Efforts of the Planning and Design Center for Greener Ships (GSC)

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1. INTRODUCTION

Initiatives to achieve the SDGs (Sustainable Development Goals) and the ESG (Environmental, Social and Governance) investment associated with those efforts are now part of the code of conduct of most of the companies. In particular, moves to reduce greenhouse gas (GHG) emissions have brought about a substantial transformation in the sense of values in corporate activities and products, and efforts to implement global warming countermeasures are accelerating at an increasing pace worldwide.

In international maritime shipping, the International Maritime Organization (IMO) adopted the Initial IMO Strategy on the Reduction of GHG emissions from Ships (hereinafter, GHG Reduction Strategy) in April 2018 with an interim target of reducing total GHG emissions by at least 50% compared to 2008 by 2050 and a long-term target of zero to be achieved as early as possible in this century. However, international shipping has already entered an era where efforts are premised on "2050 net-zero," as can be seen in announcements of 2050 net-zero strategies by leading shippers in both Japan and other countries. In these circumstances, environmental performance, beginning with reduction of GHG emissions and the related technologies, now have an increasingly large value for ships.

Because Japan is surrounded by the sea, maritime industries, and particularly shipping and shipbuilding, are indispensable industries for this country, but in order to survive in the face of fierce international competition, it is necessary to accelerate efforts to realize competitive ships by integrating various environment-related technologies ahead of global competitors.

Against the backdrop of this social and industrial transformation, the Planning and Design Center for Greener Ships (hereinafter GSC) was established in October of 2020 by a group of volunteering companies that supported its purposes as the core organization for mobilizing the capabilities accumulated by the Japanese shipbuilding industry to date, integrating environment-related technologies that already exist and will be developed in the future, and continuously planning and proposing state-of-the-art ships. As of March 2022, the member companies were (in alphabetical order) Imabari Shipbuilding Co., Ltd., Japan Marine United Corporation, Mitsubishi Shipbuilding Co., Ltd., Mitsui E&S Machinery Co., Ltd., Naikai Zosen Corporation, Namura Shipbuilding Co., Ltd., Nippon Kaiji Kyokai (ClassNK), Onomichi Dockyard Co., Ltd., Oshima Shipbuilding Co., Ltd., Shin Kurushima Dockyard Co., Ltd., Shin Kurushima Sanoyas Shipbuilding Co., Ltd., and Sumitomo Heavy Industries Marine & Engineering Co., Ltd.

The GSC conducts wide-ranging information collection and technology development which extends beyond the framework of individual companies, and promotes the planning, development and commercialization of advanced environmental ships integrating diverse environment-related technologies in response to strengthening of environmental regulations in the medium- to long-term with the aim of contributing to the development of the Japanese shipbuilding industry.

2. TRENDS IN REGULATIONS AND FUELS RELATED TO DECARBONIZATION AFFECTING SHIP DESIGN

2.1 Trends in Regulations for Reduction of GHG Emissions in International Shipping

Due to the difficulty of assigning emissions to specific countries when ships operate under flags of convenience and third-party transportation is common, and due to a single global market of international shipping, reduction of GHG emissions in international shipping is being promoted in the form of uniform worldwide efforts and regulations through discussions in the IMO. Fig. 1 presents an overview of the technical and operational GHG emission reduction measures established by the IMO.

The international regulatory framework begins with two measures approved for introduction in 2011: the Energy Efficiency

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Design Index (EEDI) which mandates ship energy saving performance in the design stage of new ships; and the Ship Energy Efficiency Management Plan (SEEMP), an operational measure which requires that a plan showing the most efficient operational methods for CO_2 emission reduction be carried on board ships. Introduction of the EEDI system promoted reduction of GHG emissions through improvement of ship types and improved propulsion efficiency by the employment of energy-saving equipment. However, in spite of ongoing increases in the number of low-carbon LNG-fueled ships, the transition to zero-carbon fuels has not been achieved.

As operational measures for GHG emission reduction, efforts to achieve efficient ship operation have been made through SEEMP up to the present, but there were still no regulations that directly required reduction of CO_2 emissions in ships. However, based on the above-mentioned GHG Emission Reduction Strategy of the IMO, revisions of Annex VI of the MARPOL Convention for introduction of EEXI (Energy Efficiency Existing Ship Index) and CII (Carbon Intensity Index) regulations were adopted at the 76th session of the Marine Environment Protection Committee (EMPC 76) held in June 2021. Under the EEXI regulation, ship energy efficiency performance regulations are applied retroactively to certain types of existing ships, while CII is a new regulation based on CO_2 emission results, as a data collection system for rating fuel economy performance. The EEXI and CII regulations are scheduled to be introduced from 2023.

The EEXI regulation is a technical GHG reduction measure which is intended to reduce the amount of CO_2 emissions from ships in service by providing standard values for the fuel economy (fuel oil consumption) performance of those ships. This regulation is applicable to all ships of 400 GT or larger engaged in international maritime shipping, irrespective of the date when ship construction was completed. It should be noted that this is not intended to be a stepwise strengthening of the regulatory values, but rather, is set to be a constant value equivalent to the level of Phase 2 of EEDI (EEDI-II). By introducing EEXI, fuel economy performance similar to the level of newly built ships at this time is also required to ships in service.

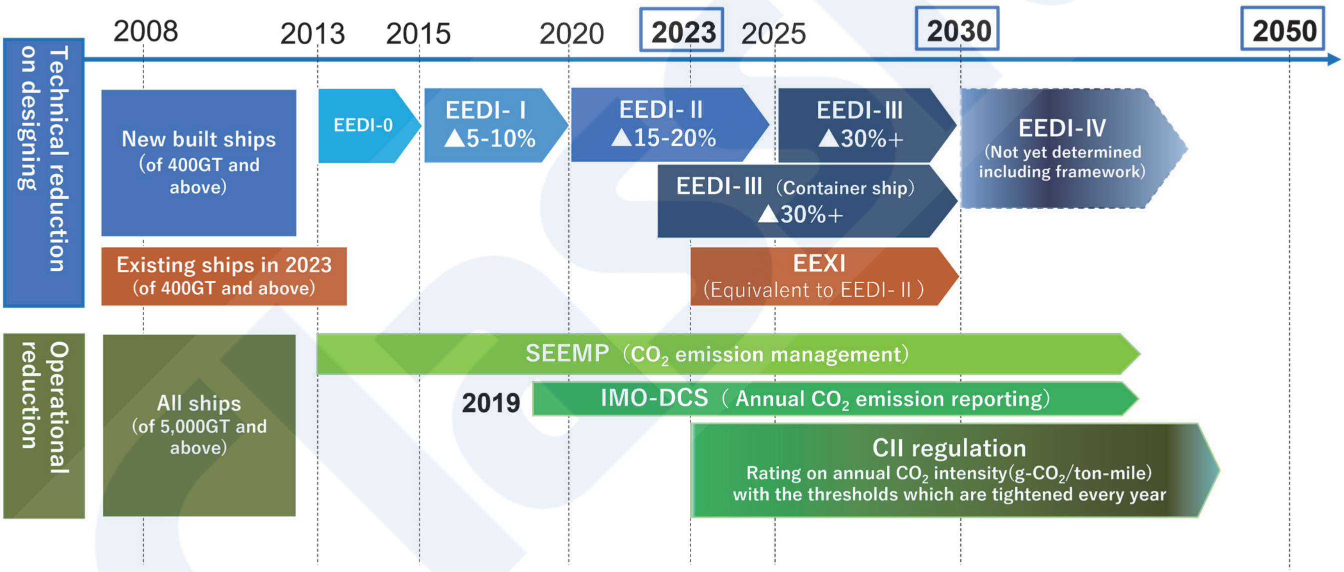

Fig. 1 Overview of technical and operational GHG emission reduction measures

The CII (Carbon Intensity Index) rating system for GHG emission intensity performance is a regulation with a large potential impact on the design of ships in the future. Until now, the core of regulations in ship design was the EEDI regulation, which is currently in the Phase 2 stage. Although Phase 3 is also scheduled for the future, the EEDI regulation is nevertheless a traditional approach to regulation of ship design by the IMO. That is, if a ship conforms to the EEDI requirements at the time of commissioning, a certificate is issued, and in principle, operation can continue for the life of the ship so long as the same condition is maintained.

In contrast, under the CII regulation, the annual GHG emission performance of ships are rated in 5 levels from A to E, and ships with a low rating (defined as the D rank for 3 consecutive years or E rank for 1 year) are given guidance on improvement by the supervising agency. As a system, the CII regulation is classified as an operational regulation for promoting improvement of environmental impacts, but because CII requirements can also affect the ship's loading capacity, the CII system also affects ship design. Among a noteworthy feature of this system, because threshold value (reduction factor) for ratings is automatically tightened each year, a ship's rating evaluation will gradually decrease even if that ship maintains the same fuel consumption performance as when newly constructed. Threshold values have been decided up to 2026, and while it has been decided that the values will also be tightened in 2027 and thereafter, the actual values are still undecided. This point, that is, the annual tightening of values, is completely different from the traditional EEDI approach mentioned above. Moreover, because this evaluation is based on actual emission results, this system may also have a large effect on ship design in cases where it is not possible to meet the requirement by operational measures alone, for example, by sailing at a slower speed. Depending on future CII threshold values aiming at achievement of 2050 net-zero emissions, a situation in which ships with a product life exceeding 20 years must switch to a zero-carbon fuel at some point during a voyage are also assumed.

Fig. 2 shows the results of a trial calculation of the CII reduction factor for achieving the 2050 net-zero target, when the target is the threshold value for the C rank (median value) of the CII rating.

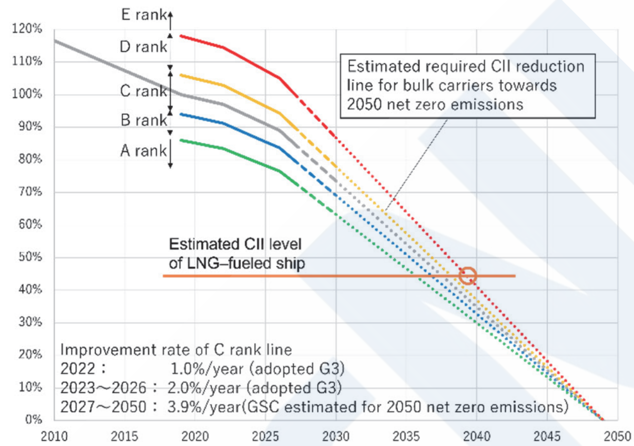

Fig. 2 Future reduction ratio (improvement rate) of CII rating (assumed by GSC)

As shown in this figure, in order to achieve the 2050 net-zero target, efforts to reduce CO_2 emissions by nearly 4% per year are required. Even assuming a ship reduces CO_2 emissions to CII performance of around 50% by energy saving measures and switching to LNG fuel, its rating will fall to the E rank in the second half of the 2030s, which means that conversion to a zero-carbon fuel will be necessary, as shown in Fig. 3. Moreover, at the present point, the only regulatory penalty is guidance on improvement, but there are also moves, particularly among major shippers and financial institutions, to evaluate the CO_2 emissions of chartered ships and ships financed by loans. Specifically, Sea Cargo Charter is a framework which was established by shippers, and the Poseidon Principles are an agreement among financial institutions for evaluating "climate alignment." The purpose of these two initiatives is to encourage reduction of CO_2 emissions in line with the reduction targets of the IMO. Since the IMO's fuel efficiency indexes are used in those evaluation indexes, it appears that this will heighten the business pressure on ships with low CII ratings in chartering and procuring financing in the future.

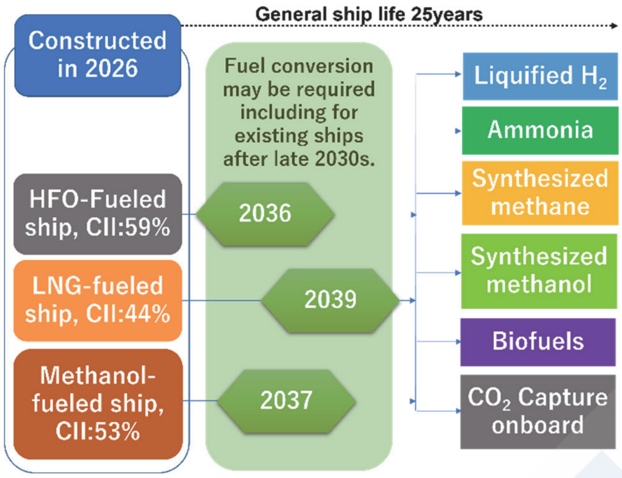

Fig. 3　Fuel conversion scenarios considered by the GSC

2.2　Trends in Low-Carbon and Zero-Carbon Fuels

Various zero-carbon fuels are possible, including hydrogen, ammonia, synthetic methanol and biofuels, among others. The GSC has made trial calculations of fuel costs based on trends in the production technology for these fuels, and has collected and analyzed information on the current status of the fuel supply infrastructure. Based on survey results, the properties and future supply potential of various alternative fuels are summarized in Appendix. While it is not possible to determine the future selection of fuels at present, when examining the diffusion of alternative fuels in international maritime shipping, it is especially important to consider stable combustion, storability on ships, handling on ships (i.e., safety and environmental impacts), cost, availability and other related factors. Referring to materials prepared by the IEA, NEDO, etc., Fig. 4 shows the assumed production costs of the alternative fuels targeted for the period from 2030 to 2050.

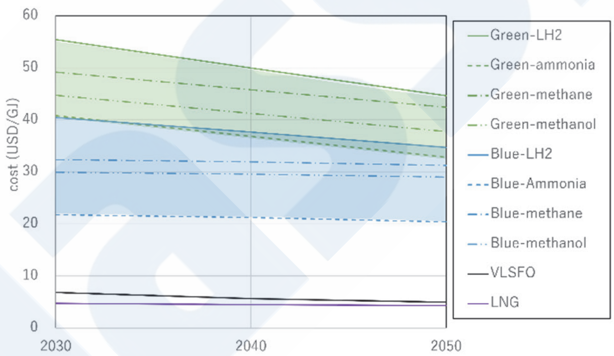

Fig. 4　Assumed production costs of alternative fuels (trial calculation by GSC)

A trial calculation and comparison from the viewpoint of fuel production costs was carried out for “green” fuels (liquid hydrogen, ammonia, synthetic methane, synthetic methanol), which are produced using a hydrogen feedstocks obtained from renewable electric power, and “blue” fuels, which are derived from natural gas + CCS (liquid hydrogen, ammonia, synthetic methane, synthetic methanol). Here, the trial calculations for the feedstock CO_2 for synthetic methanol were made for DAC (direct air capture)-derived and bio-byproduct-derived CO_2. The assumed production and supply process was production and storage of the alternative fuel in Australia → transportation to Japan → storage and secondary transportation in Japan → bunkering to ships. However, the cost of bunkering was not included in the calculations.

Approaching 2050, the cost of green fuels is expected to decline as the cost of renewable electric power decreases, but overall, blue fuels are more economical, and the most inexpensive is blue ammonia. Per unit of heating value (GJ), the cost differential between blue ammonia and heavy oil and LNG is around US$15, and by CO_2 conversion, the difference is approximately US$ 250 to 300/t-CO_2, while liquefied hydrogen incurs very high costs for liquefaction, storage and transport. It goes without saying that changes in these prices are possible, depending on future innovations in production technology, but based on the technologies assumed at present, the cost outlook is as outlined above.

2.3 Outlook for Zero-Carbon Fuels for Ocean-Going Ships

As alternative fuels for ocean-going vessels, at present, the GSC considers the leading scenario is to be expanded use of LNG as a low-carbon fuel for the time being until the 2030s, followed by conversion to blue ammonia. The reasons for this are as follows.

- From the viewpoints of the available supply amount and supply bases, LNG must inevitably be considered a realistic solution as a fuel for promoting low carbon for the time being. However, greater attention must be given to measures to prevent methane slip (unburned fuel that is not fully combusted in ships).
- In terms of the assumed fuel production cost for zero-carbon fuels (both green and blue), blue ammonia is the most advantageous. Diffusion of liquefied hydrogen is expected to be difficult for various reasons, including not only the high cost of liquefaction, storage and transportation, but also the difficulty of shipboard storage and handling. While ammonia is a toxic substance and N_2O is a concern, engine makers and ship classification societies are promoting equipment development and preparation of guidelines assuming measures to cope with those issues, and it is thought that these problems will not be significant obstacles to diffusion.
- In the case of carbon-neutral synthetic methane and synthetic methanol, the cost and supply capability of DAC-derived and bio-derived CO_2 are unknown, and the handling of emission rights for CO_2 derived from exhaust gas capture is also an issue.
- With biofuels, there are issues in terms of production scale, and competing demand for biooil for use as an aviation fuel has also been pointed out, suggesting that it will be difficult to secure the necessary amount of fuel for ships (although use as a pilot fuel for certain types of engines is expected).

Although blue ammonia is predicted to be relatively inexpensive among the various zero-carbon fuels, it is assumed that the prices will still be significantly higher than that of the current ship fuels. Therefore, in realizing the conversion to zero-carbon fuels, backing in the business aspect by promotion of investment in decarburization and the establishment of an international regulatory system by the IMO will be indispensable.

From the viewpoint of ensuring a smooth energy transition, there are also strong opinions in favor of synthetic fuels (methane and methanol) because these fuels can use the existing infrastructure. Moreover, on short-distance routes, the total amount of energy required is small, suggesting the possibility of using hydrogen or electric power (fuel cells, batteries, etc.). Thus, various types of fuels are expected to be used in the future, depending on the route and type of ship.

3. DEVELOPMENT OF NEXT-GENERATION ENVIRONMENTAL SHIPS FOR REDUCTION OF GHG EMISSIONS AND ZERO EMISSIONS IN INTERNATIONAL SHIPPING

3.1 Directions in Next-Generation Ships Based on Regulatory and Fuel Trends

Based on trends in the regulation of GHG emissions, technologies related to zero-carbon fuels and trends in construction and improvement of infrastructure for international maritime shipping, since its inception, the GSC has carried out a study of the form of ships in the transition period of the shipping industry leading to 2050 net-zero carbon, while conducting various surveys and analysis on regulatory trends, trends in alternative fuels and trends in related technologies. There are large elements of uncertainty in regulatory trends, trends in the development of technologies related to alternative fuels and trends in the construction of bunkering infrastructure, and the future image is still opaque. However, based on the assumption that fuel conversion during the transition period will progress from LNG to ammonia, the GSC is carrying out the conceptual design and basic plan for next-generation ships as a concrete solution under the situational awareness and policies described below.

- An actual fuel consumption rating system (CII regulation) will be introduced by the IMO, heightening the importance of the environmental evaluation and product life of ships in product evaluations.
- The threshold values for ratings under the CII regulatory system become stricter each year.
- Assuming introduction of a “2050 net-zero” target by the IMO, the target ships should have competitiveness through the transition period from 2025 to 2050 (assuming introduction in the market around 2025).
- Ammonia is judged to be a strong candidate for a zero-carbon fuel for international maritime shipping.
- As the assumed scenario, use of LNG as a low-carbon fuel expands until the 2030s, followed by conversion to ammonia for zero emissions. However, the possibility of synthetic methane is also considered.
- Considering the product portfolio of the Japanese shipbuilding industry, the main target ship types for development to achieve

zero carbon in the large ship field and the development of next-generation mainstay products for the Japanese shipbuilding industry are bulkers, tankers and container carriers. General applicability of designs will also be secured by development which targets medium- and small-scale ships with a high degree of design difficulty.

As the concrete concept of fuels targeted for development, pros and cons were evaluated considering the lifetime cost of the ship, the outlook for fuels, and flexibility in responding to an external environment filled with uncertainties. As a result, four fuel concepts were selected as development targets from among the various candidate concepts. These were LNG-DF (Dual Fuel) (CII improved type), LNG-DF (ammonia-DF conversion-ready type), HFO-mono-fuel (ammonia-DF conversion-ready type) and ammonia-DF. Fig. 5 shows the image of the transition of these concept ships.

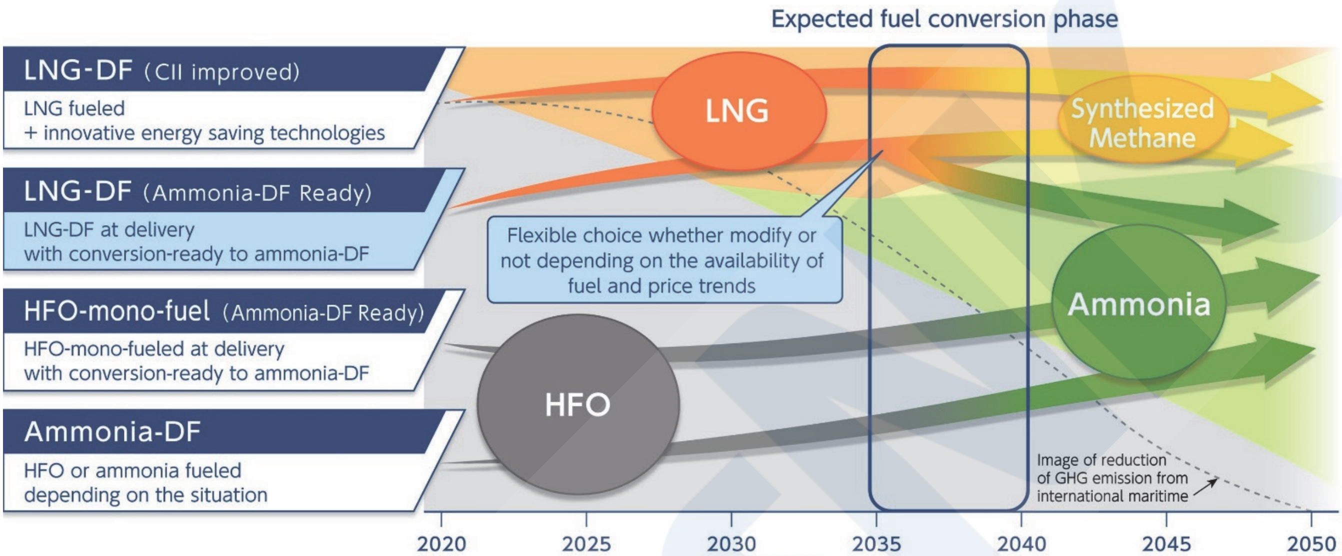

Fig. 5　Image of solutions (ship concepts) in transition period

As the main design issue when studying ships that use low environmental load LNG or ammonia fuel, the energy density of the fuel has a large influence on the design of the fuel tank capacity and form. Fig. 6 shows the relationship of the energy density per unit of volume and energy density per unit of weight for various alternative fuels and the assumed (possible) tank forms.

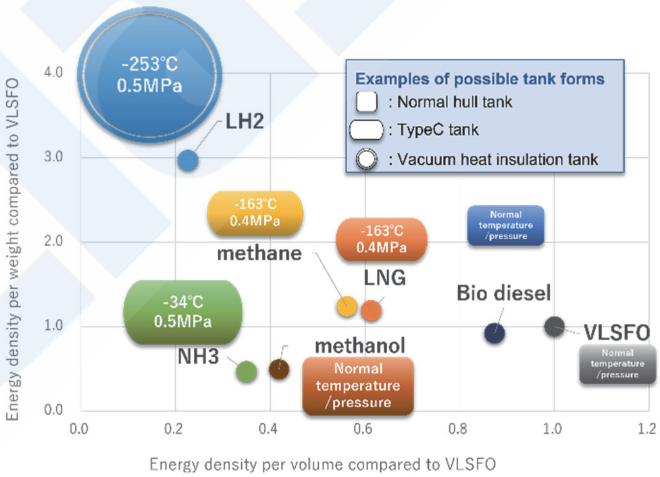

Fig. 6　Image of energy density of fuels and possible tank forms

Based on the relationship between the heating value and volume of the fuels, in order to securing a cruising range of 20 000 SM, which is equivalent to that of a ship using heavy fuel oil (HFO), it is necessary to secure a volume about 1.7 larger than that of HFO when using LNG and about 2.7 larger when using ammonia. Therefore, in this ship, ingenuity will be required in order to arrange the fuel tanks without greatly affecting the cargo carrying capacity of the ship, within the range of the dimensional limits allowed by terminals at ports where the ship is expected to call.

Since it is necessary to handle fuels with properties that are completely different from those of conventional HFO, that is, fuels that have the properties of a low temperature at atmospheric pressure, gasification by penetrating heat, high inflammability, toxicity and combustibility different from that of HFO, the fuel supply system will differ greatly from the types used to date. It is also important to consider safety, including the arrangement of the fuel tanks, fuel supply equipment, living quarters and so on, as well as fire prevention, fire extinguishing system and securing evacuation routes. In addition, while GHG emissions must be reduced more than in the past in order to achieve zero emissions, the cost of zero-carbon fuels is predicted to be far higher than that of conventional fuels. Therefore, in addition to study of the arrangement of the equipment, the GSC is also conducting an evaluation of energy-saving equipment for reducing the consumption of expensive zero-carbon fuels in order to improve economy to determine whether those equipment should be adopted or not. Moreover, the evaluation of energy-saving equipment is not limited simply to the direct merit of fuel consumption improvement, as in the past. That is, it is also necessary to evaluate equipment that will be employed in the ship from new viewpoints, since improvement of the CII rating can also be expected to have the effect of extending the product life of the ship.

3.2 Example of Design of Greener Ships

As part of the development described above, the GSC developed Japan's first design for an ammonia-fueled Panamax bulk carrier in cooperation with its member shipbuilding companies and received Approval in Principle (AiP) from the ship classification society Nihon Kaiji Kyokai (ClassNK) on January 20 of this year. Fig. 7 shows the general arrangement (GA) plan of the ship which received AiP.

In the design that received AiP, various items were studied in accordance with the ClassNK Guidelines for alternative-fueled ships (in this case, ammonia-fueled), including the general arrangement, fuel supply concept, fire prevention, fire extinguishing and evacuation routes, the concept of hazardous areas, ammonia treatment countermeasures, the emergency evacuation procedure during bunkering, trim and restoring force calculations, etc., and the necessary safety measures were implemented. A study was also carried out considering the arrangement and capacity of the ammonia fuel tanks, which have a much larger volume than HFO tanks, in order to design a safe, easy-to-use ship, for example, by minimizing the effect of the larger tanks on the ship's cargo carrying capacity and cruising range. The design was also prepared considering development to larger-scale ships, such as Capesize vessels, and "ammonia-ready" LNG-fueled bulk carriers, etc., assuming retrofitting for ammonia after the vessel is commissioned.

The main features of this ship are as follows.

- Arranging the living quarters in the stern enables an efficient layout of the large-volume ammonia fuel tanks while maintaining the same main dimensions as a conventional ship.
- The lifeboats are separated from the ammonia fuel tanks, securing a safer evacuation route so that crew members do not have to pass through the area near the ammonia fuel tanks during an emergency.
- The ammonia fuel tank capacity secures an sufficient cruising range assuming the Far East-Australia round trip and South America-South Asia routes, which are main routes for bulk carriers.
- A HFO capacity equivalent to that of conventional ships is secured to cope with uncertainty about the supply of ammonia fuel during the fuel transition period.
- A cargo hold capacity equivalent to that of a conventional HFO-fueled Panamax bulk carrier is secured.
- Safety measures are taken referring not only to the ClassNK guidelines, but also the guidelines of other main ship classification societies.
- Development to "ammonia-ready" LNG bulk carriers supposing retrofitting after vessels are commissioned is also considered by adopting a common layout and structure with LNG ships in the basic arrangement, such as the tank layout, etc.

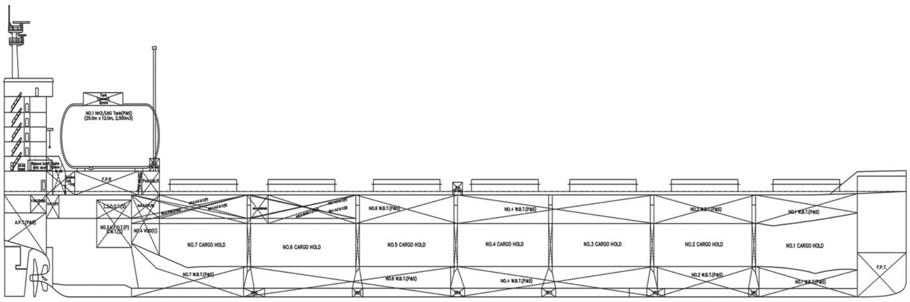

Fig. 7　General arrangement (GA) plan of AiP-approved ship

Table 1 shows principal particulars and Figs. 8 and 9 show appearances.

Table 1　Principal particulars of AiP-approved ship

Principal particulars		
LENGTH(O.A.)		abt. 228.9　M
LENGTH(B.P.)		225.45　M
BREADTH(MLD)		32.26　M
DEPTH(MLD)		20.10　M
DEADWEIGHT		abt. 80,400　MT
MAIN ENGINE	MCR	8,000 kW
SERVICE SPEED		abt. 14.2 KNOTS
NH_3 FUEL TANKS		2,500m^3 x 2sets

Fig. 8　Appearance of AiP-approved ship (from bow)

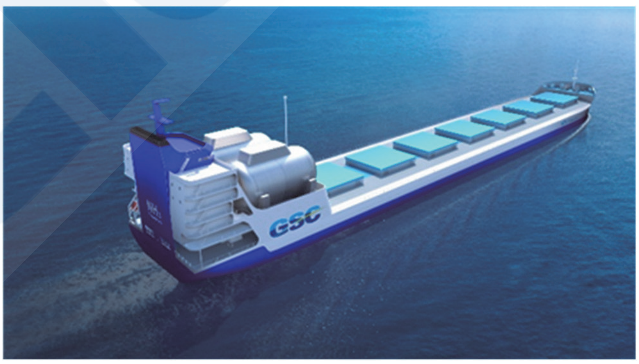

Fig. 9　Appearance of AiP-approved ship (from stern)

4. CONCLUSION

Dizzying changes in world trends targeting the achievement of 2050 zero emissions, including regulatory moves, are expected in the future, and heightened awareness of the environmental value of decarbonization increases the pressure to adopt evaluation standards that are contrary to economic efficiency. It is also possible that the introduction of the CII rating system will have a serious impact that limits the product life of ships, even though a long operating life of more than 20 years after construction has been taken for granted until now. Based on these kinds of global trends, users who operate and manage ships must now make more difficult decisions than in the past regarding the business risks associated with the decarbonization of ships, and the types of ships which they should purchase during the transition period to zero carbon.

In order to respond to these circumstances, the GSC is examining what types of ships should be supplied during the transition period based on ongoing information collection and analysis, and is carrying out development, in recognition of the fact that providing rational solutions for the shipping and shipbuilding industries is a critical issue.

In the development of actual next-generation environmental ships, the GSC is developing its study of the current proposed solutions to a more detailed design in cooperation with its member companies, and will deepen its study so as to make it possible to offer actual proposals to customers. In parallel with this, we are also conducting a study of indispensable common issues for realizing solutions, which include the technologies and systems, safety, environmental performance, the response to use of multiple fuels assuming fuel switching, and further improvement of fuel economy necessary when using new fuels in collaborative work with marine equipment manufacturers, and hope to reflect this work in future design.

Through these activities, the Planning and Design Center for Greener Ships (GSC) is aiming to contribute to the decarbonization of Japanese maritime industries and the development of the Japanese shipbuilding industry.

REFERENCES

1) Hiramatsu Sai, Takeuchi Tomohito: Planning and Design Center for Greener Ship’s (GSC’s) Mission and Activities, Journal of the Japan Institute of Marine Engineering, Vol. 57, No. 1, 2022.
2) Takeuchi Tomohito: Outlook for Decarbonization in the Ship Field, Journal of the Japan Institute of Energy “Enermix,” Vol. 101, No. 2, 2022.

APPENDIX

Properties and Future Supply Potential of Various Alternative Fuels Based on the Results of Survey by the GSC

APPENDIX

The following table shows the properties and future supply potential of various alternative fuels based on the results of survey by the GSC.

	VLSFO	LNG	Liquefied hydrogen (LH_2)	Ammonia	Carbon recycled (CR) synthetic methane	CR synthetic methanol	Biodiesel (FAME)
Lower heating value (GJ/t)	40.4 (39.8～41.7)	48.0 (46.5～50.4)	120.0	18.8	50.0	19.9	37.1
Liquid density (t/m^3)	0.93	0.48	0.0708	0.7	0.422	0.79	0.885
CO_2 conversion factor (CO_2-t/fuel-t)	3.126	2.693	0	0	(0＊)	(0＊)	0
Volume ratio per unit heating value (VLSFO ratio, in liquefied state)	1.00	1.63	4.42	2.86	1.78	2.39	1.14
CO_2 emission per unit heating value (CO_2-g/GJ)	77.38	56.10	0	0	(0＊)	(0＊)	0
Byproduct GHGs and global warming potential (GWP; according to IPCC AR5)		Methane (methane slip) GWP: 28		N_2O, GWP: 265	Methane (methane slip) GWP: 28		
Boiling point (°C)	200～400	abt.-161	-253	-33	-161	65	345～354
Shipboard storage method (liquid state)	Normal temperature/normal pressure Hull tanks	Type C (low temperature or pressurized), or independent rectangular tanks/membrane	Vacuum heat-proof tanks	Type C (low temperature or pressurized), or independent rectangular tanks/membrane	Type C (low temperature or pressurized), or independent rectangular tanks/membrane	Normal temperature, normal pressure Hull tanks	Normal temperature, normal pressure Hull tanks
Properties during shipboard storage (liquid state)	Normal temperature, normal pressure	-160～-140°C, 0.07～0.5MPa	app.-250°C, 0.5MPa	-30～-10°C, 0.07～0.5MPa	-160～-140°C, 0.07～0.5MPa	Normal temperature, normal pressure	Normal temperature, normal pressure
Ignition point (°C)	abt.407	abt.537	560	630	537	440	256～266
Cycle of low speed ship engine	Diesel	Diesel/Otto	Diesel/Otto	Diesel/Otto	Diesel/Otto	Diesel/Otto	Diesel
Pilot fuel	Not necessary	Necessary	Necessary	Necessary	Necessary	Necessary	Blend with FO

Future potential for supply expansion (global/land use) Points to note and influencing factors	▲～△ Decreasing investment in petroleum	△ Decreasing investment in gas	◎ Hydrogen as a whole (gas and liquid) is expanding, but liquefaction for hydrogen carriers is extremely limited.	○ Land-side demand is expanding (entry of energy industry, scaling up and cost reduction).	△～○ Carbon neutrality (CN) of feedstock CO_2 gas, long-term assurance	△～○ Future outlook of expanded use of methanol fuel on land (automobiles, thermal power plants, etc.) is unknown.	○ In the 1st generation, conversion of land use is a problem. In the 2nd generation, depends on increased crops and conversion technologies.
Future potential for supply expansion (ship use) Points to note and influencing factors	▲～△ Decreasing on-land demand	○ Criticism of methane slip	▲～△ (Liquefied hydrogen)	○	△～○	△～○	△ Competition with pilot fuel use or aviation fuel use
Bunkering infrastructure	◎	△～○ Currently expanding	None	Possible to use import/export infrastructure?	△～○ Possible to use LNG infrastructure		Possible to use FO infrastructure?