Technology Trends and MHI Activities for LNG Carriers

- Diverse Shipbuilding and Marine Products in the LNG Supply Chain -

SAI HIRAMATSU*1 KAZUYOSHI HIRAOKA*1

YOSHIKAZU FUJINO*1 KENJI TSUMURA*1

With natural gas garnering greater attention as an energy option with low environmental impact, shipbuilding and marine products in the liquefied natural gas (LNG) supply chain have become increasingly diverse. Mitsubishi Heavy Industries, Ltd., (MHI) through a variety of activities, has been introducing many products that meet customer needs. Taking a long-term perspective, MHI continues to be active in the development of products that offer dependability, economic efficiency, and low fuel consumption, such as continuous tank-cover LNG carriers with drastic weight reductions and performance improvements, fuel-efficient and environmentally-friendly ultra-steam turbine (UST) and slow-speed diesel with gas injection and re-liquefaction (SSD-GI) propulsion plants, regasification vessels that significantly reduce fuel consumption during the regasification process, and reliable highly economic LNG floating production storage and offloading units.

1. Introduction

Mitsubishi Heavy Industries, Ltd., (MHI) has built forty-two liquefied natural gas (LNG) carriers since delivery of its first in 1983. While safe, reliable, and economically efficient LNG carrier technologies are being developed through the design and shipbuilding process, the recent rise in LNG demand has generated diverse customer needs for shipbuilding and marine products in the LNG supply chain. This article describes MHI's activities in the development of highly novel products that take into account diverse supply sources, the need for lower environmental impact, and product development requirements at both upper and lower supply chain streams.

2. Larger LNG Carriers and Diverse LNG Supply Sources

2.1 Trends

The cargo capacity of LNG carriers in the late sixties, when LNG was first introduced in Japan, was about 70,000 m^3. The standard size of LNG carriers increased to 125,000 m^3, 135,000 m^3, and then to 145,000 m^3 as operational experience was gained and the need for economic efficiency became a priority. An LNG carrier with a capacity in excess of 200,000 m^3 was recently built for a specific project. The transportation cost per unit load decreases with larger sizes; however, due consideration must be given to design concerns and potential compromised compatibility with receiving terminals as the vessel size increases. Meanwhile, gas field developments in cold regions, such as Norway and northern Russia, are gathering great interest as new sources of LNG, which has traditionally been sourced from South East Asia, Australia, and the Middle East. LNG carriers operating in such cold climate zones require particular considerations for the hull structure, main engine, propeller/shaft, and outfitting to meet the challenges of navigating in cold regions or through ice. Furthermore, the increased demand for gas has prompted moves to develop small- to mid-sized offshore gas fields, previously not deemed economically viable, by using LNG-FPSOs (floating production, storage, and offloading units). This chapter describes LNG carriers for cold climates and MHI's activities regarding issues related to large-sized vessels.

Details of activities related to LNG-FPSOs are provided later in Chapter 4.

*1 Manager, Ship & Ocean Engineering Department, Shipbuilding & Ocean Development Headquarters

2.2 LNG carriers for cold climates

Through participation in northern gas field projects, such as Snohvit (Norway) and Sakhalin (Russia), MHI has developed practical designs and specifications for building LNG carriers for use in cold climates (title photo and **Figure 1**). Based on such designs and experience in shipbuilding, new development of LNG carriers able to navigate in even more extreme temperature is currently underway. For new sources of LNG specifically, to address potential situations where icebreaking is needed during winter navigation, MHI has so far conducted propulsion plant reviews, simulation of iceberg collisions, and global strength evaluations during ramming operations (**Figure 2**). With respect to the tank type, a self-supporting tank, spherically-shaped and fixed to the hull, that is resistant to deformation effects in the outer shell, is regarded as the most suitable for LNG carriers for arctic climates, and is being considered for future applicability in a spherical tank LNG carrier with a continuous tank cover described in the next section.

Figure 1 Arctic Princess

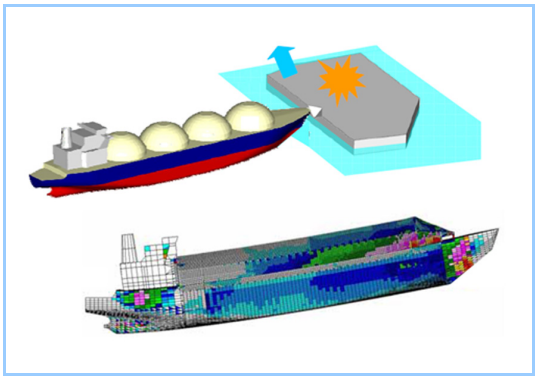

Figure 2 Strength evaluation during ramming operations

2.3 Spherical tank LNG carrier with continuous tank cover

MHI has developed a next-generation spherical tank LNG carrier with a continuous tank cover, nicknamed Sayaendo, meaning “peas in a pod” (**Figure 3**). This carrier has obtained approval in principle (AIP) from classification societies such as the Lloyd's Register of Shipping (LR), the Det Norske Veritas (DNV), the Nippon Kaiji Kyokai (NK) and the American Bureau of Shipping (ABS). Whereas a conventional spherical tank carrier is equipped with hemispherical-shaped domes covering each aluminum alloy tank individually, the new carrier has a continuous tank cover integrated with hull over all tanks.

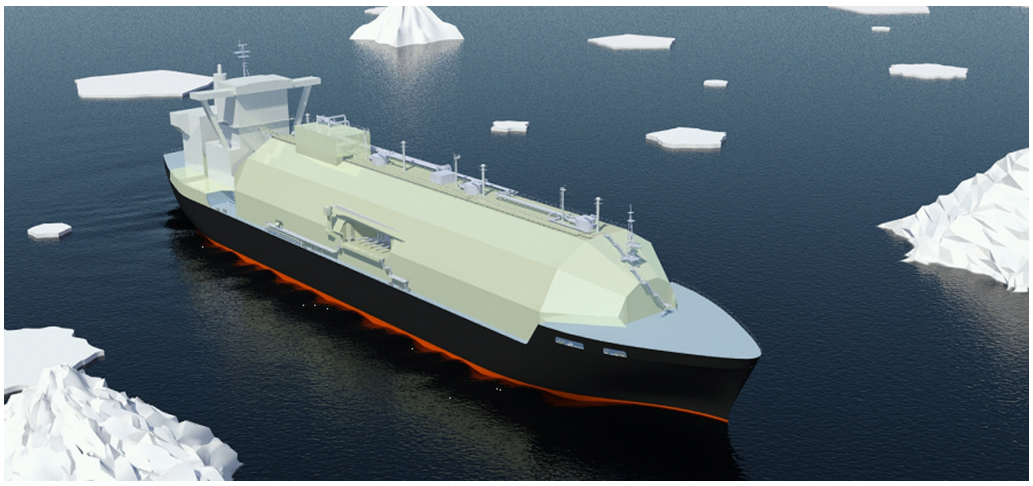

Figure 3 Continuous tank cover LNG carrier Sayaendo

The continuous tank cover significantly contributes to the overall hull strength integrity. It also allows optimal layout of steel materials needed to maintain strength and enables more compact carrier dimensions. Such structural benefits contribute to a reduction in the hull steel weight of about 10 percent, improved fuel consumption due to reduced displacement, and better terminal compatibility. These advantages make the Sayaendo design suitable for a large spherical tank LNG

carrier. The continuous tank cover also allows for elimination of conventional complex structures that support tank-top piping, cables, and passages, thus contributing to improved maintenance. Other gains, such as reduced exposure of supporting structures and outfitting, and higher protection to maintain global strength integrity against ice impact loads, also make the new design suitable for operating in cold areas or in ice-bound seas.

3. Diverse Propulsion Plants

Propulsion plants for LNG carriers have diversified rapidly in recent years in response to accelerated energy-saving demands triggered by sharp increases in fuel prices and tighter environmental regulations. This has led to the development of electric propulsion with dual-fuel engines (EpDFEs) and diesel with re-liquefaction (DRL) carriers in addition to conventional steam turbine ships. This chapter introduces five types of propulsion plants developed so far, including ones already in operation, and describes MHI's new activities in this field. As plant suitability must be evaluated case-by-case according to individual project characteristics, five choices are offered to MHI customers to better accommodate their diverse needs.

3.1 Conventional steam turbine (CST) plant

CST plants, which use steam generated by dual-fuel boilers to drive the main turbine, have been the most widely used propulsion plant since the arrival of LNG carriers. MHI, which also manufactures turbines and boilers, has built nearly 40 LNG carriers with CST plants, achieving a proven record of superior reliability. While rating very high in maintainability and fuel-selection flexibility (e.g., single burning of heavy oil or gas, dual burning at any mixture rate), CST plant efficiency is lower than that of other types of propulsion plants.

3.2 Ultra-steam turbine (UST) plant

A high-efficiency UST plant based on the reheat cycle enables an approximate 15 percent improvement in plant efficiency compared to a CST plant, while retaining the merits of conventional turbine plants. The UST plant offers reliability levels equivalent to a conventional plant in addition to high maintainability and fuel-selection flexibility. With plant efficiency comparable to other plants, the UST plant is considered the most economical plant overall. Positioned as the next-generation plant, the UST plant was developed as a company-wide project jointly-led by MHI's Technical Headquarters, Power Systems Headquarters, and Shipbuilding and Ocean Development Headquarters (**Figure 4**).

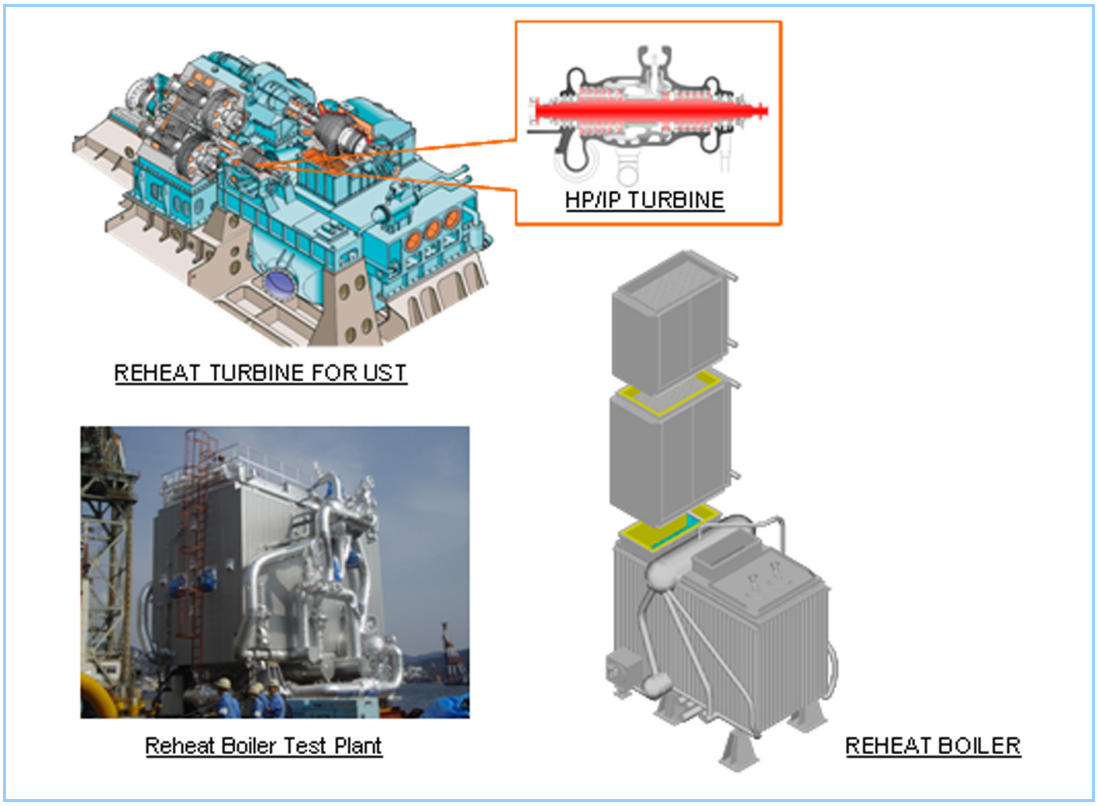

Figure 4 MHI high-efficiency propulsion plant (UST)

3.3 EpDFE plant

While the recently introduced EpDFE, two electric propulsion motors with four or five sets of dual-fuel diesel generator engines, boasts high plant efficiency with about a 20 percent fuel-cost improvement over a conventional turbine plant, it has higher maintenance requirements compared to conventional plants. Also of concern is its lower profitability due to increased boil off gas (BOG), generated by the LNG spray used to lower the intake temperature to ensure proper functioning of the gas compressor, becoming surplus gas during frequent reduced power operations. MHI has built two EpDFE LNG carriers so far (**Figure 5**).

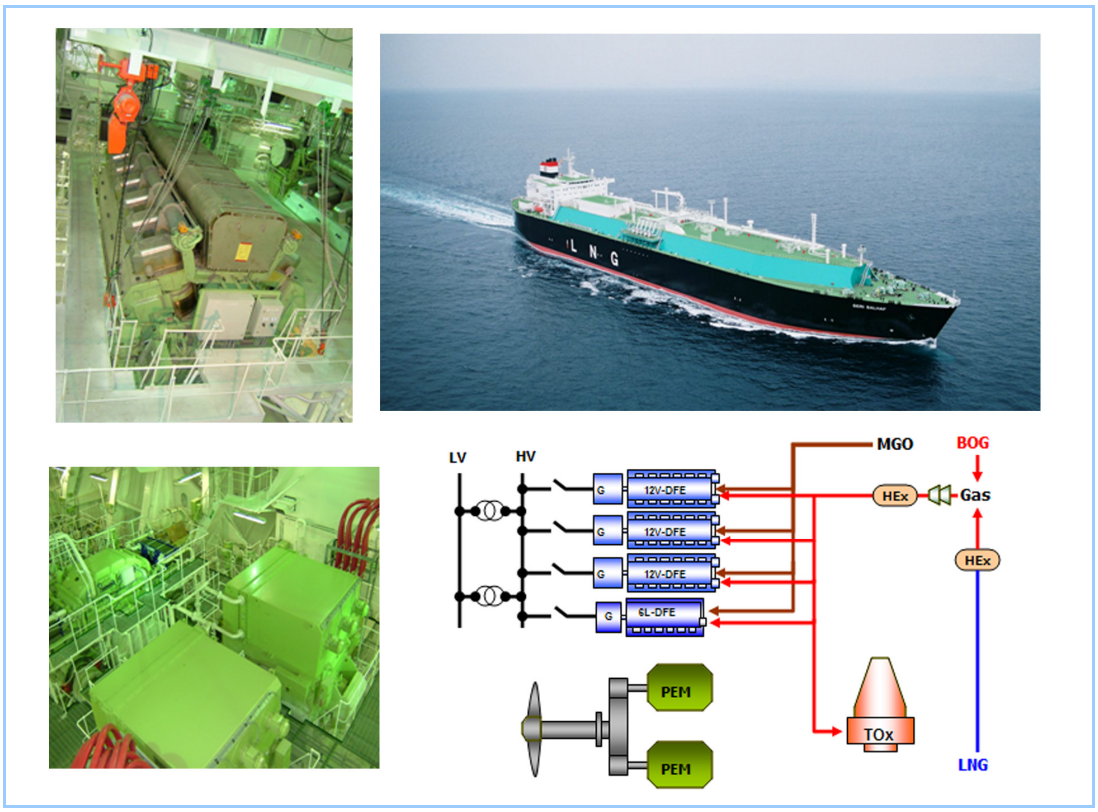

Figure 5 LNG carrier "Seri Balfaf" with EpDFE plant

3.4 DRL plant

A DRL, a heavy fuel-oil single-burning slow-speed diesel engine combined with BOG re-liquefaction, is generally equipped with twin engines and twin shafts to offer maintainability and redundancy during the carrier's operations. The system achieves high plant efficiency and does not waste BOG, regardless of engine load. While in excess of forty DRL LNG carriers have been delivered globally, the limitation in fuel selection, heavy oil only, makes their operational profitability subject to the influence of the heavy oil-to-gas price ratio. Moreover, as with conventional carriers, the use of heavy oil-burning diesel engines in DRL LNG carriers necessitates various actions in order to comply with increasingly strict environmental regulations. MHI became the first company in the world to install a BOG re-liquefaction system, the most crucial element of a DRL plant, with the construction of the steam turbine-powered LNG Jamal, which has demonstrated steady performance since its commercial launch in 2000.

3.5 Slow-speed diesel engine with gas injection and re-liquefaction (SSD-GI) plant

An SSD-GI, a twin-shaft plant with gas injection added to the slow-speed diesel engine used in the above-mentioned DRL system, offers high plant efficiency and flexibility in fuel selection, thus maintaining steady profitability unaffected by gas price fluctuations. While the use of a high-pressure reciprocating compressor is currently required in the gas supply system to provide the engine with high-pressure fuel gas of nearly 300 bar, a recently devised supply system equipped with a high-pressure liquid pump and evaporation system has come into the spotlight. However, due to its inability to treat naturally generated BOG and to perform pressure control in the cargo tanks, the new system will require the addition of a re-liquefaction system, as with the DRL system. MHI's re-liquefaction system enables partial re-liquefaction to reduce

overall re-liquefaction volumes by utilizing part of the BOG as re-liquefaction fuel, thus achieving improved system efficiency. It also offers an environmental advantage with the use of a steam-driven N_2 compressor. Furthermore, a high-pressure gas supply system with a liquid pump, currently in development, enables MHI to offer an environmentally friendly and high-efficiency plant by combining it with the above-mentioned slow-speed diesel with gas injection and re-liquefaction system (**Figure 6**).

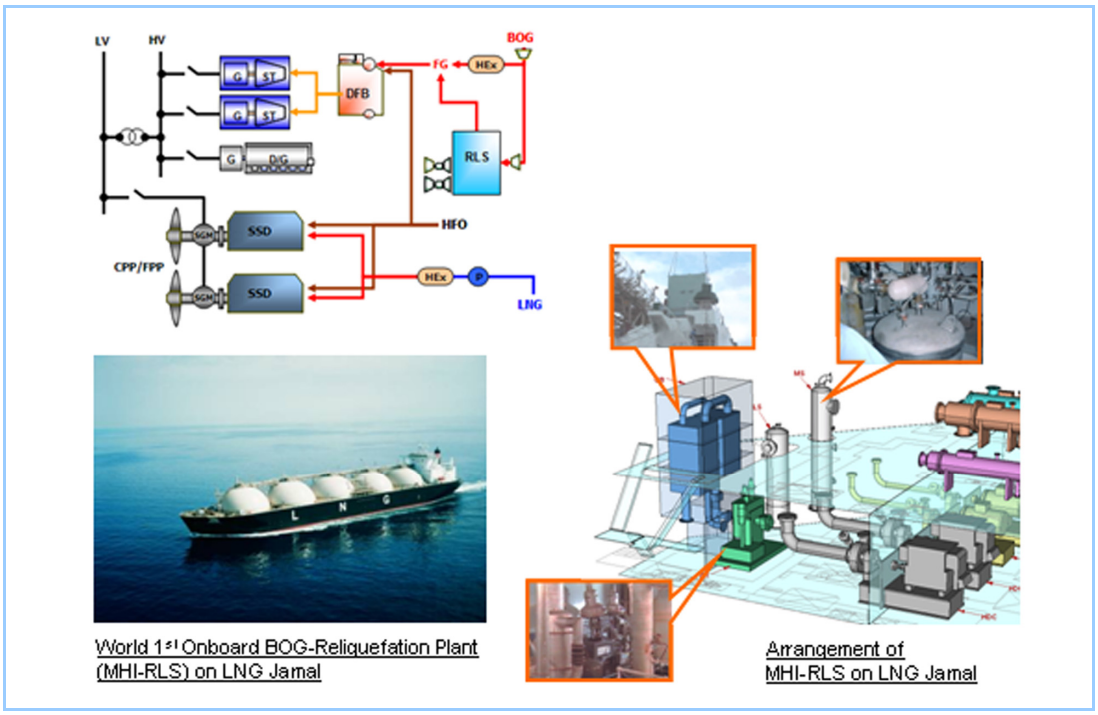

Figure 6 SSD-GI with re-liquefaction plant

4. LNG Marine Products

4.1 Trends

Generally, LNG has been produced from large-scale gas fields on land or near shore by a gas liquefaction facility installed on land. The liquefied gas is then transported in an LNG carrier to on-land re-gasification terminals in consumer countries, and once returned to its gaseous state at the terminals, the natural gas is distributed to customers. However, increasingly diverse gas fields and growing environmental concerns at terminal locations have made building liquefaction or re-gasification facilities on land difficult and/or not commercially viable. Attracting keen attention as an alternative to address these issues are floating production, storage, and off-loading units for liquefied natural gas (LNG-FPSOs) with on-board liquefaction facilities that directly receive and liquefy natural gas from offshore fields, and store and deliver it to LNG carriers. Another alternative is a regas vessel equipped with an on-board re-gasification facility that returns stored LNG to its gaseous state on site and distributes this to consumers. This chapter describes MHI's development of on-board re-gasification (regas) vessels and LNG-FPSOs in an effort to satisfy the diverse needs in LNG supply chains.

4.2 Regas vessels

As the increasingly diverse LNG trade prompts expanded needs in re-gasification terminals, numerous projects premised on employing LNG carriers with regasification facilities (regasification vessels or RVs) or floating storage and regasification units (FSRUs) with LNG tanks and regasification facilities are currently underway, and some are already in operation. Several advantages apply to RVs and FSRUs when compared with land-based regasification terminals. These include the relative ease in securing sites and construction permits, short lead times, low costs, low risks associated with delayed delivery and cost increases, and mobility of facilities. These advantages contribute to popularity in developed countries, including the U.S., where construction of land-based terminals is difficult due to environmental concerns, and in emerging countries that need to set up a plant in a short amount of time to satisfy current short-term demands for gas imports while the long-term needs may still be unclear.

Drawing from expertise garnered through its experience in designing and building numerous LNG carriers, MHI has developed a unique, energy-efficient, and environmentally friendly RV (**Figure 7**). MHI's RV, with its excellent fuel efficiency, low environmental load, and flexibility allowing optimal operation depending on offshore site conditions, enables efficient and reliable operation while leveraging the characteristics of the spherical tank system.

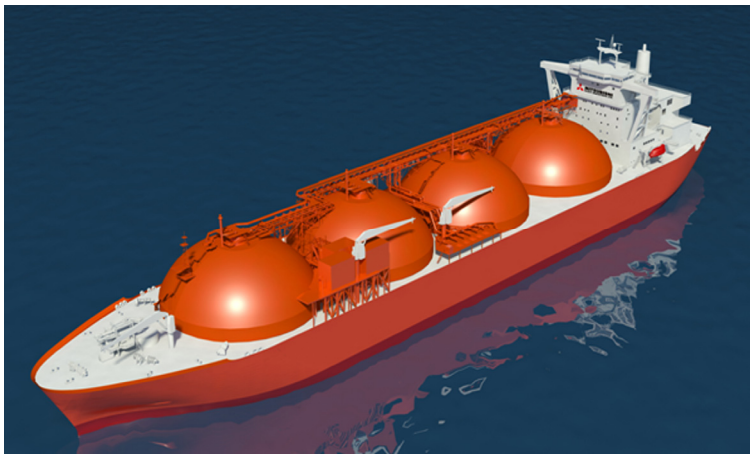

Figure 7 MHI on-board regasification vessel

4.3 LNG-FPSO

Recently, stranded gas reserves (i.e., large-scale offshore gas fields further out to sea and yet-to-be developed small- and medium-scale gas fields) have been regarded as new sources of LNG production. As a result, the advantages of LNG-FPSOs, such as offshore production, storage, and offloading capabilities, as well as mobility, have come into the spotlight as a new LNG production system. Unlike a conventional LNG carrier, an LNG-FPSO must continuously perform offshore LNG production, storage, and offloading without docking for repair, making the reliability of LNG storage tanks significantly more critical. Also important is the need for higher economic efficiency than other options as the floating structure, which includes an area sufficient for an LNG production plant.

Based on its extensive experience in constructing LNG carriers and FSO and FPSO units for oil production, MHI has developed a highly economical and reliable spherical tank LNG-FPSO for small- to medium-scale gas fields, obtaining an AIP from LR (**Figure 8**). Furthermore, other AIPs were also obtained from ABS, LR and NK for MHI's own design of independent prismatic tank Type B, developed for use on LNG-FPSOs in large-scale gas fields (**Figure 9**). Both methods offer optimal performance of LNG-FPSOs that meets diverse customer needs.

Figure 8 MHI's spherical tank type LNG-FPSO

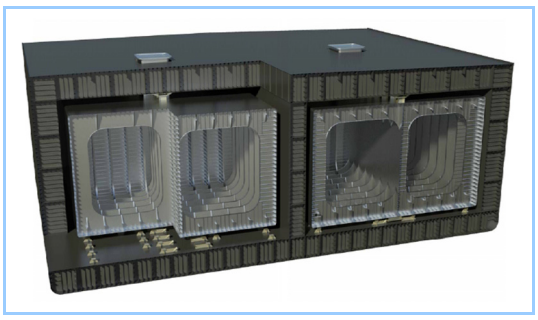

Figure 9 MHI's independent prismatic tank Type B (two row)

5. Conclusion

With a wide range of technologies and expertise garnered through its extensive experience in constructing LNG carriers, MHI is capable of offering various products with highly innovative options in terms of vessel types, specifications, propulsion plants, and liquefaction and regasification systems to meet increasingly diverse customer needs in LNG supply chains. Going further with its proven technologies, MHI continues to provide environmentally friendly products that are safe and reliable, and which offer superior economically efficiency.