoting microbial growth. Additionally, FAME contains more oxygen than HVO or conventional fuels, which accelerates the oxidation process in storage tanks. This oxidation can result in the formation of peroxides, which continue to react with the fuel's components. Certain metals, such as copper, brass, tin, zinc, and lead, can also accelerate the oxidation process. The resulting peroxides and other compounds may clog and corrode fuel supply systems and engine parts, leading to increased maintenance requirements. To limit microbial growth and oxidation, additives can be mixed into the fuel. [31]

FAME diesel also performs poorly in low temperatures. Its viscosity increases rapidly as the temperature drops, and its cloud point is around 1 °C, compared to about -9 °C for conventional diesel. The cloud point indicates when the fuel begins to crystallize, leading to fuel gelling, which makes it more difficult to transport fuel from the tank to the engine. [32] [33]

The characteristics of FAME diesel must always be considered when planning its use and during operational activities. Since microbial growth and oxidation in FAME diesel can cause significant problems, it is essential to regularly monitor the fuel's condition and clean the tanks and other fuel system components as needed. Additionally, in cold conditions, using FAME diesel may require preheating the fuel or adding cold flow improvers to enhance its performance in low temperatures.

Citations: [30], [31], [32], [33]

Technical aspects

Use as fuel

In recent years, the maritime industry has shown growing interest in the use of bio- and renewable diesels. Shipping companies have recognized the potential of these alternative fuels to reduce carbon emissions and achieve more environmentally friendly operations. In addition to their environmental benefits, the ease of adoption and compatibility with existing diesel engines make these fuels an attractive and cost-effective option for maritime operators.

Since HVO and FT diesel are “drop-in” fuels, their integration into existing ships is much easier compared to many other new fuels. HVO diesel, in particular, has already accumulated considerable operational experience across various types of vessels. The adoption of HVO and FT diesel is further facilitated by the fact that these fuels can be bunkered using the existing fuel infrastructure. [34]

In addition to the ease of adoption, the fuel properties of renewable diesels are the closest to fossil fuels compared to other alternative fuels. This makes them even more appealing to shipping companies. However, the availability of these renewable diesels remains limited, and their relatively high cost poses challenges to wider adoption. [35]

Currently, the most commonly used bio- or renewable diesel fuel in the maritime industry is FAME diesel, typically blended with conventional fuels. [36] The proportion of FAME diesel in the fuel blend can vary, but a safe limit for use in ship engines without engine modifications is up to 7% by volume. This limit is also set in the maritime fuel standard ISO 8217:2017. Recently, fuel manufacturers have started selling blends with 10%, 20%, or even 30% FAME, and these higher blends have not caused significant operational issues. [37]

The use of pure FAME diesel would likely require some modifications to the engine and fuel supply system. FAME diesel, for instance, can cause corrosion in various materials. Additionally, FAME diesel has stronger solvent properties than many other fuels, which may dislodge deposits in pipelines and engine components, leading to clogged filters and problems with pump operation. [38]

Citations: [34], [35], [36], [37], [38]

Environmental aspects

Greenhouse gas emissions

The lifecycle emissions of bio- and renewable diesels are highly dependent on the raw materials used in their production. The total emissions can also vary significantly across studies, depending on what factors are included in the calculations. For instance, some studies account for emissions from land use and cultivation, while others exclude these factors.

Generally, second-generation bio- and renewable diesels, produced from waste and residue, result in much lower lifecycle emissions compared to first-generation bio- and renewable diesels, which are made from energy crops. This is because the cultivation of energy crops causes significant emissions related to land use and agricultural practices. In fact, the emissions from first-generation bio- and renewable diesels can sometimes be as high as, or even exceed, those of fossil fuels. [39] In contrast, the lifecycle emissions of second-generation bio- and renewable diesels are typically 70–100 % lower than those of marine gas oil (MGO). [40]

The lifecycle emissions of FAME and HVO diesels are also affected by the production methods used for methanol and hydrogen in their respective processes. [41] [42]

Nitrogen oxides emissions

The nitrogen oxide (NOx) emissions from bio- and renewable diesels tend to be relatively high compared to other new fuels. According to a report published by the ICCT, NOx emissions from HVO and FT diesels are estimated to be 5–20 % lower than those of MGO. In the case of FAME diesel, the NOx emissions vary depending on the method of assessment. Lifecycle modeling estimated that FAME's NOx emissions are about 13 % higher than those of the fossil fuel it was compared to, while laboratory tests showed 12–29 % lower emissions. [43]

Sulfur oxides emissions

Bio- and renewable diesels contain very little sulfur, which results in significantly lower sulfur oxide (SOx) emissions when used as fuel. In the case of FAME, SOx emissions are reduced by around 90%, while HVO and FT diesels produce no SOx emissions at all. [44]

When blended with traditional fuels, these diesels also lower the total sulfur content in the fuel mix, further reducing SOx emissions. [45]

Other emissions

FAME diesel produces 40–90 % fewer particulate matter emissions than traditional fuels. [46] Moreover, FAME contains more oxygen than fossil fuels, resulting in cleaner combustion and lower emissions of pollutants such as black carbon. For example, tests on a 9 MW ship engine using B50 (50 % FAME, 50 % MGO) and B100 (100 % FAME) showed 36–45 % and 60–63 % reductions in black carbon emissions, respectively, compared to MGO. The reduction potential varied by a few percentage points depending on the measurement method. [47]

Fuel spills

In the event of fuel spills, bio- and renewable diesels are less harmful to the environment compared to traditional fossil fuels. They break down more quickly in natural environments and cause less long-term damage to aquatic ecosystems. [48] [49]

Citations: [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49]

Summary

Bio- and renewable diesels are already in use in the maritime sector, and shipping companies have shown growing interest in these fuels in recent years due to their many advantages. A key strength of renewable diesels is that they can be used in existing combustion engines and infrastructure without modifications, making their adoption and use much easier and more cost-effective compared to many other alternative fuels. In contrast, using pure biodiesel requires changes to ships and fuel infrastructure to accommodate the specific properties and requirements of biodiesel.

The use of bio- and renewable diesels also offers several environmental benefits. These fuels produce significantly lower SOx and particulate emissions than traditional maritime fuels and have the potential to reduce greenhouse gas emissions from shipping. However, the extent of greenhouse gas reduction depends heavily on the feedstock used to produce bio- and renewable diesels. For example, first-generation bio- and renewable diesels cause higher greenhouse gas emissions due to the impact of land use and cultivation practices. As a result, the lifecycle emissions of these first-generation diesels can be on par with, or even higher than, those of fossil fuels. Second-generation bio- and renewable diesels, on the other hand, generate much lower lifecycle emissions compared to fossil fuels.

The role of these diesels in environmentally friendly maritime logistics is likely to grow in the future, but this growth may be slowed by challenges such as the availability of feedstocks, competition with other industries, and the costs of the fuels themselves.

Strengths

+ FT and HVO diesels can be used as “drop-in” fuels, meaning they can be utilized in existing diesel engines and fuel infrastructure without modifications

+ Second-generation bio- and renewable diesels have significantly lower lifecycle emissions compared to fossil fuels

+ The energy density of bio- and renewable diesels is the highest among all alternative fuels, making them more efficient

+ Their use helps reduce SOx and particulate emissions, contributing to cleaner air

+ In case of fuel spills, the environmental impact on nearby ecosystems is relatively minor, as these fuels biodegrade faster

+ The use of bio- and renewable diesels is relatively safe, with smaller environmental risks compared to some other fuels

Weaknesses

- First-generation bio- and renewable diesels generate significant greenhouse gas emissions due to land use and farming practices

- The cultivation of energy crops for these fuels often occurs on land that could otherwise be used for food production, raising ethical concerns

- Energy crop yield failures can severely impact the availability of bio- and renewable diesels, making them less reliable

- FAME diesel has poor storage and cold weather properties, which must be considered in its use

- NOx emissions from bio- and renewable diesels, especially FAME, are higher compared to many other new fuels

- The properties of FAME diesel can vary significantly depending on the feedstock used in production

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