VI. Study of MH Production System and Evaluation of Economics and EROI

VI. 1. Basic Plans and Issues of MH Production System

(1) Objective

The aim of this study was to show a full picture of the MH production system that consists of wells, subsea systems, flowlines and riser/umbilical systems, offshore gas processing facilities, and transportation facilities to provide processed gas to onshore customers, in order to extract necessary technical elements, estimate costs, and evaluate environmental impacts.

In the R&D program Phase 2, we gathered basic information about gas production systems through various case studies with reference to development of conventional oil and gas fields in deep water.

In the R&D program Phase 3, we selected several candidate production systems based on the studies conducted in Phase 2, and then analyzed the requirements for commercialization and issues currently recognized for each selected system in order to identify the basic plan of production systems that could be used for future commercial production.

(2) Configuration of MH Production System

The MH production system is the entire system that is necessary to produce gas from MH reservoirs, process the produced gas, and deliver it to the customers. It consists of subsystems of production, processing and transportation.

The production system, which primarily corresponds to wells and subsea systems, is for extracting gas from MH reservoirs. The processing system, which corresponds to offshore platforms, etc., is for removing water and impurities from produced gas. In some cases, this system also includes facilities for converting gas into electricity. The transportation system, which corresponds to LNG (Liquefied Natural Gas) vessels, subsea pipelines and subsea cables, is for delivering processed gas or electricity to customers.

(3) Details and Results

The components (production, processing and transportation) of the MH production system need to conform to the conditions related to MH concentrated zone itself such as the conditions of reservoir, location, weather and sea, seabed and so on. Also, the sales methods may become a constraint condition for the system components. Therefore, we considered the feasibility in terms of the condition of sales methods (business model) and initially extracted the candidates of MH production system. Table 1 shows the comparison of business models and the extraction results of the MH production system candidates.

Next, we narrowed down the candidates to the following three options for further study from technical, economic and social viewpoints. Table 2 shows the feasibility, advantages and tasks /

issues of the three options. Although all the three options have tasks / issues, they also have advantages and could be feasible depending on future conditions. Accordingly, all the three options detailed below remain subject to further study.

・Option 1： Offshore Platform System (Fig. 1)
・Option 2： FLNG (Floating Liquefied Natural Gas) System (Fig. 2)
・Option 3： SSL (Sub-sea to Land) System (Fig. 3)

① Subsea Pipeline Model (Options 1 & 3).
This model needs large-scale investment including compensation for fishery rights holders to lay subsea pipelines, therefore it is important to investigate whether there is sufficient gas demand commensurate with such investment in the area around the onshore delivery point for each MH concentrated zone. This system is considered to have relatively few issues, and if we overcome such technical issues and realize stable operation and supply, it could become a major business model for commercial production. Two schemes, offshore platform system (Fig. 1) and SSL system (Fig. 3), were set as Option 1 and Option 3 of the MH production system candidates, respectively.

② FLNG Model (Option 2).
FLNG operation has already started in some conventional gas fields, however, overall experience is still poor in both numbers and operating time. In addition, the sea conditions around the FLNG-applied fields are relatively calm, therefore it is considered that there still remains technical uncertainties in terms of the applicability to the ocean around Japan where weather and oceanographic conditions are severe. Although this business model has technological challenges, it has the highest affinity with existing LNG business chains. Therefore, FLNG System (Fig. 2) was set as Option 2 of the MH production system candidates.
As it is difficult to identify significant advantages of the options other than Options 1-3, and while considerable technical issues and uncertainties about the market are recognized, we removed them from the candidates in this study. However, we should keep those options in mind because technical innovations or new findings relating to them may drastically change the situation.

As the options except for Option 1-3 are difficult to find significant advantages while considerable technical issues and uncertainties about market are recognized, we removed them from the candidates in this study. However, we should keep those options in mind because technical innovations or new findings relating to them might drastically change the situation.

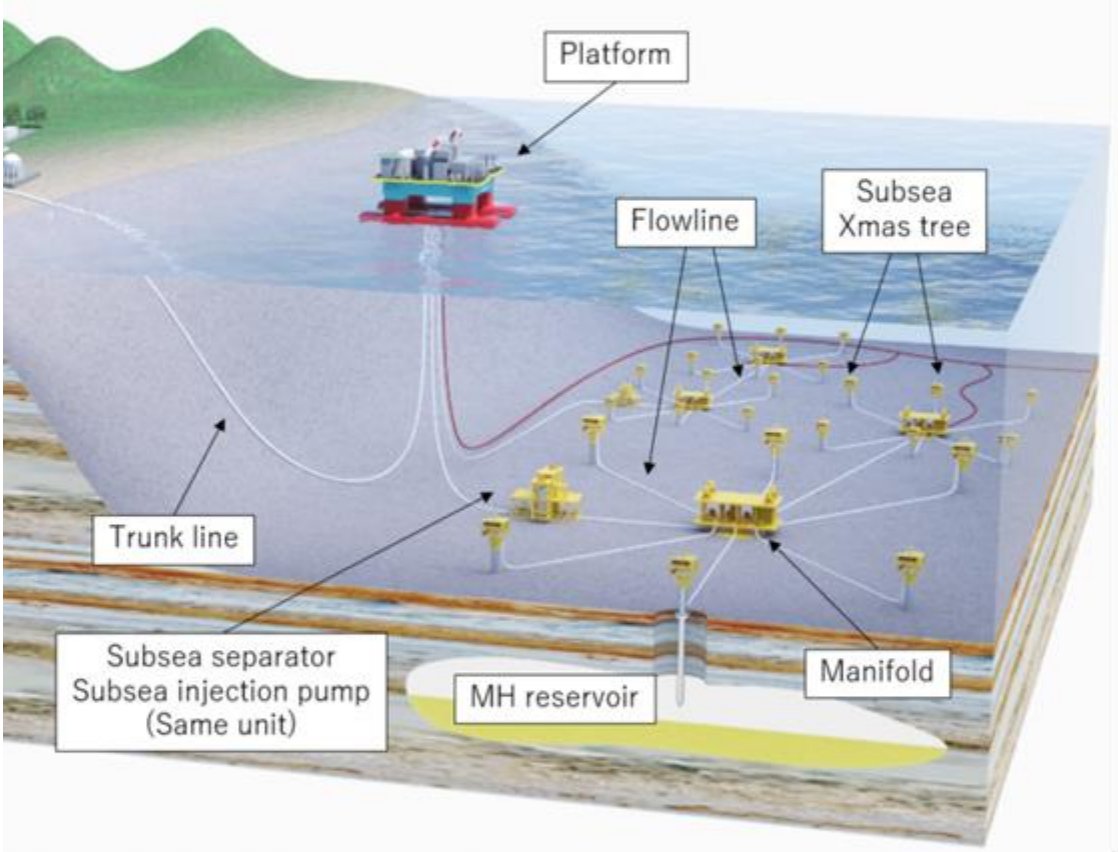

Fig.1 Overview Picture of Offshore Platform System

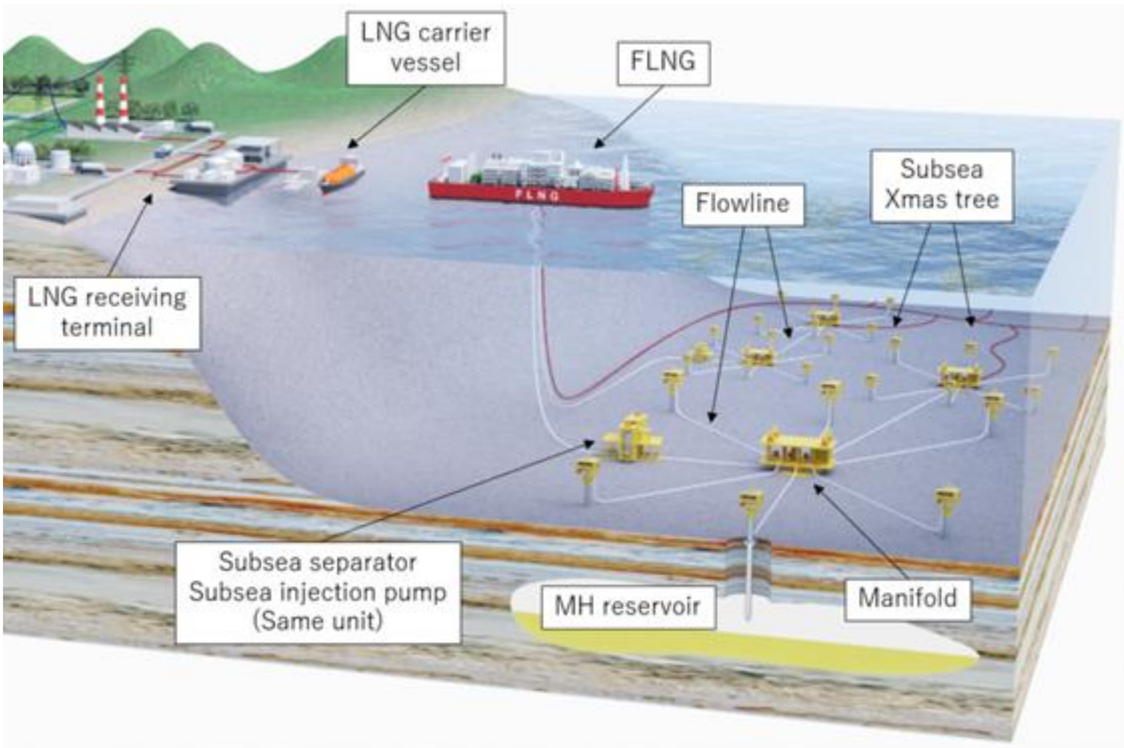

Fig.2 Overview Picture of FLNG (Floating Liquefied Natural Gas) System

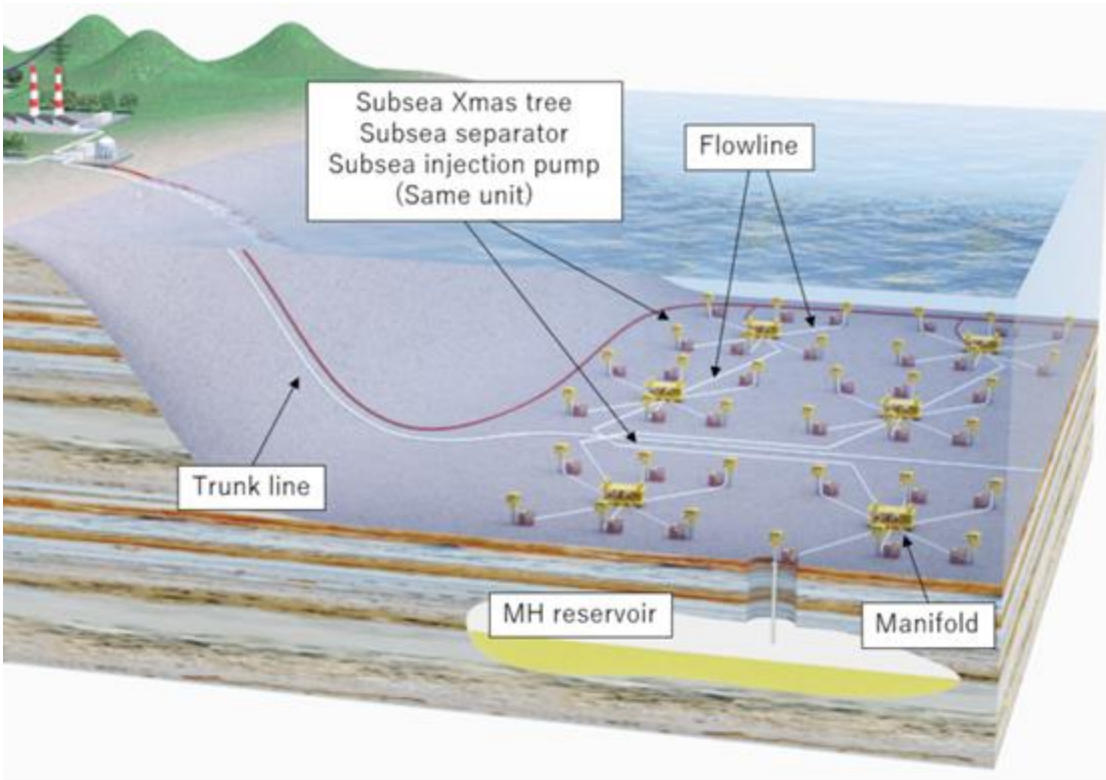

Fig.3 Overview Picture of SSL (Sub-sea to Land) System

Table 1 Comparison of Business Models and Extraction Results of MH Production System Candidates

No.	Sales Method	Point on Feasibility	System Candidate (Gas Processing / Transportation)
1	・Transport gas to land by subsea pipelines.	・With stable operation and supply, it may be a major business model. ・Existing technology can be utilized.	・ Offshore Platform System/Subsea pipelines ・Subsea Station/Subsea pipelines
2	・Sell gas as LNG liquefied offshore to land or abroad.	・Despite technological challenges, it has high affinity with existing LNG business chain.	・FLNG vessels/LNG vessels
3	・ Sell gas as CNG (Compressed Natural Gas) produced offshore to land or abroad.	・The market is small.	・Not a candidate.
4	・Transmit electricity generated offshore to land by subsea power cable.	・With stable operation, it may be a major business model.	・Not a candidate.
5	・Transport chemical products made offshore to land by subsea pipelines.	・Remain opaque.	・Not a candidate

Table 2 Comparison Table of Selected MH Production System Options

Gas Production System	Feasibility	Advantages	Tasks / Issues
Offshore Platform System (Option 1)	・As most of the equipment can be used by improving existing equipment, technical difficulty is relatively low.	・Few new development elements	・Necessary to match the platform design to severe weather and oceanographic conditions in Japan. ・Pipelines may interfere with existing subsea infrastructure such as cables.
FLNG System (Option 2)	・Same as above.	・No interference with subsea infrastructure such as cables. ・Suitable for Japan's natural gas infrastructure.	・There are few achievements. ・There are unknown factors such as operations under severe weather and oceanographic conditions. ・FLNG construction cost is higher than that of a normal platform.
SSL System (Option 3)	・Same as above.	・Few new development elements. ・Platform is not needed, so hardly affected by weather or oceanographic conditions.	・Depending on the distance, an expensive and massive subsea compressor is needed. ・Pipelines may interfere with subsea infrastructure such as cables ・Difficult to deal with emergency. ・Cost is high in the case of ESP installment for each well.

(4) Conclusion

Several candidates for the MH production system were investigated and compared in terms of feasibility, and consequently three promising options were selected. Regarding identifying the options, we conducted a technical survey and economic evaluation.

Each option has advantages and disadvantages, in addition, there is high uncertainty about the technical subjects and the business environment such as future gas demand at this point in time. Therefore, it is premature to decide which option is the best.

In order to make such a production system more realistic and the optimum one in the future, it would be necessary to reflect the prediction of production behavior based on the results of the offshore production tests and take into account the more acceptable conditions from the viewpoint of customers. In addition, it is necessary to review the MH production systems repeatedly in view of the progress of research and acquisition of new data/information.

VI.2 Evaluation of the Economics and EROI

(1) Objective

The economic efficiency and Energy Return on Investment (EROI) should be sufficiently high in order for methane hydrate (MH) to be established as a commercial resource, however, it is difficult to elaborately discuss them because of the high level of uncertainty regarding technical matters and the future business environment.

However, in order to proceed with the MH research and development flexibly and reasonably adjusting the roadmap to focus on future commercial production, responding to the progress in relevant technology and the changes in the outlook of the external environment, it is necessary to evaluate the economics and EROI, based on the currently assumed production system and gas production behavior.

This chapter describes the necessary conditions of the MH concentrated zone for future commercial production and the calculation result of EROI, which were studied on the basis of the latest findings and assumptions gained through the MH offshore production tests.

(2) Background

We announced the economic efficiency of the production system as the result of the R&D program Phase 1 in FY2008. Since then, we have investigated production systems such as offshore platforms, subsea production/separation systems, and subsea pipelines, which would be applied to future production systems, and accumulated cost data for these systems.

The first MH offshore production test was performed in the R&D program Phase 2. We obtained the actual data on the production behavior through the test, even though it lasted for just six days.

On the other hand, as medium- and long-term attempts to realize MH commercial production, the basic studies of the production systems that could be applied to commercial production under Japan’s oceans were carried out in parallel with the actual production tests.

(3) Details and Results

① Economic Evaluation

A. Estimation of Long-Term Production Behavior

In order to estimate long-term production behavior by reservoir simulation, it is necessary to understand the parameters that show the properties of MH layers, such as net gross ratio, porosity, MH saturation, permeability, etc.

We set up these parameters based on the core and logging data so that the production behavior of the offshore production test could be reproduced.

We used the “MH21-HYDRES” reservoir simulator jointly developed by the University of Tokyo, Japan Oil Engineering Co., Ltd. and AIST under MH21, to help predict production behavior.

Fig.1 shows an example of the predicted production profile.

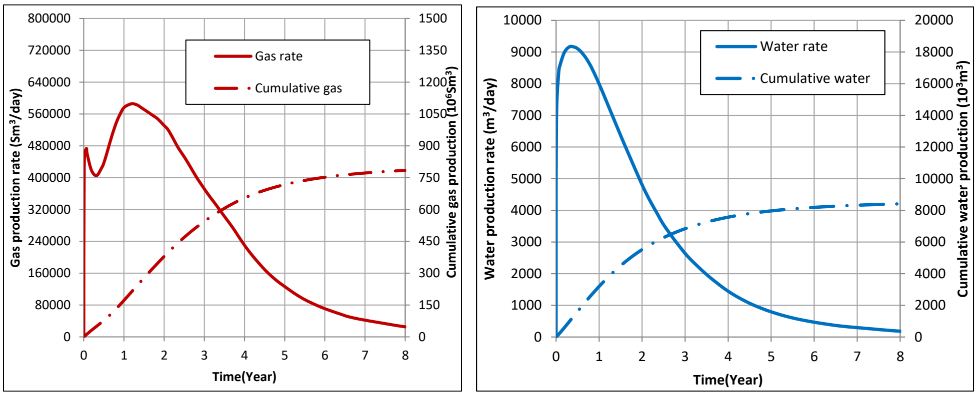

Fig.1 Predicted production profile of the assumed largest MH concentrated zone (For one well)
(Left) Gas production rate, (Right) Water production rate

B. Conditions/Assumptions for Economic Evaluation

As the gas production period of the second MH offshore production test was approximately one month, the long-term gas production behavior is still uncertain, which means there remains various levels of uncertainties such as the number of production wells and the capacity of production facilities for future commercial production. Therefore, for economic evaluation, it is necessary to make a range of assumptions to supplement such uncertain parameters.

Table 1 shows the conditions/assumptions for economic evaluation, and Fig. 2 shows the schematic view of the MH production system.

Table 1 Conditions/Assumptions for Economical Evaluation

Items	Conditions/Assumptions
MH concent -rated zone	・Base models were created based upon the characteristics of expected MH concentrated zones
Reservoir	・Assumed on the basis of the existing well data and sedimentological studies (It is assumed that it is uniformly continuous in the horizontal direction throughout MH concentrated zone)
Production methods (including production simulation)	・Depressurization method with a bottomhole pressure of 3 MPa ・One production well covers an area of approximately 600 sq m (equivalent to a gas drainage area of 350 m radius) ・Assumed no exchange of heat or fluid between the inside and outside areas ・Do not consider any impact on productivity caused by sand flow and accompanying issues, or deformation of sand layers caused by MH dissociation.
Gas Sales method	・Gas is transported via a subsea pipeline to the shore near the MH concentrated zone and sold to a utility company. ・No odorization or calorific value adjustments ・Gas is boosted and sold at 5.6 MPa. (for power plants) ・Gas sales price is assumed according to its calorific value.
Gas Production system (Fig. 2)	・Multiple wells are connected to a manifold, and produced gas and water are collected. ・A subsea separator is placed after the manifold. Gas is collected at the platform, pressurized and dehydrated, and pumped to the shore via a subsea pipeline. ・Produced water is reinjected into the layer below the MH reservoir after being separated on the seabed. ・Assumed electrical submersible pumps for depressurization are placed after separators, not installed in each wellbore.

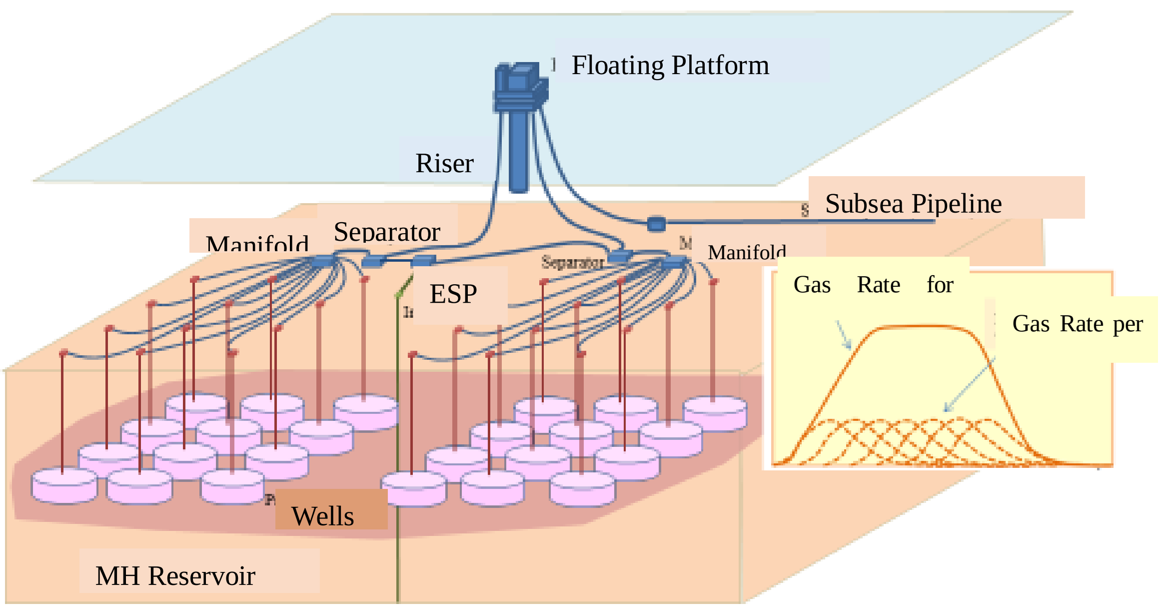

Fig.2 Schematic view of gas production system

C. Prediction of LNG Price

Assuming a scenario in which commercial production is realized in the 2030s as stated in the Basic Plan on Ocean Policy formulated by the Japanese government, the gas production cost must be competitive against the LNG price at that time.

It is assumed that the LNG price in Japan within the period 2030－2050 will be $10－11/MMBtu based on outlooks of the IEA and EIA. However, the LNG price should be assumed to be within a certain range due to the difficulty of predicting the supply and demand around the world. While using $10/MMBtu as a guide, we considered the highest actual price of $18/MMBtu as an upper limit. In addition, as the LNG price must include profit for the developers, we set a criterion of an IRR (Internal Rate of Return) of 10% on this trial calculation.

D. MH Concentrated Zone Conditions for Commercial Production

In the implementation plan of "MH R&D Program of Phase 3," the following are described as criteria for commercial production.

・The duration of gas production from each well can be expected to last for several years.

・Gas production rate from each well can be expected to exceed several tens of thousands m3/day and more.

We roughly calculated the conditions to satisfy the requirement of IRR of 10% based on an LNG price of $10/MMBtu. From the calculation results, the initial MH in-place volume in a concentrated zone and the average production rate per well were indicated as follows.

(The MH recovery factor is not known at present, so it should be considered to be with a certain range.)

・Initial MH in-place volume should be approximately 50 billion m3 or more

・The average production rate per well is about 150,000 m3/day and more. (Expected well life: eight years)

Similarly, in the case of the LNG price of $18/MMBtu, the results are as follows:

・Initial in-place MH volume should be approximately 10 billion m3 or more.

・The average production rate per well is about 50,000 m3/day and more. (Expected well life: eight years)

Table 2 shows the MH concentrated zone conditions required for commercial production.

Table 2 MH Concentrated Zone Conditions Required for Commercial Production

Criterion (the LNG Price $10/MMBtu)　　(LNG $18/MMBtu)

MH in-place / Gas production rate (8 years average)	Large More than 50 billion m3 (2 TCF)	Medium 10 - 50 billion m3 (0.4 - 2.0 TCF)	Small Less than 10 billion m3 (0.4TCF)
High More than 150,000 m3/day	◎ (Priority：High)	○ (Priority：Medium)	× (Not Applicable)
Medium 50,000-150,000 m3/day	○ (Priority：Medium)	Bench Mark △ (Priority：Low)	× (Not Applicable)
Small Less than 50,000 m3/day	× (Not Applicable)	× (Not Applicable)	× (Not Applicable)

Although the existence of several MH concentrated zones has been confirmed by drilling and/or well logging in the Eastern Nankai Trough, such areas where the existence of MH has been directly confirmed are extremely limited. However, the existence of MH concentrated zones has been indicated by the integrated interpretation based on seismic data even in areas other than the Eastern Nankai Trough, and we evaluate that some of the indicated MH concentrated zones could be commercially developed when the LNG price is $10/MMBtu (Table 2), although the evaluations are based on various assumptions that contain many uncertainties at the moment. These assumptions should be verified and the evaluation should be continuously reviewed along with demonstrating the necessary technologies.

② Calculation of Energy Return on Investment (EROI)

A. Calculation method

Fig. 3 shows the concept of the EROI calculation method. Among the factors required for the calculation, the input energy is estimated from the total amount of energy of each activity at the various stages in the life cycle. Therefore, it is important to set the evaluation scope and organize the corresponding unit energy consumption in preparation for the calculation.

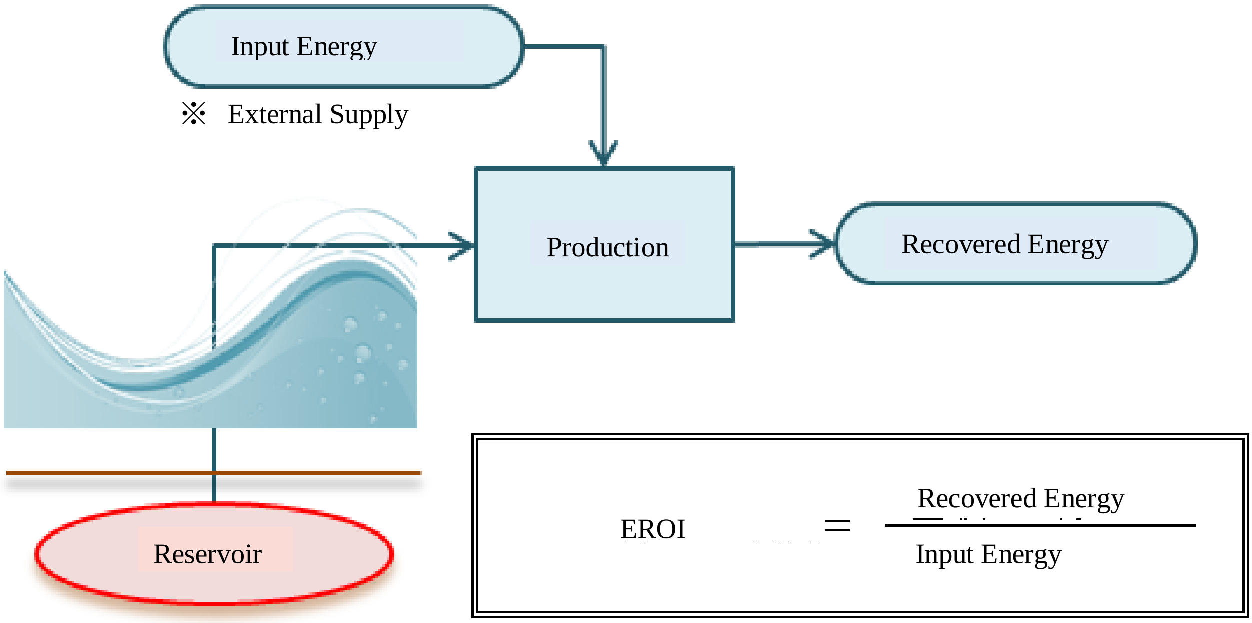

Fig.3 The concept of EROI calculation method

B. Evaluation Scope

There are roughly two approaches to evaluate EROI. One is to cover all energy consumption including energy consumed for manufacturing the facilities used for drilling, liquefaction, transportation, and other activities. The other is to cover only energy consumption for the operation of each facility. Nowadays, the latter approach is common as the energy consumption during the operation is much larger than the facility manufacturing energy in any system.

However, when considering the MH production system for the ocean around Japan, it is necessary to drill a large number of wells (though the drilling depth is shallow) and install many subsea facilities in comparison with conventional oil and gas development, therefore the former approach, which covers all the energy consumption including the consumed energy for manufacturing, was selected for this evaluation. On the other hand, we excluded the conversion to secondary energy such as electricity and city gas from the evaluation scope, because there is no difference between existing energy and MH in the conversion process.

Fig. 4 shows the concept of EROI evaluation range.

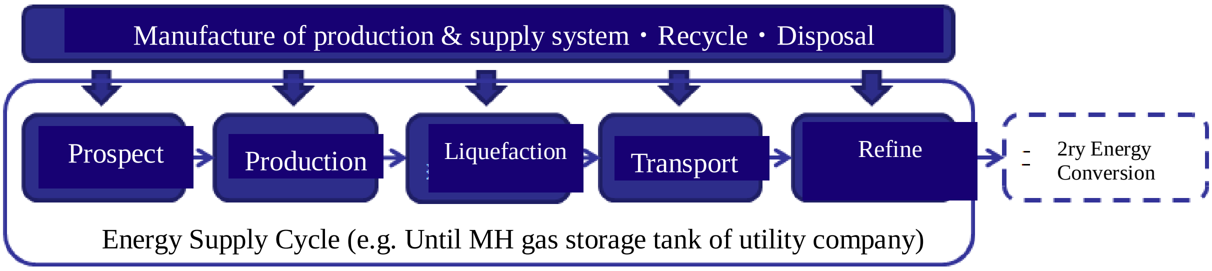

Fig. 4 Concept of EROI evaluation scope

C. Evaluation of EROI

Fig. 5 shows the calculated results of EROI and the past results evaluated for conventional fossil fuels.

For offshore platforms and Sub Sea to Land (SSL) systems, the EROI was estimated at around 10 ~ 16. These values are inferior to those of imported coal and crude oil but almost the same as those for heavy oil. EROI for the FLNG system was approximately 5, which is slightly lower than the value for LNG, which is 6. As mentioned above in the economic evaluation section, the calculation is still subject to many uncertainties at present and we believe it is too early to conclude which option would be ideal or whether MH development would be inferior or not compared with existing energy based on those calculated values. However, it would be reasonable to continue R&D into MH while focusing on future commercial production from the viewpoint of effective utilization of domestic energy.

This trial calculation was carried out by Mizuho Information & Research Institute Inc. through Japan Methane Hydrate Operating Co., Ltd. (JMH) which we consigned for this study.

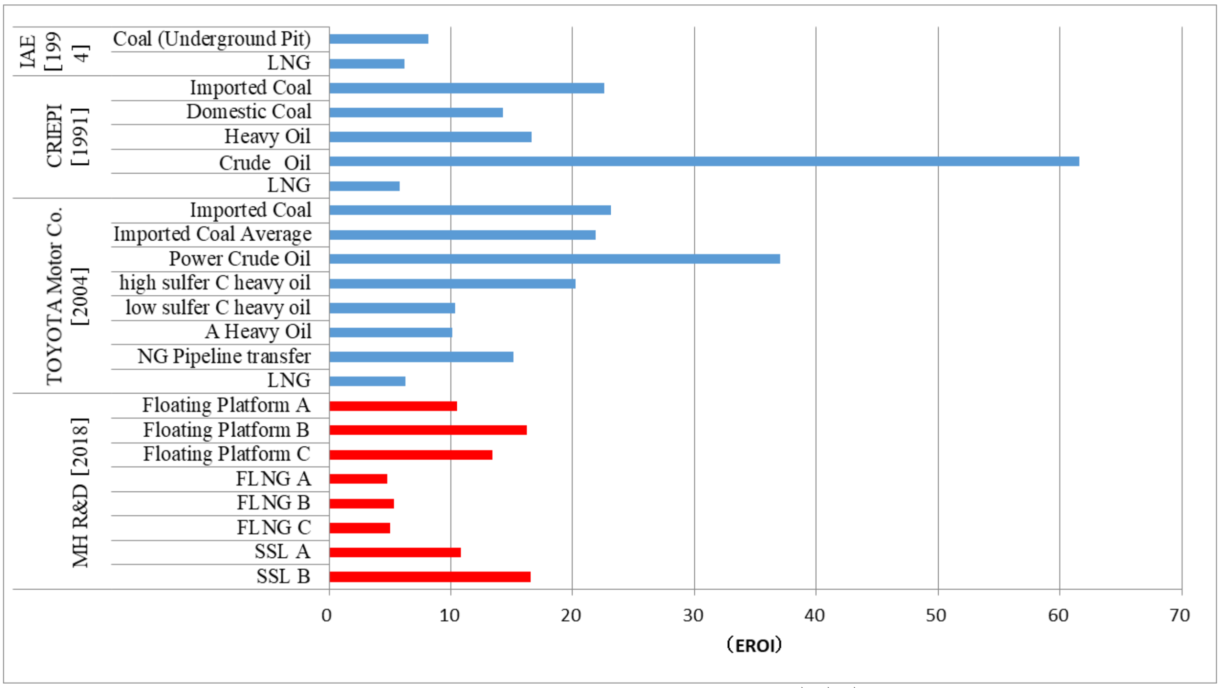

Fig. 5 the Calculated result of EROI [2) 3) 4)]

③ Enhancement Recovery Methods of MH

The depressurization method, which depends only on pressure reduction, is the best method in terms of the EROI, but the dissociation ability of MH is not so high. Accordingly, it may be necessary to apply any production enhancement mechanism such as additional heat supply together with depressurization. Therefore, we investigated the proposed production enhancement methods through literature surveys and interviews. These methods have not yet reached the field verification stage, and we should continue to monitor their development. They are summarized below.

A. Dual Horizontal Wells

This is a similar method to SAGD (Steam-Assisted Gravity Drainage) used for oil sands production in Canada. Two horizontal wells (the lower well is used as an injection well, and the upper is used as a production well) are drilled into the MH layer. Hot water or CO2 is injected from the injection well and dissociated gas is recovered from the upper well.

B. Combined Geothermal Application

Geothermal hot water (40-50℃) is collected directly from the deep stratum and circulated into the sand layer just below the BSR (Bottom Simulating Reflector). Heat is supplied to the MH layer to induce MH dissociation and improve gas productivity.

C. Geothermal Application

This method involves injecting hot water warmed by deep geothermal activity into an MH layer where the permeability has been increased to some extent as a result of gas production by the depressurization method.

D. Injection of Different Type Gases

This method makes MH dissociation accelerate by injecting different types of gases such as CO2 and N2 into the MH layer.

E. Deep Depressurization

This method aims to facilitate the MH dissociation with ice formation heat by reducing the bottomhole pressure below the original target of 3 MPa to intentionally generate ice.

F. CO2/Water Emulsion Injection

When CO2/water emulsion is injected into the MH layer, CO2 hydrate is generated. This method uses the formation heat of CO2 hydrate to dissociate MH.

G. Hydraulic Fracturing

This method aims to improve the initial permeability of MH layers via the hydraulic fracturing method, which is widely used for shale gas development.

H. Ultrasonic Irradiation

Ultrasonic irradiation is considered to improve the MH dissociation rate and contribute to MH gas production.

(4) Conclusion

We carried out economic evaluation and EROI calculations based on the results of R&D program Phases 2 & 3. In addition, we also examined the proposed production enhancement methods of MH.

The following are summaries of these studies.

① Economic evaluation

As a result of evaluating the economic efficiency, it became clear that the economic efficiency is greatly affected by the gas production rate per well. In other words, the key to reach commercial MH development should be to find methods to attain higher gas production rate and total gas recovery per well.

The evaluation results suggested that there may be a possibility of commercial production depending on the conditions of MH concentrated zones, economic conditions, and the actual production behavior, etc.

However, as we have not yet fully grasped the actual gas production behavior, it is difficult for a private enterprise to make a decision to take the initiative in the MH business based on this trial calculation that contains a range of uncertainties at present. It will be critical to gain further understanding of gas production behavior from MH layers in order to help eliminate such uncertainties.

② Trial Calculation of EROI

We tried to calculate EROI using assumed gas production rates over a wide range. The EROI of MH was estimated at around 10 ~ 16, which is almost equivalent to that of heavy oil. Since many uncertainties are still contained in the latest calculations, and because it is too early to conclude whether or not MH development would be inferior compared to development of existing energy sources, it would be reasonable to continue R&D into MH with a focus on future commercial production from the viewpoint of effective utilization of domestic energy.

③ Enhancement Methods of MH Dissociation

As productivity improvement should be inevitable when aiming for the commercial stage, we investigated the proposed production enhancement methods of MH. However, these methods have not yet reached the field verification stage, and we should continue to monitor their future development.

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