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

Fuel Info Package: Ethanol

samk
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SATAKUNTALIITTO
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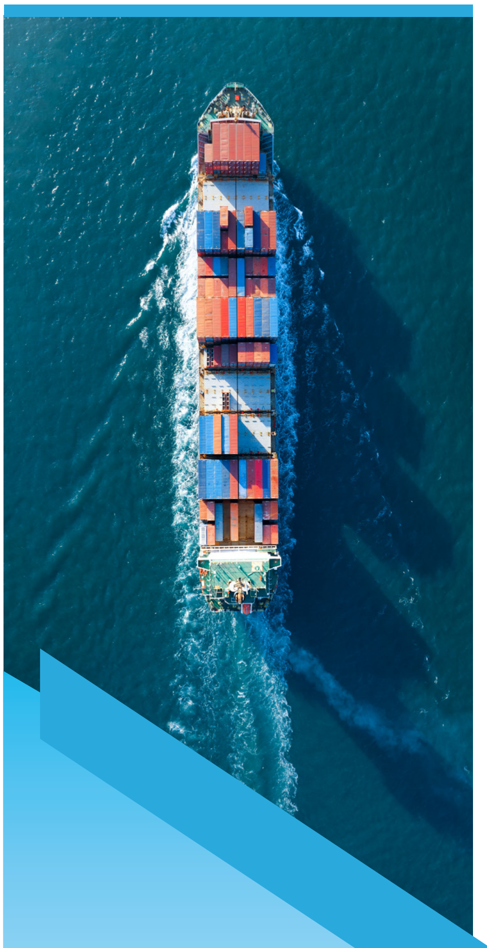
Basic information



Ethanol

Ethanol (C_2H_5OH) is a carbon-based compound that belongs to the group of alcohols, consisting of two carbon atoms, five hydrogen atoms, and one hydroxyl group (-OH). Ethanol is also known as ethyl alcohol. At normal temperature and pressure, ethanol is a colorless, flammable liquid with a characteristic odor typical of alcohols.

Ethanol has been used in road traffic as an additive to gasoline since the late 1970s. Its addition to gasoline raises the fuel's octane rating and improves its combustion properties. With the introduction of ethanol, the use of lead as an additive in gasoline could be discontinued, which was significantly more harmful to the environment. Additionally, the use of ethanol reduced various emissions, such as carbon monoxide, because the oxygen contained in ethanol allowed for cleaner combustion in internal combustion engines. [1] Today, ethanol usage in gasoline is very common, and it is the most widely used biofuel in road traffic. In 2015, as much as 87 % of all produced ethanol was used for fuel purposes. [2]

Ethanol has also garnered some interest among maritime operators, as it has the potential to significantly reduce emissions produced by shipping. However, this interest has not been as pronounced as the attention given to the use of methanol or ammonia. Furthermore, the adoption of ethanol would require significant investments in infrastructure and technical modifications to vessels. Nevertheless, ethanol can provide a sustainable and environmentally friendly solution to the emission challenges in shipping, and its true role in future marine logistics remains open.

Important notes:

1. Ethanol is the most common biofuel for road transport in the world

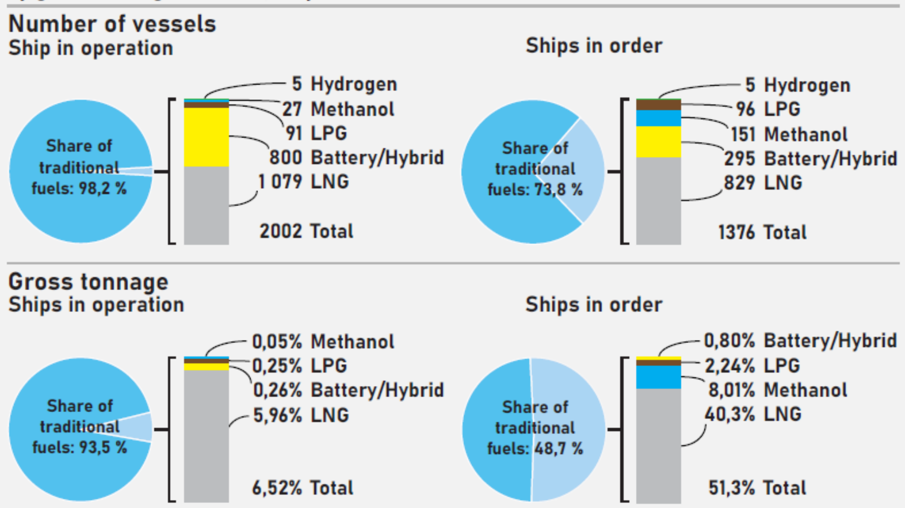
2. The life cycle emissions of ethanol strongly depend on the raw materials used in its production

3. Ethanol produces significantly fewer SOx, NOx, and particulate matter emissions than fossil fuels

4. Ethanol is a carbon-based fuel, so its use generates carbon dioxide emissions

5. The interest of industry players in using ethanol as a fuel for maritime transport is not as high as for other alternative fuels

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], [Figure 1]

Production methods

Ethanol can be produced in various ways, but most of the world's ethanol is made from different biomass sources, which is referred to as bioethanol. The production methods for bioethanol, like other biofuels, are divided into different generations depending on the biomass itself and the production method.

First generation bioethanol:
First-generation bioethanol is produced from various crops that contain large amounts of carbohydrates, such as sugars or starch. Sugar-based raw materials include sugarcane, sugar beets, and sorghum, while the most common starch-based raw materials are corn, cassava, wheat, and rye. [3]

The production of first-generation bioethanol begins with the pretreatment of the raw material. In pretreatment, the biomass is typically first ground and mixed with water. After this, the biomass-water mixture is treated with heat and enzymes that break down the biomass's cellular structure and release the sugars contained in the biomass into the mixture. Once the sugars are released from the biomass, the mixture is transferred to a fermentation reactor, where yeast or bacteria use the sugars in the mixture to produce ethanol and carbon dioxide. This is called fermentation. After fermentation, the resulting mixture is processed to separate ethanol and other components, such as water. This is often done through distillation or other separation methods. [4]

Second generation bioethanol:
Second-generation bioethanol is produced from lignocellulosic waste, which typically comes from agricultural and forestry by-products. Examples of agricultural waste include various plant parts, such as straw, leaves, or other residues. By-products from the forestry industry, such as wood chips and forest residues, are also well-suited for bioethanol production. Generally, any waste containing cellulose or hemicellulose can be utilized in the production of second-generation bioethanol. [5]

The production of second-generation bioethanol resembles the production of first-generation bioethanol in many ways. The only practical difference between these processes is that in the production process of second-generation bioethanol, lignin, which comes from lignocellulosic waste, is separated from the biomass-water mixture after pretreatment. Lignin is not needed for the fermentation process, and its removal increases the proportion of sugars in the biomass-water mixture. This improves the efficiency of the fermentation process and increases the amount of ethanol produced. Lignin is typically burned, allowing the energy contained in it to be utilized in bioethanol production. [6]

Third and fourth generation bioethanol:
In addition to first and second-generation raw materials, bioethanol can also be produced using microorganisms. Third-generation bioethanol is produced from various algae, while fourth-generation bioethanol is produced using genetically modified microorganisms. However, these production methods are still in the developmental stage and are not yet widely commercially used. [7]

Other methods to produce ethanol:
Ethanol can also be produced from synthesis gas, which itself can be made in various ways. In this process, synthesis gas is typically fermented using Clostridium bacteria, which convert the carbon, oxygen, and hydrogen in the synthesis gas into ethanol. In addition to ethanol produced from synthesis gas, ethanol can also be synthesized from ethylene and water. [8]

Citations: [3], [4], [5], [6], [7], [8]

Properties and safety aspects

Fuel properties

Verrattuna perinteisiin fossiili- Compared to traditional fossil fuels, ethanol (EtOH) has a relatively low heating value. When comparing the energy densities of fuels, the difference between ethanol and traditional fuels becomes even more pronounced due to ethanol's low density. As a result, ethanol requires approximately twice the volume to store the same amount of energy as heavy fuel oil.

When using pure ethanol as fuel for ships, pilot fuels may be utilized in the combustion engines. [9] This works by igniting the pilot fuel first in the combustion chamber due to rising temperature and pressure. The energy released from the pilot fuel then ignites the ethanol in the chamber. The type of pilot fuel and its proportion of the total fuel amount depends on the type of combustion engine. Ethanol can also be used in various blend ratios with other fuels. [10]

Safety aspects

Ethanol is the active ingredient in alcoholic beverages, so its effects on humans are well known. However, these effects are significantly milder than many other new fuels, meaning its use as a fuel is somewhat safer. Exposure to ethanol vapors can cause various symptoms depending on the duration of exposure and the concentration of ethanol vapor in the air. Milder symptoms include nasal irritation and respiratory effects, while longer exposure times or higher concentrations can lead to central nervous system symptoms, fatigue, and headaches. Liquid ethanol, on the other hand, can cause irritation to the eyes and skin. Additionally, ethanol can be absorbed through the skin into the body. When ingested, ethanol affects both the digestive system and the central nervous system, causing various symptoms, including nausea and vomiting, as well as impairments in coordination, reaction time, and judgment. Higher levels of exposure can lead to unconsciousness and, in severe cases, respiratory or circulatory failure. [11]

The fire safety of ethanol is also important to consider, as ethanol has a relatively wide flammability range in the air and a low flash point. These properties make it a highly flammable substance, and this is crucial to keep in mind during its use. [12]

	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: [9], [10], [11], [12], [Table]

Production

Global production
In 2023, approximately 88 million tons of ethanol were produced for fuel purposes. The largest producing countries were the United States and Brazil, which together accounted for about 80 % of total production. [13] Although many methods for ethanol production have been developed, nearly all ethanol intended for fuel use is first-generation bioethanol, with corn being the most common raw material. [14][15] However, corn cultivation requires a significant amount of land, as bioethanol produced from corn needs nearly double the cultivation area compared to, for example, sugarcane or sugar beets to produce the same amount of bioethanol. [16]

Additionally, a study published in 2022 revealed that corn-produced bioethanol in the United States has increased the extent of agricultural areas, which in turn has led to significant carbon dioxide emissions. These emissions largely stem from the clearing and tilling of previously untouched land, which releases carbon that was previously stored in the soil into the atmosphere. Due to the released carbon, the lifecycle emissions of corn-produced ethanol may even exceed those of fossil fuels. [17]

The results of this and other similar studies raise questions about the environmental friendliness of corn-produced ethanol, and in the long term, this may also affect its production levels. The growth of first-generation bioethanol in the EU is additionally influenced by a law that came into force in 2015, which restricts the use of arable land for the cultivation of biofuel raw materials. The law aimed to limit competition and conflicts between food production and biofuel production. [18] However, the construction of second-generation bioethanol production facilities is continuously increasing, which will boost the production of lignocellulosic ethanol.

Future outlooks in Finland and Satakunta
St1 has produced bioethanol in several locations in Finland, including Kajaani, Lahti, and Vantaa. The Kajaani production facility utilized sawdust as a raw material, while bioethanol in Lahti and Vantaa was produced from food industry waste. However, the company announced the closure of these factories towards the end of 2023 due to production and economic challenges. For example, the Kajaani demo plant could only produce one-fifth of the ten million target, while the Lahti and Vantaa plants faced difficulties with raw material supply. [19][20]

However, two new production facilities are planned in Finland, in Pori and Haapavesi, which would produce bioethanol from wood-based raw materials. The annual production capacity of the Pori facility is estimated to be around 45 000 tons, while the larger Haapavesi facility is expected to produce approximately 65 000 tons of ethanol annually. In addition to bioethanol, the plants would also produce biogas. [21][22]

Citations: [13], [14], [15], [16], [17], [18], [19], [20], [21], [22]

Technical aspects

Infrastructure, transportation and storage

Ethanol already has an established infrastructure due to its widespread production and use, particularly in road transport. Additionally, the infrastructure built for gasoline can also be partially utilized for ethanol. [23]

Typically, ethanol is transported using trucks or trains. For longer journeys, such as international trips, ethanol is transported by tankers in the same way as other liquid fuels. In addition to these transportation methods, ethanol can also be transferred via pipelines. The pipeline does not need to be built specifically for ethanol, for example, gasoline transfer pipelines can be utilized for ethanol transportation, provided the necessary cleanings are performed and the pipeline materials are suitable for ethanol. [24]

Like methanol, one of the strengths of ethanol is its easy storage. Unlike many other alternative fuels, such as hydrogen, LNG, and ammonia, ethanol remains in liquid form at normal temperature and pressure, as its boiling point is 79 °C. This characteristic means that storing ethanol does not require as much energy as storing those other fuels. Ethanol can also be practically stored in the same tanks used for gasoline storage. [25]

Due to its low flash point, ethanol storage and handling have their own risks that must be considered and minimized, especially when used on ships. Fuel tanks and other components in contact with the fuel may require additional protective devices or systems to ensure safe use. Such protective devices or systems may also be necessary for compliance with various international regulations and standards, such as the SOLAS regulation. [26] Additionally, it is important to consider ethanol's property of absorbing water and its corrosiveness in various materials. [27][28]

Use as fuel

Most of the produced ethanol fuel is used in road transport as an additive to gasoline. Typically, the proportion of ethanol in fuel is about 5–10 vol%. [29] There is also fuel available on the market, such as E85 fuel, which consists of 85 % ethanol and 15 % gasoline. However, the use of E85 fuel usually requires various conversion kits before it can be used in a car's combustion engine. [30] Ethanol is also widely used in heavy road transport, with the first ethanol-powered trucks in the United States introduced as early as 1992. [31] In addition, in recent years, various heavy transport companies, such as Scania, have launched their own ethanol-powered trucks. Unlike passenger cars, these trucks use fuel with an ethanol content of about 95 %, with the remaining 5 % consisting of additives that improve combustion properties. [32]

In maritime logistics, ethanol has not yet been adopted. The main reason for this is that ethanol is not compatible with current ship engines without modifications. For example, ethanol's viscosity is lower than that of diesel, so changes to the fuel injection system are likely. Additionally, the combustion properties of ethanol differ from those of diesel, which may require modifications to cylinders and other parts of the engine. [33] However, interest in utilizing ethanol in maritime transport is growing. For instance, at the end of 2023, Wärtsilä and the Brazilian ethanol producer Raízen initiated a collaboration aimed at implementing ethanol in maritime transport. [34] Furthermore, several engine manufacturers have indicated that the use of ethanol could be practically possible with minor modifications to methanol engines, so increased interest and research into ethanol as a fuel in maritime transport can be expected in the future. [35]

Citations: [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35]

Environmental aspects

Ethanol has significant potential to reduce greenhouse gas emissions in maritime transport. However, the amount of reduction depends on the raw materials used in ethanol production. The use of ethanol as fuel also results in fewer other harmful emissions compared to conventional fuels. It should be noted, that since there are currently no ethanol-powered ship engines, the emissions caused by ethanol are often partially estimated based on emissions data from road transport engines. [36]

Greenhouse gas emissions

The EU's new Renewable Energy Directive RED II sets a reference value of 94 gCO2e/MJ for the lifecycle emissions of fossil fuels. Generally, the lifecycle emissions of ethanol are lower than those of fossil fuels, but they can vary significantly depending on the origin of the biomass and the production method. The lifecycle emissions of first-generation bioethanol made from wheat are about 32% lower than the reference value for fossil fuels in the RED II directive. For bioethanol produced from sugarcane, this figure is as high as 71%. If emissions from land cultivation and land use are taken into account, the emissions of bioethanol produced from wheat can be on par with those of fossil fuels. However, the emissions of bioethanol produced from sugarcane remain about half of those from fossil fuels. Second-generation bioethanols, on the other hand, reduce emissions by 75–90 %. [37]

Nitrogen oxides emissions

The nitrogen oxide emissions resulting from the use of ethanol are lower than those produced by heavy fuel oil. However, the amount of NOx emissions is higher than that of a ship equipped with an SCR system using heavy fuel oil. In practice, the SCR system would also be compatible with ethanol-powered ships. NOx emissions could also be reduced by using exhaust gas recirculation (EGR) systems or by optimizing engine operating values. [38]

Sulfur oxides emissions

Ethanol contains no sulfur, which is why the sulfur oxide emissions it produces are practically negligible. However, such emissions may arise from pilot fuel if it is used. Due to its low SOx emissions, ethanol is an excellent fuel alternative for areas with sulfur oxide emission control. [39]

Other emissions

Compared to traditional fuels, ethanol produces very low amounts of particulate matter emissions. [40]

Fuel spills

In general, managing ethanol leaks is easier than managing leaks of LNG, hydrogen, or ammonia, because ethanol does not vaporize and disperse into the air in the event of a leak. This makes the collection and containment of ethanol technically simpler.

Compared to other fuel leaks, ethanol leaks are also not nearly as harmful to water ecosystems. Ethanol completely mixes with water, diluting it and partially neutralizing the risks it poses. [41]

Citations: [36], [37], [38], [39], [40], [41]

Summary

Ethanol is the most common biofuel for road transport worldwide, but it has not yet been adopted in maritime transport. Unlike many other alternative fuels, such as hydrogen, ammonia, or methanol, the introduction of ethanol in shipping has not received the same attention from industry players. This is evident, for example, in the fact that ethanol-powered marine engines are not yet available on the market, nor are they expected to be in the coming years. The number of projects related to the adoption of ethanol is also very limited compared to other alternative fuels.

However, with tightening climate policies and regulations, this may change, as ethanol has great potential to reduce various emissions. For instance, ethanol produces significantly lower NOx, SOx, and particulate matter emissions compared to traditional fossil fuels. On the other hand, ethanol's lifecycle emissions are highly dependent on the raw material from which it is produced. This is particularly evident with first-generation bioethanol, where the cultivation of some raw materials can result in massive greenhouse gas emissions due to land preparation and use. In some cases, these emissions can be so high that ethanol's lifecycle emissions exceed those of fossil fuels. Second-generation bioethanol does not have this problem, as its production can utilize various wastes and by-products from agriculture and the wood processing industry.

While ethanol has the potential to offer a more environmentally friendly alternative to traditional fuels like heavy fuel oil, its adoption in shipping still requires further research and development. Potential adoption will also require significant investments in infrastructure and technical modifications to vessels.

Strengths

+ Ethanol is the most common biofuel for road transport worldwide
+ Its energy density is better than that of many other new fuels
+ Ethanol is easier to handle and store compared to many other alternative fuels
+ It produces extremely low NOx, SOx, and particulate matter emissions
+ The impact of ethanol leaks on aquatic ecosystems is relatively small compared to other fuels
+ Ethanol could potentially be used in methanol engines

Weaknesses

- Ethanol is not yet used in maritime transport, so the standards and practices for its use are still in development
- The use of ethanol as a marine fuel has not generated as much interest among industry players as other alternative fuels
- Its energy density is lower than that of fossil fuels
- Being a carbon-based fuel, ethanol use results in carbon dioxide emissions
- Depending on the raw material, ethanol's lifecycle emissions can be higher than those of fossil fuels
- Competition with road transport demand may limit its growth as a marine fuel

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