International Journal of GEOMATE, Aug., 2022, Vol.23, Issue 96, pp.163-170
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2022.96.gxi373
Geotechnique, Construction Materials and Environment

FLOATING AUTOMATED FACTORY SYSTEM FOR EFFECTIVE UTILIZATION OF SEABED RESOURCES AND REDUCTION OF GREENHOUSE GAS EMISSIONS

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ABSTRACT: Japan has the sixth-largest Exclusive Economic Zone in the world, covering approximately 4.47 million square kilometers. Methane hydrate is known to exist under the seafloor, with approximately 100 times the amount of Japan's annual natural gas consumption. To minimize the cost from extraction to the processing of such seabed resources, the installation of facilities that can generate electricity directly above the sea area where the resources are located is considered the most efficient strategy for the extraction and conversion to energy. Furthermore, methane gas can be converted to hydrogen gas through a steam reforming process, thereby minimizing greenhouse gas emissions. By arranging various factories around the facility as floating structures, it will be possible to reduce the costs from product processing to the manufacturing of finished products. Further, floating factories can minimize tsunami damage when compared with factories on reclaimed land in the coastal areas. To effectively utilize energy resources and reduce greenhouse gas emissions, we propose a floating structure that can consolidate the respective movements of people, products, and logistics from the seafloor to the sea and its surroundings.

Keywords: Energy resources, Methane Hydrates, Marine Space, Vertical production city, Floating structure

1. INTRODUCTION

Following the period of high economic growth in the 1970s, Japan has grown into a wealthy country. With this social development, power consumption has grown dramatically, and today, Japan is the third highest consumer of energy in the world. However, the energy resources self-sufficiency rate of Japan is below 9.6%, and the country relies on importation for more than 80% of its energy resources. Currently, global energy policy is in a transitional period, and various systems are being considered.

With the Fukushima Daiichi Power Plant accident during the Great East Japan earthquake, Japan faces a turning point in energy policies. In the future, there will be a need for less dependence on imported resources and the securing of safe and clean domestic energy sources. Thus, currently, seabed resources around Japan have attracted attention.

Methane hydrates, the most representative seabed resources, are natural gas resources called "fire ice." Compared to conventional fossil fuels, CO_2 emissions during methane combustion are about half. Thus, it is a potential clean energy source. About 6 trillion cubic meters of methane reserve in the waters of the Nankai Trough were also reported [1].

Based on this survey, to commercialize methane hydrates as a new domestic energy resource, the Ministry of Economy, Trade, and Industry established the "Methane Hydrates Development Plan in Japan" in July 2001. This development plan was a long-term plan that covered the period from 2001 to 2018. This development plan aims to (1) clarify the status and characteristics of methane hydrate in the seas surrounding Japan, (2) estimate the methane gas reserves in promising methane hydrate-bearing offshore areas, and (3) select methane hydrate resource fields from the promising methane hydrate-bearing offshore areas and study their economic potential, (4) conduct offshore production tests in selected methane hydrate–resource fields, (5) develop technologies for commercial production, and (6) establish a development system that considers environmental conservation. In March 2013, the Agency for Natural Resources and Energy conducted a gas production experiment with methane hydrates and recorded the first success in the world. With this experiment, the transition to commercial production of methane is anticipated in the 2020s [2].

In this paper, we propose an island city of a floating automated factory system using methane hydrates as the main energy source. It is anticipated to be the new domestic energy resource.

2. PLAN BACKGROUND

2.1 Energy in Japan

While Japan is a major energy consumer, its self-sufficiency rate of energy resources, excluding nuclear power, is only 9.6%; thus, the country depends on importation for the majority of its energy needs (Fig. 1, 2).

From the energy resource explorations to energy production in Japan, consider oil as an example; Oil accounts for half of Japan's energy needs.

The process is as follows: exploration overseas, → primary refining process → loading on ships at a port → transport by sea → unloading at a port → final refining process at a petrochemical complex → production at each factory → cities and consumers.

Shipping oil from the Middle East, where 90% of oil supply comes from, involves risks as ships must pass through the Persian Gulf, which has unstable political situations, and the narrow Strait of Hormuz and the Strait of Malacca. In addition, since the ships travel a long distance of 12,000 km, the cost of logistics is quite high. It takes about 45 days to make a round trip, during which a large number of greenhouse gases are emitted (Fig. 3) [3].

2.2 Outlook of Domestic Energy Production

In Japan, which depends on importation for most of its energy resources, such as oil and coal, it has been a challenge to find new energy resources that can replace the limited resources. Following the Fukushima Daiichi nuclear power plant accident, the world demands a stop to the dependence on nuclear power, and there is increasing anticipation for renewable natural energy, such as solar and wind power. Natural energy has many challenges, such as varying output by climate conditions, the low energy density per area, and high cost. In Japan, one of the promising possibilities considering the viewpoint of securing various types of energy is in the oceans around Japan.

2.3 Methane Hydrates as an Energy Resource

Methane hydrates have recently gained attention as a next-generation energy resource. It has been reported that there is a rich reserve of methane hydrates in the oceans surrounding Japan. This potential is suggested by what is known as a bottom simulating reflector (BSR). As the deep seafloor has low temperature and under high pressure, methane hydrates are stable. Since the lower limit of the stable range for methane hydrates can be estimated using BSR, the location of the reserves can be explored once the existence of methane hydrates is confirmed.

Marine production tests confirmed BSR along the

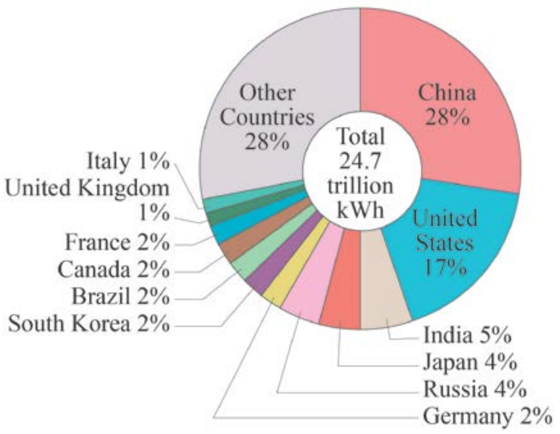

Fig. 1 Power consumption rate by country [4].

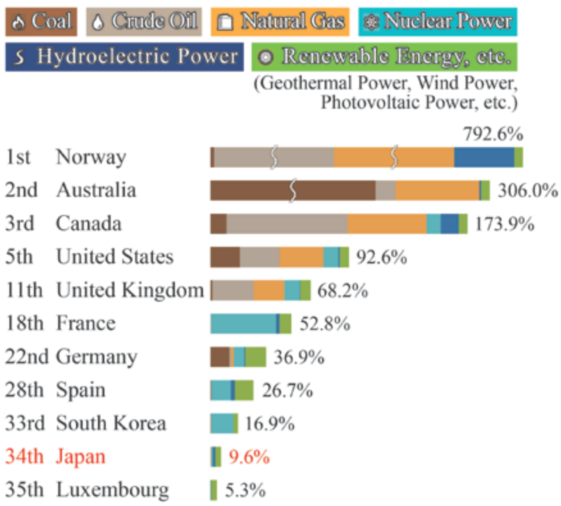

Fig. 2 Self-sufficiency rate of energy resources by country [2].

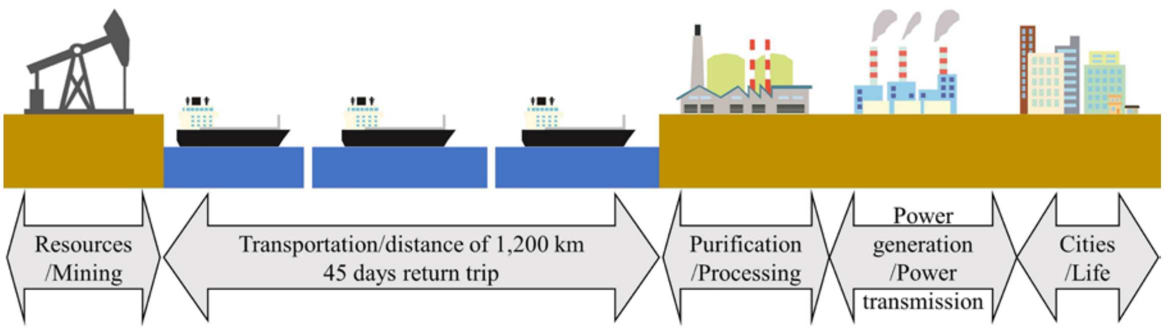

Fig. 3 Process of oil resource mining to production for Japan

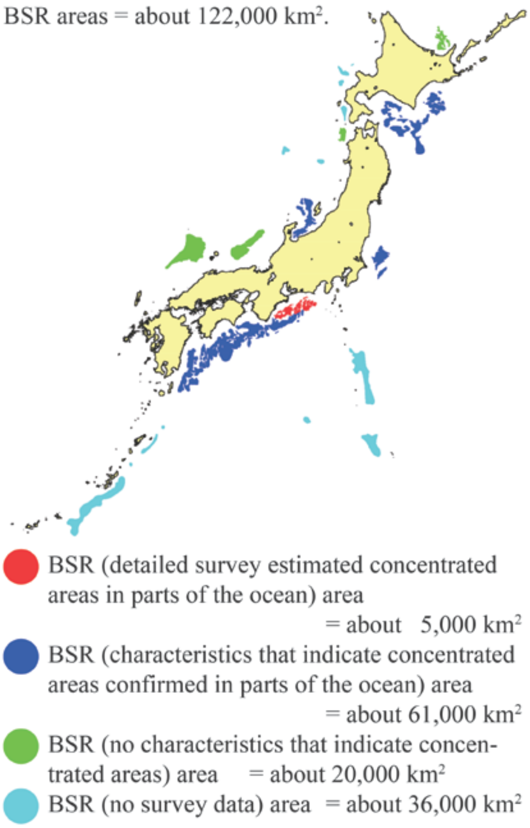

Fig. 4 BSR distribution in oceans around Japan [5]

shoreline of Shikoku to Kyushu, south of Hokkaido, and offshore of Boso and Noto Peninsulas. The estimated amount of methane gas contained in the methane hydrates found at the seafloor of the eastern Nankai Trough, located offshore of Aichi and Mie Prefectures, is equivalent to 10 years' worth of natural gas imported. If other locations are added, the resource is anticipated to exceed 100 years (Fig. 4).

In addition, according to the survey report published by Fuji Keizai Group in 2014, methane-hydrate demand will reach 213 billion yen by 2030. Thus, its commercialization is accelerating.

Though Japan relies on imports for the majority of natural gas, the successful commercialization of methane hydrates makes it possible for Japan to become the next-generation energy resource powerhouse [6,7].

2.4 Uses of Methane Hydrates

Methane gas obtained from methane hydrates is the main component of liquid natural gas currently imported to Japan. According to the Agency for Natural Resources and Energy, Ministry of Economy, Trade, and Industry, it emits less methane gas, sulfur oxide, nitrogen oxide, and CO2 compared to oil and coal, and if we take oil as 100, then the ratio of petroleum to oil is considered to be as low as Sox is 0, NOx, is 20, and CO_2 is 57. [8]. Methane gas can be used as an energy source in various applications, such as city gas, fuel for power generation, natural gas vehicles, and fuel cells. Turning it into natural gas hydrate under atmospheric pressure and temperature of 15°C to 20°C, it becomes easy to manage.

It is important to convert this methane gas into hydrogen gas instead of using it as is. The steam-reforming method, in which methane reacts with water, is widely used in the Industry. This method allows easy manufacturing of hydrogen as a new energy for the 21st century, and its diverse use is anticipated [9].

2.5 Use of Marine Space

The land area of Japan is 370,000 km^2, which is only 1/400 of the total area of the world. Furthermore, when forests, uncultivated fields, lakes, and ponds are excluded, the remaining land area is only 20% of the total area. However, since Japan has the 6th widest exclusive economic zone in the world, which is 10 times the land area, it is filled with potential for marine development. Thus, to create space on water, a very large floating structure, mega-float, is being developed. The Technological Research Association of Mega-Float, established in 1995, advanced technological development, and during the Great East Japan earthquake, a mega-float was used as a floating disaster prevention base for Muroran. Thus, mega-floats are used for various facilities [10].

2.6 Preparation Against Disasters

Japan is one of the most earthquake-affected countries in the world and has experienced many major earthquakes, such as the Great Hanshin–Awaji and Great East Japan earthquake. Earthquakes that are predicted to have more than 60% probability of occurrence in the next 30 years include Tokai/Tonankai earthquake, the earthquake directly below Tokyo, the Tokachi earthquake, and the Miyagi Offshore earthquake. Specifically, according to the estimation by the Japan Meteorological Agency, the Nankai Trough earthquake is estimated to be M8 or larger, and various measures are being taken to prepare for it. During the Great East Japan earthquake, tsunamis stopped the operation of several power plants along the shoreline, which led to a large-scale power shortage. With such experiences, a base with disaster prevention function on the sea, which is less likely to suffer disaster damage, would be vital in recovery.

3. FLOATING PRODUCTION FACILITY

3.1 Characteristics and Plans for A Floating Structure

Here, we propose a floating marine production facility that is mainly supplied with methane hydrates, which are anticipated to be widely used as a domestic energy resource in the future. The plan will fully utilize the properties of a floating structure [11].

1. A floating structure does not require land and can be placed in an area with the likely presence of rich marine resources to obtain a stable supply.
2. Methane and hydrogen gases require completely sealed space. Thus, gas tanks can utilize the internal space of a mega-float.
3. A floating structure is easy to relocate, move, and process; thus, it can accommodate the expansion of a project.
4. Expansion through floating structures, such as mooring of production facilities, factories, and hotels, is easy.

3.2 Plan with Power Generation Function

By combining a floating structure and power generation function in a plan, the following advantages are anticipated (Fig. 5).

1. Independent production and operation on the ocean become possible, allowing for long-term activities.
2. Majorities of the automotive Industry located on the shoreline anticipate exports. Cooperating and linking with a floating structure, it would be possible to share power and produce on the ocean.
3. Perform the entire hydrogen production process offshore using the methane steam reforming method.
4. Combining with lithium in the seawater, lithium-ion batteries can be manufactured, providing a power storage function.
5. A floating structure is not vulnerable to earthquakes. Therefore, during a disaster, it can play a role in the recovery base by providing power to the affected area and so on.

4. CONCEPTUAL PLAN

4.1 Site Selection

Based on the abovementioned plans and policies, the following site selection criteria are proposed: the sea is in a calm condition; the area is rich with resource reserves to provide a stable supply.

4.2 Planned Marine Area

With these selection criteria, the seabed of "eastern Nankai Trough," located offshore of Aichi and Mie Prefectures (Fig. 6), was selected. This area

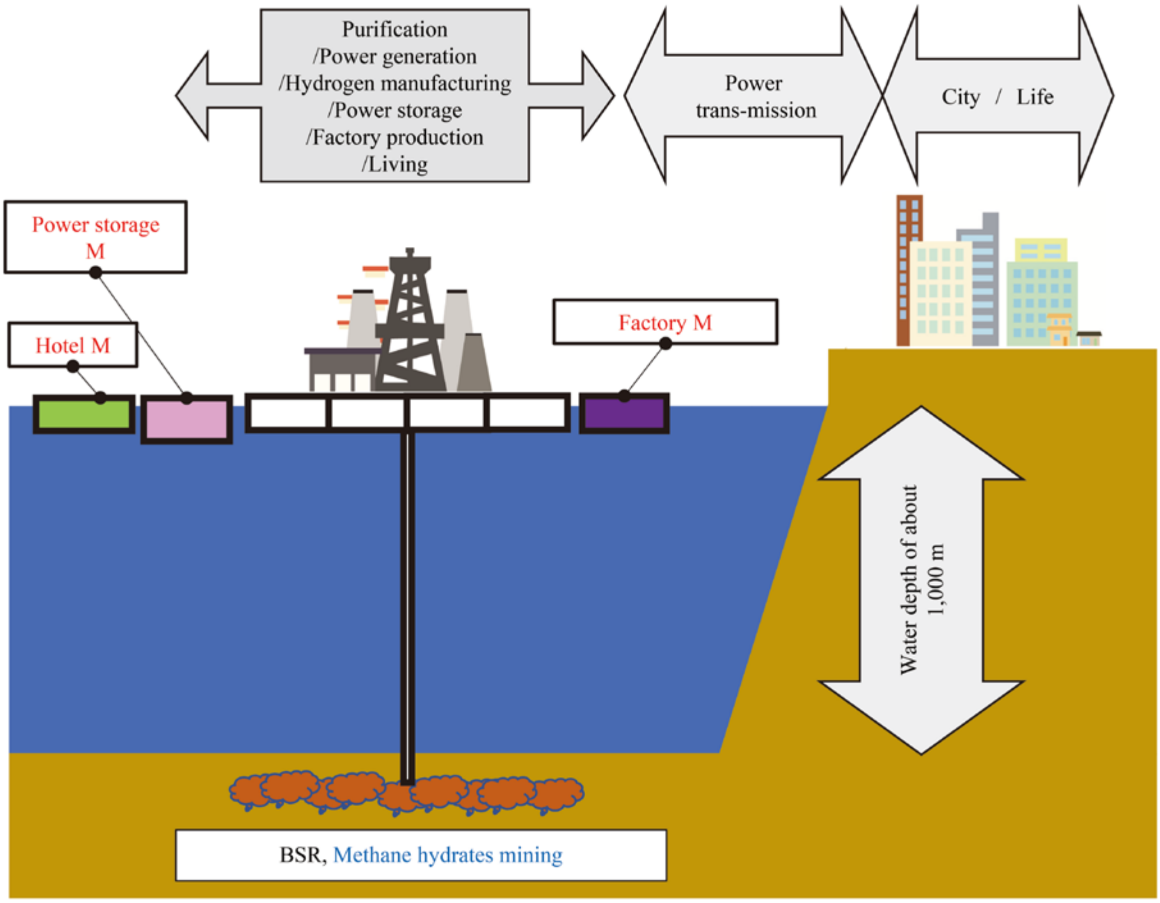

Fig. 5 Functional configuration diagram of a floating production facility

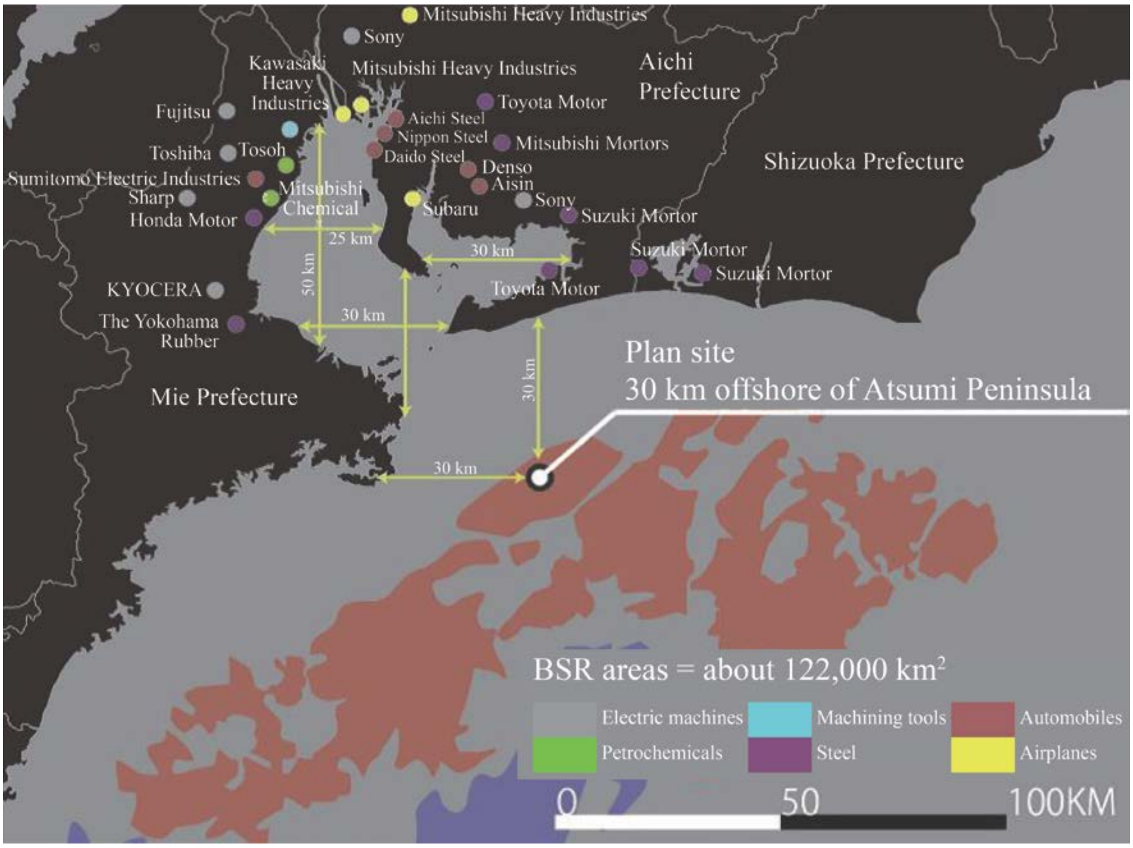

Fig. 6 Plan site: Eastern Nankai Trough at 30 km offshore [5,6]. The colored circles indicate the location of plants for key industries in Japan.

is not affected by the Kuroshio Current throughout the year, and it is located 30 km from Atsumi Peninsula, where the Chūkyō Industrial Area is situated.

Produced methane gas is used to generate power within the facility, converted and processed as hydrogen, and shipped to surrounding floating factories or the Chūkyō Industrial Area [12,13].

4.3 Selection of A Floating Structure- FPSO

A floating production, storage, and offloading system (FPSO) is a facility where oil and gas are produced on the sea and stored in a tank located in the facility. Then, they are loaded in transport tankers. It is the most popular type of production facility (60% or more of floating marine oil/gas production facilities). Today, there are about 160 FPSO bases in operation around the world. These facilities are built inside a mega-float (Fig. 7).

4.4 From Methane Hydrate Drilling to Hydrogen Production

We employ the CO_2-in-Water Emulsion Injection method, which is also used to extract natural gas resources. The CO_2-in-Water Emulsion Injection method involves drilling to a methane-hydrate layer

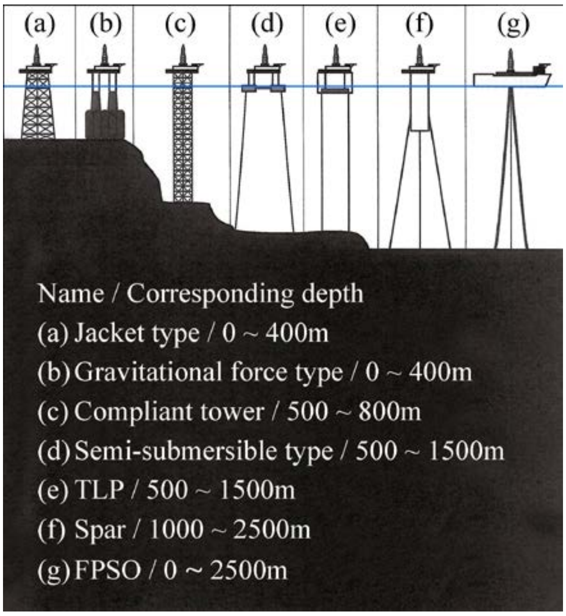

Fig. 7 Floating structure type comparison

at around 1000 m below the seafloor, which breaks down methane hydrates into methane gas and water, which the gas is collected. It can provide a stable supply under various conditions [14]. Hydrogen is further produced using the steam reforming process, in which the methane gas is reacted with water. This method is currently widely used in the Industry.

5. CONSTRUCTION PLAN

5.1 Introduction Function/Scale Calculation

Following the plan background and basic policies, we perform the introduction function and scale calculation. As the major function of the proposed facility, four functions, including the residence/activity department, power generation department, production department, and storage department, are introduced.

5.2 Facility Plan That Makes Life Comfortable on The Sea

Infrastructure maintenance is performed for a long-term life on the sea. Based on the above introduction and scale calculation, we proposed to install five facilities with the residences at the core where 270 staff resided. The plan has five facilities with residences at the core. It includes a food production building, in which exhaust heat from the power generation facilities is effectively utilized for cultivation in the plant factory. It also includes an accommodation building, where researchers and workers can stay and work leisure building for workers on break temporarily, and a sports building dedicated to indoor sports. Since life would be monotonous on the sea, the facility plan provides refreshing experiences (Fig. 8).

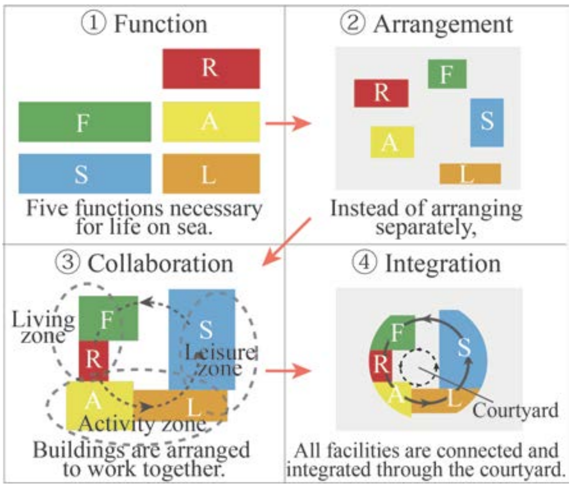

Fig. 8 Overall facility configuration
A: Accommodation building, F: Food production building, L: Leisure building, R: Residential building, S: Sports building.

5.2.1 Food production building

During power generation, CO_2 emitted from the boiler is recovered and effectively utilized to grow plants. Thus, the environmental effect is minimized. Modules are determined based on the basic dimensions of equipment and plant beds in the plant factory, and cultivation is performed at each unit. The smallest cultivation room grows 36 species in a year with two levels per day. It is estimated to grow 200,000 heads of lettuce and approximately 560 kg of tomatoes per year.

5.2.2 Residential building

The residential building is designed to accommodate the 176 staff from the production department, 44 staff from the power generation department, and 50 staff from other departments, totaling 270 staff.

5.2.3 Accommodation building

The accommodation building will have functions to house researchers, workers, and other stakeholders and support their activities. During a disaster, it provides disaster countermeasure functions, accepts affected people, and accommodates 200 households.

5.2.4 Leisure building

The leisure building will have a 300-seat theater and an event center. It would be used during breaks, providing entertainment to the facility.

5.2.5 Sports building

The sports building will allow a total of 13 types of sports, including tennis, dancing, and basketball, promoting mental and physical health. As an environmental plan, the facility would effectively incorporate natural light and reduce environmental loads.

6. PROPOSAL FOR A SELF-SUSTAINING MARITIME CITY

6.1 Energy-producing Maritime City

In addition to the extremely low cost of energy production to processing, another advantage of this city is that it produces hydrogen directly from methane, resulting in low CO_2 emissions. Furthermore, by preparing various facilities as modules, the facilities can be extended or reduced, depending on the function.

The disadvantage of floating structures is that they are costly because they are not currently mass-produced. However, since it is not premised on moving, it does not require equipment such as steering, engine, and fuel like ships, so it is expected that the cost will decrease if it is mass-produced.

6.2 Maritime Cities with Modular Systems

The greatest advantage of this system is that the production costs and risks involved in moving resources for energy production are extremely low.

Since a mega-float is a floating structure, its position can be changed according to the mining conditions of the seabed resources. Furthermore, it can be combined with a manufacturing factory, power storage, hotel, residential building for workers, and so on, as modules above or near the floating structure. Such a system with limited movements of energy resources, objects, and people can be called a vertical production city.

6.3 Island City Prepared for A Disaster

In the proposed facility, located 20–30 km offshore of Japan, the impact of earthquakes and tsunamis would be extremely small; thus, the advantages of the facility during disasters, such as earthquakes and tsunamis, are significant. In other words, the module design of such a floating structure can be considered a proactive disaster prevention measure.

7. CONCLUSIONS

The following conclusions can be drawn from the above discussion on the design and construction plan of an autonomous marine city

1. This paper provided a straightforward solution to the ongoing offshore research with a critical role in ensuring sustainable development in controlling CO_2 emissions by providing clean energy.
2. This study formulated a detailed methodology to achieve the hypothesis under study considering Design, Construction, and Manufacturing.
3. This research provided a clear plan and explored the diversity in offshore construction methods, aiming to provide a sustainable energy flow chain to consumers on land.

8. REFERENCES

[1] Agency for Natural Resources and Energy, Natural Resources and Fuel Department, Promotion of Resource Development in Oceans Around Japan, 2017, https://www.meti.go.jp/shingikai/enecho/shigen_nenryo/pdf/021_04_00.pdf, May 2017, pp.13-19 (in Japanese).

[2] Agency for Natural Resources and Energy, Japan’s ENERGY (2018 EDITION) 10 questions for understanding the current energy situation, 2019, p.2 (in Japanese).

[3] Alashhab MS., Mlybari EA., Developing a Robust Green Supply Chain Planning Optimization Model Considering Potential Risks. International Journal of GEOMATE, Vol.19, Issue 73, 2020, pp. 208–215.

[4] Japan Atomic Energy Relations Organization, Graphical Flip-chart of Nuclear & Energy Related Topics, https://www.ene100.jp/zumen/1-1-10, 29 January 2021 (in Japanese).

[5] MH21-S R&D consortium, The distribution map of BSRs related to methane hydrates, offshore Japan, 2009, https://www.mh21japan.gr.jp/pdf/BSR_2009.pdf. (in Japanese)

[6] Fujii T., Suzuki K., Tamaki M., Komatsu Y., and Takayama T., Reservoir properties and heterogeneity of turbidite sediment revealed from the exploration of methane hydrate in the eastern Nankai Trough, Japan. Journal of the Japanese Association for Petroleum Technology, Vol. 8, Issue 1, 2016, pp.84-95 (in Japanese).

[7] Tanaka S., Brief mention of the first phase of Japan’s Methane Hydrate R&D Program. Journal of the Japanese Association for Petroleum Technology, Vol. 74, Issue 4, 2009, pp.265-269 (in Japanese).

[8] Agency for Natural Resources and Energy, "Metanation" technology to achieve carbon neutrality of gas, https://www.enecho.meti.go.jp/about/special/johoteikyo/methanation.html, May 2022 (in Japanese).

[9] Hirata K., Katagiri K., Maeda T., Shinoki T., and Funaki J., Hydrogen Production by Ethanol-Steam Reforming Using Cu/ZnO/Al2O3 Catalyst. Transactions of the Japan Society of Mechanical Engineers. B, Vol. 79, Issue 808, 2013, pp.2587-2591 (in Japanese).

[10] Sato C., Principal Characteristic of Mega-Float and Its Structure Planning Flow. Journal of the Japan Welding Society, Vol. 69, Issue 4, 2000, pp.304-308 (in Japanese).

[11] Sato C., and Kawamura A., A Study of Ultra-large Floating Marine Structure and the Result (Part 3): Floating Structure Design Techniques, A Study of Durable Technologies: Chapter 4 A Study of Floating Structure Design Techniques. Techno Marine, Vol. 841, 1999, pp.512-529 (in Japanese).

[12] Aksyutin O.E., Ishkov A.G., Romanov K.V., Grachev V.A., The Carbon Footprint of Natural Gas and Its Role in The Carbon Footprint of Energy Production. International Journal of GEOMATE, Vol.15, Issue 48, 2018, pp.155-160.

[13] Aksyutin O.E., Ishkov A.G., Romanov K.V., Grachev V.A,.The Influence of Methane on Climate Change. International Journal of GEOMATE, Vol.16, Issue 55, 2019, pp. 153-159.

[14] Tanaka Y., Sasaki T., Miyake S., Masuda Y., Naganawa S., and Nagano J., Experimental Study on CO_2-in-Water Emulsion Injection Method for Enhanced Methane Hydrate Recovery, CSMH-5 2013 (5th Comprehensive Symposium on Methane Hydrate). Methane Hydrate Research Center, AIST, 2013, pp.1-4 (in Japanese).

[15] Deyama R., Proposal: Next-generation Floating Offshore Gas Production Facility: Designing a Complex R&D facility of the Atsumi Peninsula,

Aichi Prefecture, Graduate Thesis, Department of Oceanic Architecture and Engineering, Graduate School of Science and Engineering, Nihon University, 2016 (in Japanese).