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DEVELOPMENT OF NATURAL GAS OCEAN TRANSPORTATION CHAIN BY MEANS OF NATURAL GAS HYDRATE (NGH)

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ABSTRACT

While alternative natural gas transportation technologies against currently available pipeline or liquefied natural gas (LNG) are expected to develop to be suitable for small and medium or remote gas fields, Mitsui Engineering & Shipbuilding Co., Ltd. (MES) has been studying natural gas hydrate (NGH) transportation chain and advocated at ICGH2005 the NGH chain was economical compared with conventional LNG system under some conditions.
Meanwhile, MES has been carrying out research and development on the relevant technology development including construction of 600 kg/day class NGH production and pelletizing plants and a re-gasification facility and the process technology resulted from this R&D leads to the forthcoming demonstration plant of 5 ton/day production (under construction) to be dedicated to the demonstration project of small-lot NGH land transportation in western Japan.
As the latest achievement, MES and Mitsui & Co., Ltd. (Mitsui) established NGH Japan Co., Ltd. (NGHJ) in April 2007, in order to study in detail on actual viability of NGH ocean transportation chain. NGHJ, MES and Mitsui have been conducting a practical feasibility study on certain cases in Southeast Asia in cooperation with 6 Japanese leading companies related to natural gas businesses. The study suggests that NGH chain was appropriate as a media for transportation from Southeast Asia to Japan and regional transportation within Southeast Asia in view of economics.

Keywords: demonstration project, NGH Japan, feasibility study, base case

1. INTRODUCTION

Since the idea of ocean transportation of natural gas by means of natural gas hydrate (NGH) utilizing so called "self-preservation effect" was advocated by Dr. Gudmundsson of Norwegian University of Science and Technology in 1996, various kinds of research on NGH ocean transportation chain have been made in all over the world, as in the case of Marathon Oil Corporation which constructed a test plant of NGH production and started its experimental operation in the United States.
Mitsui Engineering & Shipbuilding Co., Ltd. (MES) has been continuously investing in research and development for NGH technology, just like as it has been conducting its research and development on NGH production process, carrier ship, and re-gasification process, etc. since 2001, and as it constructed the experimental plant for process development (Process Development Unit: PDU) and the research and development facility for scale-up of the process (Bench Scale Unit: BSU) and continued their experimental operation. Meanwhile, MES executed a new conceptual design (Figure 1.) and economic feasibility study of an NGH ocean transportation chain by means of NGH pellets based on enormous amount of data and knowledge accumulated through those research and development, and it introduced that NGH supply chain was regarded as economical by the cost advantage of 18 to 25% in the case of

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transportation of 0.4mtpa (NG)(1,500 nautical miles) to 1mtpa (NG)(3,500 nautical miles) according to the specific comparison of NGH supply chain and LNG supply chain in its economic feasibility study.
In this manuscript, we illustrate the latest situation of the further research and development and the up-to-date feasibility study that MES and Mitsui, the NGH business partner of MES, have been implementing for advancement of commercialization of NGH ocean transportation chain, particularly about the joint study on international NGH ocean transportation chain made by the group of 9 companies that have a keen interest in NGH technology.

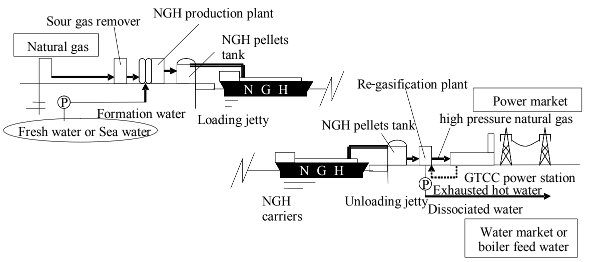

Figure 1. Natural gas ocean transportation chain by means of NGH pellets

2. LATEST SITUATION OF R&D AND UP-TO-DATE FEASIBILITY STUDY

MES is, in cooperation with The Chugoku Electric Power Co., Inc. (CEP), currently implementing the demonstration project of natural gas land transportation by means of NGH, with the assistance of New Energy and Industrial Technology Development Organization (NEDO) for three years since 2006. In the project, we constructed the NGH pellet production plant of 5 ton/day (NGH) using waste cold heat of LNG at Yanai Power Station of CEP, and we will deliver NGH by the dedicated NGH lorry (pellet container) to the natural gas based cogeneration and a collective housing several kilometers away, where NGH would be dissociated to natural gas and water and consumed (Project Y). Although the project is different from the business model of ocean transportation, the typical expectation for the function of NGH, it will greatly contribute to enhancement of NGH commercialization, since the practical data of production, storage, transportation and re-gasification would be accumulated while natural gas is actually delivered by means of NGH and consumed.
On the other hand, in parallel with the progress of research and development, MES and Mitsui, who has the considerable experience of value chain development and business operation of natural gas by means of LNG, established NGH Japan Co, Ltd. (NGHJ), the joint company dedicated for commercialization of NGH, and they took a step further from "the desk study" and are implementing a practical evaluation of the viability and study of commercialization.

3. JOINT STUDY BY 9 JAPANESE LEADING COMPANIES

As the latest achievement, MES and Mitsui are currently executing an up-do-date feasibility study on natural gas supply chain by means of NGH with the assistance of Japan Oil, Gas and Metals National Corporation (JOGMEC) since November, 2007. The study is led and directed by NGHJ and implemented in conjunction with the other 6 Japanese leading companies related to natural gas business, consisting of E&P companies, shipping firms and natural gas users (INPEX Corporation, Japan Petroleum Exploration Co., Ltd., Mitsui O.S.K. Lines Ltd., NYK Line, The Chugoku Electric Power Co., Inc., and Tokyo Gas Co., Ltd.)
In this project, the research group composed of the companies that have the considerable experience and track record of natural gas related business is studying the feasibility as the total supply chain comparing with the corresponding supply chains of small sized LNG and compressed natural gas (CNG), by exchanging each data and perceptions. The study is more objective than before in both quantitatively and qualitatively, since the member companies belonging to the different industry sectors with each interest are discussing the issues and evaluating the viability from various points of view. The outline of the study is introduced below.

4. OBJECTIVE OF FEASIBILITY STUDY

(1) Natural gas field to study
First of all, since the study started from the purpose that it aims at the feasibility of the natural gas transportation by means of NGH to Japan, the study group investigated the natural gas reserves, energy policy, the positioning of natural gas and their prospect of Southeast Asian countries as well as the current situation and future forecast of natural gas

demand of each countries. As the result of the analysis of the investigation, we selected the case, as the principal study objective, in which the natural gas is converted to NGH and delivered to Japan from the natural gas field that is already found but unmonetized in Indonesia, considering the following; a) small and medium gas field are much located, b) the conditions of transportation distance seems severe in the case of Japanese destination, c) the supply record of LNG is sufficient.

(2) Conceptual design of NGH supply chain

The study assumes the case in which NGH production plant of 1mtpa (NG) is constructed in Indonesia. Following the investigation described in (1), the group studied the pretreatment process and NGH production process, designed based on the latest technology concept composed of scale-up and compactification, and developed the specifications of equipments and materials. As for the re-gasification plant, the group assumed to construct the plants of 0.25mtpa (NG) each in consideration of gas users located in Japan, and designed in the same manner as the production plant. As for the carrier ship, after the studying the navigation route that links export terminal in Indonesia and receiving terminals in each region in Japan and its schedule, the group designated specifications, size and fleet constitution, taking the consideration of the amount of NGH to transport.
In addition, it estimated the cost of equipment and materials, design and engineering, and construction based on these engineering data and calculated the cost of plants and ship carrier with the accuracy of +/- 20%.

5. BASE CASE OF SUPPLY CHAIN TO STUDY

The study presumes the introduction to power plant and city gas supply as the application of natural gas at demand side in Japan, and it compared to supply chains with LNG and CNG, which is the same sort of medium as NGH in terms of physical conversion.
In comparison, the group designated first the hypothetical chain model as the "base case" of the evaluation, considering practicality and identification of conditions (apples to apples). At the same time, it set a study condition range for the factors of production capacity, transportation distance, etc. and analyzed the sensitivity of the economy, and made them a basic material of the study on optimized business model and scenario of introducing NGH.
Although the detailed conditions of the each sector of supply chain are described in the next chapter and thereafter, essentials of base case are shown in Figure 2. and conceptual diagram of natural gas supply chain is illustrated in Figure 3.
Meanwhile, chemically converted media such as GTL (Gas to Liquid) and DME (Dimethyl Ether) are scoped out from the study, since their application is assumed as substitute for liquid fuels.

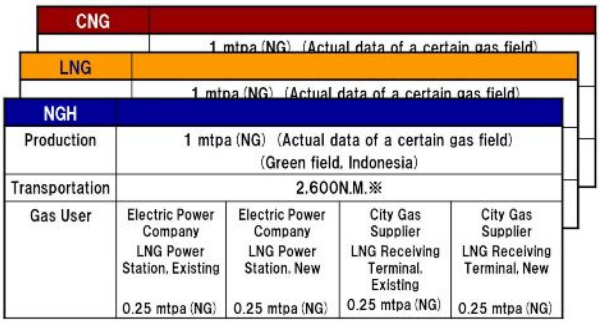

Figure 2. Essentials of base case of the study

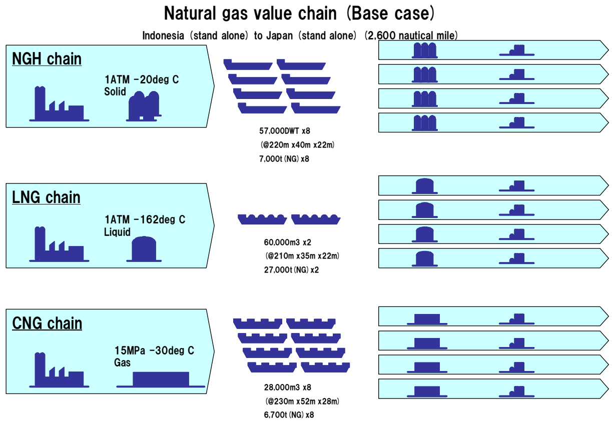

Figure 3. Conceptual diagram of natural gas supply chain

6. EXPORT TERMINAL

(1) Basic conditions

The study dealt in the project to develop the unmonetized small and medium stranded gas field due to the market distance and insufficient economy as the business case, construction of NGH production plant to be located in green field on the land next to shipping port was designated as the base case. The necessary utilities were assumed to be procured within the terminal.
As for the upper stream cost (exploration and production) and the cost of transportation up to the

production plant, they are evaluated as the feed gas cost, and the feed gas was assumed to be received at the battery limit (BL) of the plant.
On the other hand, the small and medium gas field that could be monetized may be 0.5 to 3TCF class, taking the account of the economy of the upper stream. If the operation period is supposed to be 8,000 hours per year for 20 years, the production capacity would be 1 to 3mtpa (NG)[1]. In the case in which the product gas would be sold to Japanese users, production of 1mtpa (NG) was designated as the base case considering the transportation distance with reference to the past study. In addition, 3mtpa class (NG) is supposed to be the bottom line of economical production capacity in the case of LNG, the study tried to find out the cross point with the LNG curve by analyzing the sensitivity in accordance with the capacity.

(2) Conditions of the raw materials
Although associated gas is imaginable as the small and medium gas resource in addition to the ordinary natural gas, the study dealt in the typical composition of feed gas which is ordinary in East Kalimantan, Indonesia. Since the feed gas includes CO2 and H2S that is unwelcome to the product gas, their removal is necessary. Next, the heavy gas is further removed and the residual C1 rich gas was supposed to be utilized as the fuel gas for NGH production.
In this study, the recovered heavy gas shall cover the necessary energy in the plant, and the amount of the raw gas that corresponds to the 1mtpa of C1 rich gas in the case of NGH production was figured out. Also in the case of LNG and CNG, the internally required energy and the product gas shall be covered with the same amount of the feed gas as the case of NGH (Figure 4.).

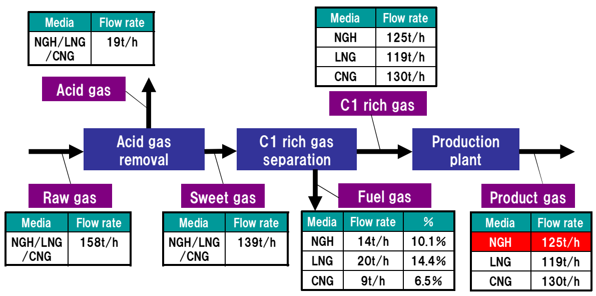

Figure 4. Material balance of feed gas processing

Consequently, LNG process produces less product gas since it requires much energy, and CNG process produces more product gas since less energy is required. In the end, the economy of each medium was evaluated in view of the economy per the amount of the product gas.

(3) NGH production plant
NGH production process is composed mainly of the following four section; 1) NGH slurry formation, 2) Dehydration, 3) Pelletizing, 4) Cooling and Decompression. Since NGH production process of MES is high pressure system (5.4MPa/4℃), there is a limitation for scaling-up the equipment. In this study, the maximum capacity is designated as 6,000ton/day (NGH) per train and therefore the total capacity of four trains was amounted to 24,000 ton/day (NGH). The diagram of the train constitution of NGH supply chain is shown in Figure 5.

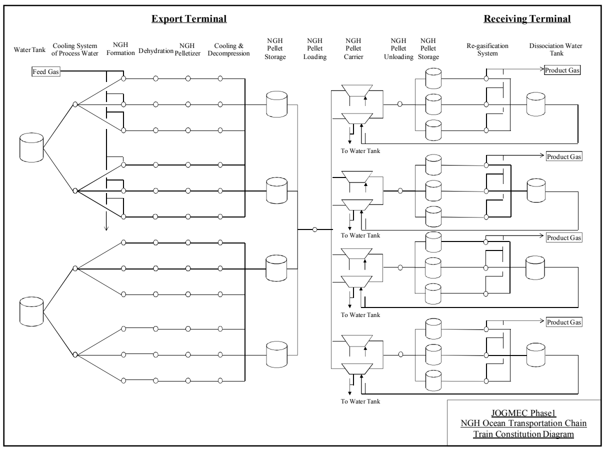

Figure 5. Train constitution of NGH Supply chain

(4) Storage and shipment system
As for the capacity of the storage at the export terminal, the amount of two-day production was added to the total cargo capacity of the carrier ship, considering the risks including delivery delay (39,000m3 x 4). The system of NGH storages is based on the existing silo system for coals. In addition, the raw material water tank was also equipped in order to receive the water dissociated at the receiving terminal and conveyed back in the ballast tank (46,000m3 x 2). Besides, the loading system (24 hours/ship) from the storage tank to the carrier ship was adopted (2,400t/h x 24 hours). Layout of NGH export terminal (1mtpa) is shown in Figure 6.

[1] 1TCF ÷ 20 years (constant production) ＝50BCF/year ≒ 1.35BCM/year ≒ 1mtpa

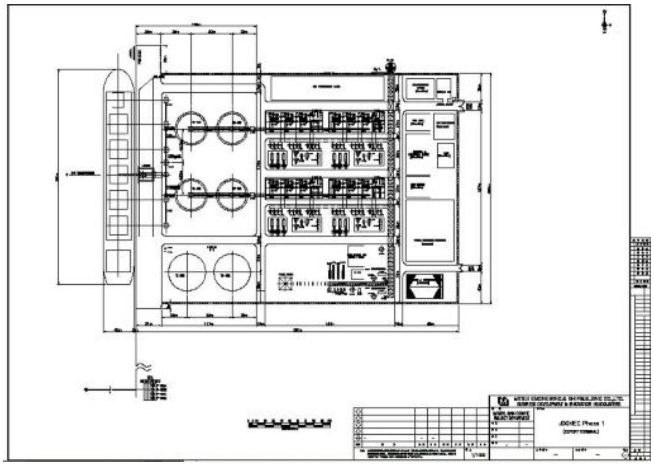

Figure 6. Layout of NGH export terminal (1mtpa)

7. RECEIVING TERMINAL

(1) Possible NGH capacity to adopt

Historically, Japanese leading electric power companies and city gas supply companies have been adopting LNG. In this study, NGH was assumed to be introduced as a complement to LNG. In the meantime, assumption of the capacity of 0.25 to 1mtpa (NG) to adopt is practical, considering a demand for natural gas of an existing terminal. As for the dissociation water, it is assumed to be entirely recovered as the base case, since it is subject to requirement of wastewater treatment in the case its application is limited in electric power or city gas business.

As the NGH adoption scenario at electric power company, the following two cases were assumed;

Case P1: Adoption as the substitute for the existing LNG (0.25mtpa (NG) class)

Case P2: Adoption at the grass-roots construction or expansion of NGH based power station (0.25mtpa (NG) class)

※ Case P2 is inclusive of fuel conversion needs, industrial application, demand of joint thermal power station, etc.

As the NGH adoption scenario at city gas supply company, the following two cases were assumed;

Case G1: Adoption for the existing LNG terminal (0.25mtpa (NG) class)

Case G2: Adoption at grass-roots construction of NGH terminal jointly by the group of small and medium users (0.25mtpa (NG) class)

(2) NGH adoption by electric power company

In the adoption of NGH by the electric power company, gas turbine combined cycle (GTCC), oil based thermal power station, and coal based thermal power station would be the target of introduction. In the case of GTCC, where the power plant is already ready for natural gas, NGH can be introduced without serious remodeling, except for control system. But the entire fuel conversion to NGH is not practical. For the meantime, partial adoption of NGH is expected to facilitate diversification of fuel source. Adoption at grass-roots construction or expansion of GTCC is imaginable.

(3) NGH adoption by city gas supply company

Although most of the city gas suppliers are small and medium, the major suppliers can study to introduce NGH of 0.25 to 1mtpa (NG). Since they totally rely on LNG for gas source, adoption of NGH is expected to be helpful for diversification of gas source and cost reduction.

In addition, it is possible that the major suppliers may study on construction of small and medium receiving terminal in accordance with the expansion of supply area. NGH is adoptable in such cases. On the other hand, NGH may be applicable for further small-lot transportation (possibly by domestic vessel or lorry) for the sake of small and medium suppliers. In the case of small-lot transportation, higher price could be secured (substitution for LPG) while cost may increase. Adoption of NGH would be possible in such a situation, though it is subject to marketability and economic efficiency.

(4) Storage system

NGH requires space for storage almost ten times of that for LNG, taking void space in the tank into account. Tank capacity has to be designated, considering availability of lands and the situation that NGH would be used as complement to LNG at LNG terminal.

In this study, its capacity was assigned to be capacity of carrier ship plus consumption amount of two days (34,000m3 x 3) and the capacity of NGH carrier was designated 57,000DWT in the base case. In addition, storage tank of dissociation water was also assumed to install (60,000m3 x 1).

(5) Re-gasification system

In the case adopted as complement to the existing LNG terminal, NGH is assumed to be used for base load operation, since the cheaper source is expected to be consumed preferentially. In the case adopted at grass-roots construction or expansion, capability of load control is requisite in accordance with demand of electricity or city gas. Consequently, in re-gasification of NGH, high pressure gas of 5MPa class has to be continuously obtained by continuous dissociation of NGH supplied at -20℃ under the atmospheric pressure. This study is based on scale-up of re-gasification system utilizing continuous pressor equipment (amount of NGH pellet processing: 250 ton/hour, amount of outgoing gas: 32 ton/hour). Layout of NGH receiving terminal (0.25mtpa) is shown in Figure 7.

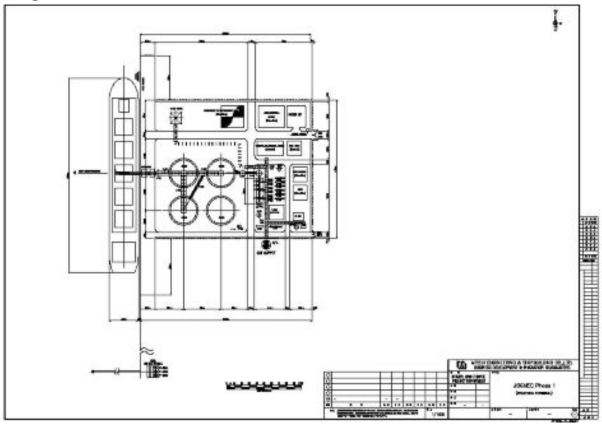

Figure 7: Layout of NGH receiving terminal (0.25mtpa)

8. OCEAN TRANSPORTATION

(1) Study of transportation distance

In the study, the average transportation distance was designated as 2,600 nautical miles (approx. 4,800 km) with reference to the navigation route between Japan and Bontan where LNG export terminal for Japanese market is located, as the export terminal was assumed to be located in East Kalimantan, Indonesia. The distance is rather negative condition for NGH transportation. It takes 7 to 8 days for the carrier ship at 15 knot.

(2) Model of NGH pellet carrier

The concept of NGH pellet carrier is based on refrigerated bulk carrier and has an enclosed cargo hold system to store NGH pellet in the natural gas at -20℃ under the atmospheric pressure. In order to reduce the gas users' initial investment, the unloading system was supposed to be equipped with the carrier ship. As for the unloading method, a mechanical system is adopted which is ordinary as a method for coals and other solid cargo.

(3) Size of carrier ship and fleet constitution

As the result of a study on an optimal transportation chain that links export terminal and receiving terminals, size of the carrier ship and the fleet constitution was designated as 57,000DWT x 8, considering the followings; 1) the recent port conditions in Japan that is expected to receive a large-scale LNG carrier of QFLEX type (210,000m3, 315m x 50m x 12m), 2) Requirements of users to minimize the land for storage tanks, 3) Draft of the carrier that can be received by the existing LNG terminal (less than 12 m), 4) Japanese port situation to disapprove unloading at multiple ports, etc. As for the carrier ship in LNG supply chain, size of the carrier ship and the fleet constitution was designated as 60,000m3 x 2, considering the factors such as 1) LNG cannot be stored for a long period, 2) Multiple carriers should be prepared from the viewpoint of security as a project, 3) carriers can be procured from the market on spot in case of an emergency, etc. Size of the carrier ship and the fleet constitution was designated as 29,000m3 x 8 in the case of CNG supply chain in the same manner.

9. COST ESTIMATE

The group estimated capital expenditure (CAPEX) and operational expenditure (OPEX) for each of supply chains of NGH, LNG and CNG. In estimation, it reflected the skyrocketing prices of equipments and materials, by adopting plant cost index, prices of steel products and foreign currency exchange rate as of end of January, 2008. As for OPEX, it is designated as the accumulation of the annual amount discounted by 10% for the project life of 20 years.

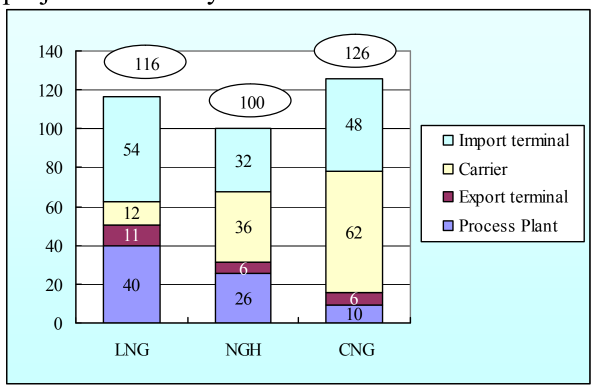

Figure 8. Comparison of Life Cycle Cost (LCC)

Figure 8. shows the comparison of life cycle cost (LCC) of supply chains of NGH, LNG and CNG, just by totaling CAPEX and OPEX. Each figure in the graph is the relative value, when the total LCC of NGH is looked on as 100.
Total supply chain cost of NGH was proved lower than LNG by 14% and lower than CNG by 20%. NGH could be regarded as competitive against LNG and CNG, when we compare LCC throughout the project life in the base case.

10. ECONOMICAL EVALUATION

(1) Summary of economical evaluation on base case

The study dealt with the supply chain in which natural gas, produced at a gas field of 1TCF reserve in Indonesia, is converted to either of NGH, LNG or CNG, delivered for 2,600 nautical miles by ocean transportation and finally supplied for four users (electric power company and city gas supply company) with grass-roots introduction or expansion needs as the base case. In the case, cost of NGH was confirmed lower than LNG by 14% and lower than CNG by 20% on the basis of LCC for 20 years. The financial analysis using Internal Rate of Return (IRR) based on the estimated costs suggests that the project economics of NGH ocean transportation chain attains the level that could be considered as worth serious consideration of actual investment, although it is subject to the relevant conditions and circumstances.

(2) Sensitivity analysis

In addition, the group conducted a sensitivity analysis in accordance with several kinds of parameters. According to the analysis, on the premise of transportation for 2,600 nautical miles equivalent to the distance from Indonesia to Japan, NGH can constantly expect economic efficiency between 1 and 3mtpa (NG) class production. NGH indicates an efficient level even in the case of 1.5mtpa (NG) in which LNG is generally considered as uneconomical. Consequently, NGH could be confirmed as advantageous against the other media including CNG in the case of these production capacities (Figure 9.). In the next place, sensitivity by transportation distance was analyzed and the additional cases of 1,000 nautical miles (domestic in Indonesia) and 3,500 nautical miles (West Australia to Japan) as well as the base case (Figure 10). Although NGH is always advantageous to LNG in every case, it is more suitable for the shorter-distance transportation project under the current conditions of soaring cost of equipments and materials. Particularly about CNG, it seems competitive only in the case of short distance project, since it is the most sensitive to the distance.

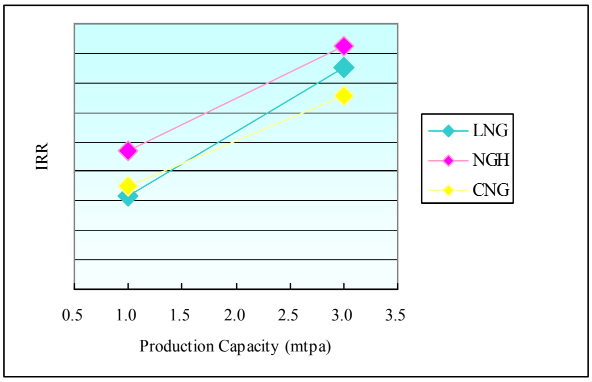

Figure 9. Sensitivity analysis by production capacity

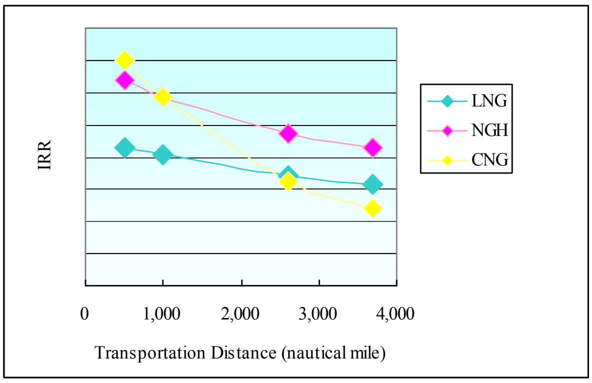

Figure 10. Sensitivity analysis by transportation distance

11. CHALLENGES

Despite the perceptions that NGH is advantageous under the certain conditions, the subject of further investigation was also discussed. The challenges are principally categorized to two issues.

(1) Optimization of NGH supply chain

According to the study, in the natural gas transportation chain from small and medium gas field of 1TCF class to Japanese users and the chain within the Southeast Asian region, NGH was confirmed to be more economical than LNG and CNG under some conditions, and it is also confirmed a certain level of project feasibility can be secured even under the current gas market. Nevertheless, since LNG is a well matured medium, strong inducement of introduction of

NGH by user side should be investigated. From now on, optimization for the currently designed entire chain covering from NGH production to consumption is requisite in addition to the further cost reduction. Issues such as the study of the handling of the dissociation water, establishment of unloading method of NGH pellets, and further study of ejection method from the storage tank are taken for examples.

(2) Deepening of scenario for introducing NGH

Although the existence of scenario for introducing NGH was confirmed as described in (1), the further practical scenario should be studied that is more suitable for the actual commercialization.
Although the study dealt in the case in which NGH is produced by the land plant after feed gas is delivered from a virtual gas field in Indonesia, the actual small and medium gas fields are often located offshore. In the case pipeline up to the land plant can be assumed uneconomical considering the amount of gas reserve, there may be an idea that production at NGH-FPSO is practical. In the case of FPSO project, the construction period could be shortened. Besides, the scenario that can demonstrate the advantage of NGH should be further discussed, considering the governmental policy of the country endowed with gas and distance from gas field to market and so on.

(3) Study of the pilot project

Since the capacity of NGH production plant of the ongoing Project Y is 5 ton/day (NGH) and is quite small comparing to the assumed capacity of per 1 train of commercial project of 6,000 ton/day (NGH), further consideration has to be made in order to shift to the commercialization phase. Therefore, the materialization of the pilot project of 100 to 200 ton/day (NGH) is much required in order to study on the issues for the scale-up and compactification of the process in terms of technological and operational aspects. The study group is currently studying the requirements for the pilot project and is also developing its master plan.

12. CONCLUSIONS

In this study, the advantage of NGH was confirmed under the certain conditions.
Meanwhile, monetization of the small and medium gas field is the topic that attracts every interest all over the world, and the various kinds of relevant technologies are simultaneously under development. Even in the technology of the well matured LNG, development of small-scale production process of land plan and, furthermore, small-scale FPSO is in progress. Although NGH is proved currently competitive, it loses the opportunity to be launched to the market, if it missed the appropriate the timing. MES and Mitsui are exerting every effort in order to materialize the early commercialization by addressing the challenged described in Chapter 11.

13. ACKNOWLEDGEMENT

This manuscript mostly introduced the essentials of the report of the up-do-date feasibility study on natural gas supply chain by means of NGH, implemented in conjunction with INPEX Corporation, Japan Petroleum Exploration Co., Ltd., Mitsui O.S.K. Lines Ltd., NYK Line, The Chugoku Electric Power Co., Inc., and Tokyo Gas Co., Ltd. with the assistance of Japan Oil, Gas and Metals National Corporation (JOGMEC). We greatly appreciate these companies for their considerable contributions and JOGMEC for its financial support.

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