Development of Next-Generation LNGC Propulsion Plant and HYBRID System

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In recent business of new building LNG carriers, demands have frequently been made for a alternative propulsion system to replace the steam turbine propulsion. In the background to this are sharp increases in worldwide LNG demands and the advent of new style of LNG trade, leading to a strong intention to improve transportation costs by introduction of the enlargement of cargo tank capacity and alternative propulsion systems in many new LNG projects. Furthermore, an abrupt increase in number of ships in service has led to a serious shortage of propulsion system operators, who need to be skilled for steam turbine propulsion plant. These occasions in recent years stimulated the development of new techniques represented by the boil-off-gas (BOG) re-liquefaction plant and the duel fuel gas engine has been put into practical use in quick succession. Developments of alternative propulsion system are now being promoted mainly focused on diesel engine application, while Mitsubishi Heavy Industries, Ltd. (MHI) is going ahead with the development of various types of propulsion systems. This paper introduces the HYBRID LNG system originated and developed by MHI, making mention also of the latest trends in substitute propulsion systems.

1. Introduction

All LNG carriers(Note 1) now in service adopt the steam turbine propulsion system with duel fuel boiler. Since the oil crisis, conversion of the propulsion system has been made in almost all merchant ships, by the application of low-speed diesel engine(Note 2) directly coupled with propeller. In the case of LNG carriers, however, the current system is adopted in all such carriers because it is the best method of treating BOG safely and efficiently.

In LNG carriers that transport LNG in the refrigerated condition, BOG is inevitably produced as a result of heat coming from outside the tanks. In order to control the tank pressure rise, BOG is utilized as boiler fuel to get propulsive force by the steam turbine.

In cases where the combustion heat of BOG is in excess of the required propulsive force, surplus heat is disposed of in the sea water. In cases where the combustion heat of BOG is less than the required propulsive force, the required heat is made up by additional burning of heavy fuel oil (bunker oil) or forcing vaporization of LNG. The current system is capable of using both LNG and heavy fuel oil as fuel, and thus of selecting the most economical fuel mixture.

Moreover, it has a better serviceability ratio, reliability and maintainability among the propulsion systems and is in no way inferior to the latter except in the aspect of thermal efficiency.

However, use of this propulsion plant has become less common in general merchant ships lately. In addition, it has become much more difficult to train and secure crew members capable of meeting the sharp increase in newly built ships because of the high level of skill required. Mainly for these reasons, development of a substitute propulsion system has been promoted.

Note 1: The "LNG carrier" referred to here means a ship for large-scale transportation of LNG in the saturated condition at atmospheric pressure and does not include small-sized pressurized tank type.

Note 2: 2-cycle long-stroke diesel engine

2. Alternative propulsion plant

2.1 Requirements for propulsion plant

For the LNG carrier propulsion system, there is a requirement not only for improved thermal efficiency but also for safe and efficient treatment of BOG.

For efficient treatment of BOG, there are two methods; one is to use BOG as "fuel for various types of engines" and the other is to "save it by re-liquefaction." Techniques related to the re-liquefaction of BOG and gas fuel utilized engines have recently been put into use rapidly in the marine field.

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(1) BOG reliquefaction plant (**Fig. 1**)

The S/S LNG Jamal, built at MHI's Nagasaki Shipyard and put into service in November 2000, is an LNG carrier equipped with the world's first LNGC onboard re-liquefaction system. Having successfully passed its overhaul inspection in first dry dock in August 2003, this system has the operation result for nearly four years. With the conventional type steam turbine adopted as its propulsion system, this carrier is operated using cheap heavy fuel oil, and saving BOG by re-liquefaction on voyage with cargo loaded.

The re-liquefaction process adopts the intermediate cooling system using the Brayton cycle in which nitrogen is used as refrigerant. In this process, BOG is liquefied and subcooled in the pressurized condition, and is then returned to the tank. There is no consumable supply including refrigerant nitrogen, for the nitrogen is produced from the air on board. For compression of BOG, a system in which two units of centrifugal single-stage compressors (motor-driven) are adopted for the purpose of sharing it for boiler supply, and they can also be connected in series for boosting supply to re-liquefaction.

For compression of nitrogen, centrifugal, three-stage compression is adopted in which the 1st and 2nd stages are driven by a steam turbine and the 3rd stage one is driven by a nitrogen expansion turbine for the purpose of the power recovery of expansion process. Also, by development of a dedicated control device for re-liquefaction system, automation of starting procedure and unmanned continuous operation during normal navigation were realized, leading to a reduction in work load and high skill of operators.

(2) Dual fuel engine

This four-cycle internal combustion engine(Note 3) for generator drive is capable of achieving high thermal efficiency (48% on lower calorific value basis) and low NOx emission rate (up to 3 kg/kWh: on gas fuel burning). It was adopted as the main engines of an electrical propulsion LNG carrier being built (as of 2004) at ALSTOM's Shipyard in France.

This engine, which is capable of being operated by Gas Mode (Otto-cycle) using fuel gas as main fuel and diesel oil as pilot fuel, and Oil Mode (diesel-cycle), is called the dual fuel engine (DFE).

Since this engine is very low in gas supply pressure (ca. 5 bar) and features excellent safety as compared with the high-pressure gas injection type diesel engine, it is well suited for use as a marine engine. Moreover, it is different from so called "gas engine" which uses gas only, in that it is possible to simplify the engine configuration because they can be operated by diesel oil on voyage with no LNG loaded.

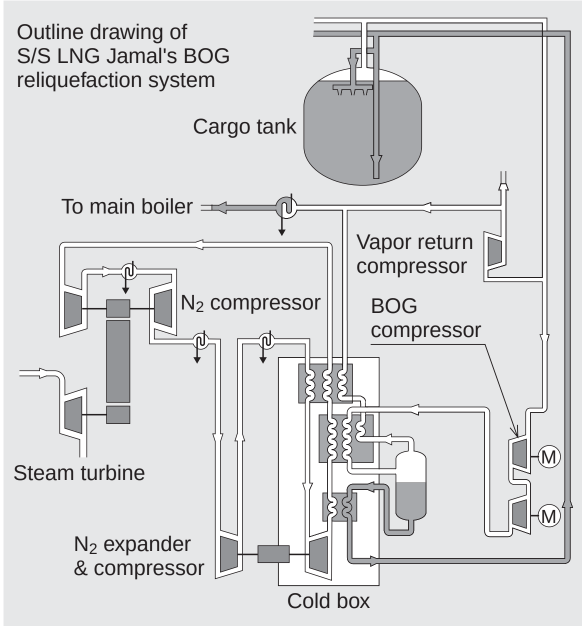


Fig. 1 Outline of LNG Jamal reliquefaction system

Note 3: Based on the performance data of 50DF of Wartsila Corporation.

2.2 MHI's R&D for alternative propulsion systems

Promising alternative propulsion systems now under development around the world are based mainly on the application of diesel engine to propulsion plants. In addition to these, however, MHI has developed a wide variety of alternative systems including a high-efficiency steam turbine propulsion system and utilization of gas turbine (**Fig. 2**).

From the view of engine power conversion to propulsive force (propeller driving force), they are categorized into the direct system and indirect system.

(1) Direct coupled system (directly coupled with engine)

The low-speed diesel engine, thanks to its excellent operating performance at high power and its wide power range, can be driven directly coupled with a fixed-pitch propeller. Moreover, since it is popular for use in large-scale merchant ships, there is no problem in how to secure operators. However, since this engine is inferior to the steam turbine engine in terms of the serviceability ratio and maintenance load, two units of the same type engines (twin-screw vessel) are required in many cases in order to secure redundancy for maneuvering.

While the high-pressure gas injection type low-speed diesel engine has also been put to practical use in a power-generating facility installed on land, but it is not preferred as a marine engine for reasons of reliability, operating results and high-pressure gas handling. Therefore, its combination with a BOG treating system such as BOG re-liquefaction plant is additionally required.

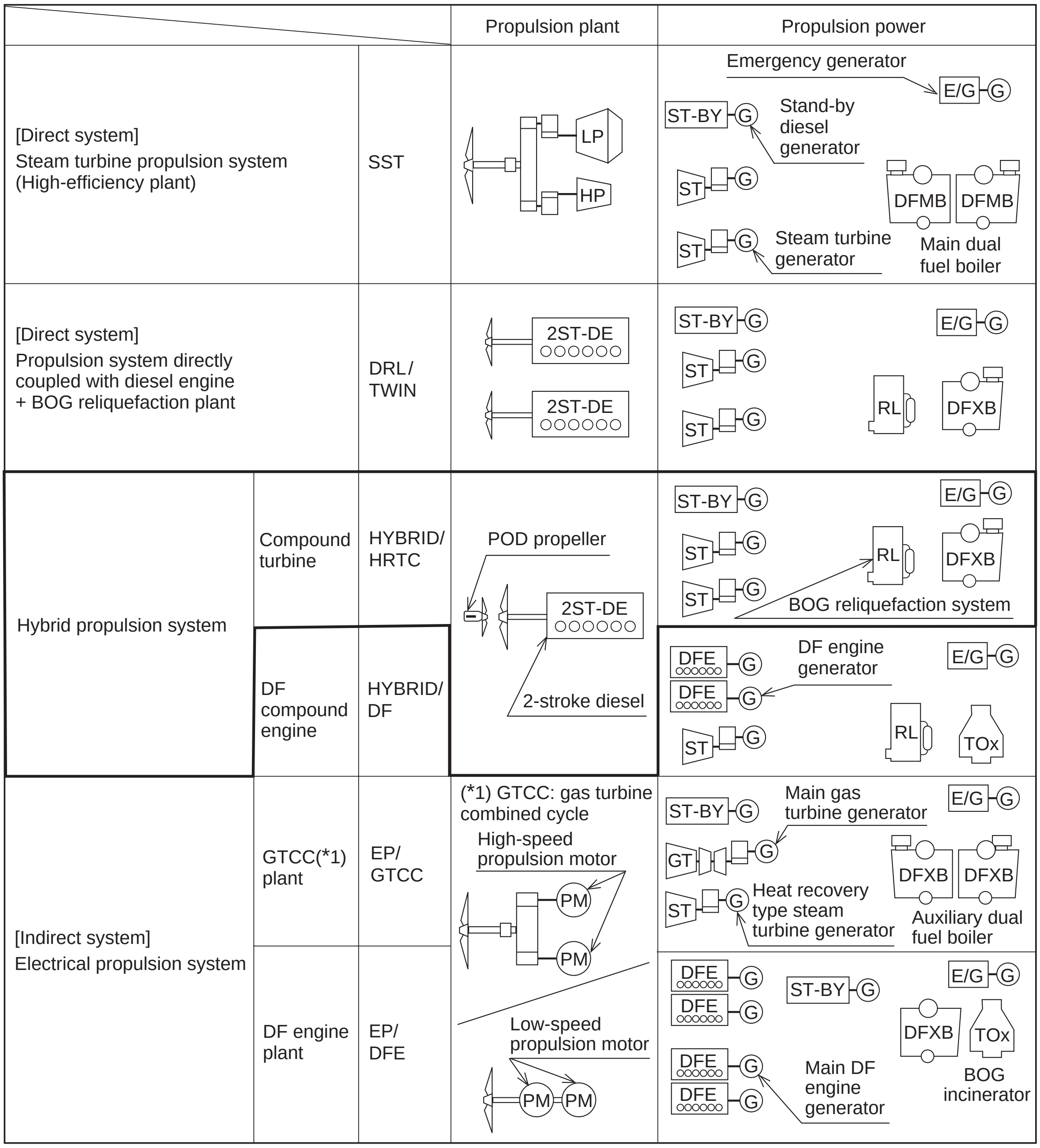


Fig. 2 Substitute propulsion candidate systems

(2) Indirect system (electrical propulsion)

Since it is considered unsuitable to couple DFE and a gas turbine directly with the propeller in view of the operating performance, the indirect system by electrical propulsion is selected.

For the propeller driving propulsion motors, a highly redundant structure consisting of two motors coupled together is required. Therefore, a system in which two high-speed type motors are decelerated, and a low-speed type directly coupled system, will be taken as candidates (actually this system is adopted in the case of the newly built ship of electrical propulsion type mentioned above).

The electrical propulsion system is in common use as the engine for passenger ships because of its high reliability and low vibrations/noise, but is not usual for large-scale merchant ships because it is expensive solution for many cases.

For this reason, it is usually taken importance on the evaluation of the balance between the fuel cost improvement and the increase in initial investment.

3. Hybrid propulsion system

The HYBRID LNG system proposed originally by MHI is a system in which diesel engine propulsion and auxiliary electrical propulsion as well as re-liquefaction system and gas combustion system are combined in the propulsion plant and BOG treating plant, respectively.

3.1 Hybrid propulsion plant

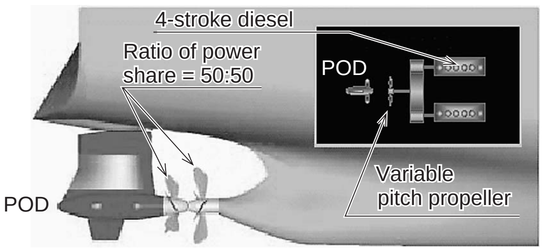
The CRP POD system (**Fig. 3**) adopted for the first time in the world for a ferry boat built by MHI and put into service in June 2004 is considered to be a suitable propulsion system for high-speed vessels and high-powered ships such as next-generation high-speed container ships. This system can achieve high power, fuel cost improvement and high maneuverability with comparative ease.

The propulsion plant in the HYBRID LNG system is also of similar structure consisting of a low-speed diesel engine and electrical propulsion plant.

The ratio of power share between the diesel engine and POD is determined by the maneuvering around coastal and portal area (low-steaming navigation), with POD alone taken as the basic requirement and in consideration of the additional propulsive force during ocean going navigation.

3.2 Hybrid BOG treatment plant

The auxiliary power system in the HYBRID LNG system can treat BOG in a safe and efficient manner by adjusting the quantity of BOG to be re-liquefied and that to be fired, thus adapting to the circumstances in combination with the re-liquefaction system (**Fig. 4**). The cogeneration system, in which waste heat from the main engine and the heat generated upon partial combustion of BOG are utilized, supplies electric power to POD and liquefying power, which are the main source of power consumption. In case of LNG carriers, the liquefying power is considerably higher than any other ship service power (3 to 5 MW when the entire quantity of BOG is liquefied in a 135 000 to 200 000 m^3 hull form).



The "HAMANASU" for Shin Nihonkai Ferry Co., Ltd.

Fig. 3 Hybrid propulsion system adopted for ferry boats

Since existing marine (commercial) techniques are applied to this system, including the re-liquefaction system, dependence on the skill of crew members is considered to be less than in other alternative propulsion systems.

3.3 Optimization of liquefaction plant by peak shaving

The quantity of BOG shows significant fluctuations during a voyage (**Fig. 5**). In cases where a large quantity of BOG is generated temporarily, the HYBRID LNG system utilizes BOG in excess of the liquefying capacity as boiler fuel (heat source). The re-liquefaction system is optimized by shaving of liquefaction to natural BOG on voyage with cargo loaded, thus enabling high-efficiency operation at most period of voyages.

3.4 Environmental protection measures

In recent years, there has been a marked tendency toward compulsory use of low-sulfur fuel and intensified control of emissions of nitrogen oxides (NOx) from engines, particularly in the coastal areas of Europe and West Coast of the USA.

LNG is a clean fuel having no sulfur content and is lower in price than marine diesel oil and low-sulfur heavy oil. LNG carriers with HYBRID LNG system are operated mainly by diesel engines during navigation at sea, but cruise with POD at low steaming during coastal and portal navigation, while BOG is used as boiler fuel and excessive BOG is saved by re-liquefaction.

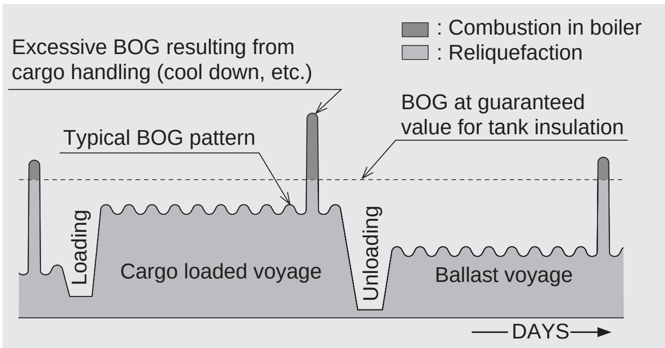


Fig. 5 BOG generating patterns and peak shaving of liquefaction
The capacity of the reliquefaction system is designed with natural boil-off (guaranteed value for tank insulation) used as reference, and temporarily generated excessive BOG is used as boiler fuel.

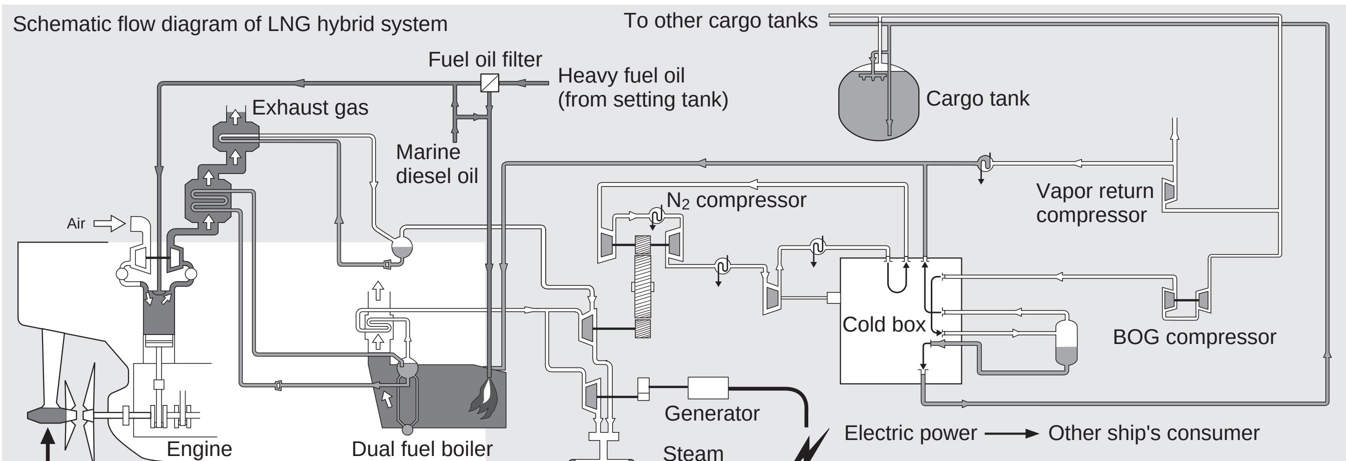


Fig. 4 Outline of hybrid system

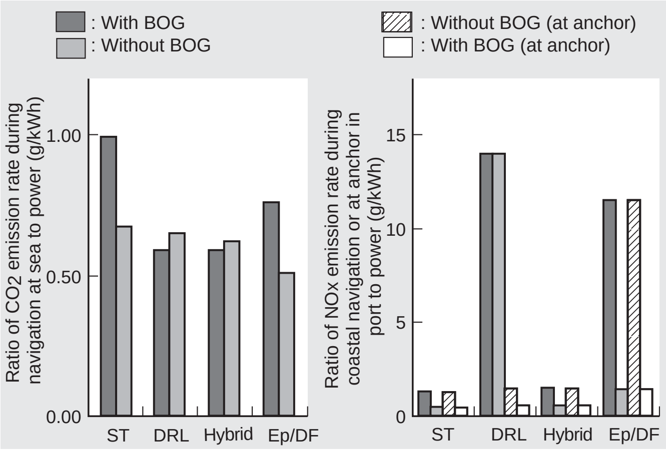


Fig. 6 Comparison of CO_2 and NOx emission rates

This system requires neither excessive gas treatment nor use of expensive marine diesel oil and low-sulfur heavy oil, and achieves zero emission of sulfur oxides (SOx). Moreover, the gas combustion process in the boiler has a very low NOx emission rate as compared with that of internal combustion engines (**Fig. 6**).

4. Evaluation of freight rate reduction effect

4.1 Ship price and fuel cost improvement

Significant fuel cost improvement is expected for all alternative propulsion systems, but initial investment may increase in all cases. No alternative systems are considered attractive unless relative merits and demerits lead to a reduction in total freight cost. In the case of the HYBRID LNG system, the line of balance lies at the fuel cost reduction rate of around 15 to 20% as against the increase in ship price (**Fig. 7**).

4.2 Evaluation of fuel cost

On the other hand, the fuel cost depends on the unit cost (ratio) of LNG/fuel oil (**Fig. 8**). Since the unit price ratio may fluctuate depending on the mode of LNG transaction (CIF, FOB, etc.) and the fuel oil market conditions, it is desirable to achieve fuel cost improvement over as wide a range as possible. In the case of the HYBRID LNG system, freight rate improvement can be expected if the BOG (LNG) unit price is around half or lower than the unit price of heavy fuel oil.

5. Conclusion

For LNG carrier propulsion systems, the steam turbine has occupied a monopoly position in the market. In future, however, there is a likelihood that several types of propulsion systems will coexist. MHI has been developing various types of alternative propulsion systems. In particular, the HYBRID LNG system is a system capable of meeting the needs of every customer because of its excellent features in terms of thermal efficiency, degree of freedom in choice of fuel and environmental considerations. MHI intends to propose this system positively to the newly-built LNG carrier market from now on.

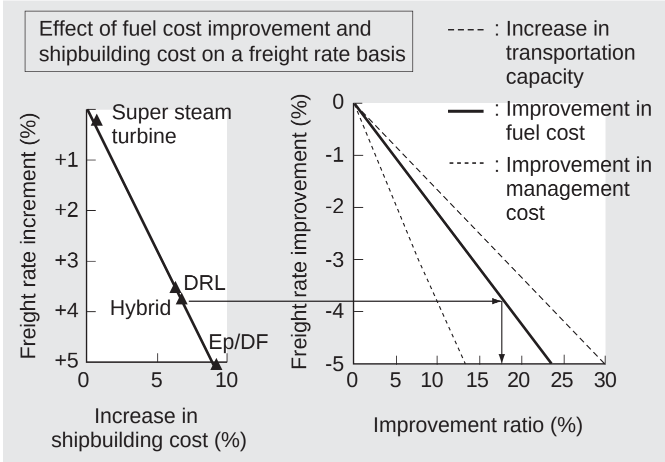


Fig. 7 Freight rate improvement effect and ship price
Line of balance between improved fuel cost and increased ship price cost on a freight rate basis.

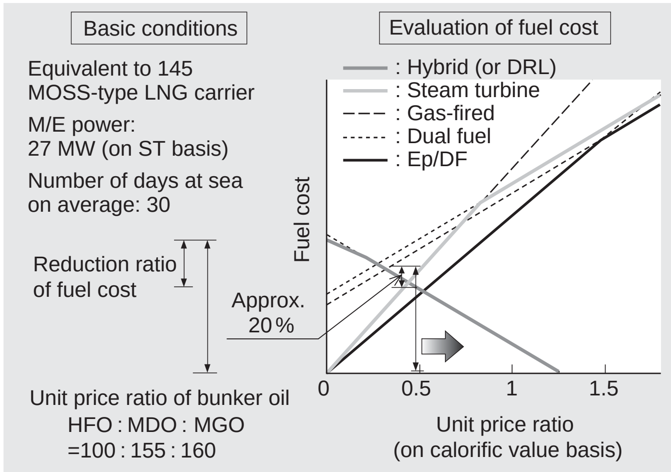


Fig. 8 Comparison of fuel cost
The abscissa expresses the price ratio of LNG/Heavy fuel oil. Its realistic value in recent market conditions is 1 or less. BOG to be stored by reliquefaction is deemed to be equivalent to LNG and subtracted from the fuel cost upon evaluation.

For BOG reliquefaction plants, proper guidance was provided by many persons concerned including those from Osaka Gas Co., Ltd., Nippon Yusen K.K. and Chiyoda Corporation, for which MHI expresses its sincere gratitude on this occasion.

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