Implementation Research of Alternative Fuels and Technologies in Maritime Transport

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1 Introduction

Ships are considered one of the strongest sources of environmental pollution. Fuel oil which is the most popular fuel for ships contains on average 3,5% of sulfur compounds. For comparison, the content of sulfur impurities in gasoline and diesel of Euro-5 environmental class cannot exceed 0.001% of the total product weight. But IMO Sulfur 2020–the resolution adopted by the International Maritime Organization, which regulates the content of sulfur components in fuels for river and sea transport–not more than 0,5%, which fundamentally changes the situation on the market of oil products for the shipping industry.

Thus works [1, 2] devoted to the analysis of cost competitiveness of alternative maritime fuels in the new regulatory framework and impact of alternative fuels on the optimal economic ship speed. In works [3–5] carbon–neutral maritime fuels production, fueling options in the maritime sector and life cycle of greenhouse gas emission assessment reviewed. Marine fuel emissions tracking along with advances in research on alternative marine fuels and future trends reviewed in [2, 6–8]. In paper [9], energy consumption of a new re-liquefaction system integrated with the Fuel Supply System (FSS) for a liquefied natural gas carrier is analyzed in comparison with conventional systems. The concept of hydrogen as a marine fuel and the possibility of transferring LNG experience to hydrogen systems was investigated in [10]. In [11–13] application of alternative maritime power port supply, knowledge gaps about offshore hybrid power plants based on fuel cells and alternative fuels as well as recent trends in the use of environmentally friendly ammonia as an energy carrier in the maritime

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industry considered. Potential alternative fuel pathways and the use of alternative fuels for maritime decarbonization researched in [14–16]. Issues related to effective safety of ship operation process in different conditions and under the influence of different factors are considered in [17–21, 23–26, 29]. Technical and operational measures to reduce greenhouse gas emissions and improve the environmental and energy efficiency of ships studied in [22]. Modeling the dynamics of the structure of the organization's development project portfolio proposed in [27, 28]. Study of environmental efficiency of ship operation in terms of freight transportation effectiveness provision and assessment of ship information security risks proposed in [30, 31]. The model of organization of the container feeder line is focused on the nature and parameters of external container flows and the development of line shipping is studied in [32, 33]. The study of the stability of economic indicators of complex port equipment use and optimization of the structure of the seaport equipment park under unbalanced workload is proposed in [34, 35]. Additional questions about the future of marine fuels, comparison and perspective, and exploration of alternative fuels and technology for greener shipping are explored in [36–38].

Thus, due to the growing demands for the use of low-carbon energy sources, alternative fuels have become widespread. The new energy sources presented are also subject to the requirements of conventional fuels used and those on the energy market, namely quality, reliability and sustainability, and are of interest for further comprehensive study.

2 Overview of Existing Alternative Fuels for the Marine Industry

Maritime transport accounts for about 11% of the world's total fuel consumption, or about 10 million barrels per day. It is an important fact that in the current situation of competition between alternative fuels, seagoing ships largely set the trend in favor of one fuel or another. Significant volumes of fuel consumption by maritime transport justify mass production of refined products, construction of fuel bases and infrastructure in general, setting the course for a certain type of fuel and betting on it in other segments of the market. Thus, after the ban on the use of heavy fuel oil from 2024, only diesel oil will remain possible. This is an opportunity for the maritime transport industry to reconsider its position before that date and to take more active steps to adapt to the new standards, in the context of the review of alternatives, among others. Undoubtedly, for making a decision on choice of priority fuel for international shipping more accurate and thorough researches on estimation of ecological footprint from alternative fuels use, starting from raw materials extraction to emissions. A separate issue is the assessment of consequences from spills of alternative fuels, which requires laboratory and field studies of spills, especially at low temperatures, high wind speeds, etc. Of additional interest is the degree of long-term environmental

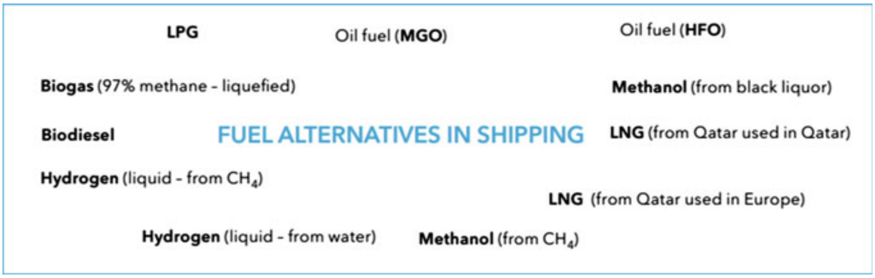

Fig. 1 Main types of alternative marine fuels

impact of blends of alternative fuels with the aquatic environment. Main types of alternative marine fuels presented in Fig. 1.

To date, LNG and sulfur fuel oil have beaten all of their competitors on price, but that does not mean that LNG will remain the leader for long. The recent gas price hike will inevitably force shipowners to think about the feasibility of gas fuel rates. It should be noted that one of the problems, which has not been solved yet, is the bunkering of ships. At present, LNG production projects are already being successfully implemented, which can serve as a source of LNG bunkering for transport ships. Nowadays, LNG bunkering can be performed by both mobile and stationary bunkers. Onshore, truck-to-ship (TTS) bunkering is used for relatively small amounts of LNG, up to 200 cubic, while port-to-ship (PTS) bunkering is used for larger volumes. Specialized LNG bunkers are used for refueling ships of various sizes and can have a capacity of up to 20,000 cubic meters, including LNG fuel for very large container ships enroute between Asia and the European Union. LNG bunkering is currently available at more than 120 ports around the world, with more than 30 LNG bunkering vessels in operation. Advantages and disadvantages of LNG fuel presented in Table 1.

3 Analysis of the Environmental Impact and Cost of Alternative Fuels

According to DNV GL, the use of LNG emits the least greenhouse gases the major ones are water vapor, carbon dioxide, methane, and ozone. However, unburned methane, which is the main component of LNG, creates emissions with 20 times more powerful greenhouse effect than carbon dioxide (carbon dioxide).

Nevertheless, according to assurances of producers of dual-fuel engines, the amount of unburned methane in modern equipment is not so large, and their use gives a reduction of greenhouse gases in shipping by 10–20%.

The carbon footprint (the amount of greenhouse gases caused by the activities of organizations, the actions of cargo transportation) from the use of methanol or hydrogen is much greater than with heavy fuel (HFO) and marine gasoil (MGO).

Table 1 Advantages and disadvantages of LNG fuel

Advantages of LNG fuel	Disadvantage of LNG fuel
The cleanest fuel is liquefied natural gas, as it produces the least amount of greenhouse gases	LNG has a higher specific energy content than fuel oil, but the energy content per unit volume is only 43% that of high sulfur fuel oil. Therefore, fuel tanks take up 3–4 times more space compared to ships operating on conventional fuel
LNG has been used as a fuel for ships since the early 2000s, so the technology is already quite mature and there are many suppliers on the market, which helps keep prices down	Bunkering problems. The general reluctance to introduce LNG-fueled engines into the shipping industry has been due in part to logistical difficulties. Liquefied natural gas for marine engines can still only be found in a limited number of ports around the world, which does not suit most players
Piston engines, gas turbines and their consumables, as well as special cryogenic fuel systems for LNG, are produced on an industrial scale and are freely available	Often ships have long itineraries in which the next point is not predetermined, which means fuel must be available at any port. Therefore, companies often take a wait-and-see approach to new technology

With renewable energy and biofuels, the carbon footprint is smaller. The most environmentally friendly fuel is hydrogen, produced from renewable energy. Liquid hydrogen can be used in the future. However, it has a rather low volumetric energy density, which leads to the need for large storage sites.

In terms of nitrogen emissions, Otto cycle internal combustion engines powered by LNG or hydrogen do not need exhaust treatment equipment to meet the Tier III standard. In most cases, dual-fuel diesel-cycle engines are not suitable to meet the standard.

The Tier III standard refers to the limitation of nitrogen oxides (NOx) emissions for LNG or hydrogen-fueled ships to reduce the environmental impact of shipping. For internal combustion engines with an Otto cycle running on LNG or hydrogen, NOx emission limits are set at 3.4 g/kWh.

To achieve the Tier III standard for Otto-cycle internal combustion engines fuelled by LNG or hydrogen, various technologies must be used to reduce NOx emissions, such as a catalytic converter, exhaust gas recirculation systems, high-temperature combustion systems, etc. In general, to achieve Tier III for Otto-cycle internal combustion engines running on LNG or hydrogen, many different technologies are required to reduce NOx emissions, which can make these engines less harmful to the environment.

For example, the Tier III standard refers to the limitation of nitrogen oxides (NOx) emissions for ships using diesel internal combustion engines. This standard was introduced to reduce the environmental impact of shipping, in particular air pollution. To meet the Tier III standard, marine engines must use various technologies to reduce NOx emissions, such as water injection systems to reduce combustion temperatures, catalytic converters, exhaust gas recirculation systems, and others. For new vessels

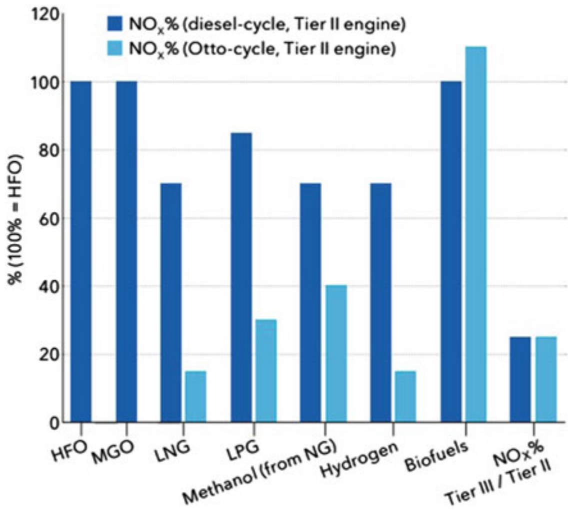

Fig. 2 Nitrogen emissions from different fuels Source: DNV GL

built after January 1, 2016 and having engines with a capacity of more than 130 kW, Tier III compliance is mandatory. For ships built before January 1, 2016, the Tier III standard is optional, but may be applied on a voluntary basis. Data of nitrogen emissions from different fuels presented in Fig. 2.

The price of implementation is not the main criterion for choosing a particular technology, but the price of fuel is. It depends on several factors, including the hard-to-predict ones. For example, according to sources, the lowest price in the previous decade is observed on HFO. Only LNG and LPG can compete with it. The price of methanol produced from natural gas is higher than that of LNG. Biofuels are produced from biomass and are traditionally more expensive than Brent oil. These fuels are likely to compete with MGO in the future. Dispersion of prices for possible marine fuels given in Fig. 3.

Hydrogen is not considered here because it is much more expensive than other fuels. It is completely uncompetitive on the market in terms of price. It will have a chance only with significant subsidies or high taxes on conventional fuel. Speaking about fuel production, it is worth noting that all fuels except LNG would require significant investments if the decision is made to use one or the other on a mass scale. LNG production is much higher than the fuel needs of the global fleet, so switching to it is possible today.

4 Conclusions

Environmental concerns and rising fuel prices lead to the need to find new solutions for shipping. There are not many alternatives. At the same time the legislation has already determined the conditions for the use of LNG, followed by methanol and

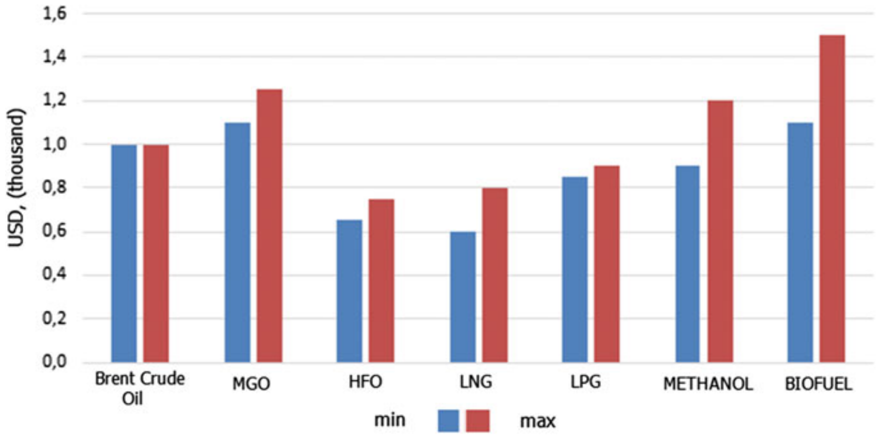

Fig. 3 Qualitative dispersion of prices for possible marine fuels (*Source* DNV GL, IEA)

biofuels. According to experts, development of IGF Code (International Code of Safety for Ships Using Gases) for LPG and hydrogen will take a little time. In order to comply with the IMO requirements by 2050 it will be necessary not only to convert the fleet to another, more environmentally friendly type of fuel, but also to develop new technologies to reduce greenhouse gas emissions from ships. One of the most promising technologies is the use of fuel cells, but it is still only in its infancy. Any ban is not only a limiting factor, but also creates a field of opportunities for qualitative development. Therefore, banning HFO can stimulate the development of the market for alternative marine fuels, such as LNG and methanol. This is especially important in light of the poorly understood environmental impact of new blends of petroleum fuels. The use of alternative fuels will allow ship owners to ensure the sustainability of operations over the long term with respect to atmospheric pollution. The consequences of spills of new types of fuels, including low-sulfur petroleum fuels, are not well understood. However, for climatic conditions, the effects of marine water pollution from spills are a key factor. The use of distillate fuels will result in an immediate increase in operating costs, and installing a scrubber may not be the right investment when residual fuels are banned, and the investment in equipment will not have time to pay off. Shipowners have even greater risks when building new vessels that require high capital investments. By aggregate properties oil and petroleum products have no competitors on the world market. But regular informational throw-ups of "oil is running out" and carbon addiction stimulate attempts to find a replacement for oil as a fuel and raw material for the chemical industry, therefore the most obvious candidates for such a replacement are ethanol and methanol.

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