A Comprehensive Technical Analysis of Alternative Fuels

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ABSTRACT

The maritime industry is undergoing a significant transformation to reduce greenhouse gas emissions and comply with stringent environmental regulations, spearheaded by the IMO and the EU. Consequently, GHG emissions from ships become a cost factor, and therefore strategically reducing GHG emissions from ships is crucial. This necessitates not only further energy efficiency improvements but also the essential adoption of alternative fuels with lower environmental impacts. A wide variety of alternative fuels are available to be selected based on factors such as ship type, size and route. Not only technical aspects but also the overall trend of alternative fuels including fuel availability and cost projections are to be considered in adopting the alternative fuel. ClassNK carried out a detailed study which explored the potential, benefits, challenges, costs, and future outlook of alternative fuels, and issued "ClassNK Alternative Fuels Insight" in May 2024. This paper delves into the key findings of the study.

INTRODUCTION

The drive towards decarbonization in the maritime industry has intensified in recent years driven by global environmental concerns and regulatory pressures. The International Maritime Organization (IMO) has set ambitious targets to reduce greenhouse gas emissions, prompting the exploration and adoption of alternative fuels.

Amidst the pressing need for society-wide reduction of GHG emissions, it is anticipated that GHG emission regulations in international shipping, spearheaded by the IMO and the EU, will be strengthened. Consequently, we are entering an era where GHG emissions from ships become a cost factor. In such a business environment, strategically reducing GHG emissions from ships is crucial. This necessitates not only further energy efficiency improvements but also the essential adoption of alternative fuels with lower environmental impacts.

A wide range of alternative fuels is available for use in ships. When adopting alternative fuels, it is crucial to select the appropriate fuel based on factors such as the ship type, size, and route. Therefore, it is essential to not only consider technical aspects but also to grasp the overall trend of alternative fuels, including factors such as fuel availability and cost projections.

In the light of the above, ClassNK carried out a detailed study which explored the potential, benefits, challenges, costs, and future outlook of alternative fuels, and issued a "ClassNK Alternative Fuels Insight". [1] This insight provides a detailed analysis of several promising alternative fuels, highlighting their potential, benefits, challenges, costs, and the technological advancements required for their successful integration into the maritime sector.

REGULATIONS

When considering the adoption of alternative fuels, understanding the GHG-related regulations that are expected to be strengthened in the future is crucial above all else. In this regard, the GHG-related regulations of the IMO and the EU play a central role in GHG emission reduction measures in international shipping.

In July 2023, the IMO revised its initial strategy on the reduction of GHG emissions from ships and adopted the "2023 IMO GHG Strategy," which includes the goal of achieving net-zero GHG emissions by or around 2050. Serving as the foundation for future discussions on reducing GHG emissions from international shipping, understanding this strategy is crucial for the shipping industry. ClassNK has published a white paper titled "Pathway to Zero-Emission in International Shipping - Understanding the 2023 IMO GHG Strategy -" to facilitate understanding of this strategy. [2]

The IMO is currently discussing a new regulatory framework for “mid-term measures”, aiming for implementation in 2027. [3] There are several proposals from the IMO member states that has both technical and economic elements.

The proposed technical elements include a Greenhouse Gas Fuel Standard (GFS) by the EU, and International Maritime Sustainable Fuels and Fund (IMSF&F) by China, Brazil, and others.

The proposed economic elements include Feebate by Japan, Feebate by ICS, Bahamas, Liberia, GHG Levy by 9 island countries, a proposal by Canada, and Green Balance Mechanism by WSC.

In Europe, the implementation of the European Union Emissions Trading System (EU-ETS) in the maritime sector began in 2024, and in 2025, FuelEU Maritime will be introduced. When assigning ships to European routes, it is essential to accurately understand the contents of these regulations in order to minimize regulatory compliance costs as much as possible. ClassNK has issued "FAQs on the EU-ETS for Shipping" [4] and "FAQs on the FuelEU Maritime," [5] each explaining the overview of the regulations and the essential preparations for compliance in a Q&A format specific to European regional regulations.

With these regulations in place, GHG emissions from ships will become a cost factor, making it crucial for the future of maritime business to strategically reduce GHG emissions from ships.

The additional costs that ships will incur due to these regulations depend on their specific provisions. However, it is conceivable that these costs could eventually reach levels equivalent to annual fuel costs. Since the scope of emissions targeted and the anticipated costs vary between each regulation, it is crucial to thoroughly understand the details of each regulation in order to minimize regulatory costs across the fleet.

UNDERSTANDING TRENDS

ClassNK has compiled data on the trends in adopting alternative fuels in shipping. The data include ships with a gross tonnage of 5,000 and above, and subject to IMO DCS and CII, which are likely to be subject to IMO's mid-term measures. The data is compiled as of the end of December 2023. Additionally, LNG carriers have been excluded from the data on alternative fuel ships to provide a more accurate representation of the adoption status in ship types other than LNG carriers.

The number of alternative fuel ships is steadily increasing, and it is projected that by 2026, the number of alternative fuel ships excluding LNG carriers will exceed 1,000. While there is a noticeable trend in orders for methanol fueled ships, LNG fueled ships still dominate the orderbook for alternative fuel ships.

When categorized by ship type, the adoption rate of alternative fuel ships in bulk carriers and product/chemical tankers appears relatively lower compared to other ship types. Nevertheless, there is evidence of alternative fuel ships being adopted across all ship types, including large and small to medium-sized vessels. This suggests that ongoing efforts are being made to address design challenges associated with the utilization of alternative fuels.

The trends in alternative fuel ships for newbuilding and in-service are given in Fig. 1 and Fig. 2, respectively.

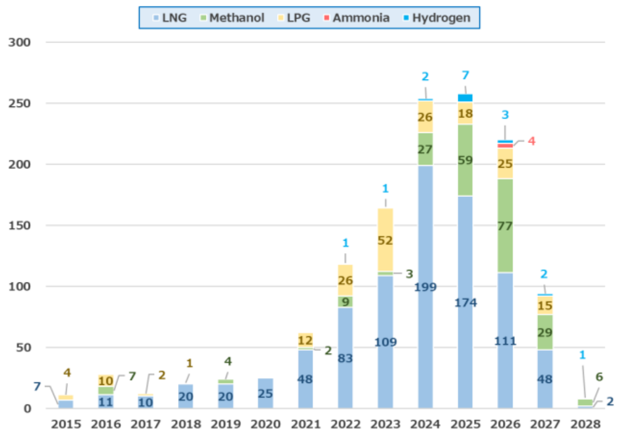


Fig. 1 Trend of newbuilding ships using alternative fuels

ALTERNATIVE FUELS

When considering the adoption of alternative fuels, it is important to understand the characteristics of each fuel, such as their properties and GHG emissions, and to grasp factors like cost and projected supply. In this section, the attributes of various alternative fuels envisaged for use in international shipping, providing insights into their costs, supply prospects, and other relevant factors are outlined in this section.

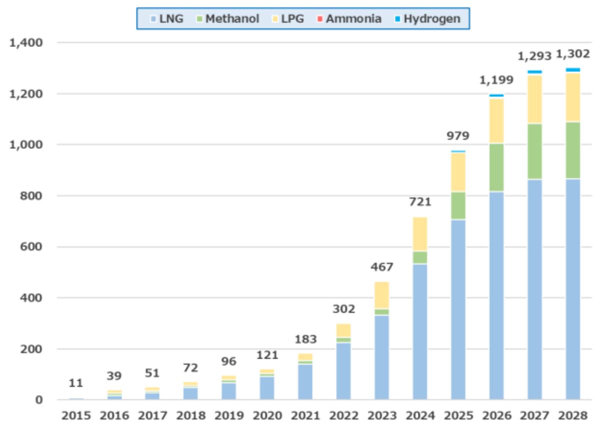


Fig. 2 Trend of in-service ships using alternative fuels

Several alternative fuels that show promise for the maritime industry are identified as briefed below, and each of these fuels offers distinct advantages and faces unique challenges in terms of adoption and implementation. It is difficult to predict which fuel will become dominant and many factor are to be considered such as manufacturing technology trends, cost projections, supply trends, lifecycle emissions, etc. A timeline of the fuel transition is shown in Fig. 3.

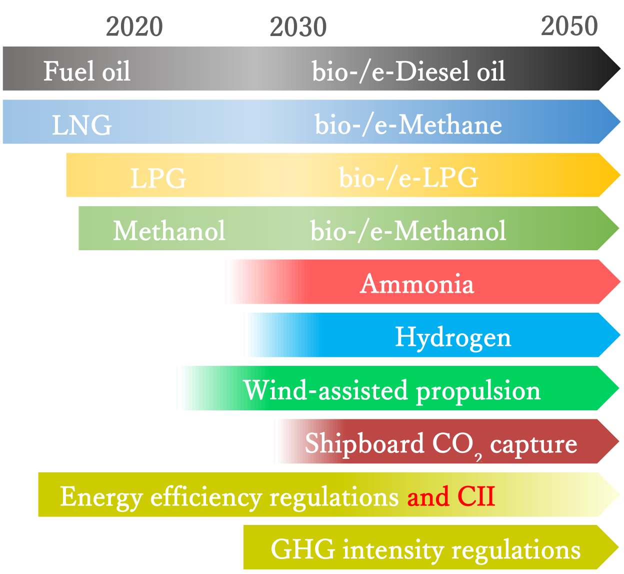


Fig. 3 Timeline of the alternative fuel transition

Some features of the alternative fuels are given below:

Liquefied Natural Gas (LNG): LNG is a well-established alternative fuel known for its lower carbon emissions compared to traditional marine fuels. It also significantly reduces sulfur oxide (SOx) and nitrogen oxide (NOx) emissions, contributing to improved air quality. The use of LNG is supported by a relatively mature infrastructure, including LNG bunkering facilities and a growing fleet of LNG-powered vessels.

Methanol: Methanol is gaining traction as an alternative fuel due to its potential to reduce CO2 emissions. It can be produced from renewable sources, making it a sustainable option. Methanol engines are relatively mature, and the fuel can be stored and handled with ease, facilitating its adoption in both new builds and retrofitted vessels.

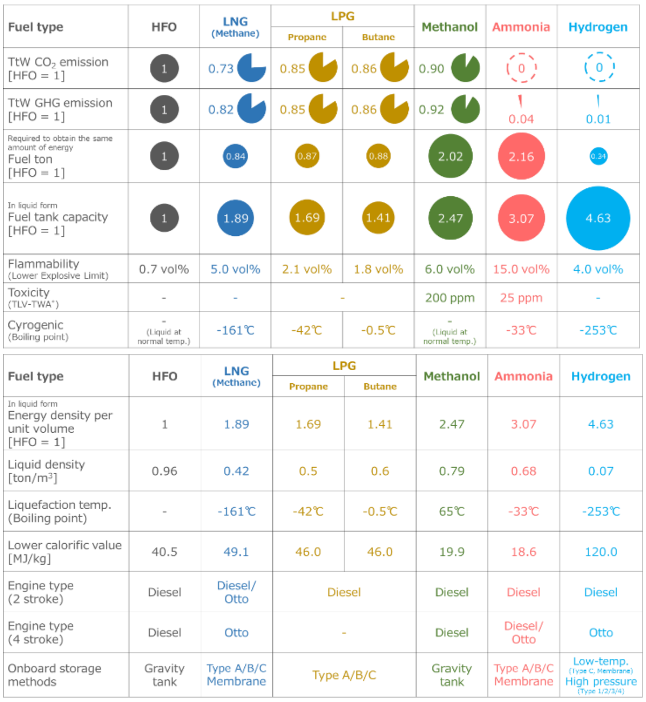
Ammonia: Ammonia is another zero-carbon fuel that can be produced from renewable energy. It offers the advantage of existing distribution infrastructure. However, safety concerns due to its toxicity and corrosiveness, as well as the need for specialized engine modifications, require further research and development.

Hydrogen: Hydrogen, particularly green hydrogen produced from renewable sources, is considered a zero-emission fuel. It holds significant promise for the maritime industry, though challenges related to storage, handling, and the development of hydrogen infrastructure need to be addressed. Hydrogen can be used in fuel cells or internal combustion engines, offering versatility in its application.

Biofuels: Biofuels, derived from biomass, present a renewable alternative that can significantly reduce carbon emissions. They are compatible with existing engines, reducing the need for extensive modifications. However, challenges related to feedstock availability, production costs, and competition with food production must be addressed.

PROPERTIES OF ALTERNATIVE FUELS

As alternative fuels vary significantly in energy density (per weight and volume) depending on the fuel type, the required fuel amount and necessary fuel tank capacity can differ greatly compared to conventional fuel oil. Accurately understanding the physical properties of each fuel is the first step in considering the adoption of alternative fuels. The properties of alternative fuels are given in Fig. 4.



Fuel type	HFO	LNG (Methane)	LPG Propane	LPG Butane	Methanol	Ammonia	Hydrogen
TtW CO_2 emission [HFO = 1]	1	0.73	0.85	0.86	0.90	0	0
TtW GHG emission [HFO = 1]	1	0.82	0.85	0.86	0.92	0.04	0.01
Required to obtain the same amount of energy Fuel ton [HFO = 1]	1	0.84	0.87	0.88	2.02	2.16	0.34
In liquid form Fuel tank capacity [HFO = 1]	1	1.89	1.69	1.41	2.47	3.07	4.63
Flammability (Lower Explosive Limit)	0.7 vol%	5.0 vol%	2.1 vol%	1.8 vol%	6.0 vol%	15.0 vol%	4.0 vol%
Toxicity (TLV-TWA*)	-	-	-		200 ppm	25 ppm	-
Cyrogenic (Boiling point)	- (Liquid at normal temp.)	-161℃	-42℃	-0.5℃	- (Liquid at normal temp.)	-33℃	-253℃

Fuel type	HFO	LNG (Methane)	LPG Propane	LPG Butane	Methanol	Ammonia	Hydrogen
In liquid form Energy density per unit volume [HFO = 1]	1	1.89	1.69	1.41	2.47	3.07	4.63
Liquid density [ton/m^3]	0.96	0.42	0.5	0.6	0.79	0.68	0.07
Liquefaction temp. (Boiling point)	-	-161℃	-42℃	-0.5℃	65℃	-33℃	-253℃
Lower calorific value [MJ/kg]	40.5	49.1	46.0	46.0	19.9	18.6	120.0
Engine type (2 stroke)	Diesel	Diesel/ Otto	Diesel		Diesel	Diesel	Diesel
Engine type (4 stroke)	Diesel	Otto	-		Diesel	Diesel/ Otto	Otto
Onboard storage methods	Gravity tank	Type A/B/C Membrane	Type A/B/C		Gravity tank	Type A/B/C Membrane	Low-temp. (Type C, Membrane) High pressure (Type 1/2/3/4)

Fig. 4 Properties of alternative fuels

Alternative fuels have different calorific values compared to conventional fuel oil, resulting in changes in the required fuel amount (in tons) when transitioning to alternative fuels. It is important to understand the estimated fuel volume required for each fuel type depending on the ship type and size when considering the adoption of alternative fuels. The required amount of alternative fuel compared to conventional HFO in tons is given in Table 1.

Table 1 Amount of required alternative fuels Vs HFO

HFO	1.00 t
LNG	0.84 t
LPG	0.87 t
Methanol	2.02 t
Ammonia	2.16 t
Hydrogen	0.34 t

AVAILABILITY OF RENEWABLE ENERGY

Green hydrogen serves as the raw material for green ammonia and green methanol. Production of green hydrogen requires an increase in the adoption of renewable energy. The renewable energy needed for green hydrogen production is estimated. The annual HFO consumption in international shipping is about 220 million tons. The amount of hydrogen required to produce the methanol and ammonia equivalents are given in Table 2.

Table 2 Hydrogen requirement for alternative fuel production equivalent to HFO consumption (in million tons - mt)

HFO 220 mt	Methanol equivalent 440 mt	Ammonia equivalent 470 mt	Hydrogen equivalent 70 mt
Required Hydrogen	84 mt	85 mt	
Required renewable energy*	530 GW x 365 days of operation	540 GW x 365 days of operation	450 GW x 365 days of operation

* Calculated power consumption is based on 5.0 kWh per Nm^3-H_2.

Renewable energy capacity growth is shown in Fig. 5. [6] There is about 4,000 GW of renewable energy capacity worldwide. However, most of it is currently used directly as electricity. For the decarbonization of international shipping, the key point moving forward will be finding ways to introduce and expand the use of renewable energy for green hydrogen production.

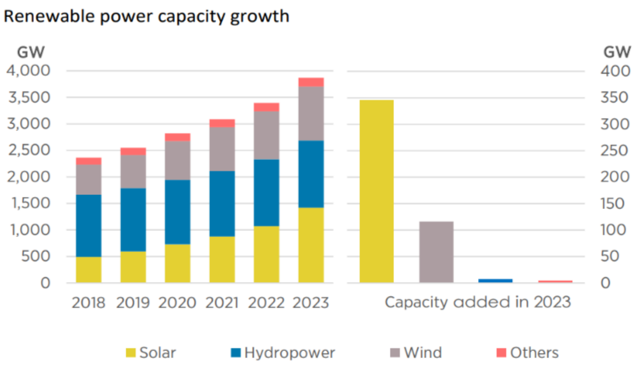


Fig. 5 Renewable power capacity growth

2023 IMO GHG STRATEGY INDICATIVE CHECK POINTS

The indicative checkpoints at 2030 and 2040 on the path to achieve the 2023 IMO GHG Strategy of net-zero by

2050 is shown in Fig. 6. Based on this, the amount of zero-emission fuels needed on a well-to-wake basis is calculated. Ships of 5,000 gross tonnage and above engaged in international voyages (ships subject to IMO DCS) are considered for this calculation.

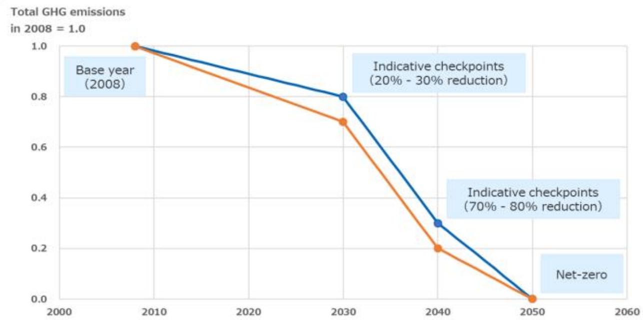


Fig. 6 IMO GHG Strategy indicative checkpoints

The 2023 IMO GHG Strategy outlines the requirement of zero-emission fuel to achieve the indicative checkpoint at 2030 as 5-10%. However, the study finds that to achieve the indicative check point at 2030, 25% of the fuel used in international shipping needs to be zero-emission fuel. This in terms of green methanol is 106 million tons (mt), and for green ammonia, 114 mt. Considering the current production level of green methanol and green ammonia of about 20,000 tons/year, it would be challenging to achieve the indicative checkpoint in 2030.

Similarly, it is challenging for the indicative checkpoint at 2040, where the share of zero-emission fuels needs to be 72% which translates to 311 mt of green methanol and 333 mt of green ammonia.

The number of zero-emission ships needed to consume the above fuel volume as of 2030 is 352 million gross tonnage (mGT). That is, 85 mGT ships needs to be introduced per year till 2030 to achieve this. Considering that the current annual newbuilding deliveries are about 60 mGT, it may be very challenging to achieve this target.

Similarly, to achieve the indicative checkpoint at 2040, 77 mGT of ships need to be introduced per year from 2031-2040. It will be very challenging to achieve this target, without coordinated effort from all involved.

ALTERNATIVE FUEL PRODUCTION

Several projects are ongoing to produce green hydrogen, blue hydrogen, green ammonia, blue ammonia, green methanol, and others. A typical example of the production scale of green methanol (including planned production) is shown in Fig. 7 and Table 3. Methanol is not only used directly as marine fuel but also required for the production of biodiesel such as FAME (Fatty Acid Methyl Ester). Please note that production projects are not limited to the shipping sector.

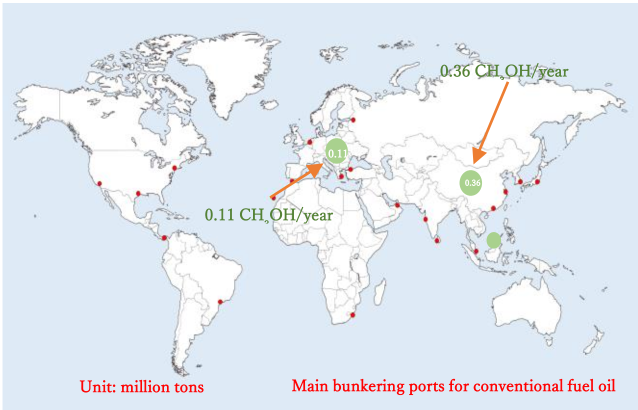


Fig. 7 World green methanol production

Table 3 World green methanol (CH_3OH) production

Country/ Region	Number of projects	Annual production capacity (total)
China	3	365,867 tons CH_3OH/year
Europe	9	119,675
Asia	1	3,918

REGULATORY TRENDS

The IMO has been actively developing rules and guidelines for various alternative fuels, including zero- and low-emission fuels. The governing rules and the equivalent class rules are given in Table 4.

FUEL COSTS

Alternative fuels available for ships vary widely, but the cost of each alternative fuel is expected to be 1.5 to 4 times higher than that of conventional fuel oil by 2030. While the cost gap between conventional fuel oil and alternative fuels is expected to narrow in the future as production expands and regulations are introduced, price trends based on supply and demand remain uncertain. Therefore, when considering the adoption of alternative fuels, it is crucial to assess the trend of fuel costs. The cost projection of alternative fuels by 2030 is given in Fig. 8.

Table 4 IMO and class rules governing alternative fuels (as of 8 May 2024)

Alternative fuels/ Related technologies	IMO Rules/Guidelines	ClassNK Rules/Guidelines
LNG	**IGF Code**	Rules for the Survey and Construction of Steel Ships / Guidance Part GF SHIPS USING LOW-FLASHPOINT FUELS
Methanol	*Interim Guidelines for the Safety of Ships Using Methyl / Ethyl alcohol as Fuel (MSC.1/Circ.1621)*	Guidelines for Ships Using Alternative Fuels (Edition 2.1) Part A Guidelines for Ships Using Methyl/Ethyl Alcohol as Fuels Part B Guidelines for Ships Using LPG as Fuel Part C Guidelines for Ships Using Ammonia as Fuel Annex 1 Alternative Fuel Ready
LPG	*Interim Guidelines for the Safety of Ships Using LPG Fuels (MSC.1/Circ. 1666)*	
Ammonia	Under development (Finalisation is scheduled for September 2024 at CCC10.)	
Hydrogen	Under development (Finalisation is scheduled for September 2024 at CCC10.)	Under development
Fuel Cell	*Interim Guidelines for the Safety of Ships Using Fuel Cell Power Installations* (MSC.1/Circ.1647)	Guidelines for Fuel Cell Power Systems On Board Ships [Second Edition]

Existing rule | *Existing guidelines* | Guidelines under development

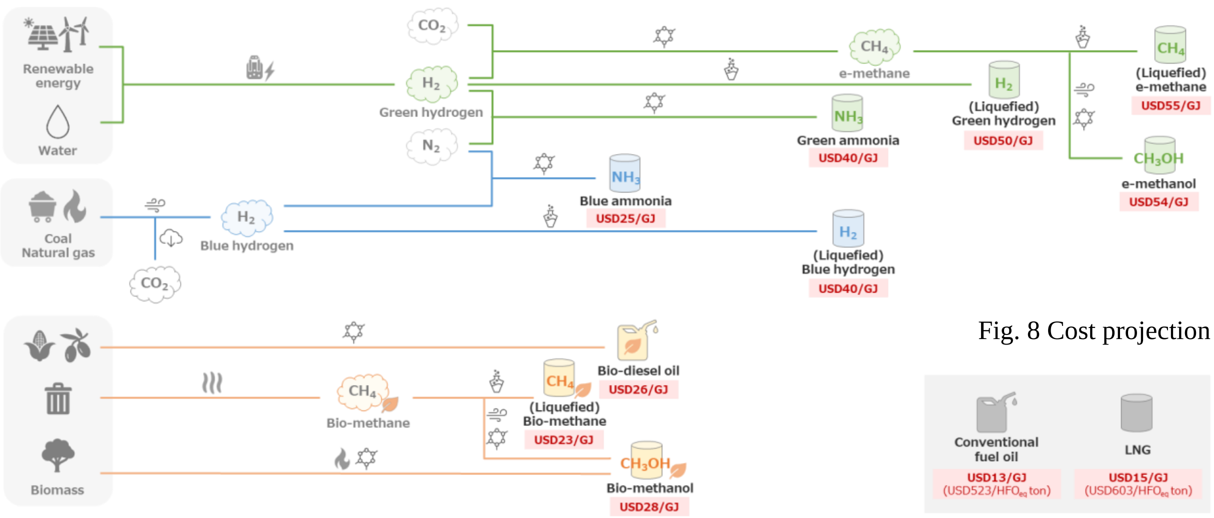


Fig. 8 Cost projection of alternative fuels

The total cost in the adoption of alternative fuels includes the significant components of shipbuilding or conversion costs, fuel costs, and regulatory costs. An image to compare the costs is shown in Fig. 9. The shipbuilding and fuel cost will increase compared to conventional fuel. The primary factors contributing to regulatory costs are the EU's EU-ETS and FuelEU Maritime, as well as the IMO's mid-term measures. While EU regulations target GHG emissions in EU-related voyages, IMO regulations are likely to cover GHG emissions in all voyages, potentially leading to relatively higher regulatory cost burdens.

The shipbuilding cost for conventional fuelled ships in general is showing an upward trend from around 2020. For alternative fuelled ships, it can be typically 10-20% higher compared to conventional fuelled ships.

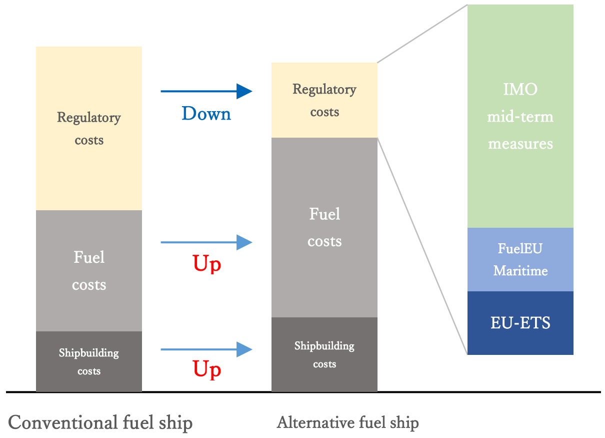


Fig. 9 Cost comparison between conventional fuel ship and alternative fuel ship

CHALLENGES OF ALTERNATIVE FUELS

Transition and adapting to alternative fuels are challenging. Some points to consider are given below:

Infrastructure: The transition to alternative fuels requires significant investment in infrastructure for production, storage, and distribution. While LNG and methanol have relatively established infrastructures, hydrogen and ammonia require extensive development.

Cost: Alternative fuels are generally more expensive than traditional marine fuels. The initial investment in new technologies and infrastructure, along with higher fuel prices, poses economic challenges for shipowners and operators.

Technical Barriers: Each alternative fuel comes with its own set of technical challenges. For instance, hydrogen requires advanced storage solutions, while ammonia poses safety risks due to its toxicity and corrosiveness. Engine compatibility and fuel quality standards also need to be addressed.

Regulatory and Safety Standards: Developing and harmonizing international regulations and safety standards for alternative fuels is essential to ensure safe and efficient adoption. This includes guidelines for fuel handling, bunkering procedures, and crew training.

Despite these challenges, shipping companies are gradually adopting alternative fuels. LNG has seen considerable adoption in recent years, particularly in the cruise and container shipping sectors. Companies like CMA CGM and Carnival Corporation have invested in LNG-powered vessels, citing environmental benefits and compliance with emission regulations.

Stena Line, a major ferry operator, has been a pioneer in methanol adoption. Their vessel, Stena Germanica, was retrofitted to run on methanol, demonstrating the feasibility of converting existing ships. Methanol's liquid state at ambient temperature simplifies storage and handling, making it a practical choice for retrofitting.

Hydrogen projects are still in the pilot phase, with several prototypes and demonstration vessels under development. The HySHIP project, which aims to develop a hydrogen-powered cargo vessel, is one such project. This project illustrates the collaborative efforts required to overcome technical and infrastructural challenges.

As for ammonia, partnerships between shipbuilders, engine manufacturers, and fuel producers to develop ammonia-compatible engines and bunkering systems are ongoing. One notable project is the NYK Line's collaboration with Japan Engine Corporation to develop an ammonia-fuelled vessel, aiming for operational deployment by 2030.

FUTURE OUTLOOK AND RECOMMENDATION

A multifaceted approach is needed to achieve decarbonization goals. No single alternative fuel will be a silver bullet; instead, a combination of fuels tailored to specific ship types and routes will be necessary. The future outlook includes:

Technological Advancements: Continued research and development are crucial for overcoming technical barriers. Innovations in fuel cells, engine design, and energy storage will enhance the viability of alternative fuels.

Policy Support: Governments and international bodies must provide strong policy frameworks and incentives to accelerate the adoption of alternative fuels. This includes subsidies, tax incentives, and funding for infrastructure projects.

Industry Collaboration: Collaborative efforts between stakeholders, including shipowners, fuel producers, technology providers, and regulatory bodies, are essential. Knowledge sharing and joint ventures can drive innovation and reduce costs.

Public Awareness: Raising awareness about the benefits of alternative fuels and the industry's efforts to decarbonize can garner public support and encourage investment. Transparency in environmental performance and sustainability initiatives will build trust and confidence.

CONCLUSION

The ClassNK Alternative Fuels Insight report provides a comprehensive overview of the current state and future prospects of alternative fuels in the maritime industry. While significant challenges remain, the potential environmental and regulatory benefits make the pursuit of alternative fuels imperative. By addressing infrastructure needs, reducing costs, and fostering collaboration, the maritime industry can navigate the complex transition towards a sustainable and decarbonized future.

The 2023 Revised IMO GHG Strategy specifies indicative checkpoint in 2030 and 2040 with respect to the availability of alternative fuels and the number of ships to run on these alternative fuels. At the current level of production of alternative fuels and the delivery of ships that run on these fuels, it will be very challenging to achieve the indicative checkpoints.

The path forward involves a blend of innovation, policy support, and industry cooperation. As alternative fuels gain traction, the maritime sector will be better positioned to meet global emission targets, ensuring a cleaner and more sustainable future for generations to come.

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