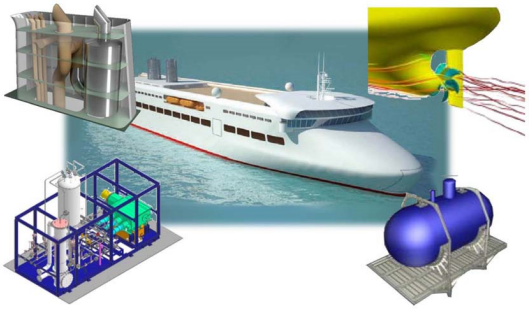
Approach to Environmental Solutions in the Marine Engineering Business



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Ships can transport large volumes of cargo at a time and are an environmentally-friendly means of transportation compared to others. In recent years, however, the tightening of various environmental regulations related to ships has been promoted in consideration of the burden on the environment. The scope of these regulations is wide, ranging from regulations on air pollution and global warming related to NOx, SOx and CO_2, to regulations on the preservation of the ecosystem, and appropriate measures for each regulation must be taken. Mitsubishi Shipbuilding Co., Ltd. (MHI-MSB) provides various environmental solutions to correspond to the need for reducing a wide range of environmental burdens in the shipbuilding and ocean development field. Among them, the energy-efficient hull-form, SOx Scrubber System, LNG fueled ship and LNG Facility for Marine Applications are described in this report.

1. Introduction

MHI-MSB provides new values that correspond to the fast-changing and evolving market environment and technological innovation (or customer needs), through its engineering business in the shipbuilding and ocean development field. In recent years, there have been concerns about the influence of the growing energy consumption of ships associated with the increase of marine transportation in terms of environmental issues in the marine field. Environmental regulations related to ships have been tightened one after another, and the need for solutions to cope with regulations is growing. In addition, natural gas as a clean energy, which is environmentally-friendly compared to other fossil fuels, has been in increasing demand, and the need for liquefied natural gas (LNG) carriers and ships or floating power generation facilities using natural gas as fuel is also on the rise. In this report, environmental solutions to these needs that we provide are described.

2. Coping with environmental regulations surrounding ships

Ships can transport large volumes of cargo, offer high transportation efficiency, and are an environmentally-friendly means of transportation compared to land or air transport. On the other hand, marine transportation has been increasing globally, and measures to deal with environmental issues have been required. Against this background, various regulations for the purpose of reducing the environmental burden of ships on the atmosphere and oceans have been set by the International Maritime Organization (IMO), and they will continue to be tightened. Therefore, the need for solutions to cope with regulations has grown.

Table 1 shows an overview of environmental regulations on ships. The contents of the major regulations are also described below.

The CO_2 emissions regulations (EEDI regulations) target only newly-built ships and establishes that the amount of CO_2 emissions in the transport of 1 ton of cargo for 1 mile should be the regulation value or less, and the conformance is checked by the model tank test and through sea trials. At present, Phase 1 of the regulations (10% reduction from the reference line value) has commenced and will be tightened in stages.

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Table 1 Environmental regulations on ships

Purpose	Regulated item	Regulation target	Content of regulations	Measures
Reduction of greenhouse effect gas Protection of ozone layer	CO_2 emissions (EEDI* regulations)	Newly-built ships Converted ships	Reduction rate from the reference line value (Building contract date) ** Phase 1 (from 2015) 10% reduction Phase 2 (from 2020) 20% reduction Phase 3 (from 2025) 30% reduction	Energy-saving hull-form/ energy-saving device Liquefied gas fuel Energy-saving propulsion plant
	Substances that destroy the ozone layer	All ships	Complete abolition of CFC (chlorofluorocarbon) Complete abolition of HCFC (hydro CFC) from 2020	Refrigerator in which alternative refrigerant can be used
Prevention of air pollution	SOx emissions Particulate matter PM	All ships	Concentration of sulfur in fuel oil General sea area: 0.5% or less from 2020 Emission control area***: 0.1% or less from 2015	Low-sulfur fuel oil Liquefied gas fuel SOx scrubber
	NOx emissions	Engine output 130 kW or more	Reduction rate from the primary regulations in 2000 (date of keel laid) General sea area: (from 2011) about 20% reduction Emission control area****: (from 2016) about 80% reduction	Liquefied gas fuel SCR (Selective Catalyst Reduction NOx Removal Equipment) EGR (Exhaust Gas Recirculation)
Protection of ecosystem	Ballast water	All ships	Effect from September 2017 The device shall be installed by the time of the next certificate renewal inspection. The quantity and size of plankton and bacteria contained in discharged ballast water	Ballast water treatment device
Prevention of marine pollution	Oil	All ships	Concentration of oil in waste water: 15 ppm or less	Oily water separator
	Wastewater	All ships	The quantity of Escherichia coli, the amount of suspended solids, etc., in waste water	Wastewater treatment device

* EEDI: Energy Efficiency Design Index
** Varies depending on type and size of ship.
*** Emission control area: North Sea, Baltic Sea, North America, the Caribbean Sea (U.S.A.)
**** Emission control area: North America, the Caribbean Sea (U.S.A.)
(Also includes the North Sea and Baltic Sea for ships constructed on and after January 1, 2021.)

The SOx regulations were instituted for the purpose of reducing the emission of SOx from ships, which is regarded as a causative agent of acid rain, etc. SOx in the exhaust gas from ships depends on the concentration of sulfur content in the fuel oil, and the regulations are intended to control it. For general sea areas and emission control areas (ECA), respectively, regulations have been tightened in stages. In 2020, the use of fuel oil with a sulfur content of less than 0.5% in general sea areas will become mandatory. As an alternative to the conversion of fuel oil, the use of conventional heavy fuel oil is permitted on the condition that SOx in the exhaust gas is removed by a SOx scrubber.

The ballast water control regulations were instituted for the purpose of preventing adverse effects on the ecosystem due to the migration or proliferation of aquatic organisms in sea areas that are not their original habitats. The installation of a device (ballast water treatment device) for sterilizing plankton and bacteria in ballast water using agents or ultraviolet light is required, and it must be applied to all newly-built ships from September 2017.

The movements in the marine industry to deal with these environmental regulations are as follows:

- Keen interests to adopt energy-efficient hull-form
- Studies of shifting to propulsion plants using clean fuel such as LNG or LPG
  (Studies must be made with an eye to the development of fuel supply infrastructure)
- Installation of a SOx scrubber as an alternative to low-sulfur fuel has been actively investigated
  (Requiring an investment decision under the situation that the future price difference between low-sulfur fuel oil and general fuel oil is uncertain)
- Installation of ballast water treatment devices on existing ships
- Scrapping of aging ships that require further investment for environmental measures
- Concerns about increase of crew workloads resulting from the operation and maintenance of additional devices and systems

MHI-MSB provides high-quality environmental solutions to these various market movements (needs), which will be explained in the subsequent sections.

3. Efforts in hull-form licensing business

3.1 Environmental regulations and hull-forms

Among environmental regulations surrounding ships, the regulations that have a particular effect on the hull-form are the EEDI regulations for the purpose of reducing CO_2 emissions, and the step-by-step tightening of the regulation values is defined by the International Convention for the Prevention of Pollution from Ships (MARPOL Convention). It is required that relative to the EEDI average value for the ships that entered service during the period of 1999 to 2008, the EEDI regulation value should be reduced by 20% for ships contracted in 2020 and onward and be reduced by 30% in 2025 and thereafter. For the improvement of EEDI, conversion to low-CO_2 emissions fuel, etc., is also an effective means, but first and foremost, the development of a hull-form with good propulsion performance is required.

3.2 Licensing hull-form

Under the aforementioned circumstances, demand for the development of high-performance hull-forms has grown, and we started the full-fledged licensing of hull-forms to third party shipyards from 2012. In the licensing of hull-form, MHI-MSB offers flexible services according to the requests of customers such as shipyards or ship owners. We can provide a hull-from from the lineup of developed ships or a customized hull-form including the initial design and propeller design. MHI-MSB has developed 20 hull-forms so far, including a wide range of ship types such as container carriers, bulk carriers, car carriers and RoRo ships.

3.3 Development of hull-form in consideration of operational profile

EEDI is one of the important indices that show the energy-saving performance, and it is the value at the summer load line and 75% MCR (Maximum Continuous Output) defined by the regulations and does not always represent the performance in the actual operational state.

Therefore, if the development of a hull-form is conducted with attention directed only to EEDI, the situation where the fuel efficiency under actual operation becomes poor may occur. In particular, due consideration must be given in the development of container carriers, which have large cargo volumes, and ships that have varying drafts or speeds based on the sea routes.

In the development of a hull-form, MHI-MSB proceeds development and optimizations in consideration of the actual operational conditions (draft, speed) and the duration. The distribution of the operational conditions and the duration is called the operational profile, which is prepared according to the estimated operating routes and schedule. **Figure 1** shows an example of the operational profile. Accordingly, the performance in each operational condition is estimated, as are the required horsepower and fuel consumption under each condition. The combination of these data allows a quantitative calculation of the overall fuel efficiency performance under actual operation. By changing the hull-form so that the fuel consumption is minimized and adjusting the propulsion performance, MHI-MSB determines the hull-form with the highest fuel efficiency under actual operation.

Thus, MHI-MSB not only meets regulations, but also develops hull-forms that satisfy our customers with their performance under actual operation.

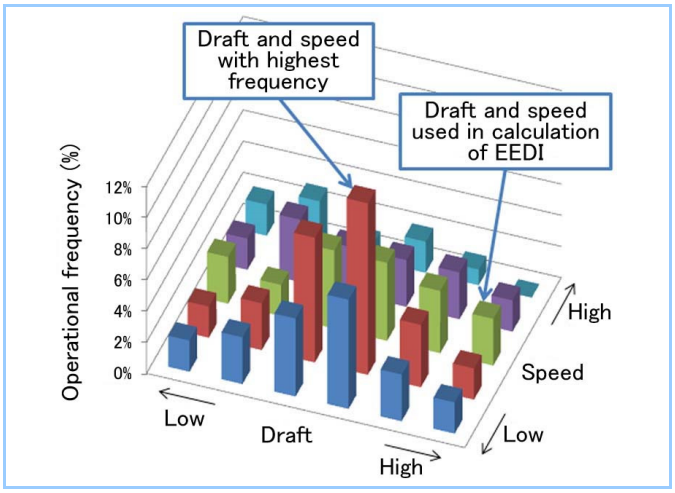

Figure 1 Example of operational profile

3.4 Contribution to the environment using our comprehensive hull-form development capability

MHI, as a private company, owns the world's largest tank test facilities not only a towing tank, but a cavitation tank, a seaworthiness-maneuverability water tank, a shallow water tank and a large wind tunnel facility. The results of many tests conducted so far are maintained as a database, and by using the database and the feedback from ships that we have built, we can provide a high-accuracy performance estimation for a wide range of ship types and models.

High-efficiency propellers and energy-saving devices such as Reaction Fins can also be combined to build a hull-form. Thus, MHI-MSB has comprehensively developed optimal hull-forms (**Figure 2**).

MHI-MSB has continuously made efforts to develop next-generation energy-saving devices and to establish CFD analysis technology using large-scale parallel computing and we will continue to contribute to the environment through the provision of fuel-efficient hull-forms.

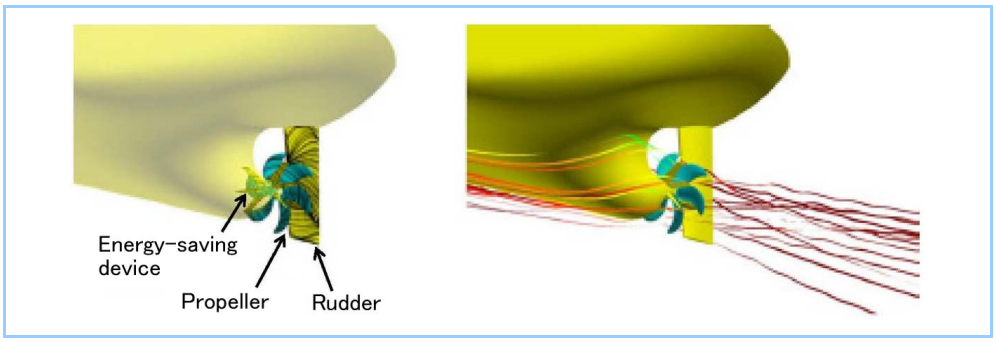

Figure 2 Integrative analysis situations of rudder, energy-saving device and propeller

4. SOx scrubber system

4.1 Background

Due to the sulfur contained in heavy oil fuel used in ships, SOx, which is regarded as a causative agent of air pollution and acid rain, is contained in exhaust gas emitted from ships. Under the MARPOL Convention, the standards for the sulfur content in fuel oil have been tightened in stages to reduce SOx. In Emission Control Areas (ECAs) including the North Sea area and Baltic Sea area in the European and North American coastal zones, the sulfur content of fuel oil must be 0.1% or lower. Outside the ECAs, the use of fuel oil with a sulfur content of 0.5% or lower will become obligatory from January 1, 2020.

The MARPOL Convention allows the continuous use of conventional heavy fuel oil with a high sulfur content only if an exhaust gas cleaning system which can reduce SOx in exhaust gas to the regulation value or lower is installed.

4.2 SOx scrubber system

MHI built a scrubber demonstration plant where the evaluation and verification of desulfurization performance are conducted using exhaust gas input from a 2-stroke diesel engine. Since 2010, MHI and Mitsubishi Kakoki Kaisha, Ltd. have jointly developed an exhaust gas cleaning device based on wet-type scrubber technology. The Hybrid SOx Scrubber System is a product developed based on the findings obtained from the aforementioned demonstration plant. This system is a "hybrid type" system which has two methods for cleaning the exhaust gas: open-loop mode in which the intake seawater is directly sprayed into the exhaust gas, and closed-loop mode in which the exhaust gas washing water is circulated while being neutralized by caustic soda (NaOH). This system provides a sufficient exhaust gas desulfurization capacity that is applicable in various sailing areas including oceans, rivers and ports.

An overview of the open-loop system is shown in **Figure 3**. The seawater pumped from outside the ship is sprayed into the scrubber tower, where it comes into contact with the exhaust gas and separates and absorbs SOx. The seawater used for washing is discharged as waste water to the outside.

An overview of the Hybrid Scrubber System is shown in **Figure 4**. This system can operate in both closed-loop mode and open-loop mode. In closed-loop mode, the circulation water taken in

from the tank at the lower part of the scrubber tower is sprayed into the scrubber tower and comes into contact with the exhaust gas, thereby separating and absorbing SOx. After that, the washing water is returned to the tank. The washing water is acidic due to the absorbed SOx, and therefore, NaOH is injected as appropriate while the pH in the circulation line is monitored, so that the pH is maintained within a certain range. In addition, the specific gravity of the circulation water is monitored, and some of the circulation water is treated by the waste water treatment device as needed to remove turbid matter. In closed-loop mode, since recirculation water treated as described above is used, stable exhaust gas washing can be conducted independently of the properties of the seawater in sailing areas.

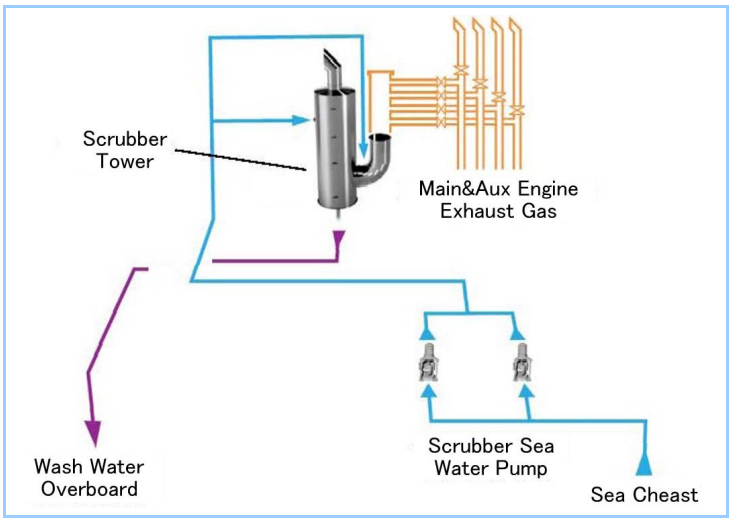

Figure 3 Open-loop system

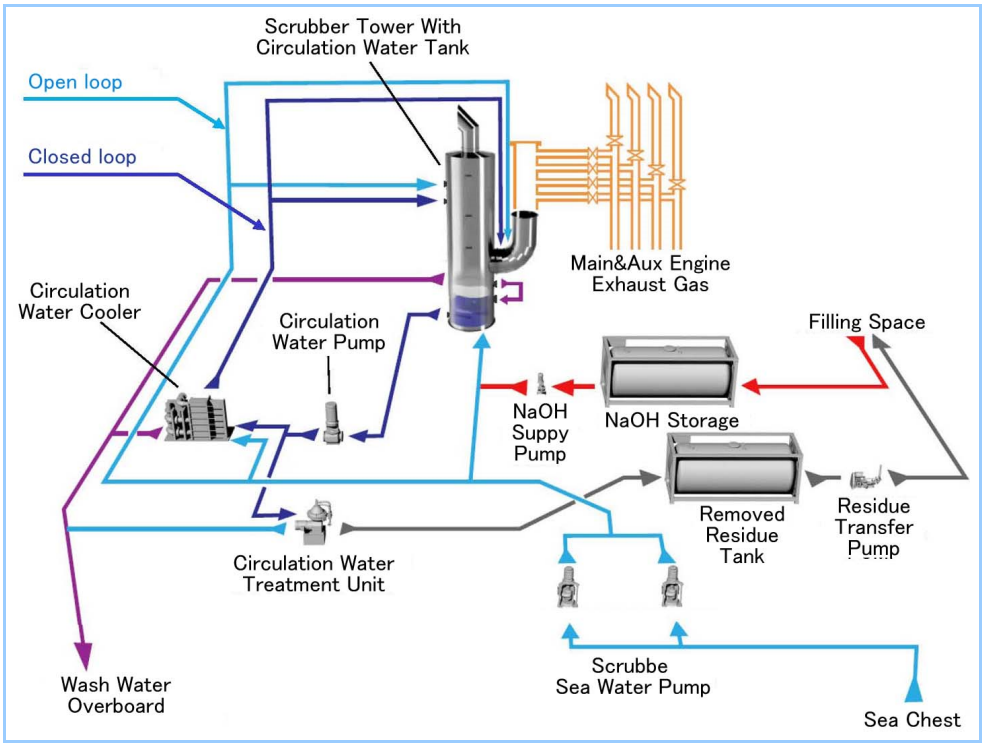

Figure 4 Hybrid system

In the hybrid system, the number of elemental components is increased compared to a system offering only open-loop mode. Therefore, the degree of difficulty in design and installation work tends to be higher. In order to lighten the load, we can also provide a container package (**Figure 5**) as an option, in which the main auxiliary components are modularized and built in a shipping container.

The SOx scrubber system does not require a change or modification of the engines and their fuel supply systems, which offers a major advantage for ships in service. In its installation, engineering services including the preparation of drawings for modification and procedures for the

approval of the country of the ship's registration are required. MHI-MSB also provides a retrofit engineering package including the preparation of drawings for modification and the preparation of documents for the approval of the country of the ship's registration based on our experience in the shipbuilding field.

Figure 5 Full view of hybrid system container package

5. LNG fueled ships

One of the most effective measures for the SOx regulations that will be applied to general sea areas in 2020 is conversion from conventional heavy oil fuel to LNG fuel. Differing from heavy oil, LNG does not contain sulfur and so it is not only SOx-free, but also has a low C/H ratio of methane, which is the main component of LNG. Therefore, LNG enables the reduction of roughly 20% of the CO_2 that is produced in the generation of the same heating value, and it is regarded as a very promising alternative fuel. On the other hand, the building of LNG fueled ships is technically very difficult for a shipyard with little experience in building liquefied-gas vessels such as LPG carriers or LNG carriers, and engineering support for the shipyard is required. To meet this need from shipyards, MHI-MSB provides gas handling facilities and engineering services for LNG fueled ships based on the liquefied-gas technologies cultivated through our many years of building and servicing LNG/LPG carriers.

Figure 6 shows the fuel gas supply unit modules for ship (for dual fuel 2-cycle direct-injection engine). **Figure 7** shows the fuel gas supply unit modules for ship (for dual fuel 2-cycle premixed engine), **Figure 8** shows the LNG fuel tank unit (IMO Type C tank). **Figure 9** shows the fuel gas supply demonstration plant for ship. This plant is a onshore plant having a similar specification to the fuel gas supply unit modules for ship. With this plant, tests can be conducted using LNG to demonstrate the performance and the reliability of equipment.

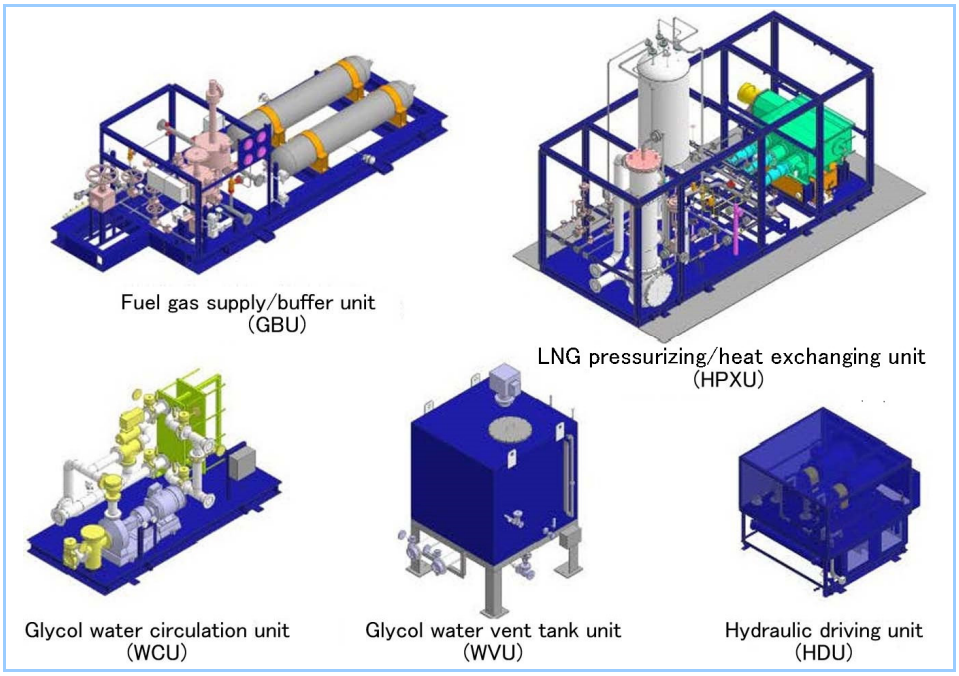

Figure 6 Gas supply facility modules for ships (for dual-fuel 2-cycle direct-injection engine)

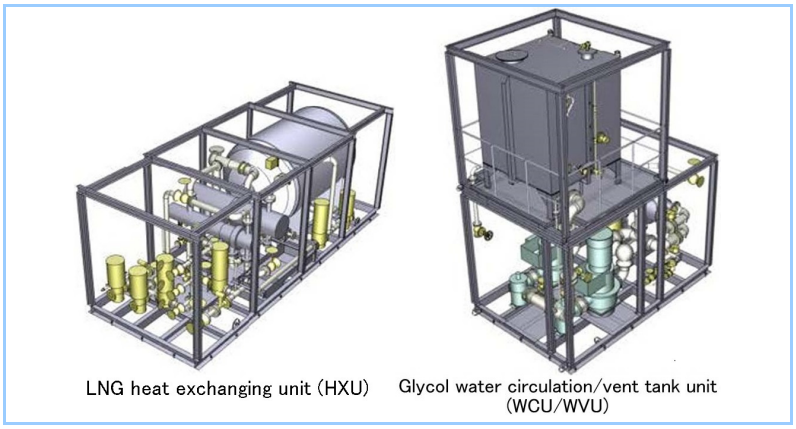

Figure 7 Fuel gas supply unit modules for ships (for dual fuel 2-cycle premixed engine)

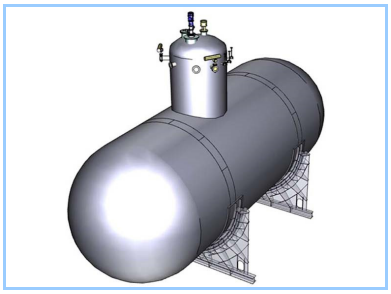

Figure 8 LNG fuel tank unit (IMO Type C tank)

Figure 9 Fuel gas supply demonstration plant for ships

The features of our equipment are as follows:

- Optimum gas supply equipment that matches various engines can be proposed.
- Provision of modules enables labor saving in installation at shipyards.
- Based on the test results at the demonstration plant, highly-reliable equipment can be provided.

In the provision of each fuel gas supply unit to shipyards, MHI-MSB and Diesel United, Ltd. cooperate to sell the package of a dual-fuel 2-cycle premixed engine (X-DF engine) and a fuel gas supply unit. This sales system allows ship owners and shipyards to enjoy the following advantages:

- Unification of sales contract window and after-sale service window (Single Window)
- Clarification of responsibility for LNG fuel part (Single Responsibility)
- Labor saving in shipyard work (specification adjustment, etc.)

In addition to the provision of the aforementioned facilities, MHI-MSB proposes total solutions including engineering services for initial studies, trial operation and the delivery of LNG fueled ships. We also support shipyards in the building of LNG fueled ships, and we have made further efforts to promote their use.

We have provided the gas supply units for dual-fuel engine demonstration facilities to ship engine manufacturers and engineering services to shipyards for the purpose of obtaining the approval in principal (AIP) of LNG fueled ship design. In the future, we will continue to provide high-quality environmental solutions, thereby contributing to the reduction of environmental load.

6. LNG facility for marine application (MHI-GEMS)

6.1 Offshore deployment of LNG supply chain

In the production process of liquefied natural gas (LNG) and natural gas, sulfur is removed. When LNG or natural gas is used as fuel in an internal combustion engine, nitrogen oxide, soot and dust generated in exhaust gas can be reduced to a very low level, and they are environmentally-friendly fuels.

Recently, in emerging countries where the electric power demand is growing sharply, demand for LNG has grown rapidly in many places around the world. In the shipping field, LNG is also in increasing demand, and mainly to comply with environmental regulations for coping with air pollution in coastal countries, LNG has started to be used as fuel for ships.

LNG requires a larger equipment investment compared to other fuels. MHI proposes the

offshore deployment of an LNG supply chain with reduced investment so that the use of LNG can be economically realized even for small cities (regions). We expect that this proposal will be promising to emerging countries where industry is developing at a remarkable pace, in particular in Southeast Asia, South Asia and South and Central America. In the future, it will also be useful for industrial development in Africa. In these regions, the quick securement of electricity at low cost is in demand. In many cases, a relatively low amount of electricity is demanded at first, and construction within a short time is required. The proposed LNG supply chain with floating production and receiving facilities allows the step-by-step expansion of investment starting on a small scale, and it can be completed within a short time.

In addition, in regions where the surrounding infrastructure has not been fully developed and the offshore supply area is large, a floating facility enables the building of ships including lifelines at shipyards and delivery to a site. Therefore, a floating facility is advantageous in terms of development in emerging countries, which require gradual facility enhancement through relocation/replacement, as well as in the development of small and medium-scale gas fields.

6.2 MHI-GEMS

Based on technologies for cryogenic storage, re-liquefaction, regasification, gas combustion and use of liquefied gas as fuel that have been cultivated in the business of building and repair of LNG carriers and LPG carriers, MHI-MSB developed the liquefied gas equipment and modules to be installed on ships and floaters and commercialized them as MHI-GEMS (Gas ship Equipment Module and System), in addition to operating the engineering business.

Figure 10 shows the proposed supply chain and one example of the group of facilities to be installed on each ship or floater. We supply a package of on-board or floating LNG facilities such as power plant for the floating LNG production, storage and off-loading facility (FLNG), the re-liquefaction facility for LNG carriers, Type C LNG storage tanks for small or medium-scale LNG carriers, floating LNG storage units, etc., and LNG regasification facility (MORV: Marine Open Rack Vaporizer adopted) for floating LNG storage and regasification unit (FSRU), promote the use of LNG as ship fuel and expand the LNG supply chain to cope with the electricity demand in emerging countries through distributed gas-fired power generation to contribute to the reduction of the emission of environmental load substances in the ocean.

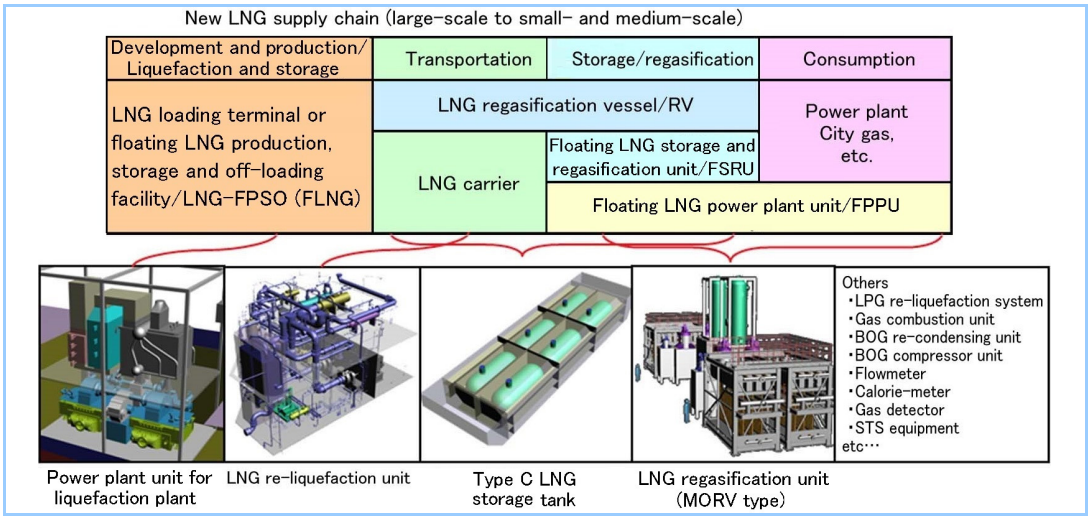

Figure 10 New LNG supply chain (large-scale to small- and medium-scale)

7. Conclusion

In this report, solutions on the theme of the environment among our products and technologies in the shipbuilding and ocean development field were described.

The need for solutions using environmental technologies in various fields has continued to increase, such as the provision of efficient marine transportation and environmental load reducing systems, the use of environmentally-friendly clean energy, and next-generation energy solutions using the ocean. MHI-MSB will continuously contribute to the sustainable development of our society through the provision of more steady and effective solutions that correspond to customer needs in the marine engineering business.