Design Concept and Features of the Mitsubishi LNG-FPSO (Floating Production, Storage and Offloading Unit)

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In recent years, floating production, storage and offloading units (LNG-FPSOs) have been attracting considerable attention. LNG-FPSOs can produce, store and offload liquefied natural gas (LNG) offshore and can be moved. Mitsubishi Heavy Industries, Ltd. (MHI) has developed an economical and reliable LNG-FPSO that features spherical LNG storage tanks and is intended for medium- and small-scale gas fields. The LNG-FPSO was developed based on our solid performance in the construction of liquefied gas carriers and oil FSOs/FPSOs. MHI cooperates with BW Offshore Ltd., one of the world's leading FPSO contractors, to make attractive proposals for spherical tank-type LNG-FPSOs in the global market. MHI has also developed independent prismatic tank type B, which is MHI's own design and is intended for large-scale gas fields. We can provide optimal LNG-FPSOs utilizing either of the tank systems responding to various customer needs.

1. Introduction

Generally, liquefied natural gas (LNG) has been produced in onshore liquefaction terminals from the gas supplied from onshore gas fields or large-scale offshore gas fields that were not very far from the coast. However, the development of these gas fields has nearly been saturated. Large-scale offshore gas fields that are far from the coast, as well as undeveloped medium- and small-scale gas fields, have begun to attract attention in recent years. In line with the active development of these "stranded gas fields," which have been confirmed to exist but have yet to be developed, liquefied natural gas floating production, storage and offloading units (LNG-FPSOs) have become attractive. FPSOs are floating units equipped with facilities for the production, storage and offloading of oil and gas. FPSOs for oil have been constructed and delivered by several companies, including MHI, because they have the advantage of being able to move to other oil fields for reuse when the target fields dry up. However, FPSOs for LNG are still in the planning stages. MHI has developed a reliable and economical LNG-FPSO based on our solid performance in the construction of liquefied natural and petroleum gas carriers (LNG/LPG carriers) and oil FSOs/FPSOs. The design concept and features of the LNG-FPSO are explained below.

2. Design Concept of the Mitsubishi spherical tank type LNG-FPSO

2.1 Tank system

The tank systems incorporated in LNG carriers are compared in **Table 1**. LNG-FPSOs, unlike conventional LNG carriers, have to continue offshore production, storage and offloading of LNG without periodic inspections and repairs in dry docks. Therefore, LNG storage tanks must have a higher level of reliability than LNG carriers. If the LNG storage tank is damaged, the production of LNG may have to be stopped to repair the tank, resulting in a significant loss. Furthermore, in an LNG-FPSO, LNG produced by the production plant on the hull is continuously stored in the tanks, so the LNG levels in the storage tanks constantly change. This means that unlike LNG carriers, the LNG levels in the tanks remain intermediate for a long time. In addition, an LNG-FPSO floats on the ocean surface and is affected by the motion of the waves. The tank walls are subjected to impact pressure attributable to sloshing (periodic rolling of the LNG surface

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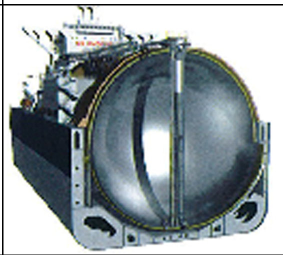
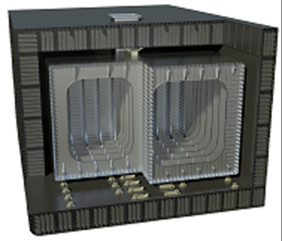
caused by hull motion) of the stored LNG, which may cause damage to the tanks. For this reason, the LNG storage tank has to remain free from damage caused by sloshing, regardless of the LNG level. Therefore, MHI considers either a spherical tank system or an independent prismatic tank system as a candidate for LNG storage tank systems. In LNG-FPSOs intended for medium- and small-scale gas fields, spherical tanks should be used because they can provide enough area for medium- and small-scale LNG production plants as described in Section 2.2 and also because they are economical due to their low construction costs. In addition, their safety and reliability have already been proved by the number of spherical tank-type LNG carriers. Independent prismatic tank systems will be used for large-scale gas fields, as described in Section 4.

Table 1 Comparison of tank systems for LNG carriers

	Sphere	Membrane (NO96)	Independent prismatic tank type B
Tank shape			
LNG filling level	Not restricted (no sloshing problem)	Restricted (sloshing problem)	Not restricted (no sloshing problem)
Installation area of LNG production plant	Fore or aft of LNG storage tank	Above LNG storage tank	Above LNG storage tank
Tank construction cost (comparison in MHI case)	Low	Slightly high	High

2.2 Layout

An example of the layout of a spherical tank type LNG-FPSO developed by MHI is shown in **Figure 1**. In the figure, the equipment is laid out as follows, from fore to aft. The reverse layout has already been developed as an option.

(1) External turret for single point mooring
(2) Flare stack
(3) LNG production plant (on the upper deck)
(4) Condensate tank (in the hull)
(5) Utility equipment room (in the hull)
(6) LNG storage tank
(7) Accommodation with a helicopter deck

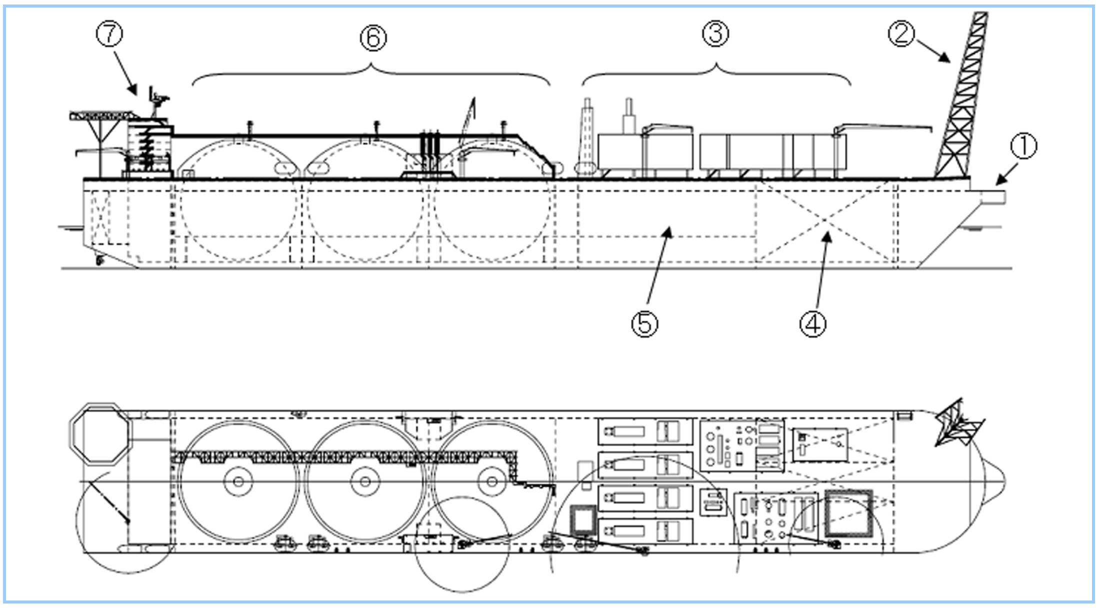


Figure 1 Layout of a spherical tank type LNG-FPSO

LNG-FPSOs produce LNG from natural gas extracted from gas fields and therefore, the units are equipped with LNG production plants. An LNG production plant is generally composed of pre-treatment units that remove impurities such as acid gas, moisture and mercury from the natural gas and liquefaction units that liquefy the natural gas after pre-treatment. Therefore, an area to install the plant is needed on the hull. This area was created on the upper deck by extending the hull with a flat upper deck, as shown in the layout drawing. A complete production plant can be installed on the hull without the need to install any part of the plant on land or on a separate hull. The internal space of the extended hull is used efficiently by providing storage tanks for condensates that are contained in the natural gas (or LPG tanks), as well as a utility equipment room for producing and supplying the utilities such as steam, electric power and cooling water, etc., needed for the production plant. In addition, the area for installing the LNG production plant was expanded by reducing the number of LNG storage tanks, which was realized by increasing the diameter of the tanks compared with those used on conventional LNG carriers.

Ballast tanks, which are properly divided and arranged at appropriate locations around the hull, adjust the trim and draught of the hull, responding to changes in the LNG/condensate storage amounts so that the hull remains horizontal and within the movable range of the offloading equipment.

2.3 Main specifications

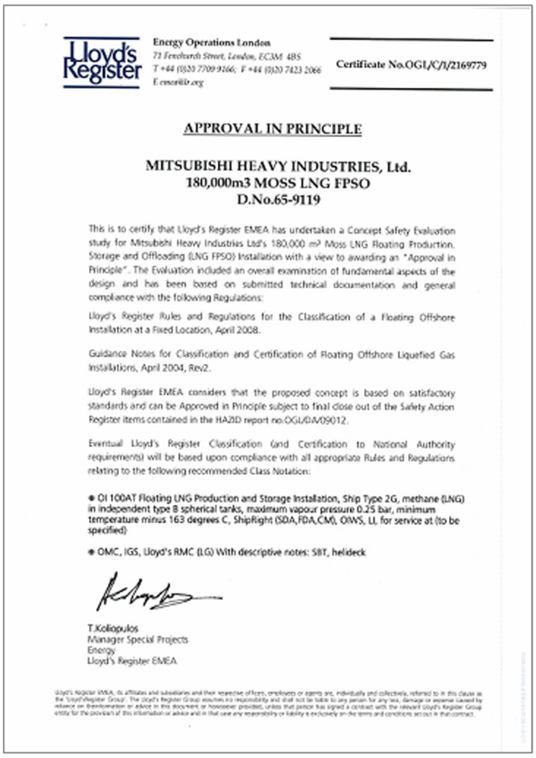
Examples of the main specifications of a spherical tank type LNG-FPSO are shown in **Table 2**. If a wider area is required to install the LNG production plant, the hull can be extended further.

Table 2 Main specifications of the spherical tank type LNG-FPSO (example)

LNG storage tank capacity (-163°C, 100%)	180,000 m^3/3 tanks
LNG production capacity	2 million tons/year
Area for installing the LNG production plants	Approx. 10,000 m^2 (Approx. 170 m L × 60 m W)
Condensate storage tank capacity	100,000 m^3/3 tanks
Hull length × hull width	390 m × 60 m
Complement	160

2.4 Class approval

We conducted a risk assessment of the basic design of the spherical tank type LNG-FPSO with Lloyd's Register of Shipping (LRS) of the UK and obtained an approval in principle (AIP), which means the basic design (including the safety features) is appropriate (**Figure 2**).



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Certificate No.OGL/C/1/2169779

APPROVAL IN PRINCIPLE

MITSUBISHI HEAVY INDUSTRIES, Ltd.
180,000m3 MOSS LNG FPSO
D.No.65-9119

This is to certify that Lloyd's Register EMEA has undertaken a Concept Safety Evaluation study for Mitsubishi Heavy Industries Ltd's 180,000 m³ Moss LNG Floating Production, Storage and Offloading (LNG FPSO) Installation with a view to awarding an "Approval in Principle". The Evaluation included an overall examination of fundamental aspects of the design and has been based on submitted technical documentation and general compliance with the following Regulations:

Lloyd's Register Rules and Regulations for the Classification of a Floating Offshore Installation at a Fixed Location, April 2008.

Guidance Notes for Classification and Certification of Floating Offshore Liquefied Gas Installations, April 2004, Rev2.

Lloyd's Register EMEA considers that the proposed concept is based on satisfactory standards and can be Approved in Principle subject to final close out of the Safety Action Register items contained in the HAZID report no.OGL/DA/09012.

Eventual Lloyd's Register Classification (and Certification to National Authority requirements) will be based upon compliance with all appropriate Rules and Regulations relating to the following recommended Class Notation:

- OI 100AT Floating LNG Production and Storage Installation, Ship Type 2G, methane (LNG) in independent type B spherical tanks, maximum vapour pressure 0.25 bar, minimum temperature minus 163 degrees C, ShipRight (SDA,FDA,CM), OIWS, LI, for service at (to be specified)
- OMC, IGS, Lloyd's RMC (LG) With descriptive notes: SBT, helideck

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Figure 2 AIP certificate issued by LRS for the spherical tank type LNG-FPSO

3. Features of the Mitsubishi spherical tank type LNG-FPSO

The features of the Mitsubishi spherical tank type LNG-FPSO are as follows.

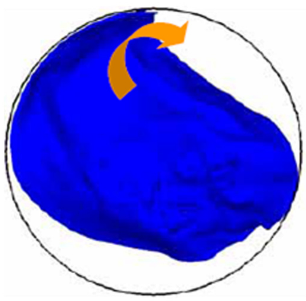
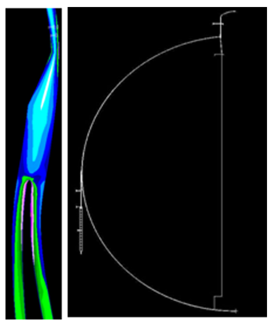
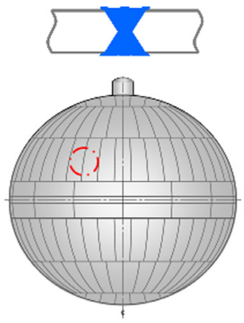
3.1 Safety and reliability

(1) Spherical tanks have extremely high levels of safety and reliability in terms of sloshing, structural analysis and quality control, which is attributable to the simple shape and structure, as well as the welding configuration. Their safety and reliability have been proved by the service performance of the spherical tanks that have been used in a number of LNG carriers for many years (**Table 3**).

(2) As the LNG production plant is located separately from the LNG storage tanks (not located above the LNG tanks):
- the shape and structure of the supports for the LNG production plant installed on the deck are not restricted by the LNG storage tanks, realizing a more reliable and simple support structure
- the LNG tanks are free from the risk of damage caused by dropped objects from cranes, for example, during maintenance of the LNG production plant.

(3) Since the LNG production plant is located far from the living quarters, crews can be assured of a safe and low-noise environment.

Table 3 Reliability of spherical tanks

Sloshing	Accuracy of structural analysis	Quality control
The impact pressure generated by sloshing does not affect the tank wall because it is spherical.	The structure is simple, allowing accurate structural analysis.	Reliable quality control is realized by full-penetration butt welding and non-destructive (ultrasonic) testing covering 100% of the welding beads.
		

3.2 Economy and short construction period

(1) By positioning the utility equipment room directly under the LNG production plant, pipes and wires connecting the two are shortened and the power used to supply utilities (electric power, steam and cooling water, etc.) to the LNG production plant is minimized.

(2) In spherical tanks, heat ingress into the tanks can be reduced by increasing the thickness of the insulation materials provided on the outer surface of the tanks, so regasification of the LNG inside the tanks can be reduced.

(3) Due to the fact that the LNG production plant is installed separately from the LNG storage tanks, installation and integration of the LNG production plant can be done in parallel with insulation and outfitting of the LNG storage tanks after the hull structure is completed (after launch). Therefore, the construction period can be shortened compared with the case where the LNG production plant is installed and integrated after completing the LNG storage tanks (**Figure 3**).

(4) The production cost of spherical tanks is low due to the lighter tank weight and shorter welding length.

(5) Requires fewer LNG storage tanks and related LNG discharging systems, etc.

As explained above, the Mitsubishi spherical tank type LNG-FPSO is superior in terms of safety, reliability and economy.

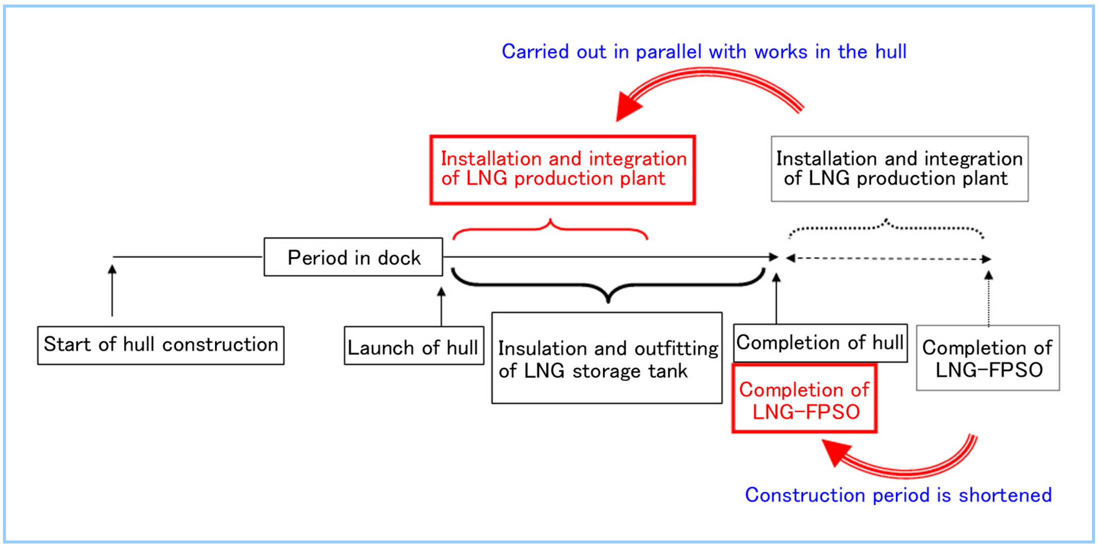


Figure 3 Construction period reduction by the spherical tank type LNG-FPSO

4. Mitsubishi Independent Prismatic Tank Type B

4.1 Outline

In addition to the above spherical tank type LNG-FPSO, which is intended for medium- and small-scale gas fields, we have also developed the independent prismatic LNG tank type B, which is MHI's own design to provide optimal LNG-FPSOs for large-scale gas fields in response to various customer needs (**Figure 4**).

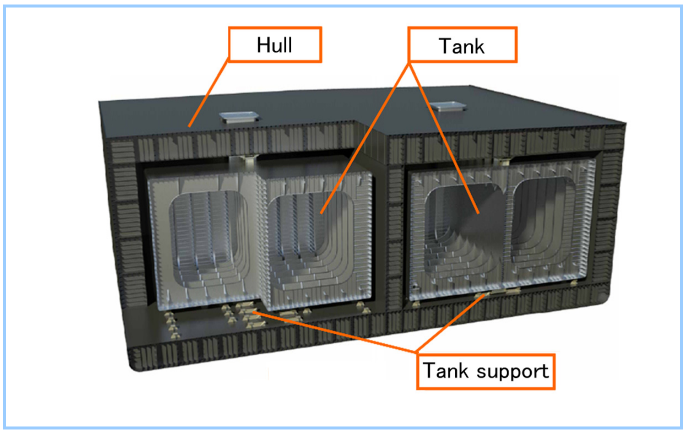


Figure 4 Mitsubishi independent prismatic tank type B example (two rows)

The basic requirements for the LNG independent prismatic tank type B are summarized as follows.

(1) It must be an independent (self-supporting) tank and must be designed using refined analysis methods with precisely calculated stress levels, fatigue life and crack propagation characteristics.

(2) It must be constructed with thermal insulation that leads LNG leaking from the tank to the partial secondary barrier.

(3) It must be made of materials appropriate for LNG.

With respect to (1), a highly reliable tank was designed by utilizing the extensive knowledge and experience accumulated through the construction of many of LPG carriers that have similar prismatic tanks (type A) and by introducing the "direct loading analysis method" (MHI-DILAM, developed by MHI) to enable a precise load and structural response prediction. When the size of the hull is larger, it is important to consider the effects of the interaction between the independent tank and the hull; their complicated behaviors can be precisely simulated using MHI-DILAM (**Figure 5**).

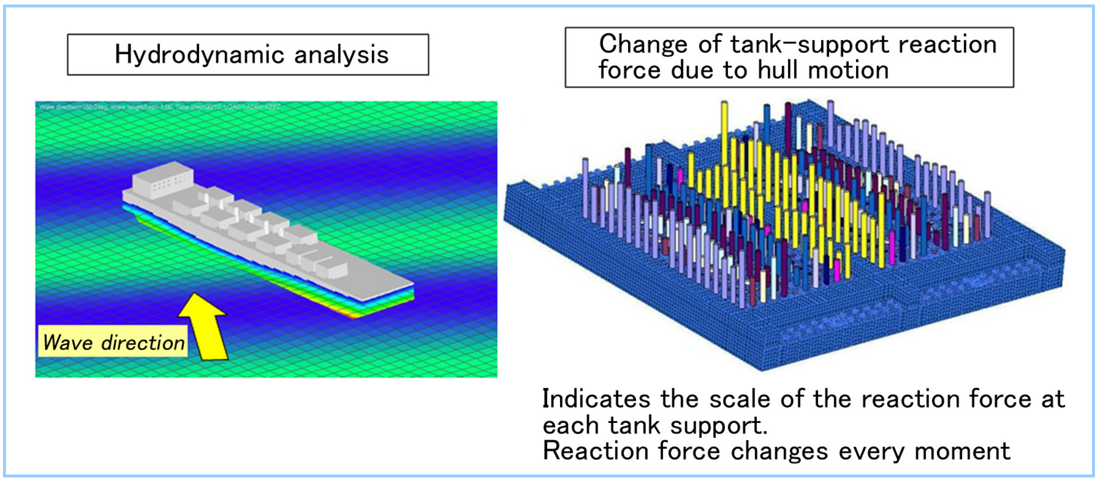


Figure 5 Reaction-force analysis of the independent prismatic tank

With respect to (2) and (3), a reliable and economical tank was designed based on the findings and experience accumulated through the construction of LNG carriers incorporating spherical tanks (type B), which share similar thermal insulation construction and materials with the newly developed tanks.

4.2 Class approval

MHI's independent prismatic tank type B obtained approval in principle (AIP) as an International Maritime Organization (IMO) type B tank from the American Bureau of Shipping (ABS), Lloyd's Register of Shipping (LRS) and the Nippon Kaiji Kyokai (NK) (**Figure 6**).

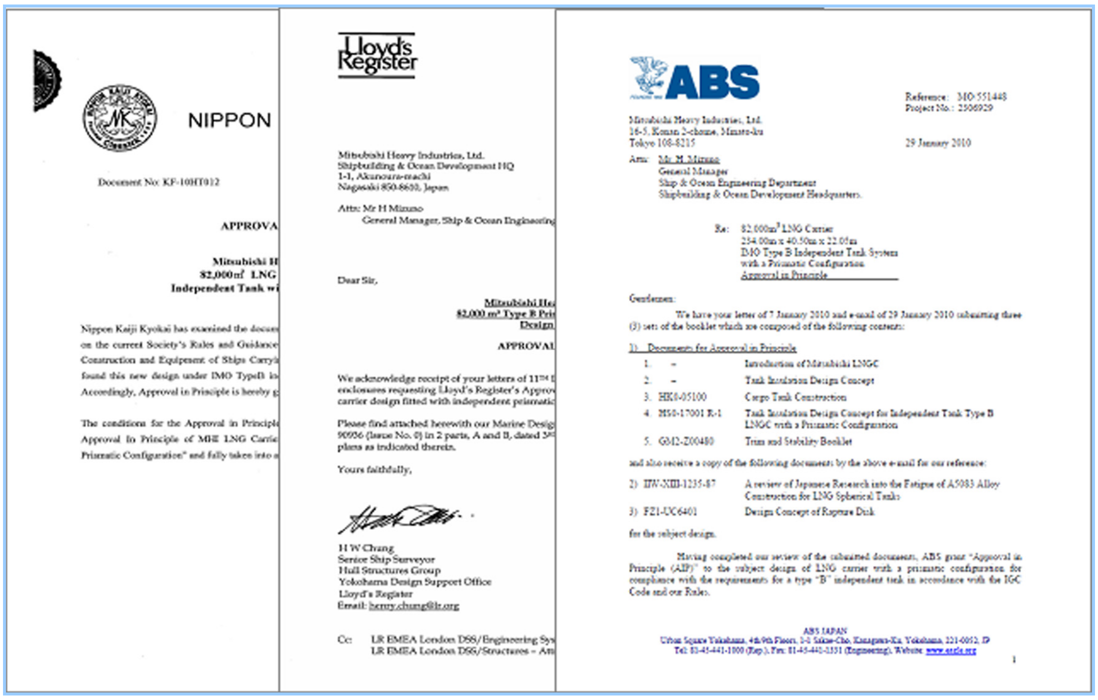


Figure 6 AIP Certificate for the independent prismatic tank type B obtained from ABS/LRS/NK

5. Conclusion

We developed our own LNG-FPSO by taking the feedback from our customers and partner, BW Offshore Ltd., into account. We believe that our LNG-FPSOs will satisfy customer needs for all small-, medium- and large-scale gas fields in terms of reliability, safety and economy. We will now start to design and construct actual LNG-FPSOs based on the above research.