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EVOLUTIONARY PROCESS OF CHANGING MARINE FUELS - TRANSITION FUELS ON THE WAY TO THE HYDROGEN ERA

Jerzy **Herdzik** [1]

[1] Gdynia Maritime University, Faculty of Marine Engineering, Department of Marine Propulsion Plants, 81/87 Morska Str., 81-225 Gdynia, Poland, e-mail: j.herdzik@wm.umg.edu.pl, https://orcid.org/0000-0002-2339-807X

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Abstract – The article presents the ongoing transformation of marine fuels - from fossil fuels to transition fuels and the final target - hydrogen. This process was forced by the legal regulations of the International Maritime Organization and the European Union Parliament. The target year is 2050, but intermediate targets should be achieved in 2030 and 2040. The base year is 2008. By the end of 2022, an increasing trend of interest in more environmentally friendly fuels was observed. However, it is far from expectations. Analyzing ships under construction and those ordered, a much higher share of renewable fuels intended for propulsion of ships is observed. The shipowners took precautionary measures. They order ships for transitional fuels, which reduce investment and operating costs, assuming that far-reaching changes will take place after overcoming significant technological problems, lowering the prices of equipment and fuel. The article analyzes the ongoing processes, justifying the sense of the actions taken. The regulations being introduced have a significant impact on the ongoing transformation processes of marine fuels. It was noted that they may have serious consequences for maritime transport, indicating potential threats.

Key words – marine fuels, decarbonization process, transient fuels, methanol, hydrogen

JEL Classification – Q42, Q47, R42

INTRODUCTION

Although the share of maritime transport in the total emission of carbon dioxide to the atmosphere is about 3%, the International Maritime Organization and the Parliament of the European Union have taken steps to reduce this emission from fossil fuel sources, mainly fuels from crude oil processing. The main goal is to achieve climate neutrality, i.e. zero emissions from fossil fuels, not including emissions from biofuels, and above all, to popularize the use of energy obtained from renewable sources, use fuels with zero carbon content in the molecule and including the so-called green electricity. As a result, a direction of changes that will be accepted has been outlined. The lack of an indication of a single way of change meant that shipowners undertake many different activities that, in the perspective of at least a dozen or so years, will enable the operation of ships whose emissions meet the established regulations [7-9].

Shipowners have been put against the wall, either their ships will meet the next tightened emission limits, or they will be forced to stop operating and scrap the ship. It is necessary to carry out economic calculations related to making a decision on further operation of a ship that does not meet the imposed emission limits. The decision to do so is related to the modernization of its power system and requires additional financial outlays. It may be decided to limit the modernization effort (up to a fixed limit) in order to meet the requirements over a period of several years, or if it is unprofitable, the ship's operation is continued until it is decommissioned. In the meantime, a new ship may be ordered to meet further tightened greenhouse gas emission limits over the next 10-25 years.

Although the limits of greenhouse gas emissions (mainly carbon dioxide) in maritime transport were adopted in the years 2015-2020 with limits at transitional stages, in general, until the end of 2022 there were minor changes in the use of new marine fuels. About 99.5% of the fuels used were crude oil-derivatives, and only 0.51% were LNG, LPG, ammonia and hydrogen [6].

The global annual demand for marine fuels is 300-330 million tons, showing an annual increase of around 3% [19] (the decline in the dynamics of sea transport occurred at the beginning of the covid-19 pandemic in 2021).

It is possible to determine the energy demand by sea transport. Taking into account the lower calorific value for current marine fuels of 42 MJ/kg and the demand of 330 million tons, it is approx. 13.86 PJ ($13.86 \cdot 10^{15}$ J) of energy contained in the fuel. Using other marine fuels, they have a different lower calorific value, assuming the same amount of energy, the demand for these fuels will be correspondingly higher or lower. Assuming that the efficiency of energy devices (internal combustion engines, steam and gas turbines) will be the same, it is possible to determine the demand for the equivalent amount of fuel which will be applied. With the use of marine fuels derived from crude oil processing, the emission of carbon dioxide alone would amount to approximately 1.03 Tg (1.03 billion ton). Due to the emissions of other greenhouse gases as well, such as: black carbon, nitrogen and sulfur oxides from marine diesel engines, equivalent CO_2 (CO_{2e}) emission is sometimes used. The difference between CO_2 and CO_{2e} is rather small, about 7÷9% more for CO_{2e} and is quite stable [2, 4, 16, 18].

Alternative marine fuels that replace marine fossil fuels have lower calorific values: ammonia 18.8 MJ/kg; methanol 19.9 MJ/kg; methyl ester (biodiesel) 37.5 MJ/kg; LPG 45.5 MJ/kg; LNG 48.6 MJ/kg, hydrogen 120 MJ/kg. The lower the calorific value of the fuel, the greater its consumption and the greater the necessary reserve in the fuel tanks, which will ensure the required autonomy of the ship [3,5,18].

The shipping decarbonization process will lead to a gradual reduction of greenhouse gas emissions, in accordance with IMO requirements. Additional steps are being taken within the EU to speed up this process.

In March 2023, The European Parliament and Council have reached a deal on cleaner maritime fuels, asking to cut ship emissions by 2% as of 2025 and by 80% as of 2050. This would apply to ships above a gross tonnage of 5,000, and to all energy used onboard in or between European Union ports, as well as to 50% of energy used on voyages where the departure or arrival port is outside of the EU or in EU outermost regions. In addition, according to the preliminary agreement, containerships and passenger ships (which consume the largest amount of fuel and, at the same time, have the highest emissions into the atmosphere) will be obliged to use onshore power supply for all electricity needs while moored at the quayside in major EU ports as of 2030. It will also apply to the rest of EU ports as of 2035, if these ports have an on-shore power supply. Certain exemptions, such as staying at port for less than two hours, using own zero-emission technology or making a port call due to unforeseen circumstances or emergencies, will apply.

1. ACTIONS AIMED AT IMPROVING THE ENERGY EFFICIENCY INDEX OF SHIPS IN OPERATION

Energy Efficiency Design Index (EEDI) has been a first step of IMO's drive to reduce the CO_2 emission from shipping and a benchmarking scheme aiming to provide an indication of a merchant ship's CO_2 output in relation to its transport work [10].

EEDI is provided by formula (1) where in the numerator is CO_2 emission from main engines and auxiliaries (calculating as a product of fuel factor $\mathbf{c_{Fi}}$, engine load Pi and specific fuel consumption SFC_i at this load) and the denominator is a product of ship's deadweight DWT and the ship's reference speed V_s [11]:

$$EEDI_i = (\textstyle\sum_i c_{Fi} \cdot P_i \cdot SFC_i)/(DWT \cdot V_s) \qquad (1)$$

The reference speed means ship's speed at 75% Maximum Continuous Rating of main engine. The units used for EEDI are: g CO_2/(ton-mile). The EEDI is an estimated measure of transport energy efficiency of a ship, which is currently under the design stage. It should be estimated for designed vessel and it is an important index for designers and builders of ships.

The second step in controlling emissions from marine engines was the introduction of the Energy Efficiency Index of a Ship in Operation (EEOI). The calculation of EEOI needs to measure some parameters during vessel operation, like:

- the distance sailed as recorded in ship's Bridge Log Book;
- the cargo mass as per Bill of Lading and Deck Log Book;
- the total fuel consumption as recorded in Engine Log Book.

It should be known the fuel coefficient $\mathbf{c_F}$ depending on the type of used fuel. An equation (2) for EEOI calculation shows the idea of index term.

$$EEOI = \frac{(\text{actual } CO_2 \text{emission})}{(\text{performed transport work})} \qquad (2)$$

The third step was to define the rules for determining the energy efficiency index of an existing ship (EEXI), which applies to ships that were not covered by the requirement to meet the EEDI index during design and construction [11].

In 2015, Royal Belgium Shipowners' Association suggested to use Energy Efficiency Technical Indicator (EETI) [10] defined as the energy efficiency (g-CO_2/(ton-mile) of a ship in a reference operating condition (speed and draught). It seems that it is a better indicator for comparing different voyages of the same ship due to changing weather conditions, different speed of the ship achieved during operation. This indicator has not been accepted as an IMO requirement, but it may be of assistance to the shipowner for further analysis. The basic method of reducing the EEOI and EEXI index is to reduce the service speed of the vessel. There is a significant reduction in the load on the main engine (relationship called the screw characteristic – propeller law) and fuel consumption with a much slower decrease in the ship's speed. As a result, fuel consumption and GHG emissions to the atmosphere decrease significantly, while the required transport effect is achieved. However, this method has a significant disadvantage, it increases the travel time and causes a lot of additional costs.

Slow steaming began to be used about 20 years ago, when the cost of marine fuels increased significantly, and this method significantly reduced the total fuel consumption for a given trip (Table 1). This method is now commonly used when the ship's voyage time is not strictly defined.

Table 1. Typical main engine load in slow steaming vessels [**20**]

Type of vessel/main engine load	10-30%	20-40%	30-50%
Container vessels	17.8	25.8	56.4
Bulk/tanker/and others	5.9	11.9	82.2

The ship's main propulsion engine is designed for long-term operation at loads in the range of 60-85% of the nominal power. In this load range, it is the most energy efficient and has the lowest specific fuel consumption. The main engines are currently adapted for long-term operation at partial loads, but the method is not correct. Unfortunately, it is not possible to replace the main engines with different nominal power multiple times in order to adapt to the current power demand at reduced ship speed. Certain possibilities are offered by drive systems with multiple main engines, including diesel-electric systems.

A wide variety of design, operational and economic solutions are presented and proposed in the IMO Action 2018 publication [9]. Reducing fuel consumption by the main propulsion engine is possible by reducing the power demand for propulsion. This can be achieved in many ways: lowering the speed of the ship, reducing the resistance of the hull (optimization of the hull shape, frequent cleaning of the underwater part of the hull, better paint coatings, etc.), optimization of the route taking into account weather conditions, better communication between the shipowner and the ship crew in order to better use ship's carrying capacity (more cargo), the distribution of cargo, or reaching the destination port at the right time.

The shipowner is interested in reducing the EEOI and EEXI indicators, especially in cases that enable them to be achieved (reducing the ship's operating costs). It should be noted that most of the actions aimed at reducing the total fuel consumption of a ship have been undertaken for several decades. As a result, further improvement of these indicators is already technically difficult (most of them have already been used) and it is increasingly difficult to meet the requirements related to increasing energy efficiency by another 10-30%.

Each vessel subject to an EEOI or EEXI requirement must have a Ship Energy Efficiency Management Plan (SEEMP) developed. It consists of three parts [12-15]:

- Part I: Ship management plan to improve energy efficiency;
- Part II: Ship fuel oil consumption data collection plan (including Data Collecting System – DCS);
- Part III: Ship operational carbon intensity plan (including calculations of Carbon Intensity Indicator – CII).

Effective January 1, 2023, SEEMP is a mandatory for the ship's crew. This is a ship-specific document that describes the plan to improve the vessel's CII rating, and hence its operational energy efficiency, for next three years. Initial revision of SEEMP Part III must be verified and kept on board the respective vessel from January 1, 2023, together with the corresponding Confirmation of Compliance (CoC). An attained CII will be calculated for the first time for any applicable vessel starting from 2024 based on DCS data for the 2023 reporting period. Currently, CII applies to ships above 5,000 GT transports goods or passengers. The calculation of the annual CII is carried out according to the formula (3):

$$\mathrm{CII} = \frac{\left[(\text{annual fuel consumption})\cdot(\mathrm{CO_2}\text{factor})\cdot(\text{correction factors})\right]}{\left[(\text{annual distance travelled})\cdot(\text{capacity})\right]} \tag{3}$$

Vessels will be rated on a scale of A to E: A (major superior), B (minor superior), C (moderate), D (minor inferior) and E (inferior performance level). A vessel rated D for three consecutive years or rated as E, will need to develop a plan of corrective actions. In this case, the SEEMP Part III must be updated with a corrective action and verified. In addition, the corrective action plan should consist of an analysis of why the required CII was not achieved [15].

Failure to meet the CII requirements within the next three years and remain with a D or E rating may result in a marine administration decision to prohibit or limit the operation of the ship.

Currently, if the shipowner decides to switch from marine fuel to biofuels, the following benefits will be obtained in accordance with the GHG regulations:

- EEDI/EEOI/EEXI - no effect;
- CII - reduction of CII if accepted by flag state;
- EU MRV (monitoring, reporting and verifying) - reduction of the annually reported CO_2 emissions.

The reason for introducing the regulation was the expected reduction of GHG emissions into the atmosphere. In case of switching to biofuels or with lower or zero carbon content in the molecule, non-compliance with energy efficiency requirements EEOI and EEXI will be probably tolerated by the administration of the flag state.

One of the basic activities of the shipowner aimed at improving the CII indicator is the use of renewable energy sources on the ship, i.e. photovoltaic cells, wind turbines, Flettner rotors, and possibly supporting sails (kite sails) [4, 8, 18].

These will be actions to meet the improvement requirements (10-30%), which will allow the ship to continue operation and achieve a minimum rating of C. The costs of rebuilding the ship's energy system are significant. They will not be undertaken for vessels that are 15 or older. Only corrective actions will be taken to keep the vessel in operation until it is decommissioned.

Actions that may improve the energy efficiency indexes of the ship below 10% will be taken (there will be a reduction in the cost of operating the ship), but may be abandoned if at least a C rating is not obtained. The shipowner's decisions must be balanced, and the financial impact assessment will be a decisive factor.

2. Shipowners' decisions regarding marine fuels for ordered ships

Limits of carbon dioxide emissions from maritime transport impose an obligation on shipowners to meet them so that further operation of ships is possible. The direct reduction of emissions corrected to lower values in the following years does not allow for meeting these requirements. It is impossible to increase the total propulsion efficiency of the ship or the resistance of the hull to reduce fuel consumption by another 10-30%. The only chance is to change the type of fuel burned to fuel currently considered more ecological, especially without carbon in the molecule [2, 16].

The simplest solution, not requiring significant changes in the fuel system of the power plant, would be to switch to synthetic fuels. Unfortunately, such fuels are practically not produced. The trace production of synthetic fuels, those considered ecological, makes such a solution impossible due to the lack of availability and its price. In general, the basic problem of maritime transport is the lack of availability of alternative fuels (fuel market), lack of distribution networks, etc. Most shipowners (apart from those with several hundred ships in their fleet) will not decide to introduce changes adapting the ship's fuel system to burn other fuels, due to uncertainty of its availability, aside from economic considerations. The largest shipowners are able to make a decision and make a financial effort to ensure the production and supply of alternative fuel (e.g. bio or green methanol) in selected places around the world, with access to them in selected ports. At the same time, they will modernize the fuel systems on their ships, adapting them to burn the second fuel. Unfortunately, this solution will be unavailable to other shipowners. The lack of structural measures, for which the countries with seaports are responsible, causes significant delays in the process of diversification into ecological fuels.

Such activities will lead to a situation in which large players on the shipping market will be able to meet the requirements. On the other hand, especially the smallest ones, will not be able to do it (because of many barriers, and above all the financial barrier). This may lead to the exit of smaller players from the market and even greater monopolization of maritime transport. In the name of combating the greenhouse effect, of which sea transport accounts for only about 3%, there will be major changes and reshuffles in the shipping market.

In the case of ordering new ships, shipowners must take into account the changes planned by the IMO and the EU in the perspective of about 20 years in the regulations regarding ship energy efficiency indicators and permissible GHG emission limits to the atmosphere. In this case, the type of ship being built, the shipowner, and the region of navigation will also be important. For specialized offshore vessels, wind farm service, the requirements that may be imposed by the company using the services, e.g. the use of ecological fuels, the level of dynamic positioning systems, additional specialized equipment, etc., should be taken into account. So many different requirements make it difficult for the future shipowner to place an order for the construction of a ship, because it is difficult to take into account all the important factors that will affect the future operation of the ship and its possibilities of use. Decisions made must be based on information on the development of ecological fuel infrastructure in ports, minimizing the risk of wrong decisions, observations of what other shipowners are doing, and above all, proposals for new ship designs offered by shipyards. The shipyard's offer must be based on rational premises regarding the ongoing changes and look ahead in order to be competitive on the shipping market.

3. SHIP SIZE AND TYPE VS. TYPE OF MARINE FUEL USED

So far, until 2022, shipowners placing orders for new ships have made conservative decisions. The type of ship and its size, the cargo carried, the shipping line had the greatest impact on the decisions on the type of fuel used on the ship. In the case of gas carriers carrying LNG or LPG cargoes, the ship's power supply system has been adapted to burn cargo vapors, the re-liquefaction of which is a significant economic cost. As a result, the combustion of gaseous fuels in engines or boilers partly solves the problem of their re-liquefaction. Condensing systems are used when charge vapors are generated that cannot be used in this way. At the same time, experience was gained in the construction and operation of gaseous fuel installations for devices generating mechanical and thermal energy on board the ship. Unfortunately, these fuels are not fully ecological, but due to the fact that they contain much less sulfur compounds, have a higher calorific value, it is possible to reduce the emission of carbon dioxide by about 20-30% and particulate matter, sulfur dioxide. The use of these fuels on other ships has a similar justification. LPG as a fuel is used on about 50 LPG carriers. On the other hand, the fleet of ships using LNG is much larger and amounted to 361 ships in 2022 (Table 2).

The method of producing these fuels is of great importance. If they come from fossil fuel sources, they will be transition fuels. If produced as synthetic fuels, the recognition as green fuels depends on the type of electricity used in the process.

There has been a significant increase in interest in the use of methanol as a marine fuel. The fleet of ships using methanol in 2022 was limited to 25 vessels. For example, methanol was used on 22 chemical tankers, 1 ro-pax vessel, 1 tugboat. Among the 59 vessels ordered, as many as 47 are container ships, 4 offshore vessels, 2 bulk carriers, and 1 cruise vessel. This is a signal that changes are accelerating and interest in methanol is increasing. An important advantage of using methanol as a marine fuel is that there is no requirement to have substitute (petroleum) fuel on board the ship in case of emergencies (e.g. leaks in the fuel system). Thanks to this, there is no need to install additional tanks for substitute fuel. There remains the problem of the increased capacity of methanol fuel tanks due to its lower calorific value (42 MJ/kg for petroleum fuels, 18.6 MJ/kg for methanol and its lower density). Table 3 presents selected parameters of marine alternative fuels that are important when making decisions about their selection.

The global methanol production currently amounts to about 75 million tons per year. Methanol is produced mainly using natural gas as a feedstock [3]. At present, only about 220 thousand tons are produced as a bio-methanol per year. In order to offset the amount of energy contained in the marine fuel currently used (approximately 300 million tons), the methanol requirement should be approximately 630 million tons. This means that the increase in methanol production necessary for use in maritime transport as a transitional fuel requires a lot of investment and, above all, time. If the fleet of ships using methanol as fuel increases, its lack (unavailability) may be a significant barrier to its dissemination. The "well to wake" (WTW) parameter of methanol is close to MDO, which puts a strong emphasis on the use of mainly bio-methanol.

Table 2. Type and number of vessels in operation and on order using LNG as marine fuel [6]

Type of vessel	Number of vessels in operation	Number of vessels on order
Crude oil tanker	49	40
Oil/chemical tankers	44	44
Car/passenger vessels	43	7
Container ships	43	181
Offshore supply vessels	36	1
Tugs	22	16
Other	124	213
Total	361	502

Table 3. Selected parameters of alternative marine fuels and biofuels [own elaboration]

Type of fuel	Density [kg/m^3]	Lower Calorific Value [MJ/kg]	Equivalent energy volume capacity to HFO=1	Equivalent demand per year [million tons]*
Bio-diesel	880	37.2	1.120	388
Renewable diesel	780	44.1	1.066	327
Fatty acid methyl esters	765	43	1.206	336
Methanol	794	22	2.099	656
Ethanol	789	28	1.660	515
Ammonia	682	18.6	2.890 / 3.468**	776
Propane	493	46.6	1.596 / 2.075**	310
Methane (LNG, SNG)	460	50	1.594 / 2.551**	289
Hydrogen (liquid)	71	120	4.303 / 8.606**	120

***** To cover energy demand for marine transport compared to 2020
****** Additional volume for thermal insulation

The fleet of ships using hydrogen in 2022 was limited to only 6 vessels (3 ro-pax, 1 tugboat, 1 ro-ro and 1 cruise vessel). An increase in the fleet of ships whose primary energy source is hydrogen, which powers fuel cells, is expected. This development will currently concern relatively small vessels engaged in short-distance navigation. By 2030, the number of hydrogen-powered ships will be well below 100, and their tonnage share will be insignificant (below 0.1%) [6].

Successful tests on ammonia-powered test engines, despite the use of a 15% pilot dose of marine diesel oil (MDO), raise hopes for significant changes in maritime transport. Combustion of ammonia makes it possible to meet the limits of carbon dioxide emissions in the perspective of 2050, despite the additional combustion of light fuel. The possible development of technology and the construction of engines with a compression ratio of over 40 would allow them to operate only on ammonia, but a significant increase in the production of nitrogen oxides in the combustion process is possible, which may be a barrier to such changes. If a decision is made to transform marine fuels into ammonia, many similar problems remain to be solved if the decision concerned the transformation to other fuels. The basic problem will remain to make the production of ammonia as ecological as possible at reasonable production costs [3].

Shipowners who have a small fleet, and thus have limited possibilities to finance the costs related to the change of currently used fuels to transitional or alternative ones, will make decisions in the perspective of a few, or at most, a dozen or so years. These will mostly be conservative decisions aimed at adjusting the energy efficiency indicators of their ships to the imposed limits.

Exploration of oil, gas and other raw materials at sea, construction and operation of offshore wind farms or other industrial installations at sea may require additional environmental protection requirements for ships that are to perform these works, especially in special areas. Additional country-specific requirements may be imposed in a country's economic zone. As a result, a shipowner willing to offer services will be motivated to introduce certain requirements to their own ships, e.g. the use of specific types of fuels, devices limiting emissions to the natural environment. For many small shipowners this will be unattainable, which will limit their business opportunities.

An alternative to improving the energy efficiency indicators of ships may be systems that capture carbon dioxide (onboard carbon capture systems – CCS) from the emitted exhaust gases [1]. They are still imperfect, basically not used in maritime transport yet, but they allow to reduce emissions by about 30%, but at the cost of additional energy expenditure for the operation of these systems. The construction of compact systems with the possibility of their installation on the exhaust system of engines to capture carbon dioxide can be an offer for shipowners who are unable to switch to carbon-free fuels. For reasons of the safety of the ship and the reliability of the propulsion components, systems will be built that can be bypassed in an emergency. This will be a niche solution, but one that should be considered.

4. Prospects of changes in the use of ecological marine fuels – discussion

Including shipping in the EU ETS can be costly. In 2022, the price of CO_2 emissions varied between EUR 70÷100/ton. With the emission of 3.12 tons of

CO_2 per ton of marine fuel, this will increase the cost of fuel by about 230-300 Euro. The cost of the issue will be an increase in fuel costs in the operation of the ship by 30÷50%.

This is a proposal from the European Commission. Its implementation depends on the results of negotiations between Commission, the European Parliament and the Council. The year 2024 is proposed for the start of billing. This is to apply to ships calling at EU ports. This will reduce the attractiveness of sea transport in EU ports and may increase the attractiveness of calling at ports outside the EU, so that the goods are then delivered to EU countries by land. The introduction of these changes will be a major challenge for shipowners who will try to mitigate the effects of these processes.

This may have the effect of accelerating changes towards carbon-free fuels or those recognized as ecological, for which CO_2 emissions will not be subject to charges. There are too many unknowns at present, but shipowners are alert to signals from the EU administration. This may be a unilateral decision of the EU, without taking into account the opinions of shipowners, the International Maritime Organization, etc.

The current state of the number of ships in operation and ordered, on which fuels not derived from crude oil processing are used as fuel, are presented in Table 4 and Figure 1. Bio-methanol has high hopes for a significant increase in the share of marine fuels. A significant limitation in its use may be its availability, due to the currently limited possibilities of its production.

This state of affairs can be regarded as highly unsatisfactory, as most of the engines on these ships will be powered by fossil fuels. Only some of them will be powered by synthetic or biomass fuels. They will mostly be produced with electricity, with a significant share of fossil fuels in its production. There is a need for far-reaching changes in the processes of electricity generation on land to make the production of next-generation marine fuels carbon-free and without carbon trace.

The biggest problem in the transition to green fuels is their availability for the shipping market [17]. The development and acceleration of processes taking place on land will enable faster changes in maritime transport. It should not be expected that fuel transformation processes will take place faster at sea than on land.

Table 4. Number of vessels in service and on order using non-petroleum based fuels [6]

Number of vessels	LNG	LPG	Methanol	Hydrogen	Biofuels[1]
In operation	361	51	25	6	No data
Ordered ships by 2026	502	78	59	19	No data
Total	863	129	84	25	No data

[1] Collectively as FAME, HVO, SVO, DME, F-T diesel, liquefied biogas LBG, upgraded pyrolysis oil and more.

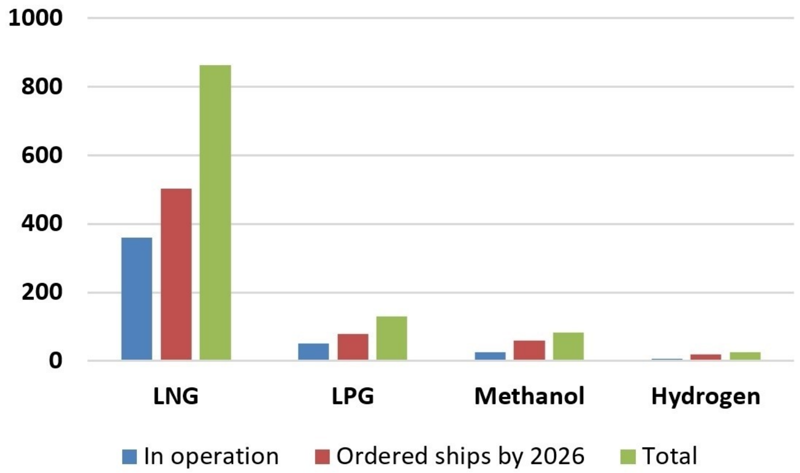

Fig. 1. Number of vessels in service and on order using non-petroleum based fuels

CONCLUSIONS

Fuel costs are already the main barrier to the development of maritime transport. A significant increase in the prices of transitional and alternative fuels may lead to serious financial difficulties for small shipowners, and even their bankruptcy. The monopolization of maritime transport can bring a lot of irreversible damage to the world economy.

The prohibition of subsidies by the states of maritime transport will slow down the processes of change. Much will depend on the decision of the maritime administration of the ship's flag state, which will decide on the assessment of the changes introduced by the shipowners' decision, whether to consider them ecological and heading in the right direction. It can be expected different decisions depending on the flag state, and at the same time pressure from the European Parliament and the International Maritime Organization, which will have their own assessments of the changes taking place.

The process of transforming marine fuels into ecological fuels must be an evolutionary process. Changes should be introduced step by step, with an indication of transition periods. Changes taking place on the shipping market should be closely monitored so as not to cause irreversible changes for the worse. I believe that the opinions of shipowners, charterers, companies operating and participating in maritime transport should be taken into account when creating new regulations by the EP and IMO.

The advent of hydrogen as a marine fuel requires the improvement of several important technologies and the reduction of costs: from its production, to transport, storage, bunkering, while meeting the condition of comparable calorific value per volume unit.

The process of decarbonization of shipping, planned for 2050 by IMO, can be achieved by switching to ammonia, which will conquer the market of marine fuels, but hydrogen seems to be the target fuel.

EWOLUCYJNY PROCES ZMIANY PALIW ŻEGLUGOWYCH - PALIWA PRZEJŚCIOWE W DRODZE DO ERY WODORU

W artykule przedstawiono postępującą transformację paliw żeglugowych - od paliw kopalnych do paliw przejściowych i docelowego - wodoru. Proces ten został wymuszony regulacjami prawnymi Międzynarodowej Organizacji Morskiej oraz Parlamentu Europejskiego. Rok docelowy to rok 2050, ale cele pośrednie powinny zostać osiągnięte w latach 2030 i 2040. Rokiem bazowym jest rok 2008. Do końca 2022 roku można było zaobserwować wzrost zainteresowania paliwami bardziej przyjaznymi dla środowiska. Daleko mu jednak do oczekiwań. Analizując statki w budowie i zamawiane, obserwuje się znacznie większy udział paliw odnawialnych przeznaczonych do napędu statków. Armatorzy podjęli środki ostrożności. Zamawiają statki na paliwa przejściowe, które obniżają koszty inwestycyjne i eksploatacyjne, zakładając, że daleko idące zmiany nastąpią po przezwyciężeniu istotnych problemów technologicznych, obniżeniu cen sprzętu i paliwa. W artykule poddano analizie zachodzące procesy, uzasadniając sens podejmowanych działań. Wprowadzane regulacje mają istotny wpływ na zachodzące procesy transformacji paliw żeglugowych. Zwrócono uwagę, że mogą one mieć poważne konsekwencje dla transportu morskiego, wskazując na ich potencjalne zagrożenia.

Słowa kluczowe: paliwa żeglugowe, proces dekarbonizacji, paliwa przejściowe, metanol, wodór.

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