ClassNK Alternative Fuels Insight

Hiroyuki WATANABE*

1. INTRODUCTION

In July 2023, new greenhouse gas (GHG) emissions reduction targets for international shipping were announced with the aim of reaching "Net-zero GHG emissions by or around 2050." This was a decisive turning point for international shipping, which made it clear that alternative fuels would be considered necessary in all international shipping in the future. Following this, international shipping embarked upon an era of large-scale fuel transition toward the year 2050.

On the other hand, a wide range of alternative fuels are available for use by ships. Owing to this diversity of fuels, which fuels are to be introduced at what timing, corresponding to the ship type and size, navigation routes, etc. will affect the maritime shipping business in the future. In order to study introduction, it is necessary to understand not only the technical aspects of alternative fuels, but also the general issues related to alternative fuels as a whole, including fuel availability, cost projections and other related factors.

To support this kind of fuel selection, ClassNK (hereinafter, the Society) issues "ClassNK Alternative Fuels Insight." This publication introduces the minimum points that must be understood when introducing alternative fuels in the four steps of "Understanding regulations," "Understanding trends," "Understanding alternative fuels" and "Understanding costs." This article presents an overview of "ClassNK Alternative Fuels Insight" to assist readers in understanding its content.

2. UNDERSTANDING REGULATIONS

2.1 GHG Emission Pricing

Why is it necessary to introduce alternative fuels? It is because GHG emissions from ships will be subject to GHG emission costs (GHG emission pricing) in the near future. The two main regulatory bodies that influence GHG emissions from international shipping, that is, International Maritime Organization (IMO) and the European Union (EU), announced respective GHG emission reduction targets of "net-zero GHG emissions by or around 2050" and "net-zero GHG emissions by 2050." While the EU target is not limited to maritime shipping and is simply a target for the EU as a whole, EU policies that forcefully promote the realization of a decarbonized economy will also affect the trends in international shipping. To realize these GHG emission reduction targets, i.e., to realize net-zero GHG emissions in international shipping, not only the improvement of energy efficiency of ships, but also the use of lower GHG emissions than conventional fuel oil, or so-called alternative fuels, will be indispensable. On the other hand, because the price of alternative fuels is generally higher than that of conventional fuel oil, the use of alternative fuels will not progress unless the price gap between the two is closed. Therefore, the IMO and EU will introduce regulations that promote the use of alternative fuels, in other words, regulations that reduce demand for conventional fuel oil. This is so-called "carbon pricing," and is intended to treat GHG emissions as a cost. The schedule for introduction of the IMO and EU regulations is as shown in Fig. 1. The IMO is targeting the introduction of regulations called "mid-term measures" in 2027, while the EU already introduced that type of regulations in 2024 as "EU-ETS for shipping," and will introduce new regulations called "FuelEU Maritime" in 2025. Thus, pricing of GHG emissions will not wait.

* Green Transformation Center, Planning Division, ClassNK

Fig. 1 Introduction schedule of GHG-related regulations

2.2 IMO Mid-Term Measures

In addition to the one large time constraint of "net-zero by 2050," the GHG emission reduction targets of the IMO also includes the "indicative checkpoints" of 2030 (20% to 30% reduction) and 2040 (70% to 80% reduction). The IMO will introduce regulations in accordance with this timeline to achieve GHG emissions reductions. The regulations introduced up to the present aiming at GHG emission reductions in the "short-term" span until 2030 are called "short-term measures" and focus mainly improvement of ship's energy efficiency. In contrast, the regulations to be introduced in the future, which aim at GHG emission reductions in the "mid-term" span until 2040, are called "mid-term measures," and as mentioned above, the focus of these mid-term measures is promoting the use of alternative fuels.

The methods for achieving the transition from conventional fuel oil based on the market mechanism by regulations that promote the use of alternative fuels, namely, pricing of GHG emissions, mainly include two methods: The first approach is simply levying fees for GHG emissions ("levying" system). In a levying system, the cost of the levy is equivalent to the amount of GHG emissions, irrespective of the type of fuel, so all fuels other than the zero-emission fuels can be subject to a cost burden. The second approach is regulation of the amount of GHG emissions per unit energy of the fuel, that is, regulation of the GHG intensity of the fuels (fuel GHG intensity system). Although the amount of fuel (weight-ton) necessary to move a ship 1 mile differs depending on the fuel, the amount of energy extracted in this process is the same for all types of fuels. Thus, by applying an index that shows "how much GHG was emitted when energy was extracted from the combustion of fuel," it becomes possible to compare the GHG emissions of each fuel equally. A typical unit of fuel GHG intensity is CO_{2eq}/MJ, where CO_{2eq} means CO_2 equivalent ($_{eq}$ is the abbreviation of equivalent). This unit is used to calculate the total amount of emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other GHGs with different warming effects by a single unit. Of course, even when calculating only CO_2, CO_{2eq} is sometimes used for convenience. MJ is a unit of energy and is the abbreviation of megajoule ("mega" means "million"). Returning to the discussion of regulations, regulations on GHG intensity are intended to limit fuel use exceeding a certain threshold by setting a uniform threshold for GHG intensity. Naturally, in implementing regulations, it would be possible to impose a compulsory limit forbidding fuel use exceeding the threshold, but realistically, implementation permits excess fuel use by asking for payment of a monetary penalty for fuel use that exceeds the threshold. In this kind of implementation, the GHG intensity system is substantially a levying system on excess GHG emissions that exceed a threshold. Moreover, since designated fuels with low GHG intensities can avoid penalties depending on how the threshold is set, not only zero-emission fuels, but also low-emission fuels have a competitive advantage in comparison with conventional fuel oil; this is a feature of fuel GHG intensity regulations. Because the relative GHG emission costs of various fuels is determined by what threshold level is set at what timing, this is the point at issue in policy discussions.

The IMO is engaged in discussions on the content of the mid-term measures toward introduction in and after 2027 along the lines of the two approaches described above. The issues in those discussions are the selection of the regulatory approach and the purpose of use of the levy income or penalty income collected by the IMO under the regulatory scheme. Candidates for the use of levy income and penalty income include refunds ("rebates") of fuel costs to ships that use high-cost alternative fuels, support for developing countries, and others.

2.3 EU Regional Regulations

The EU began introducing regulations that promote the use of alternative fuels ahead of similar efforts in the IMO. In 2024, the European Union Emission Trading System (EU-ETS) implemented by the EU was expanded to the maritime sector as "EU-

ETS for shipping." Emission trading systems are generally cap-and-trade systems that set GHG emission allowances in advance, and then allow to sell or buy ("trade") their surplus or shortage of GHG emissions. However, the most important feature of EU-ETS for shipping is that free emission allowances are not allocated to ships in advance. In other words, in EU-ETS for shipping, the ship's actual emissions are defined as a "shortage" of GHG emission allowances, and the ship must cover those emissions by purchasing GHG emission allowances. In this sense, EU-ETS for shipping is essentially a type of levy system. Furthermore, continuing from EU-ETS for shipping, "FuelEU Maritime" is a new regulation which will be introduced beginning in 2025. FuelEU Maritime is a GHG intensity regulations, as described above, and will impose monetary penalties on the use of fuels in excess of the GHG intensity threshold.

While both EU-ETS for shipping and FuelEU Maritime are ultimately regional regulations of the EU, as one feature of these regulations, their application is not limited to coastal vessels operating only in EU waters, but also include other vessels that call at ports in the EU. Thus, these policies clearly show the intention of the EU to influence international shipping. Therefore, fuel selection based on an accurate understanding of the provisions of these EU regulations is strategically important for all ships engaged in EU-related voyages. The Society issues FAQs in a question-and-answer format, presenting an overview of the EU regulations and summarizing the preparations and procedures necessary to ensure compliance with those regulations.

2.4 Increasing GHG Emission Costs

Up to this point, this paper has explained the general framework of the new regulations of the IMO and EU. However, what is the estimated cost burden that will be imposed by these GHG emission regulations? As one example, Fig. 2 shows an image of the increase in the regulatory cost burden, using a 14 000 TEU containership as an example among containerships which are considered to have particularly large fuel consumption. Because the provisions of the IMO's mid-term measures have not been finalized, here, this discussion assumes that provisions similar to those of FuelEU Maritime are adopted. Since the IMO regulations are not limited to EU-related voyages, but are applicable to the GHG emissions of all voyages worldwide, the cost burden will be large in comparison with that of EU-related regulations. As reference, the figure shows the fuel cost calculated based on the average annual fuel consumption (23 000 tons) of a 14 000 TEU containership assuming USD 522.60/ton (USD13.0/GJ) as the price of conventional fuel oil. As is clear from these results, it is possible that the regulatory cost will reach a level that far exceeds the fuel cost, depending on the provisions of the IMO's mid-term measures. Since the purpose of the new GHG emission regulations of the IMO and EU is to promote the use of alternative fuels, in other words, a changeover from conventional fuel oil, setting a level that closes the price gap between high-priced alternative fuels and low-priced conventional fuel oil is only natural.

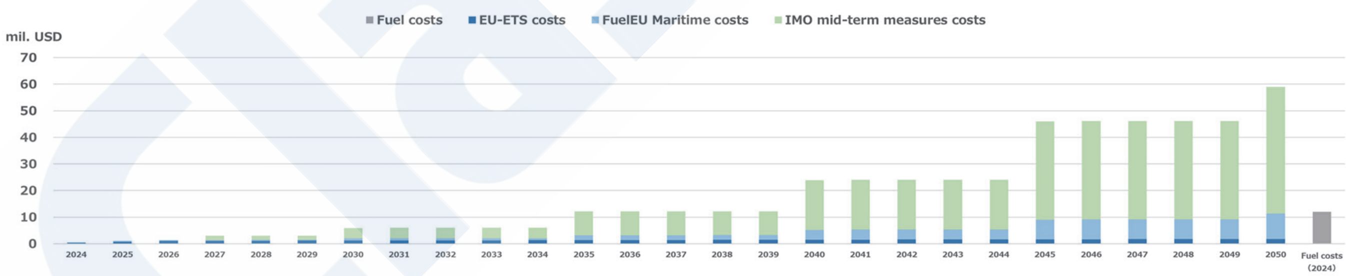

Fig. 2 Image of increasing GHG emission cost

3. UNDERSTANDING TRENDS

3.1 Trends in Adoption of Alternative Fuel Ships

After understanding GHG emission regulations, the next step is understanding trends in alternative fuels. Trends on the alternative fuel demand side impact the alternative fuel supply side, and both trends influence the availability and purchase price of alternative fuels.

In anticipation of future regulations, in international shipping, adoption of ships that can use alternative fuels is gradually increasing (hereinafter, these ships are called "alternative fuel ships"). This section and the following introduce the trends in the adoption of alternative fuel ships. It should be noted that the content introduced here is all based on information available at the end of June 2024. The subject of calculations of the total number of ships is ships with a gross tonnage of 5 000 tons and above, as these are the ships that will be subject to future IMO and EU GHG emission regulations. By limiting the subject ships to those having a gross tonnage of 5 000 tons and above, the intention is to accurately understand the trends in the vessels that will be subject to the regulations, and to accurately understand the effects of those regulations on the subject ships. The total numbers of alternative fuel ships do not include so-called alternative fuel-ready ships, which are either designed or already partially-equipped to use alternative fuels in the future. In actuality, alternative fuel-ready ships include a mix of various types, from ships in which only the design work for use of alternative fuels has been completed, to ships that are already partially-equipped for alternative fuels use. Because it would be difficult to accurately understand the possibility of converting these ships to alternative fuel ships, and also in order to avoid misunderstanding the trends in alternative fuel ships, those vessels are not included in the totals of alternative fuel ships. In addition, LNG carriers are not included in the total of LNG-fueled ships, which are one type of alternative fuel ship, because LNG carriers generally use cargo LNG as a fuel, and as a result, significant progress has already been made in the use of this alternative fuel in LNG carriers. Therefore, LNG carriers were excluded from the total number, and efforts were made to grasp the trends in the adoption of alternative fuels in ships other than LNG carriers.

3.2 Status of “Newbuilding” and “In Service” Alternative Fuel Ships

This section introduces the status of “newbuilding” and “in service” alternative fuel ships to date. Deliveries of alternative fuel ships increased rapidly from 2021 (Fig. 3). Compared with the 62 ships delivered in 2021, a total of 167 ships were delivered in 2023. By fuel, more than half were LNG-fueled ships. LNG fuel is superior to other alternative fuels in terms of development of infrastructure, fuel availability, purchase cost, etc. However, among ships scheduled for completion in and after 2024, methanol-fueled ships also have a significant share. Methanol fuel attracted attention as a result of orders for methanol-fueled ships placed by containership companies, as methanol is comparatively easy to handle onboard ships because it is a liquid at normal temperature and normal pressure. Looking at the total of alternative fuel ships scheduled for completion by 2026, when almost all orders in shipyards have been fixed, a cumulative total of 1 250 alternative fuel ships are forecast to be in service (Fig. 4).

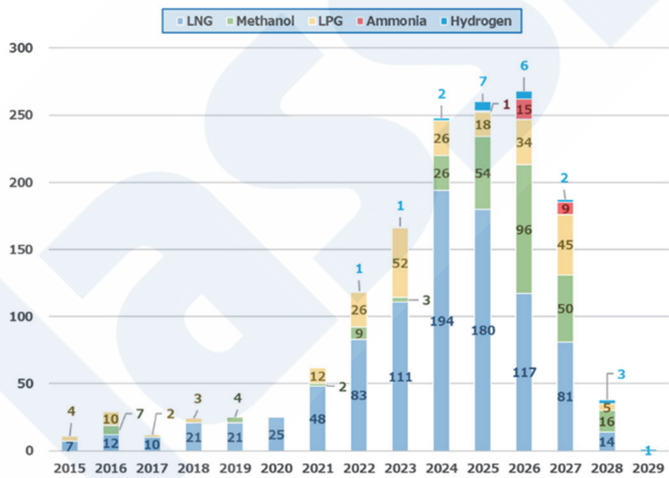

Fig. 3 Trend of newbuilding alternative fuel ships (totals by year)

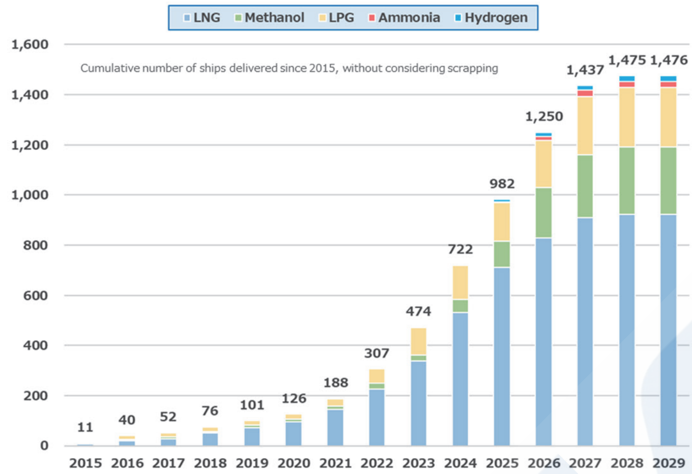

Fig. 4　Trend of in service alternative fuel ships (cumulative totals)

3.3　Trends in Shares of Alternative Fuel Ships

Although the number of alternative fuel ships is increasing continuously, what is their share in total international shipping? Fig. 5 shows the share of alternative fuel ships to all ships in service and their share in the orderbook. By number of ships, alternative fuel ships have a share of 1.7% of all ships in service, but have a share of 21.5% of the orderbook. Thus, adoption of alternative fuel ships is limited at present, but assuming full-scale enforcement of new GHG emission regulations in the future accompanying pricing of GHG emissions by the IMO and EU, rapid expansion of the adoption of alternative fuel ships can be expected in order to avoid the regulatory cost burden of continuing to use conventional fuel oil and the risk that the ships themselves may become “stranded assets.”

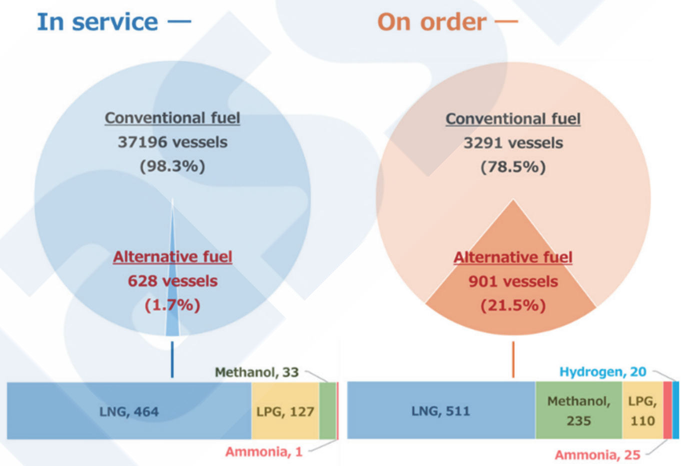

Fig. 5　Share of alternative fuel ships

3.4　Trends in “In Service” and “On Order” Alternative Fuel Ships (by Ship Type)

In order to understand the trends in alternative fuels, it is also important to understand the trends by ship type. Selection of fuel ships that go against the trends can be a high risk/high return investment. Looking at the trends by ship type, among all ships with the exception of LPG carriers, the largest number of ships in service is LNG-fueled ships (Fig. 6). In LPG carriers, adoption of LPG-fueled ships has expanded since the advent of LPG-fueled main engines. A certain number of in-service methanol-fueled ships can also be seen in the category of product/chemical tankers, because this category includes methanol carriers that transport methanol as a chemical product. Since some methanol carriers are equipped with methanol-fueled main engines which are capable of using methanol as a fuel, these vessels are methanol-fueled ships. Regarding alternative fuel ships on order, in comparison with the in-service status of alternative fuel ships, orders for methanol-fueled bulk carriers and vehicle carriers, and particularly containerships, are also increasing (Fig. 7). In addition, orders for ammonia-fueled ships can also be seen in some ship types.

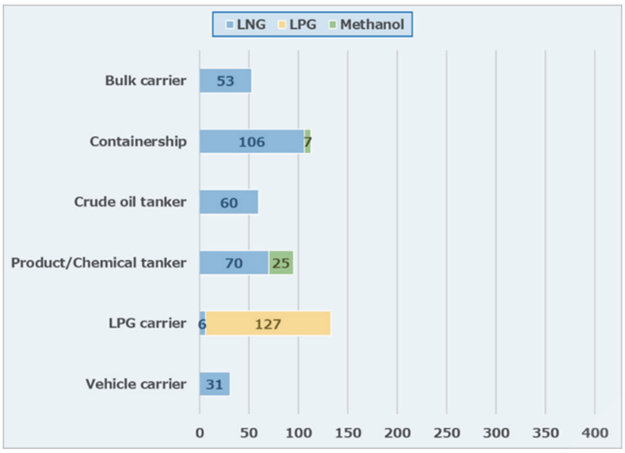

Fig. 6 Trends in alternative fuel ships in service (by ship type)

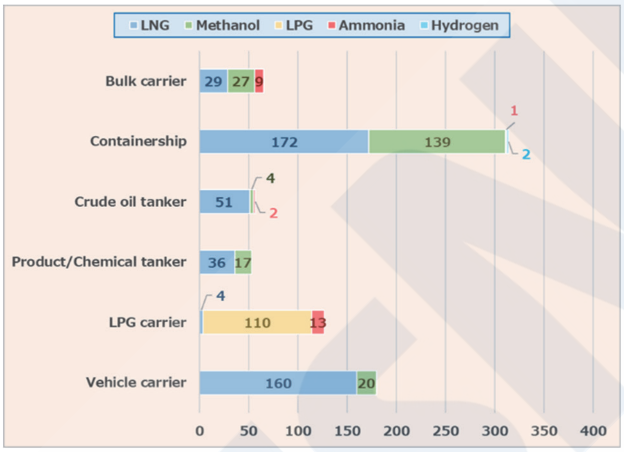

Fig. 7 Trends in alternative fuel ships on order (by ship type)

4. UNDERSTANDING ALTERNATIVE FUELS

4.1 Properties of Alternative Fuels

The step after understanding the trends in alternative fuels is understanding the alternative fuels themselves. It is only possible to select the most appropriate fuel after understanding not only their chemical characteristics as fuels, but also the differences in their emission factors as specified in regulations, costs, fuel supply-and-demand trends, etc. This section introduces the properties of each fuel. Table 1 presents a list summarizing the properties of the respective fuels.

Table 1 List of fuel properties (overview)

Fuel type	HFO	LNG (Methane)	LPG		Methanol	Ammonia	Hydrogen
			Propane	Butane			
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℃

The CO_2 emissions and GHG emissions in Table 1 were calculated based on the emission factors given in the FuelEU Maritime regulation of the EU. TtW is an abbreviation of Tank-to-Wake and means the emission when the fuel is used (burned) onboard a ship. Regarding CO_2 emissions, LNG (methane), LPG and methanol have limited CO_2 reduction effects, but substantial reductions can be expected with ammonia (NH_3) and hydrogen (H_2), as these fuels do not contain the carbon (C) which is the source of CO_2. As for GHG emissions, the GHG reduction effect of LNG is more limited than its CO_2 reduction effect because the regulations recognize the existence of "methane slip," i.e., discharges of unburned methane, when LNG (methane) is burned. Methane is a potent GHG, and is estimated to have a 30 times larger greenhouse effect than CO_2.

Due to differences in energy density per unit weight, the necessary weight (tons) of some alternative fuels is larger than that of conventional fuel oil (in Table 1, conventional fuel oil is listed as HFO). By weight ratio to HFO, an amount (tons) of methanol 2.02 times greater and an amount of ammonia 2.16 times greater than that of HFO is needed to obtain the same energy as HFO. Therefore, it should be noted that direct comparison of fuel prices based solely on a per-ton basis is misleading.

Since the volumetric energy density of alternative fuels is also different, the volume of fuel tanks for alternative fuels may also be larger than the volume for conventional fuel oil. In comparison with conventional fuel oil, the fuel tank size necessary to obtain the same energy as conventional fuel oil is 1.89 times that of conventional fuel oil for LNG, but is larger by 2.47 times for methanol, 3.07 times for ammonia and 4.63 times for hydrogen. This will depend on the design, but this increased fuel tank capacity may make lead to the reduction of cargo space; conversely, keeping the same fuel tank capacity or reducing tank capacity may require an increase in refueling when using alternative fuels.

Regarding combustibility, as a particular feature of ammonia, ammonia does not explode when its concentration in the atmosphere is not 15.0 vol% or more. This means it is less explosive than the other alternative fuels.

Where toxicity is concerned, both methanol and ammonia are toxic. In particular, ammonia is considered to have an adverse effect on human health in case of repeated exposure, even at comparatively low concentrations, and high toxicity is a concern.

4.2 Emission Factors of Alternative Fuels

When studying the introduction of alternative fuels, an accurate understanding of their respective emission factors is necessary. The emission factor is directly linked to the GHG emission cost. It is important to note that the emission factors used in each regulation may be different. Fig. 8 shows the emission factors per unit of energy for each fuel, calculated based on the emission factors given in the EU's FuelEU Maritime regulations. As noted above, in order to compare the GHG emissions of various fuels on an equal basis, the fuels must be compared per unit of energy, and not per unit of weight.

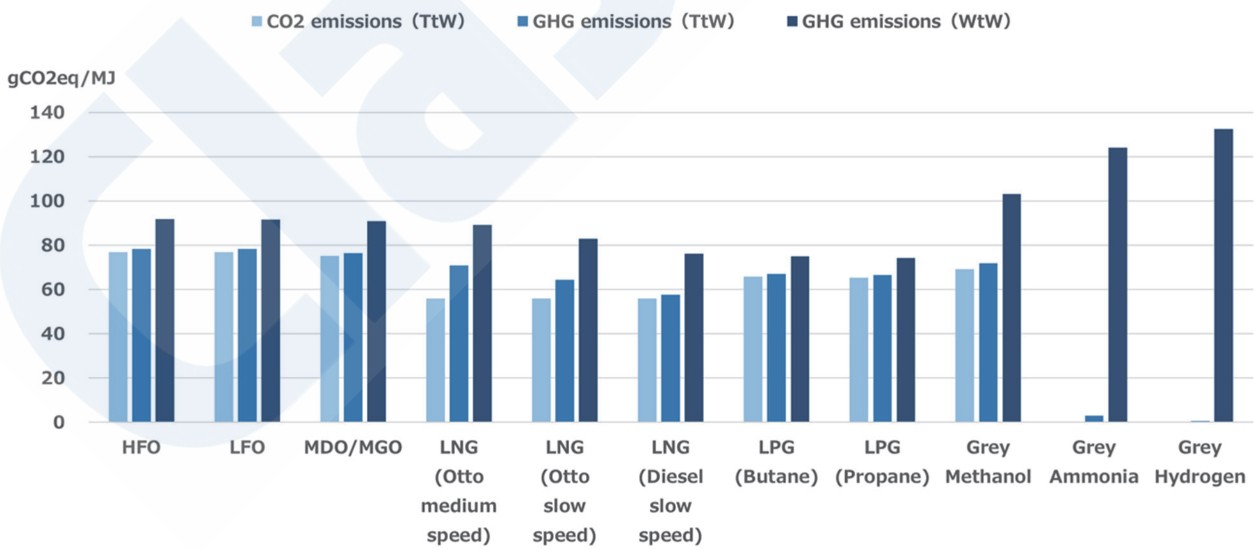

Fig. 8 Emissions per unit of energy

TtW is the abbreviation of Tank-to-Wake and means the emissions during use (during combustion) of the fuel onboard a ship. WtW is the abbreviation of Well-to-Wake and means the emissions during the entire lifecycle from production of the fuel until use (combustion) onboard a ship. In order to understand the GHG emission cost, in addition to the differences in the emission factors under various regulations, it is also important to recognize the scope of the emissions (TtW or WtW) that are the target of the regulations. For example, under EU-ETS for shipping, the target is CO_2 emissions in the TtW, and after 2026, GHG emissions in the TtW. However, the target of FuelEU Maritime is GHG emissions in the WtW. Moreover, there is a high possibility that the scope of the IMO's mid-term measures will also be GHG emissions in the WtW. However, this is undecided at present, and discussions on the emission factors to be used in the mid-term measures are continuing. Because the regulatory advantages and disadvantages of the various fuels differ greatly depending on the scope of the emissions, it is necessary to conduct a careful study of the fuel to be introduced and the timing of introduction, while considering these differences in the emission factors.

4.3 Alternative Fuel Costs

When studying the introduction of alternative fuels, understanding the cost of each alternative fuel is indispensable. Fig. 9 shows the projected costs of the various alternative fuels as of 2030, together with the production pathways. However, it is necessary to note that the cost will vary depending on actual supply and demand.

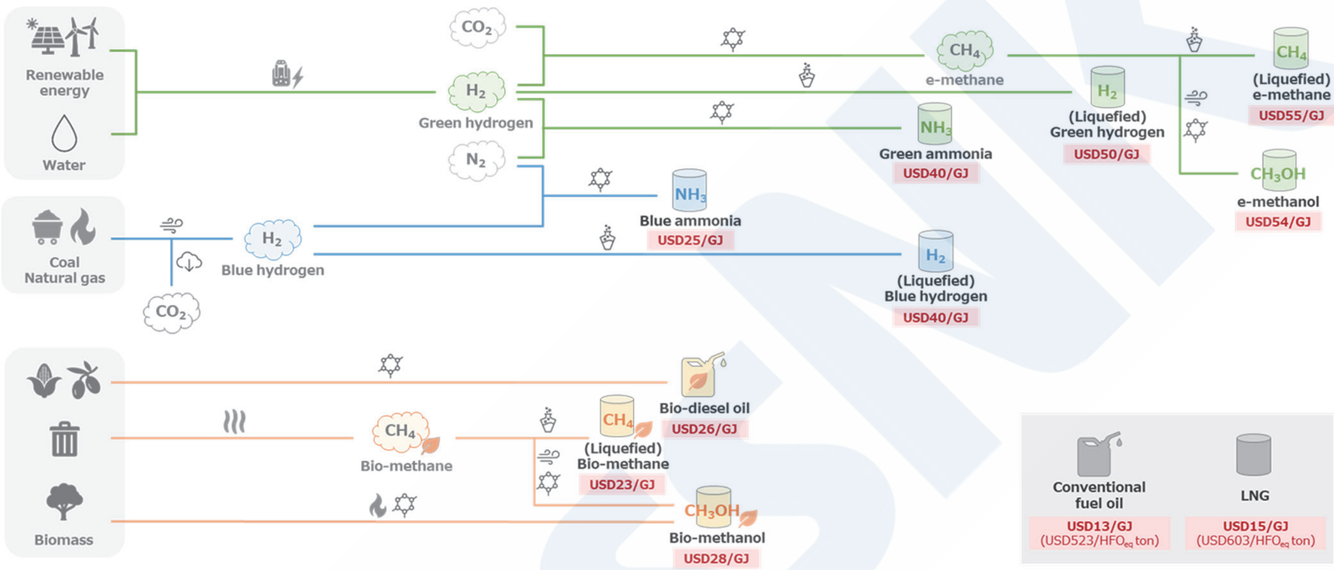

Fig. 9 Production pathways and costs of alternative fuels

With the exception of hydrogen, the alternative fuels that presumably will be used in international shipping are compounds of two or more chemical elements. Accordingly, the alternative fuels are basically produced by combining their component elements. Ammonia (NH_3) and hydrogen (H_2) are considered to be zero-emission fuels because they do not contain carbon and therefore do not emit CO_2. On the other hand, methane (CH_4), methanol (CH_3OH) and other compounds that contain carbon atoms emit CO_2 when burned. Limited to cases where these compounds are produced by capturing underlying carbon including CO_2 "from animal or vegetable materials (biomass)" or "by artificial recovery (direct air capture; DAC)" of the carbon that forms the base of the fuel, the CO_2 balance in the atmosphere is zero, and the fuels are regarded as carbon-neutral fuels. In other words, some type of carbon circulation is necessary.

Alternative fuels are broadly divided into three types, depending on the fuel production method. The first type is produced from green hydrogen extracted from water by using electricity derived from renewable energy. These are so-called e-fuel, which is an abbreviation of electrofuel. The second type is produced from gray hydrogen, which is extracted from fossil fuels, and the CO_2 emissions associated with production must be captured and stored. This type is called blue fuel. The third type is so-called biomass-derived fuel which is produced from carbon and hydrogen extracted from animal or vegetable materials (biomass).

The cost of alternative fuels is controlled by the cost of extracting hydrogen and/or carbon. The cost of extracting hydrogen from water using electricity generated by renewable energy is higher than the cost of extraction from fossil fuels, and extraction of carbon by direct air capture is more expensive than extraction from biomass. As a result, the cost of e-fuels produced from green hydrogen is the highest, and the cost of blue fuel and biomass-derived fuel is relatively low. However, in the case of biomass, there are resource-related constraints on the supply of biomass itself, so fuel availability requires particular attention.

4.4 Demand for Alternative Fuels

In this section, this paper will introduce demand for alternative fuels. Trends on the alternative fuel demand side affect the fuel supply side, and trends in supply and demand affect the availability and purchase price of alternative fuels.

4.4.1 Fuel Consumption in International Shipping

The first step toward understanding the demand outlook for alternative fuels is understanding the current consumption of alternative fuels in international shipping. Reporting of actual data on fuel consumption in international shipping by the IMO began in 2019. The IMO requires collection and reporting of data on the fuel consumption, etc. of ships with gross tonnages of 5 000 tons and above engaged in international voyages, which are the object of this system. When the Society calculated the total fuel consumption in international shipping based on the statistical values of the data released by the IMO [1], total fuel consumption (in 2023) was 216 million tons (by HFO conversion) (Table 2). In other words, to achieve net-zero CO_2 emissions in 2050, it will be necessary to replace 216 million tons of energy with alternative fuels in the coming years. While there may be increases and decreases due to future increases in maritime transport volume and improvement in energy efficiency, for example, converting all of this 216-million-tons of HFO to methanol would require 440 million tons of methanol, and conversion to ammonia would require 470 million tons of ammonia.

Table 2 Fuel consumption in international shipping (unit: tons)

	Heavy Fuel Oil (HFO)	Light Fuel Oil (LFO)	Diesel/Gas Oil (MDO/MGO)	LNG	LPG (Propane)	LPG (Butane)	Methanol	Ethanol	Other	Total (HFO eq)
2021 (28,171 ships) (1.25 bn GT)	109,169,447	64,479,128	25,732,999	12,623,121	34,973	2,028	13,031	4,849	170,501	217,710,495
2022 (28,834 ships) (1.29 bn GT)	116,576,283	57,077,835	28,285,802	10,950,408	88,774	16,673	35,523	10,890	226,739	218,339,992
2023 (28,620 ships) (1.30 bn GT)	130,441,745	40,416,174	26,600,016	12,890,011	192,405	49,887	93,876	4,137	428,263	215,833,384

4.4.2 Demand Outlook for Alternative Fuels

As mentioned above, the amount of alternative fuels necessary in international shipping in the future is huge, but realistically, supplies are gradually increasing, in line with the pace of increasing demand for alternative fuels. Fig. 10 shows the future outlook for the pace of increasing demand for alternative fuels based on the orderbooks for alternative fuel ships. This figure also includes demand for LNG fuel by LNG carriers. It is assumed that alternative fuel ships (dual-fueled ships) delivered after 2024 will use only alternative fuels, and use of a pilot fuel (conventional fuel oil) when using alternative fuels is not assumed. In other words, the demand outlook shown here is the maximum demand outlook for alternative fuels in international shipping. The actual amount of alternative fuel usage will be adjusted considering the price difference between alternative fuels and conventional fuel oil.

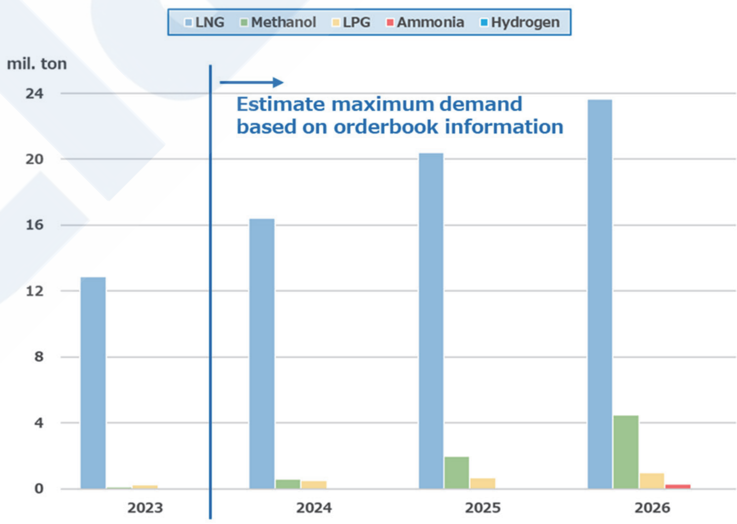

Fig. 10 Maximum demand outlook for alternative fuels

For LNG fuels, peak demand of 24 million tons in 2026 is forecast, based on mass delivery of LNG-fueled ships. Demand for methanol fuels is expected to peak at 4.5 million tons in 2026 as a result of successive deliveries of methanol-fueled ships, especially containerships. Peak demand for LPG fuel will be limited to 1 million tons in 2026, because the only type of ship that is currently expected to use LPG is LPG carriers. At present, the assumed demand for ammonia fuel and hydrogen fuel is limited, but increased demand is anticipated in the future when the development of ammonia- and hydrogen-fueled ships is complete.

4.5 Supply of Alternative Fuels

A stable supply of alternative fuels is indispensable for reducing GHG emissions from international shipping. This section introduces the future outlook for the production capacities of various fuels, which were calculated based on information in the Hydrogen Production Projects Database [2)] published in October 2023. This paper focuses on green hydrogen, green ammonia, green methanol and green methane. Green hydrogen is produced by electrolysis of water using electricity derived from renewable energy, and is a fuel with very low GHG emissions through the entire lifecycle from production through use (combustion) onboard ships. Similarly, green ammonia, green methanol and green methane produced from green hydrogen also have very low lifecycle GHG emissions or are carbon neutral. Because these kinds of green hydrogen-derived fuels will be cost-competitive under the future regulations of the IMO and EU, increasing demand is anticipated. However, since the fuel suppliers in the production projects tabulated here are not limited to the maritime shipping sector, it should be noted in advance that the supply outlook for international shipping is unclear.

4.5.1 Projected Production Capacity of Green Hydrogen

The projected production capacity of green hydrogen (all sectors) is total annual production of about 49 million tons (Fig. 11) in 2040, including the projects with the most delayed startup dates among those publicly announced. However, the actual feasibility of these projects is unclear, since the majority are currently in the conceptual or feasibility study stages. Fig. 12 shows the projected green hydrogen production capacity in 2040 by country/region. In addition to Europe, a certain number of projects are also planned for South America and Australia, which are considered to be suitable areas for green hydrogen production owing to their abundant renewable energy resources.

Fig. 11 Green hydrogen production capacity (by year)

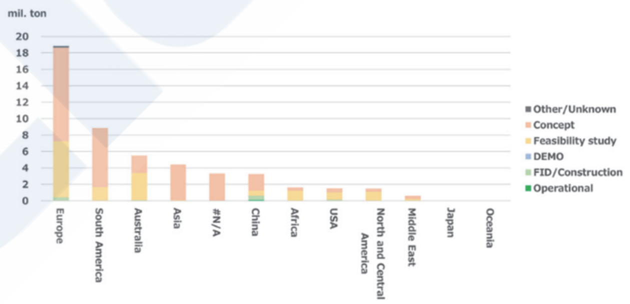

Fig. 12 Green hydrogen production capacity (by country/region)

4.5.2 Projected Production Capacity of Green Ammonia

The projected production capacity of green ammonia is a total annual production of about 220 million tons in 2043, including the projects with the most delayed startup dates among those publicly announced (Fig. 13). Comparatively large demand for ammonia is foreseen, as ammonia is expected to play the roles of an alternative fuel for coal-fired thermal power plants and use as a hydrogen carrier, and a large number of production projects are underway to meet that demand. However, since the majority of projects are still in the conceptual or feasibility study stages, their actual feasibility is unknown. Fig. 14 shows the projected green ammonia production capacity in 2043 by country/region. Many projects are located in Australia, Africa, etc.

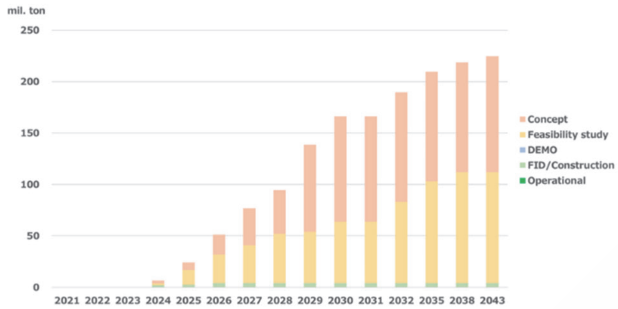

Fig. 13 Green ammonia production capacity (by year)

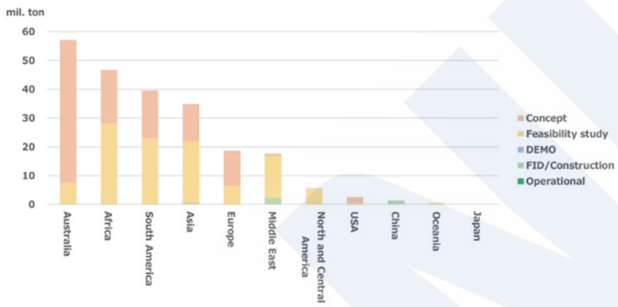

Fig. 14 Green ammonia production capacity (by country/region)

4.5.3 Projected Production Capacity of Green Methanol

The projected production capacity of green methanol is total annual production of about 5 million tons (Fig. 15) in 2030, including the projects with the most delayed startup dates among those publicly announced. Because the majority of projects are currently in the conceptual or feasibility study stages, their actual feasibility is unknown. Fig. 16 shows the projected production capacity of green methanol in 2030 by country/region. Many projects are located in Europe or the United States.

Fig. 15 Green methanol production capacity (by year)

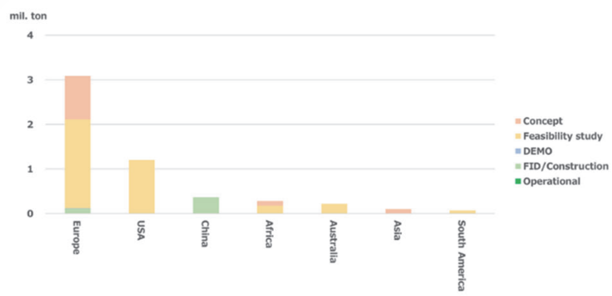

Fig. 16 Green methanol production capacity (by country/region)

4.5.4 Projected Production Capacity of Green Methane

The projected production capacity of green methane is total annual production of about 900 000 tons (Fig. 17) in 2030, including the projects with the most delayed startup dates among those publicly announced. Because the majority of projects are currently in the conceptual or feasibility study stages, their actual feasibility is unknown. Fig. 18 shows the projected production capacity of green methanol in 2030 by country/region. Many projects are located in Europe or the United States.

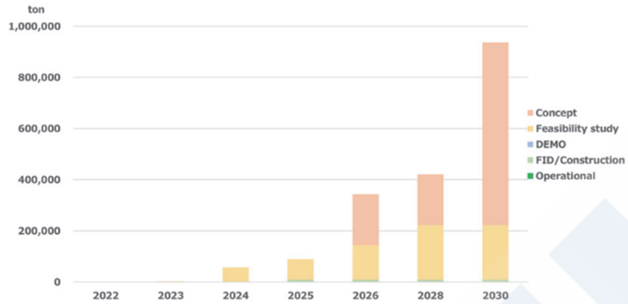

Fig. 17 Green methane production capacity (by year)

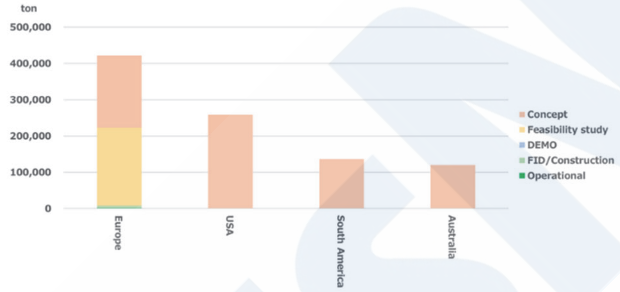

Fig. 18 Green methane production capacity (by country/region)

5. UNDERSTANDING COSTS

5.1 Cost Simulations

The final step is understanding the total cost of introducing alternative fuels. Although there are various ship-related costs, the costs that will be particularly affected by the introduction of alternative fuels are “Shipbuilding costs,” “Fuel costs” and “Regulatory costs.” As mentioned previously, future regulatory costs consist of the costs associated with the EU’s EU-ETS for shipping and FuelEU Marine and the IMO’s mid-term measures.

Introduction of alternative fuels will increase Shipbuilding costs and Fuel costs, but will decrease Regulatory costs. When introducing alternative fuels, it should be aimed for a timely transition from conventional fuel oil, based on a full discussion and sharing of the changes in the structure of these costs among stakeholders.

5.2 Example of Cost Simulation

The Society carries out cost simulations of the transition from conventional fuel ships to alternative fuel ships in order to support fuel selection. As an example of a simulation, this section introduces the results of a simulation of “Adoption of conventional fuel ship” vs. “Adoption of ammonia-fueled ship” for a 64 000 DWT bulk carrier.

Fig. 19 shows the results of a comparison of the total cost by year for the cases of “Adoption of conventional fuel ship” (vertical bars on left) and “Adoption of ammonia-fueled ship” (vertical bars on right). As costs, here, only “Shipbuilding costs,” “Fuel costs” and “Regulatory costs” are considered. Because the IMO’s mid-term measures have not been finalized, the simulation assumes the case in which regulatory provisions similar to those of FuelEU Maritime are adopted in the IMO’s mid-term measures. Assuming delivery of the ship in 2031 and a life of 20 years, i.e., until 2050, Shipbuilding costs are amortized over that 20-year period. As fuel prices, for the Conventional fuel ship, the price of Heavy Fuel Oil (HFO) is constant at USD 522.60/ton (USD 13.00/GJ) over the 20-year period, assuming that the Conventional fuel ship will use only HFO. The Ammonia-fueled ship is a dual-fuel ship and can use both HFO and e-ammonia. It is assumed that the price of e-ammonia will decrease linearly from USD 723.80/ton (USD 38.90/GJ) to USD 366.20/ton (USD 19.70/GJ) in 2050. Therefore, the fuel is selected so as to minimize the annual cost, considering the relative differences of "Regulatory cost of using HFO (continuously increasing)" and "Fuel cost of using e-ammonia (continuously decreasing)." On these assumptions, the annual cost of the Ammonia-fueled ship is reduced by continuing to use HFO until 2039 (Fig. 19). In other words, it is more advantageous to use HFO than expensive e-ammonia, even considering the regulatory costs of using HFO. Furthermore, from 2040, when the fuel cost of e-ammonia has decreased sufficiently, selection of e-ammonia results in a more decrease in annual costs than that of HFO.

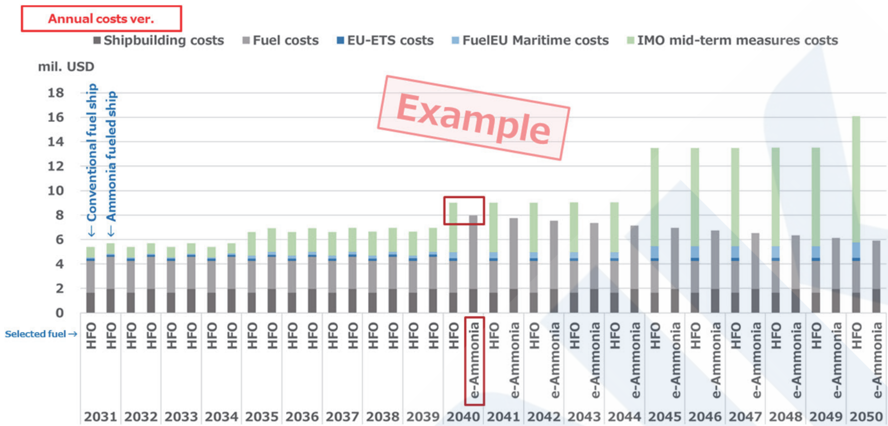

Fig. 19 Results of cost simulation (annual costs)

Fig. 20 shows the results of the simulation in Fig. 19 expressed as the cumulative total of the annual costs until 2050. When the results are expressed as cumulative costs, it is possible to understand when the crossover point between the cumulative costs of adopting the Conventional fuel ship and adopting the Ammonia-fueled ship occurs and its timing. Naturally, it is also possible to understand the difference between lifetime total costs. In this example, it can be understood that the cost difference between the adoption of Conventional fuel ship and the adoption of Ammonia-fueled ship is approximately USD 50 million over the 20-year life of the ship. This cost difference is large enough to purchase another bulk carrier of the same size, with change left over. Although the actual results will depend on the provisions of the IMO's mid-term measures and the various assumptions used in the simulation, it can be said that the results of this simulation suggest how heavy the cost burden of future regulations will be.

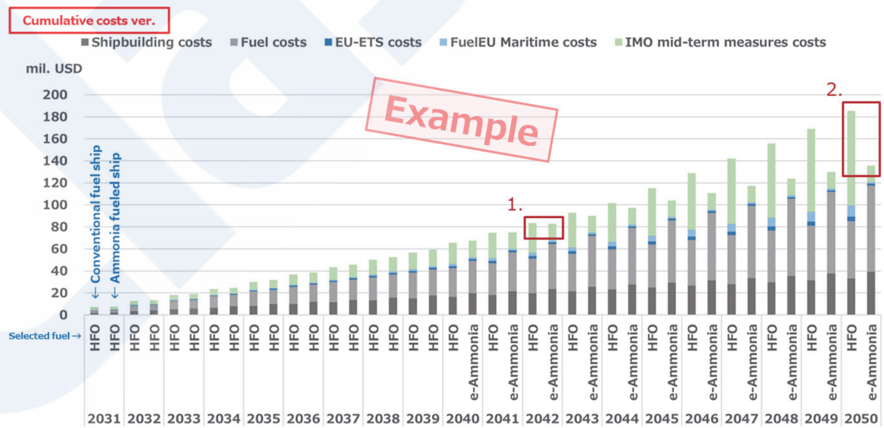

Fig. 20 Results of cost simulation (cumulative costs)

6. CONCLUSION

To assist readers in understanding the contents of "ClassNK Alternative Fuels Insight," which is issued by ClassNK, this paper has introduced the trends in alternative fuels, as increased use of these fuels will be indispensable for responding to the future regulations of the IMO and EU. At present, the estimated supplies of alternative fuels are insufficient to meet the expected demand in international shipping. To further increase production of alternative fuels, it is essential to send clear signals of demand to the supply side. Naturally, promotion of the use of alternative fuels through regulatory mechanisms will be necessary for this, but demand creation by cooperation among various stakeholders, not limited to the maritime sector, are also essential. It is my sincere hope that this paper will be of assistance when studying initiatives to expand the use of alternative fuels in the shipping industry.

REFERENCES

1) Report of fuel oil consumption data submitted to the IMO Ship Fuel Oil Consumption Database in GISIS (Reporting year: 2023)
2) IEA (2023), Hydrogen Production Projects Database