Prospects for Widespread Adoption of Next-Generation Standard EV Vessel ROBOSHIP

— Can we change the world? —

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1. ORIGIN OF THE NAME ROBOSHIP

"ROBOSHIP" is a newly coined word of "Robot" and "Ship."

In the period when one of the present authors was a child (1960s), the 21st century was still the distant future. That future was imagined as a world where mankind would be free from calamities such as war and disease and would enjoy peace, where the everyday life of humankind would progress thanks to science and technology, and "robots" would be ubiquitous. "Robots" were envisioned as a "tender-hearted child of science,"[*1] who would not only help people in the workplace, but would also do housework, sometimes discipline children, and become their friends.

The word "ship," of course, means "watercraft," but the suffix "-ship" means "state, condition of being [such-and-such]" or "[such-and-such] to be created" as used in "friendship" or "partnership."

Today, we live in the 21st century that science and technology have advanced, and humankind enjoys their blessings. However, as in the 20th century, the fear of war and disease is still with us, and we also face the new challenges such as climate change, an aging population and low birthrate.

The challenges which confront the coastal shipping industry are described in the following Chapter 2 "CURRENT CONDITIONS SURROUNDING THE COASTAL SHIPPING INDUSTRY." We named our Next-Generation Standard Electric Vessel as "ROBOSHIP" with the wish she will be a "ship to assist seafarers" and "ship to shape what the costal shipping industry should be" and hope she will provide solutions to those challenges.

2. CURRENT CONDITIONS SURROUNDING THE COASTAL SHIPPING INDUSTRY

2.1 Two Kinds of Aging (Ships and Seafarers)

The number of seafarers in the Japanese coastal shipping industry was 21,374 as of October 2020. Although the total number increased by about 260 from the previous year, the shortage of seafarers still continues, and looking at the age composition, the number of seafarers over 50 years old exceeds 50% and the aging advances. (Numbers as of October 1st, 2020. Source: Website of the Japan Federation of Coastal Shipping Associations)

Similarly, although the breakdown of coastal vessels by age shows that less than seven years old vessels account for only 16% of the total number and 29% of the total tonnage, overage vessels aged 14 years or more account for 68% of the total number and 45% of the total tonnage. In terms of average vessel size by age, the average gross tonnage (GT) for aged 14 years or more is 509 GT, whereas the average for vessels under 14 years old is more than 1,000 GT. Thus, aging is more advanced in smaller ships.

Since vessels less than 500 GT account for 77.9% of the total number of vessels, it is clear that taking measures to address these two kinds of aging have become pressing issues for the industry. (Numbers are on the fiscal 2020 year-end basis. Source: Website of the Japan Federation of Coastal Shipping Associations)

2.2 Limits to Succession of Know-How

A study[*2] conducted in 2017 pointed out that while hiring of new graduates (2.9%) exceeded the number of seafarers retiring on reaching retirement age (1.5%), seafarer shortages are nevertheless a problem due to the extremely high rate of turnover in the workforce (ranging from 14.7 to 17.1%).

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*1 From the Japanese lyrics of the theme song of the Astro Boy animated television series (lyrics by Shuntaro TANIKAWA).

*2 Toshihiko MATSUO: "Trends in Hiring and Retiring Seafarers in Domestic Shipping Industry," NAVIGATION, No. 203, submitted in October 2017.

The problem here is whether these unskilled newly-hired seafarers can be assigned quickly to actual service while the veterans who are responsible for training them are retiring rapidly. I do not mean to belittle the current seafarers' training efforts in various positions, but rather, ask whether the necessary software and hardware to assign unskilled seafarers to actual service are being prepared systematically. An aversion to change and a tendency of change-resistant and making incremental improvements without fundamental reform is one of the typical features of the use of organizations and IT systems in government agencies and companies in Japan. In the former Imperial Japanese Forces, an extreme pursuit of personal proficiency, combined with a belief in the superiority of "spiritual" virtues, later led to the relative neglect of military technologies and strategy, which contributed to the eventual defeat in the World War II. If we keep ignoring the transformation of technology which is currently in progress and attempt to overcome difficulties by applying the conventional business model, it means we have learned nothing from history.

During the World War II, Japan suffered a huge death toll the Japanese government and Imperial Forces clung to wishful thinking, unworkable paper theories, and ideas based on how they wished the situation was. Groundless optimism is to be avoided. As the American novelist Mark Twain commented, "The past does not repeat itself, but it rhymes." This maxim must not be forgotten.

2.3 Delay in Digitalization

The Japanese coastal shipping industry is lagging behind in digitalization. There are two causes for this: a delay in implementing the necessary communication environment and a strong tendency to maintain traditional practices.

It is rare for coastal vessels not to enter a port for several days, as is the case with ocean-going vessels, and the availability of cellular radio channels when they get close to land has delayed the introduction of communication equipment. The difficulty of making additional investments in the equipment of operating vessels due to low profitability has also invited delays in the introduction.

Changing traditional practices is difficult for anyone. Particularly in industries with a long history, such as shipping industry, business models and business customs tend to be fixed. As a result, daily operations are also routinized and have been streamlined over many years. In such cases, it is difficult to take the risk of introducing the new tool of digital technology. Since ship operators and seafarers do not see the merit of introducing new technology in an operation which they've already felt efficient enough, the disadvantages of introduction, such as the cost and the time required to master a new system, tend to be more obvious than the potential advantages.

Structurally, with the exception of common carriers such as passenger ships and RORO ships, the shipper-operator-shipowner hierarchy in the coastal shipping industry (industrial carriers) is also considered to be an impediment to digitalization. In addition to this characteristic hierarchical relationship among three parties, various enterprises and organizations, such as agencies, shipyards and government agencies, are also involved in each vessel's operation. As a result, it is more difficult to achieve the effects of digitalization, since what each company can get digitalized and systematized is only a part of this entire structure.

In the meanwhile, the COVID-19 pandemic has given rise to new changes in coastal vessels which have been left behind in digitalization. As one example, before the pandemic, many shipping operators had relied mainly on fax messages to exchange vessel operation information between vessels and shore, and had not begun digitalization, even assuming they were interested. However, during the pandemic, those operators have been forced to handle information transmitted electronically due to the increase in work from home and it resulted in a sharp drop in information communications by fax. In other words, there are cases where most of the information that was formerly faxed has successfully been replaced with digital information by using tools that were already available.

This means that information that was formerly sent and received via fax is now being communicated by email or SNS. The next step is to apply software to this data, which will enable data storage in a well-organized form. Analysis of this accumulated data will then make us possible to utilize this data for various purposes in the future, for example, to improve safety in vessel operation or reduce fuel consumption.

These types of analyses will not only be useful for understanding individual conditions (e.g., the status of operational management and seafarer management) but will also be integrated into a core system that can be utilized in managerial decision-making. It has been noted that face-to-face work has been limited by the COVID-19 pandemic, but this assumed disadvantage also reflects the fact that the coastal shipping industry has relied entirely on face-to-face work until now. As an advantage of this situation, the introduction of business chat tools has made it possible for seafarers and other employees, who had hesitated to speak or been unable to express opinions in face-to-face situations, to speak and express their opinions frankly.

Moreover, there is no foreseeable future in conventional personalized systems that depend on the skills of individual seafarers and employees. From this viewpoint, digitalization is a good opportunity for companies to envision their future and reconsider their survival strategies.

2.4 Delay in Environmental Protection Measures (Coastal Vessels Lagging Behind in Implementation)

The Sixth Strategic Energy Plan established in 2019 by the Japanese government declares that “Japan aims to achieve carbon neutrality by 2050, intends to cut GHG emissions by 46% relative to FY 2013 level as the newly set GHG emissions reduction target for FY 2030, and will keep tackling the challenge toward the lofty goal of 50%.” For the coastal shipping sector, the Plan states that “Japan will promote the development, demonstration, and implementation of ship technologies contributory to the modernization and operational efficiency enhancement of coastal vessels, based on innovative energy-saving technologies which include LNG fueled vessels, hydrogen fuel cell-powered vessels, and electric vessels, digital technologies and so on.”

Based on these commitments, subsidies have been made available as financial support for technological development of hydrogen- and ammonia-fueled vessels and for further enhancement of transportation efficiency using AI, IoT and other digital technologies. However, due to new technologies such as hydrogen and ammonia to be developed from now on, commercial penetration will require a long-term timeframe. On the other hand, since subsidies for enhanced transportation efficiency and other improvements focus mainly on novelty and innovativeness, therefore implementation of mass-produced products is excluded from the scope of eligibility, and as is the case of subsidies in general, the work involved in the subsidy application procedure itself places a considerable workload on applicants. These subsidies are not easily accessible, particularly for small-scale shipping operators such as coastal shipping operators. It is difficult to secure the time to achieve the target set in the Sixth Strategic Energy Plan, and support for environmental measures toward the social implementation are urgently needed.

Moreover, as explained in 2.3, the shipper-operator-shipowner hierarchy in the coastal shipping industry has also been an impediment of environmental protection measures.

2.5 Possibility of Decreased Corporate Evaluation

On March 1st, 2022, the Japanese government made a Cabinet Decision on the Bill for the Act on the Partial Revision of the Rational Energy Utilization Act. The Revision Bill adds non-fossil energy sources to the scope of energy use rationalization and requires factories to switch from fossil energy to non-fossil energy. Since it requires specified business operators, etc.to prepare mid-to-long-term plans for conversion to non-fossil energy, they must further accelerate their countermeasures.

Some of the companies listed on the new Prime market of the Tokyo Stock Exchange are substantially required to disclose their climate risk information from the spring of 2022. This requirement mandates the disclosure of information such as losses incurred from GHG emissions and is based on the concept of the Task Force on Climate-Related Financial Disclosure (TCFD) established by major countries. The TCFD requires the disclosure of climate risk information regarding Governance (e.g., the organization’s internal assessment of risks related to climate change), Strategy (e.g., increased profit due to increased demand for climate change countermeasures, for example, in EV-related fields), Risk Management (e.g., quantitative and qualitative assessment of risks specific to the company’s operations), and Index and Targets (e.g., GHG emission reduction indexing, also including the supply chain). The TCFD recommends that enterprises disclose not only their own GHG emissions, but also the total GHG emissions of their whole transaction network. Since these emissions data are supposed to cover the transportation departments of the listed companies mentioned above, their effects are naturally presumed to extend to the coastal shipping industry. Thus, how the companies address GHG emissions reduction will become an important part of corporate evaluations in the future, and companies that are unable to follow this trend may not only suffer a decrease in their corporate values, but may also find themselves in the “stranded assets” management group.

3. FEATURES OF ROBOSHIP

3.1 Features of Hull (Twin-Skeg Hull Form)

ROBOSHIP is intended to standardize coastal 499 GT cargo ships. The mainstream hull form for ships of this type is the single-screw hull. It is thought that twin-screw ships generally underperform single-screw ones of the same hull form in terms of efficiency.

However, there is the other point to consider in the case of coastal 499 GT cargo ships. While it goes without saying that large-diameter low-speed propellers offer better efficiency, the propeller diameter of coastal vessels is limited by their draft due to external factors (water depth in ports to call, etc.). This means there are limits to optimization of the propeller design, which inevitably results the higher propeller load than expected. As the ROBOSHIP is a twin-screw ship, it is possible to reduce the propeller load under these limited conditions and enable high efficiency in the propellers.

The propellers and shafts of twin-screw ships are generally supported by shaft brackets, and these hull appendages increase water resistance. For this reason, twin-screw ships are considered inferior to single-screw ships in terms of hull efficiency. However, in the twin-skeg hull form of ROBOSHIP, the shaft portions of the twin-screw are covered (skegged) with the outer shell plating. As a result, a twin-skeg ship has a smoother water flow to the propellers than conventional twin-screw ships with shaft bracket supports, and thus has the advantage of improving propulsion efficiency. Although this ship has a larger wetted surface area than single-screw ships, the design was optimized to minimize the increase in hull resistance. Fig. 1 below shows a GA image, and Fig. 2 shows the image of a twin skeg.

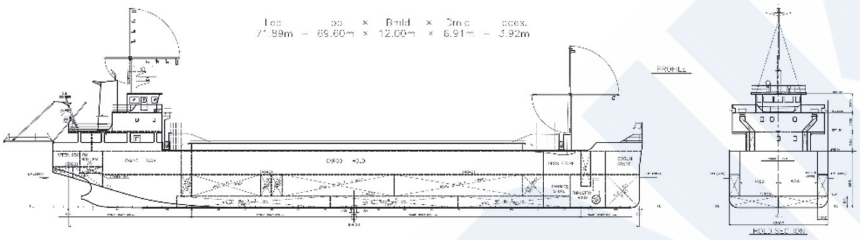

Fig. 1　GA image

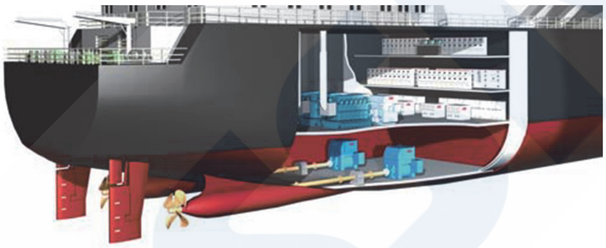

Fig. 2　Image of twin skeg

To clarify the effects of these twin-screw skeg hull forms, the Japan Railway Construction, Transport and Technology Agency (hereinafter “JRTT”), an incorporated administrative agency under the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), carried out an investigative study project titled “Hull Form Study on Twin-Screw Super Eco-Ships (SES). ”[*3] In this study, three type hull forms were developed and subjected to water tank tests. As a result, it was reported that this new design achieved 20 to 25% improvement on a shaft horsepower basis.

3.2　Features of Power Plant

The power plant of ROBOSHIP is configured by two forms of efficiency enhancement, electrical efficiency improvement through optimal power management based on the combined use of generators and batteries, and transmission efficiency improvement by use of a microgrid (DC grid + high-efficiency water-cooled inverter + PM motor).

Generators and batteries have been used in combination in previous electric propulsion systems. In conventional systems, however, only the generator or the batteries could be used at one time, and a blackout is inevitable to switch over from one mode to the other, which imposed an additional operational burden on the seafarers. ROBOSHIP allows the simultaneous use of the batteries and generators, thereby enabling active power control.

As energy conversion efficiency varies significantly depending on the power management between the batteries and generators, the control software has been improved through data collection, accumulation, and analysis, making it possible to improve energy efficiency. Energy efficiency improvements are available from the following three functions:

[*3] Joint Construction of Ship Assistance Department, Japan Railway Construction, Transport and Technology Agency: Report on the “Hull Form Study on Twin-Screw Super Eco-Ships (SES),” March 2012.

[Spinning reserve function]

In case of load fluctuations large enough to control the number of operating generators, batteries absorbs (charges and discharges) the load fluctuations and optimizes generator operation to improve energy efficiency.

In the case of generator-only electric propulsion systems, when the number of in-operation units is changed (increased) to cover load fluctuations, the load fluctuations themselves may be an obstacle to putting a standby unit into operation. An electric propulsion system with a spinning reserve function can cope with this problem. (See Fig. 3 “Conceptual image of spinning reserve.”)

Fig. 3 Conceptual image of spinning reserve

[Peak shaving function]

For generator load-leveling, this function cuts the upper and lower energy (power) demand peaks (the upper peak is cut for power discharging while the lower peak is cut for power charging), and as a result, energy loss is improved. (See Fig. 4 “Conceptual image of peak shaving.”)

Fig. 4 Conceptual image of peak shaving

[Active engine load control function]

When the generator goes under load, this function provides a battery power assist (power discharging and charging) to allow the generator engine to run in its fuel-efficient range so as to moderate load fluctuations and optimize the engine load in order to improve energy loss. (See Fig. 5 “Conceptual image of active engine load control.”)

Fig. 5 Conceptual image of active engine load control

Adoption of the microgrid made it possible to reduce the weight of the power plant as well as the footprint and volume of the associated equipment. A further improvement in energy efficiency is also expected by combined use of the microgrid and a variable speed generator.

3.3 Superiority over Conventional Ships and Conventional Electric Propulsion Ships

The propulsion system of almost all conventional ships is, of course, a medium-to-low-speed diesel engine, which is subject to load fluctuations every time the operational mode changes. Operation and maintenance of this type of system place a heavy workload on the ships’ engineers.

In contrast, electric propulsion ships in coastal service fall into three types, depending on the type of propulsion machinery, as follows:

Type 1: Generator-only systems

Type 2: Generator and diesel main engine hybrids

Type 3: Dual-mode systems switchable between the generator- and battery-powered modes

Types 1 and 2 are considered to have an energy-saving effect of 10% to 30% (on a fuel consumption basis or a cargo volume (ton-mile) basis), while also reducing the engineers' workload, which is a burden on conventional ships. However, these types rely entirely on generators to absorb load fluctuations. ROBOSHIP features the generator/battery combination described in 3.2 so that the batteries absorb load fluctuations, thereby producing an additional energy-saving effect (improvement of energy loss).

As for even Type 3, ROBOSHIP has an advantage in terms of the exclusive relationship between the generator- and battery-powered modes explained in 3.2 (i.e., only the generators or the batteries can be used at one time).

As an additional advantage of ROBOSHIP, since the power supply aboard a conventional ship relies entirely on an AC grid, enhancing electric conversion efficiency is a critical point. However, ROBOSHIP uses power plant based on a DC grid (and further, a combination of PM motors for propulsion motors and variable speed generators, as necessary), resulting in an energy efficiency improvement of up to 10% compared with a power plant based on an existing AC grid.

Figs. 6 and 7 below show examples of a conventional AC grid and a DC grid for the ROBOSHIP, respectively.

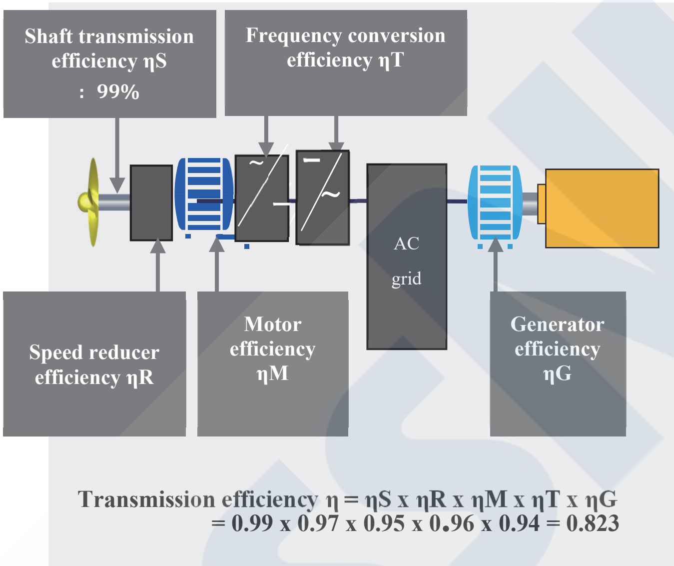

Fig. 6　Example of conventional AC grid

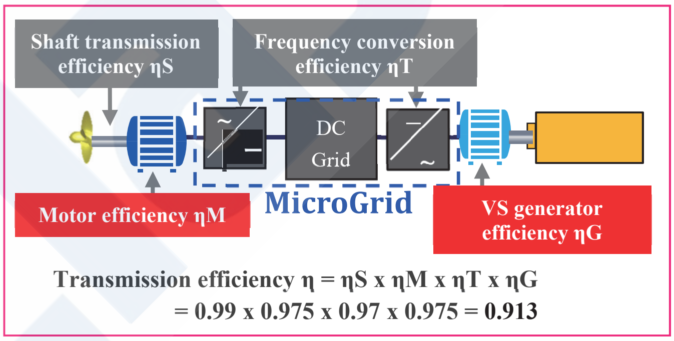

Fig. 7　Example of DC grid of ROBOSHIP

Moreover, thoroughgoing standardization and modularization provide the following advantages:

○ Cutting-edge technology usable without specialist knowledge

○ Pursuit of labor-savings in installation and maintenance

○ Simplified seafarer training

○ Reasonable battery pricing

The battery-only operation mode enables zero emissions, for example, during departure, arrival and anchorage, and is a feature not found in conventional electric propulsion ships. Since ROBOSHIP can sail on power supplied from the generators while underway, there are no particular restrictions on operational conditions, and its cruising range and speed are also comparable to those of conventional ships, operation is essentially no different from that of conventional ships.

3.4 Construction Scheme

The actual construction of the ROBOSHIP will be carried out by shipyards that build coastal vessels. To support these shipyards, Mitsubishi Shipbuilding Co., Ltd. will not only undertake the total engineering and conceptual design of the power plant, including on-shore power supplies, but will also provide engineering support in the basic design, construction and after-sales service stages.

The microgrid and associated components of the power plant will be manufactured by ABB, with IHI Power Systems Co., Ltd. who participate as the system integrator and supplier of the power plant in order to provide engineering support.

We at e5 Lab will coordinate the aspects of the actual construction work in cooperation with Mitsubishi Shipbuilding, IHI Power Systems and the shipyards that build coastal vessels.

3.5 Purpose of Introducing Marindows

As explained in Chapter 1, ROBOSHIP is an attempt to fuse a “robot” as a friend of humankind with a “ship.” To achieve this, not only the hardware, but also the software is an extremely important element. Marindows is the platform software program for this purpose and provides the marine DX (digital transformation) infrastructure to solve facing hard-to-solve problems of the maritime industry, which include climate change, energy transition, a late start in DX and a decreasing workforce due to Japan’s aging population and low birthrate.

The functions of software are digitalization, data creation and DX. The advantages of digitalization include flexible implementation conditions and the short time required for implementation, and low technical hurdles to implementation of digital tools, particularly mobile applications (“apps”) not only in new ships, but also in existing ships. Provided digital devices (PCs, smartphones, tablet terminals) that run apps, the power to charge them and a communication environment are available, an app can be used as soon as it is installed on a device. Depending on the setting of the terminal and application, apps can also be used without an always-on communication connection.

Marindows is a digitalization tool designed for ships which makes full use of these advantages of digital technology. The aim of its introduction is to promote the digitalization of coastal vessels, enable safer and more efficient vessel operation, reduce seafarers’ workloads and improve the quality-of-life aboard ships.

3.6 Functions and Superiority of Marindows

The initial version of Marindows, which is to be released in the near future, includes labor management and healthcare services of seafarers which pursued the thorough efficiency improvement by the digitization based on the legal amendments made this year (2022). Dedicated Marindows devices will be provided with preinstalled with these apps. Seafarers will use these devices to input their own data, which will then be compiled and shared to captains, onshore managers and partner companies supporting the apps, enabling easy digital handling of communications which are currently performed nondigitally and information that has not been managed until now.

The superiority of Marindows is its updateability. The functions of Marindows will be expanded successively. This point can be understood easily by analogy with mobile phone operating systems. Even state-of-the-art operating systems undergo constant research and development and repeated updating to add new functions, improve convenience and strengthen security. Marindows will also continue to evolve in the same way. In addition to labor management and healthcare services, new services to suit the needs of the worksite, such as navigation support and entertainment content for seafarers, can be introduced easily via dedicated devices and can be used immediately.

Considering the instability of telecommunication conditions at sea, the apps necessary for duties during voyages and the apps used at irregular times will be designed with specifications that allow offline use of some functions.

4. EXPANDABILITY OF ROBOSHIP

4.1 Positioning of 499 GT Standard Ship in Coastal Shipping Industry and Expandability to Other Hull Forms

The replacement of conventional coastal ships with ROBOSHIPs will have a large ripple effect because the 499 GT cargo ship, which is the target of the ROBOSHIP project, has a share of 20.6% in the coastal shipping industry (vessel count basis for 400 GT to 499 GT ships as of March 31st, 2021. Source: Website of the Japan Federation of Coastal Shipping Associations). Moreover, ROBOSHIP is also a highly versatile system, since its design can be applied to other hull forms and other types of ships by reviewing the capacity and the number of generators and the capacity of the batteries.

4.2 Expandability as a Realistic Solution

In the Prime Minister's Policy Speech to the Diet in October 2020, then-Prime Minister Suga declared that "by 2050 Japan will aim to reduce greenhouse gas emissions to net-zero, that is, to achieve 2050 carbon-neutral, decarbonized society." In line with this declaration, the transportation sector's midterm CO_2 emissions reduction target has been accelerated to a 35% reduction from 27% in FY 2030 relative to FY 2013. The FY 2030 CO_2 emissions reduction target of the coastal shipping industry, which is part of the transportation sector, has also been revised upward from a reduction of 1.57 million t-CO_2 (approx. 15% reduction) compared to FY 2013 to approximately 1.81 million t-CO_2 (approx. 17% reduction).

Since a transition to non-fossil fuels, namely, hydrogen and ammonia, is also required as an effective means of responding to Japan's "2050 Carbon Neutral" target, industrial, governmental, and academic circles have steered in unison to technological development and supply networks for this purpose.

Nevertheless, fossil fuels will inevitably still be the main energy source at the interim milestone year of 2030. Assuming the use of fossil fuels, GHG emissions reduction must be promoted using existing technologies for the time being. In this sense, the introduction of ROBOSHIP can be considered as a realistic choice for CO_2 emissions reduction at present.

4.3 Future-Oriented Expandability

The current power plant of ROBOSHIP consists of lithium-ion batteries combined with diesel generators (heavy fuel oil), and as explained in 3.3, zero-emission operation of this power plant is inevitably limited. However, the range of zero-emission operation can be expanded by increasing the battery capacity, use of LNG as a diesel generator fuel and concurrent use with hydrogen fuel cells. With progress in practical application of all-solid-state batteries on a commercial basis and development of technologies and supply networks for introducing the non-fossil fuels (hydrogen and ammonia) mentioned in 4.2, it will become possible to replace diesel generator fuels with these alternative energy sources, and in this case, complete zero emissions will become possible. Thus, it can be said that this system has expandability to allow version upgrades in line with future trends.

5. CONCLUSION

As we mentioned in section 2.1 above, the labor environment in the coastal shipping industry faces difficult situation. The 2020 National Census Results published by the Ministry of Internal Affairs and Communications last year revealed that the productive-age population (15 to 64 years old), which is the driving force of economic activity, has decreased by 13.9% from its peak in 1995. In addition, Japan also ranks low in productivity and our added value per hour of work in 2020 was US$48.10, which was the lowest among the G7 countries and was also below the average of the OECD members (US$54.00). Although companies have been striving the employment expansion for elderly people and women, the effects of those efforts alone have limit. It cannot compensate for the decrease in productive-age population unless productivity is improved.

In the global context, we are now facing with two crises, which are the COVID-19 pandemic and climate change. However, these two crises differ in that climate change has already been existed danger and its future is also scientifically predictable.

In a report released by UNPD (United Nations Development Programme) on February 8, 2022, it was stated that as of 2020, approximately 2.4 billion people were suffering food shortages, and 82.4 million people had been forced to relocate. It also predicts that a cumulative total of 40 million people mainly from developing countries, would die by 2100.

At the same time, the IPCC (United Nations Intergovernmental Panel on Climate Change) issued 6th Assessment Report on February 28, 2022 stating that "approximately 3.3 to 3.6 billion people live under conditions of extremely vulnerable to climate change." Regarding the current adaptation and its effects, the IPCC AR6 adds: "Many initiatives prioritize immediate and short-term climate risk reduction which reduces the opportunity for transformative adaptation. Long-term planning and rapid implementation over the next 10 years is required."

Failing to take action in spite of these circumstances is simply a groundless optimism, a betrayal of future generations and negligence. We must not forget that the anger of Generation Z is directed at us, our generation. We hope that the ROBOSHIP which we are promoting will contribute to solving these problems.