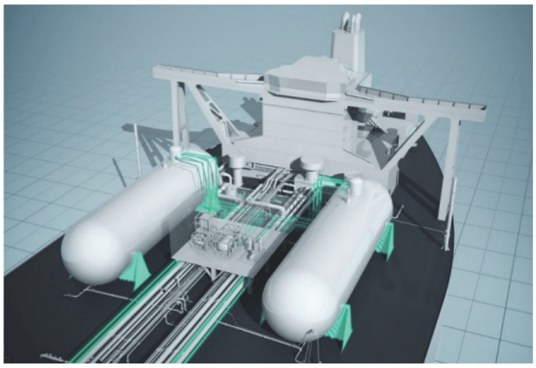
"LNG as fuel" to "Ammonia as fuel" (Ship's fuel transition to achieve carbon neutrality)



SHIN UEDA[*1] KENJI TSUMURA[*2]
YUSUKE WATANABE[*3] HIROSHI TAMURA[*4]
DAISUKE YAMADA[*5]

As was the case with the large-scale marine transportation of LNG (Liquified Natural Gas), the increasing expectations and social demand pressure on the land use of ammonia for electric power generation as an environmental measure are about to open the era of large-scale marine transportation of ammonia. The technologies for LNG carriers were applied to ships using LNG as fuel (hereafter LNG-fueled ships) and LNG fuel supply systems. It is expected that the technologies for ammonia carriers will be also applied to develop ships using ammonia as fuel (hereafter ammonia-fueled ships) and ammonia fuel supply systems. To widely promote the use of ammonia as marine fuel, it is necessary to set up ammonia related rules and training for crews, and ammonia-fueled ships and equipment should be developed as the extension of the same technology from LNG-fueled ships and equipment. In such way, it is desirable for manufacturers who provide ships and equipment and the potential operators of ammonia-fueled ships to develop in such a manner that common parts are inherited from LNG-fueled ships and equipment.

1. Introduction

In the initial LNG carriers, steam turbine propulsion plants were adopted as propulsion machinery so that the risk of vibration impact of the propulsion machinery on LNG tanks was minimized, and boil-off gas (BOG) from LNG tanks was effectively used as fuel. After that, high-efficiency marine diesel engines which allowed the use of LNG were developed, and the assessment method for vibration impact on LNG tanks and countermeasures were also established. Then, diesel electric propulsion plants were adopted, and now, most of the current LNG carriers are equipped with plants that allow direct propulsion by LNG-fueled diesel engines. The advent of marine LNG-fueled engines paved the way for the utilization of LNG fuel other than LNG carrier. Many LNG-fueled ships were begun to build and operate, as an environmental measure. It started in Europe and spreading to other contraries, and the number of LNG-fueled ships has been increasing along with the growing of environmental awareness. In Japan as well, the number of completions and construction contracts of LNG-fueled ships, which are large merchant ships, is increasing. Now we have entered the era where we can see the increase of LNG-fueled ships as well as the improvement of the port infrastructure for LNG supply including LNG bunkering vessels.

In recent years, however, increasing the sense of crisis over the global environment and climate change, it has been required at an accelerating pace to take measures for GHG (greenhouse gas) reduction and carbon neutrality, and with an eye toward post-LNG fuel, discussions and development have already been in conducting phase. LNG fuel, which emits CO_2 when it burns, has already been recognized as a bridging solution before carbon neutral fuels, as next-generation fuels, or ecosystems with CO_2 recovery are established. Many concerned parties in maritime affairs

*1 Director, Ship & Ocean Engineering Department, Mitsubishi Shipbuilding Co., Ltd.
*2 Director, Strategic Planning & Operation Office, Mitsubishi Shipbuilding Co., Ltd.
*3 Deputy Director. Ship & Ocean Engineering Department, Mitsubishi Shipbuilding Co., Ltd
*4 Manager, Nagasaki Designing Department, Mitsubishi Shipbuilding Co., Ltd
*5 Engineering Manager, Nagasaki Designing Department, Mitsubishi Shipbuilding Co., Ltd

including shipowners, shipping companies, shipyards, marine equipment manufacturers, fuel suppliers, etc., are interested in the way of the next marine energy supply for ships. The conditions and backgrounds for energy supply are different by ship type and operation pattern, and it is expected that ship's fuels in a variety of segments will coexist in the future. As shown in **Table 1**, differently from other candidate fuels, ammonia does not emit CO_2 and it has characteristics suitable for mass transportation and long-term navigation. Therefore, ammonia is recognized as a promising option.

In this report, focusing on the transition from LNG fuel to ammonia fuel, we predict how ammonia as fuel will be developed by overlapping the history of the technological conversion from LNG carriers to LNG-fueled ships and consider the technological continuity from LNG fuel to ammonia fuel. And finally, we will look at the way of development of ammonia-fueled ships and ammonia fuel supply systems.

Table 1 Characteristics of each ship's fuel

Ship's fuel (CO_2 emissions per calorific value)	Carbon-free, carbon-neutral fuel that allows diversion of infrastructure	Fuel liquefaction conditions	Fuel volume per calorific value	Suitability for mass transportation, long-term navigation
Heavy oil (1.0)	Biodiesel	Atmospheric pressure, room temperature	Base	Suitable
LNG (0.74)	Carbon recycled methane, biomethane	Atmospheric pressure, -162℃	x 1.7	Suitable
Methanol (0.90)	Carbon recycled methanol, biomethanol	Atmospheric pressure, room temperature	x 2.4	Suitable
Ammonia (0)	Green ammonia, blue ammonia	Atmospheric pressure, -33℃ or 1.8 MPaA, room temperature	x 2.7	Suitable
Hydrogen (0)	Green hydrogen, blue hydrogen	Atmospheric pressure, -253℃	x 4.5	Possible

2. Social trends toward carbon neutrality and its impact on the maritime industry

2.1 Roles of LNG and ammonia in achieving carbon neutrality

Most of countries have set GHG emissions reduction targets for 2030 and ambitious goals for achieving carbon neutrality by around 2050. The world is moving toward the realization of carbon neutrality. In various fields, solutions for proliferation of renewable energy, CO_2 reduction and CO_2 capture has been promoted.

Even in the era of fossil fuel energy as the mainstream, there is the demand for transportation because oil-producing areas and energy demand areas are located apart, and these demands have been satisfied by pipelines and/or ships. As shown in **Figure 1**, suitable areas of renewable energy resource and the areas of energy demand are also located apart. Although the supply chain has changed in the carbon neutral energy, there is still substantial demand for transportation of carbon neutral energy. Especially for long-distance routes, transportation by ship is advantageous compared to developing pipelines or power grids. In the transition period from fossil energy to carbon neutral energy, it is necessary to cope with changes in destination and transportation volume and a new balance between both energy segments. In this transition period toward the realization of a carbon neutral society, these changes in fuels as energy transport media and energy transportation demand will continuously occur. Therefore, ships - that can provide mass transportation and long-distance transportation of energy and can give flexibility in transportation routes - play an important role in this transition period.

Major carbon-neutral energy transport media include hydrogen, ammonia, synthetic methane and synthetic methanol. Hydrogen-based energy transport requires infrastructure and technologies at every stages from production through utilization, and it takes time for the system to spread.

Among the fuels for stepwise realization of carbon neutrality, ammonia is garnering considerable attention as a promising energy transport medium because it does not contain carbon and can be produced only from nitrogen and hydrogen existing in the atmosphere, and the synthesis technology for ammonia has already been established.

Another possible measure is CO_2 capture-based energy transportation using synthetic hydrocarbon together with CO_2 capture after combustion. Synthetic methane and synthetic methanol using captured CO_2 become carbon-neutral energy transport media. From the viewpoint of effective utilization of the existing infrastructure, a transition from LNG to synthetic methane is also considered to be a superior option.

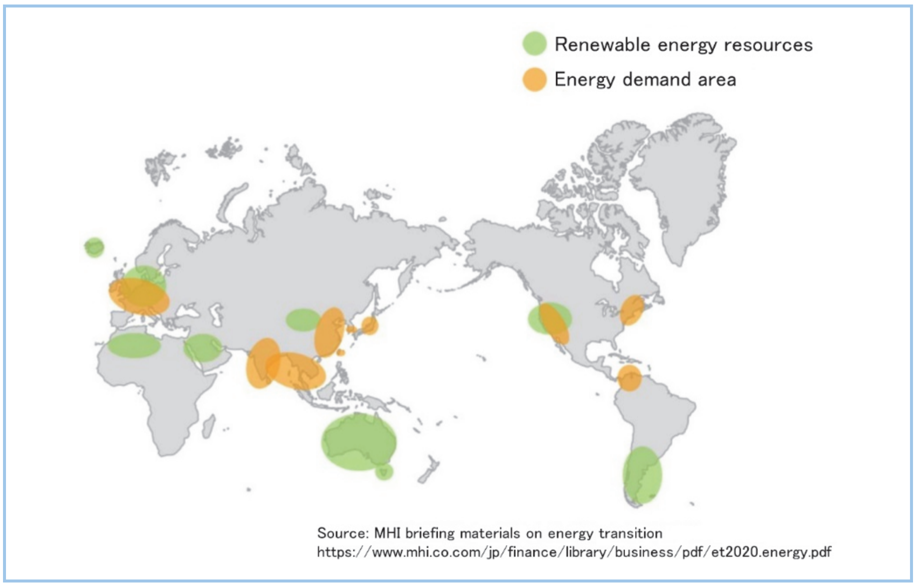


Figure 1 Locations of renewable energy resources and energy demand areas

2.2 Trend of regulations and effects on ship operation

The International Maritime Organization (IMO) adopted a strategy on the reduction of GHG emissions in April 2018 and set a medium-term target of reducing the total GHG emissions from international shipping by 50% by no later than 2050 compared to 2008 levels and a long-term target of achieving net zero emissions as early as possible in this century. At the IMO Marine Environment Protection Committee (MEPC) held in June 2021, the Energy Efficiency Existing Ship Index (EEXI) regulation for verification by the design parameters of ship fuel efficiency and the Carbon Intensity Indicator rating (CII rating) for post check of actual fuel efficiency were adopted and will come into force in 2023. Concerning the CII rating, it has been decided that the rating thresholds for GHG reduction will become more stringent every year so that the reduction rate will be increased by 1 to 2% per year until 2026, and from 2027, it will be further increased although no specific numerical value has been decided. Each ship will be rated on a five-tiered scale (from A to E). If a ship receives a rating of D, which is the fourth level, for three consecutive years or receives a rating of E, which is the lowest level, an improvement plan must be developed and there will be no choice but to take measures such as fuel conversion or slow steaming. This regulation will require ships that have poor environmental performance to be modified or to reduce the transportation capacity, and it will have a great influence on market. Viewing from the opposite side, this rating indicating environmental performance may be regarded as providing us an opportunity. It is possible to promote positive development of ships adapting to next-generation fuels and show them to environmentally conscious shipper companies and consumers. There is a possibility that the CII rating will be utilized as an indicator of environmental performance of the fleet.

LNG fuel can reduce CO_2 by about 25% compared to heavy oil and even now it is an available fuel. Therefore, the use of LNG fuel is effective solution in improving the rating quickly. Ammonia fuel is expected to contribute to a substantial improvement in CO_2 reduction as a carbon-free fuel and it can be used as an effective means for further reducing GHG. Therefore, the fuel conversion from LNG fuel to ammonia fuel has been also studied.

3. LNG fuel

3.1 Dawn of the era for land use and the large-scale marine transportation of LNG

Natural gas contains less pollutants such as sulfur and its calorific value is high. Therefore, it got an attention as a source for city gas. By pipeline transportation, the large-scale use of natural gas started in the United States before World War II and in Europe and Russia after the war. In these early days, LNG, which is produced by liquefaction of natural gas, was not suited to marine transportation because of the difficulty in handling, but in the 1970s, the transportation of LNG by ship became possible, which allowed long-distance transport of LNG, and Japan could thus start the large-scale use of LNG in land.

Japan industrialized after the war, using coal and then petroleum as energy sources. But it was accompanied by environmental problems due to serious air and water pollution by them. As a countermeasure, the use of natural gas, which is a clean energy resource, was studied, and Tokyo Electric Power Company and Tokyo Gas Co., Ltd imported LNG from Alaska, which became the starting point of the import of LNG by Japan. Then, large scale marine transportation of LNG began and became worldwide. The oil shocks gave a boost to the use of LNG, resulting in a substantial increase in transportation volume.

3.2 LNG carriers

After that, LNG carriers have achieved significant technological innovation. For example, membrane-type LNG containment systems and subsequently moss-type LNG containment systems appeared, which has created a competitive situation for multiple technologies in LNG carriers. Both containment systems have achieved a high level of success in technological and safety aspects. Then, various marine LNG technologies such as on-board re-liquefaction systems were developed, and the hull size was increased. Thus, technological innovations including manufacturing technologies have been greatly developed up to the present date. Now that the increase in hull size has reached a certain point and hull forms standardized, then now LNG carriers are considered to have reached a level of technological maturity.

Propulsion machinery for LNG carriers has developing history of unique technological evolution. In LNG carriers, it is necessary to deal with boil-off gas generating from cryogenic LNG during transportation, and gas treatment is required to control an increase in LNG vapor pressure. Therefore, for the purpose of economically utilizing boil-off gas, LNG is mainly used as propulsion fuel. In the early stage LNG carriers, steam turbines were used for propulsion plants, and subsequently, reheat steam turbines, electric propulsion by medium-speed gas-fueled generator engines, low-speed gas-fueled diesel engines, etc., were adopted. With the improvement of fuel efficiency, many technological changes have been made. LNG carriers require cryogenic technologies specific to their LNG containment system types as well as technologies different from those for other ships from the aspect of fuel use, and also require shipbuilder's engineers and ship operator's crew that have gas handling skills from the aspects of ship building and ship operation.

3.3 LNG-fueled ships

Now that marine LNG-fueled engines become widely available, the technologies for special turbine propulsion plants are not required in ship design and construction and not only for LNG carriers but it has become easier to construct LNG-fueled ships than before. In addition, the marine transportation of LNG has spread and the infrastructural support for use of LNG fuel is being established at many ports throughout the world. Therefore, the application of LNG-fueled ships is increasing. LNG bunkering vessels for supplying LNG as fuel to commercial ships are being completed one after another at various ports throughout the world, including in Japan. Concerns about LNG supply to ships are being dispelled and the conditions for introducing LNG fuel to commercial ships become better. In order to supply LNG fuel to an engine, a system for preparing LNG to the temperature, pressure and flow rate specified by the engine is required and the system also needs to have a function of maintaining LNG in fuel tanks in a correct state. Such a complex fuel supply system (LNG-FGSS: LNG-Fuel Gas Supply System) will be required for LNG-fueled ships. Each manufacturer has already developed such a system based on the technologies for LNG carriers and established the system for supplying related devices as one package. The environment has been established in which shipowners and shipyards do not need to design or procure individual devices but can use a reliable system as a package. Mitsubishi Shipbuilding Co., Ltd. started early the development and commercialization of the LNG-FGSS and provides a lineup of products. Large commercial ships using LNG as fuel are increasing because they are economically feasible, and medium-sized ships using LNG as fuel are expected to progressively increase. It is also expected that with the increase in LNG-fueled ships, LNG bunkering vessels will come into wide use and the fuel supply systems will be enhanced in the future. The problem to be noted is that the global warming potential of methane is 28 times greater than that of CO_2. It is important to continuously study reduction of unburned gas emissions from LNG-fueled engines and take measures to prevent release into the atmosphere in the processes of production, transportation and bunkering.

4. Expectations for ammonia fuel

Ammonia can be synthesized mainly from hydrogen produced by the electrolysis of water using renewable energy (green hydrogen) or hydrogen produced by the decomposition of hydrocarbon (blue hydrogen) and nitrogen existing in the air via a catalytic reaction at high temperature and high pressure (Haber-Bosch process). Since no special material for fuel is used for its production, ammonia can be produced easily in energy supply areas. At present, the global ammonia production capacity is not sufficient relative to the expected energy demand, but it is considered that there are no major problems regarding the raw material supply chain for fuel.

Ammonia can be decomposed to extract hydrogen and it can also be directly combusted. In addition, ammonia is a zero-carbon fuel which does not emit CO_2 when burned. Therefore, it is effective at reducing CO_2 emissions from thermal power generation, industrial furnaces, ships, etc., and in Japan, like LNG, ammonia is considered as energy source in these infrastructural developments. In thermal power generation, there are high expectations for the effect of significantly reducing CO_2 emissions by using only ammonia as a fuel. Ammonia is also suitable for mixed combustion with coal, and it is expected that early realization of such mixed combustion will contribute to the stepwise reduction of CO_2.

The liquefaction temperature of ammonia is relatively high compared to that of LNG. Ammonia liquefies when pressurized at room temperature and it has characteristics closer to LPG (liquefied petroleum gas) than LNG. However, from the viewpoint of corrosiveness and irritation, ammonia is more difficult to handle than LPG. Considering the irritation of high concentrate ammonia, differently from LNG and LPG, it is unlikely that ammonia will be used for city gas. But ammonia has the great advantage of being carbon free and ammonia fuel has sufficient potential and there are high expectations for use in power generation.

Recently, global environmental awareness has called for actions to be taken on a global scale, which made a huge impact on the market. It is expected that with growing environmental awareness, use of ammonia as a fuel for power generation will increase and develop along with improvement of the infrastructure at ports as was the case with LNG in the past. Probably it will lead to the dawn of large-scale marine transportation for ammonia in the same way as for LNG. For example, JERA Co., Inc., which is a large-scale Japanese power company, has announced in its "JERA Zero CO_2 Emissions 2050 Roadmap for its Business in Japan" that it will start large scale operation of mixed combustion with ammonia by 2030, achieve 20% of the ratio of mixed combustion with ammonia in all coal-fired power plants they own in the first half of the 2030s, subsequently increase the ratio of mixed combustion along with replacement of power plants, and start single fuel combustion using only ammonia in the 2040s. In addition to coal-fired power generation, for example, in gas combined cycle power generation, an idea to extract hydrogen from ammonia and co-fire it with natural gas is being considered. (In addition to the use of ammonia, the use of liquid hydrogen and methylcyclohexane as hydrogen transport media has also been studied.)

To popularize the mixed combustion with ammonia and stably supply ammonia for coal-fired power generation, the Public-Private Fuel Ammonia Promotion Council under the Ministry of Economy, Trade and Industry has set the target of achieving the annual ammonia transportation volume to Japan of about 3 million tons (which is about 126 voyages of MGC (Multi Gas Carrier)-class vessels having a capacity of $35,000m^3$) by 2030 and about 30 million tons (which is about 510 voyages of VLGC (Very Large Gas Carrier)-class vessels having a capacity of $87,000m^3$) by 2050.

Ammonia as ship's fuel is a gaseous fuel having special characteristics, like LNG, and for building and operating of ammonia-fueled ships, high-level technologies and high-level safety are required. An issue to be noted is that NOx and N_2O are generated when ammonia is burned. The global warming potential of N_2O is 265 times higher than that of CO_2. Therefore, the development of measures to reduce such emissions by engine combustion control and decomposition catalysts will be promoted. Furthermore, in the case of ammonia is produced using hydrocarbon, CO_2 is emitted during production. Therefore, an appropriate treatment such as CO_2 capture and storage will be needed.

4.1 Ammonia carriers

Ammonia carriers have been constructed in the context of LPG carriers because LPG has similar physical characteristics to ammonia. MHI constructed eighty-eight VLGCs and MGCs from the 1960s to the 2020s. Among them, six carriers are MGCs (with a capacity of 20,000m^3 to 40,000m^3) capable of carrying ammonia (**Figure 2**). They were constructed in the period from 1995 to 2005. At that time, heavy oil was used as the fuel for propulsion, but those carriers were designed so that ammonia could be transported as cargo. With consideration given to the characteristics of ammonia, the carriers are equipped with various monitoring and safety devices in addition to the cargo equipment suitable for all kinds of ammonia handling operations, such as preparatory operations for loading of ammonia (i.e., tank inerting, gassing up and cooling down), loading/unloading of ammonia and preparatory operations for dry-docking (i.e., ammonia tank warming up, inerting and aeration).

Figure 2 MGC ammonia carrier with capacity of 20,000m^3 to 40,000m^3

On the other hand, recently, in view of future demand for ammonia transportation, it is required that larger VLGCs (corresponding to MHI's 87,000m^3-class) should have specifications that allow transportation of ammonia. In the project where Namura Shipbuilding Co., Ltd. is constructing a ship for Mitsui O.S.K. Lines Group (**Figure 3**), Mitsubishi Shipbuilding Co., Ltd. provides the design and will conduct procurement of some equipment as well as construction support. In this project, Mitsubishi Shipbuilding Co., Ltd. has used the knowledge and experience obtained through the construction of VLGCs and MGCs to increase the economic efficiency by upsizing cargo tanks and also increase the fuel efficiency by improving the hull form. In addition, using the gas handling technology cultivated so far, we have introduced a system that allows LPG, which is a cargo, to be used as fuel for the propulsion of the ship. By holding LPG as fuel in the cargo tanks, flexibility during cargo handling at LPG terminals has been ensured. It has now the largest-scale specification for an ammonia-loadable ship. Furthermore, in another project, Mitsubishi Shipbuilding Co., Ltd. has started the development of a large ammonia carrier using ammonia as fuel in cooperation with Mitsui O.S.K. Lines, Ltd. and Namura Shipbuilding Co., Ltd. (**Figure 4**), and takes charge of the study and preliminary design of optimal cargo tanks, development of deck tanks, study of engine and related machinery systems, installation design of fuel supply systems, design of special equipment and cargo handling equipment and design of safety systems onboard.

As described above, technological preparations for marine transportation of ammonia are nearly completed. From now on, total optimization including upsizing of ships will be promoted according to growing demand. As was the case with LNG carriers in the past, it is expected that the large-scale use of ammonia as ship's fuel will start with ammonia carriers. Ammonia carriers have facilities and safety equipment for holding and maintaining ammonia as cargo, and they do not require any infrastructure for the fuel gas receiving such as bunkering vessels. Also, the skill of crews has been ensured for ammonia operation. Therefore, it is expected that the use of ammonia as ship's fuel will start with ammonia carriers.

Figure 3　87,000m^3-type LPG-fueled large LPG/ammonia carrier

Figure 4　Image of large ammonia carrier

4.2　Ammonia-fueled ships

Plans for marine transportation of ammonia are underway. Meanwhile, several engine manufacturers have already started the development of ammonia-fueled marine engines; the first ammonia-fueled marine engine is expected to make its debut around 2024. In some cases, ammonia-fueled engines are developed based on the technology for LNG-fueled engines, and their development speed is faster than that of LNG-fueled engines. Therefore, ammonia-fueled engines are expected to be introduced into ammonia-fueled ships at a relatively fast pace. For the supply of ammonia fuel to engines, an ammonia fuel supply system is required which prepare the temperature, pressure and flow volume of ammonia while operating and maintaining fuel tanks, and furthermore, ammonia-fueled ships need to have facilities and safety equipment for holding and maintaining ammonia like those of ammonia carriers. That is, as with ammonia carriers, ammonia-fueled ships require preparatory operations for loading of ammonia, loading of ammonia/supply of fuel and preparatory operations for dry-docking. It is desirable that these operations should be developed using the technologies for ammonia carriers and fuel supply systems and be provided as a reliable package as happened with LNG-fueled ships. Mitsubishi Shipbuilding Co., Ltd. considers it desirable to provide such a package as an ammonia fuel supply system to shipyards and shipowners (**Table 2**). To widely promote the large-scale use of ammonia as marine fuel, it is also necessary to set up ammonia related rules and training for crews, and ammonia-fueled ships and equipment should be developed as the extension of the same technologies from LNG-fueled ships and equipment and potential operators of ammonia-fueled ships to develop in such a manner that common parts are inherited from LNG-fueled ship and equipment.

Since ammonia fuel is stored at a low temperature or high pressure, it must be handled in the same way as gas fuel, as is seen with LNG fuel. In addition, it must be noted that ammonia fuel has corrosiveness and irritation, and ammonia abatement technology in addition to LNG-FGSS technology will be required. For example, treatment of a small amount of ammonia that is emitted at the interval of an engine stopping and fuel switching, or treatment of the ammonia that is emitted from fuel tank at the time of gas freeing prior to docking also needs to be considered. Facilities and equipment that allow safe operation for such purpose are also required for an ammonia fuel supply system.

Table 2 Ammonia fuel supply system packages

Example of ammonia fuel supply system package	Example of LNG fuel supply system package
Ammonia fuel tank	LNG fuel tank
Ammonia boil-off gas treatment device/re-liquefaction device	LNG boil-off gas compressor
Instrumentation equipment for ammonia fuel tank	Instrumentation equipment for LNG fuel tank
Emergency shutoff device for ammonia fuel tank/bunkering	Emergency shutoff device for LNG fuel tank/bunkering
Ammonia fuel supply equipment	LNG fuel supply equipment
Ammonia fuel pump	LNG fuel pump
Instrumentation equipment for ammonia fuel supply	Instrumentation equipment for LNG fuel supply
Ammonia abatement device	-

Example of requirements for ammonia abatement equipment
Treatment of boil-off gas from ammonia tank
Treatment of purge gas in fuel piping
Treatment of leaked ammonia gas
Treatment of gas in ammonia fuel tank at the time of regular inspection

5. Transition from LNG-fueled ships to ammonia-fueled ships

There is an already developed marine transportation network for LNG and its convenience will increase along with completion of LNG bunkering vessels. Since it takes time to establish supply and marine transportation systems for other alternative fuels, the relative superiority of LNG fuel is expected to continue longer. LNG is expected to support worldwide development as an effective energy medium option, such as a fuel, a material for synthetic fuels and a hydrogen carrier. It is also considered that ships involved in the transportation of LNG will continue to use LNG fuel.

On the other hand, for conservation of the global environment, we need to continuously pursue the reduction of GHG emissions. In connection with the previously described CII rating, at some point in the future, each ship will be required to reduce emissions beyond the use of LNG, which is a kind of fossil fuel. Depending on the future reduction target in CII rating, we will need to incorporate measures, such as use of synthetic methane, carbon offset charge or conversion into ammonia-fueled ships, into planning before the end of the service life of ships. Whether ammonia-fueled ships will be introduced or not depends somehow on the infrastructure development progress including the ammonia fuel supply capacity and the shipbuilding capability for ammonia fuel. Also, it may take time to see the real effects on market of ammonia-fueled ships depending on the timing when the ammonia fuel becomes widely used. One of the factors that will promote use of ammonia as fuel for ships is the wide use of ammonia as fuel for power generation on land, and it is considered that large-scale utilization of ammonia as fuel will probably start with ammonia carriers. This is like the way of LNG, which became widely used as ship's fuel.

Now, one of our prime concerns is when the use of carbon neutral fuels will get in large-scale stage. It is difficult to forecast the time because there are various elements to be considered such as fuel supply capacity and cost, availability, supply of engines, supply of other equipment, availability of skilled shipyards and training support of crew. Therefore, to secure flexibility in ship operation, ammonia-fuel-ready LNG-fueled ships have emerged as a new option. Ammonia-fuel-ready LNG-fueled ships are LNG-fueled ships that have designs and equipment to use ammonia as fuel partially incorporated when they are newly constructed, aiming at switching the main fuel from LNG to ammonia during ship lifetime. Before the main fuel is switched from LNG to ammonia, retrofit modification is required, but as it is originally planned, the modification cost can be reduced. Also, the modification timing can be decided after the ship is in service. Therefore, a decision will be able to make based on the comparison of the market of LNG fuel and ammonia fuel in the future. The points on planning of ammonia-fuel-ready LNG-fueled ships are as shown in **Table 3**.

To operate ammonia-fueled ships, it is also important to secure capable crews. As previously described, ammonia-fueled ships require preparatory operations for loading of ammonia, loading/supply of ammonia and preparatory operations for dry-docking. If crew's familiarity with handling of gas fuel are secured in advance, those operators can be quickly dealt with. In this regard, it is also considered important to plan with a view to transition from LNG fuel to ammonia fuel. From the standpoint of shipyards, consideration should be given so that the ammonia fuel supply system is designed to have continuity with the LNG fuel supply system; in other words, the ammonia fuel supply system/ammonia-fueled ship is designed in such a manner that common parts are inherited from the LNG fuel supply system/LNG-fueled ship. With such consideration, we would like to help shipowners and operators securing crews.

Table 3 Points on planning of ammonia-fuel-ready LNG-fueled ships

Points on planning of ammonia-fuel-ready LNG-fueled ships	
Fuel tank	Use of materials suitable for both LNG fuel and ammonia fuel
Main engine, auxiliary engine	Suitability of materials, difference in combustibility/calorific value, availability of partial modification, post treatment of exhaust gas
Fuel supply system	Differences between LNG fuel and ammonia fuel, know-how about handling of gaseous fuel
Compartments/arrangement	Arrangement of tanks, engines and a fuel supply system, fire protection structure, consideration of flammability/toxicity hazardous areas
Corrosiveness	Selection of materials in consideration of corrosiveness of ammonia and stress corrosion cracking
Abatement device	Planning on installation of an ammonia abatement device

6. Conclusion

The increase in the demand for LNG for power generation and for city gas due to the rise in awareness of environmental issues brought about the era of large-scale marine transportation of LNG. In the same way, an increase in the use of ammonia for power generation as an environmental measure may open the era of large-scale marine transportation of ammonia. The wide use of LNG as fuel by commercial ships started from the use of LNG as fuel by LNG carriers. In the same way, it is expected that the large-scale use of ammonia as fuel, first by carriers and then by other commercial ships, will expand. The technologies of LNG carriers were applied to LNG-fueled ships and they were packaged as the LNG fuel supply system. In the same way, it is desirable that the technologies of ammonia carriers will be applied to ammonia-fueled ships and they will be packaged as the fuel supply system of ammonia. To cope with environmental performance targets which are gradually becoming higher, ammonia-fuel-ready LNG-fueled ships which have an advantage in their operational flexibility are also being planned. For wide use of ammonia as fuel, not only equipment but also capable crews that can deal with ammonia fuel are required. It is important to prepare for the transition from LNG fuel to ammonia fuel including personnel training.

Accordingly, Mitsubishi Shipbuilding Co., Ltd. considers that LNG-fueled ships/LNG fuel supply systems and ammonia-fueled ships/ammonia fuel supply systems are continuous technologies and that it is desirable to develop them in consideration of continuity in usability. In the collaborative project (Project MaTIS: Marine Technology, Integration & Solutions) with Mitsubishi Heavy Industries Marine Machinery & Equipment Co., Ltd., Mitsubishi Shipbuilding Co., Ltd. is now gathering information from both companies and studying transition from LNG fuel to ammonia fuel.

References

(1) Hiroshi Morishima, All of the natural gas -The Latest Knowledge of Leading Energy in The 21st Century-, Oil and Natural Gas Review, January 2004, p.114～169

(2) Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry, Materials of the 4th meeting of The Public-Private Fuel Ammonia Promotion Council, (2021)
https://www.meti.go.jp/shingikai/energy_environment/nenryo_anmonia/pdf/004_04_00.pdf

(3) JERA Co., Inc., “JERA Zero CO_2 Emissions 2050 Roadmap for its Business in Japan”, “JERA Environmental Target 2030 for its Business in Japan”
https://www.jera.co.jp/information/20201013_539

(4) Class NK, Guidelines for Ships Using Alternative Fuels (Edition1.1), September 2021