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Moe Thida(51-108208)
Ushigami Satofumi(51-118072),
Iseki Noriko (39-117913),
Evonne Yiu (51-108221)

CBA Project Title:

Deep-sea mining of methane hydrate located around Japan's EEZ

Executive Summary

This paper aims to assess the commercial viability of deep-sea mining of the methane hydrate deposits for Japan by running a Costs and Benefits Analysis(CBA). Methane hydrate (hereafter referred as "MH") is an ice-like white solid form of natural gas resource that is composed of water and methane gas, and is sometimes called "fiery ice". Methane hydrate form in cold, high-pressure environments and are found throughout the world's oceans and beneath the frozen ground of high-latitude countries. Methane hydrate exploration surveys have been conducted in Japan around its surrounding seas since 2001. It was the discovery in 2007 that confirmed 40 trillion cubic feet of methane hydrates in the southern Sea of Kumano, commercially production of this unconventional energy source. With an energy import dependency rate of 85%, Japan is seriously considering deep-sea mining of methane hydrate which could possibly provide gas requirement to some extent for 14 years.

Methane hydrate exploration in Japan is currently undergoing the research and development(R&D) phase on determining the viability of deep sea mining methods of methane hydrate, which lie below thousands of feet of seawater and sediment. Conducted under the Research Consortium for Methane Hydrate Resources in Japan (or known as MH21), two out of a total of three scheduled phases of research has been conducted since 2001. Results of the Phase 1 research concluded that it could be commercially viable to proceed with the deep-sea mining of methane hydrate. However, while methane hydrate is a clean-burning fuel, it is also a powerful greenhouse gas, with roughly 21 times the heat-trapping potential than carbon dioxide. Taking into account of the externalities and other considerations from methane hydrate production and usage, the paper has conducted a CBA as an extension of the MH21 research.

To be precise, the innovative points of this paper come from both benefit side and cost side. With the normal benefit, sales of methane hydrate in the market (here we assume methane

hydrate will be transacted in the liquid natural gas (LNG) market), we explicitly include the enviromental effect from the reduction of crude oil/petroleum as the use of oil is substituted by the methane hydrate. We also consider the methane hydrate's environment effect in the cost part, as the production of methane hydrate also increases CO2 emission. Hence the accounting of externalities is clearly an added value of our CBA compared with the previous research conducted under the MH21 Research Consortium.

Nonetheless, our CBA result is not optimistic one. In the benchmark case, the Net Present Value is minus 15.48 trillion JPY, which is unprofitable. Then we examine sensitivity analysis in terms of two important uncertainties, which are production amount and LNG price. While the worst case is extremely undesirable, the best case and second best case (production amount is large and price is not so high) are certainly beneficial, with expected profits of 15.63 trillion JPY and 2.61 trillion JPY respectively. Since gas price is exogenous variable, it is important to increase the production amount through research and development. The availability and use of methane hydrates may also then lead to a decrease in supply of oil will decrease, as well as reduction of CO2 emission from burning oil.

In conclusion, the project is feasible and profitable under certain conditions, while we also recognize that the CBA would need to be reviewed when more precise values of production costs and externality costs (e.g. environmental impact) become available in future

I. Introduction:

With the discovery confirmed 40 trillion cubic feet of methane hydrates in the southern Sea of Kumano in 2007, Japan has been working with that hope that this unconventional energy source that could possibly provide it with enough gas to meet its demand for 14 years. Impelling technological developments into drilling and production of methane hydrate on an economical basis for future utilization will contribute to the acquisition of a long-term steady supply of energy.

Methane hydrate exploration is still undergoing the research and development(R&D) phase on determining the viability of deep sea mining methods of methane hydrate, which lie below thousands of feet of seawater and sediment. Conducted under the Research Consortium for Methane Hydrate Resources in Japan (also known as MH21), two out of a total of three scheduled phases of research has been conducted since 2001. Currently test drillings are being conducted by the Japan Oil, Gas and Metals National Corporation (JOGMEC), in association with the Japanese government and a four-month-long site survey for a four-well drilling project is slated to run from October 2011 to March 2012. If all goes well, a year later the survey and the wells will result in what Japan says will be the world's first offshore production test of methane hydrates, with commercial output to start by 2018.

However some concerns are expressed that the development of methane hydrate deposits might increase global warming risks: Scientists are concerned that the natural breakdown of methane hydrate (several times more potent than carbon dioxide) deposits as global temperatures rise will release methane into the air and thus accelerating the rate of climate change. Thus, this paper aims to assess the commercial viability of deep-sea mining of the methane hydrate deposits for Japan, by running a Costs and Benefits Analysis.

a. What is methane hydrate?

Methane hydrate is an unconventional natural gas resource. It is an ice-like white solid form that is composed of water and methane gas, and is sometimes called "fiery ice". One m^3 of methane hydrate would dissociate to $0.8m^3$ of water and methane. Methane hydrate is stable in a limited range of pressures and temperatures. Methane is the primary component of natural gas, and the development of methane hydrate follows almost the same procedure as that for natural gas.

Methane hydrates form in cold, high-pressure environments and are found throughout the world's oceans and beneath the frozen ground of high-latitude countries. Methane is a clean-burning fuel, but is also a powerful greenhouse gas, with roughly 21 times the heat-trapping potential of carbon dioxide.

b. Methane hydrate exploration in Japan

Methane hydrate fills the intergranular pore spaces among sand grains of the seafloor. These methane hydrate bearing sandy layers, or known as Bottom Simulating Reflectors (BSR) are found surrounding of Japan offshore area. According to a survey conducted by MH21, in 2000, the distribution charts of BSR offshore Japan is as summarized in Figure 1 shown below. Based on this chart, "Japan's Methane Hydrate R&D Program" started in FY2001

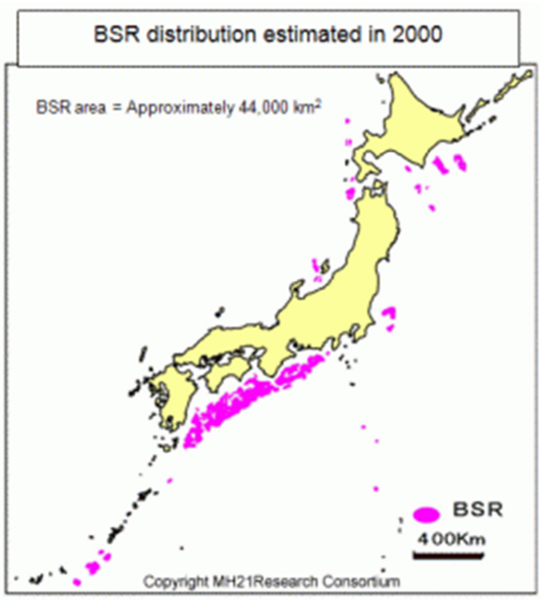


Figure 1: BSR distribution chart around offshore Japan (published in 2000)

The "Japan's Methane Hydrate R&D Program," is executed by the MH21, an industry-government-academia collaboration research group. Phase 1, which started in 2001, carried out seismic surveys and drilling surveys in the eastern Nankai Trough (the deep water zone spanning from the area off the coast of Shizuoka Prefecture to the area off the cost of Wakayama Prefecture), which was selected as the model area. These surveys showed successful results in discovering methane hydrate concentrated zones with a strong possibility for development, establishing a methane hydrate concentrated zone exploration method, and establishing a method for calculating the amount of original methane hydrate in place. Following the completion of Phase 1 in 2008, MH21 is currently advancing to Phase 2, where offshore production tests in the areas surrounding Japan are scheduled. These tests will be the world first offshore methane hydrate production test and scheduled to be completed by 2015. The main objectives of Phase 2 are to verify production methods and field development technology through the offshore production tests, while also extracting new required tasks from the test and solving them. Phase 3 which is scheduled to commence in 2016, will look in comprehensive evaluations of economic potential and environmental impact assessment in preparations for commercial production.

According to the published results of Phase 1 of the MH21 research, the following cost and production facilities related data are as summarized as in Table 1 below:

Production duration:	15 years (production commencement: 2021)
Number of wells:	49 (Well depth: 920m Well spacing: 443m)
Production lead time of each well	8 years
Postulating present construction costs:	92JPY/m3
Average production costs in production period:	46JPY/ m3 (All the assumed conditions come into effect)
Production cost- if production volume lower (by a quarter) than expected:	174JPY/m3
Average gas price in production period:	56JPY/ m3
IRR	6%
NPV (0%):	826 (100million JPY)
Payout time:	8 years

Table 1: Results of costs and production facilities related data of MH21 Phase 1

c. Current Energy Sources of Japan

Japan lacks significant domestic sources of energy resources and must import substantial amounts of fossil energy i.e. crude oil, natural gas and other energy sources including uranium. According to OECD data, Japan depends on import of primary energy stood at more than 85 percent and had a total energy requirements of 428.2 million tons of petroleum equivalent. The current dependence on oil is at about 47% (including Liquid petroleum gas), coal 21 %, natural gas 16%, nuclear 10%, renewable energy/new energy/hydro energy etc 4%, as illustrated in Figure 2 below.

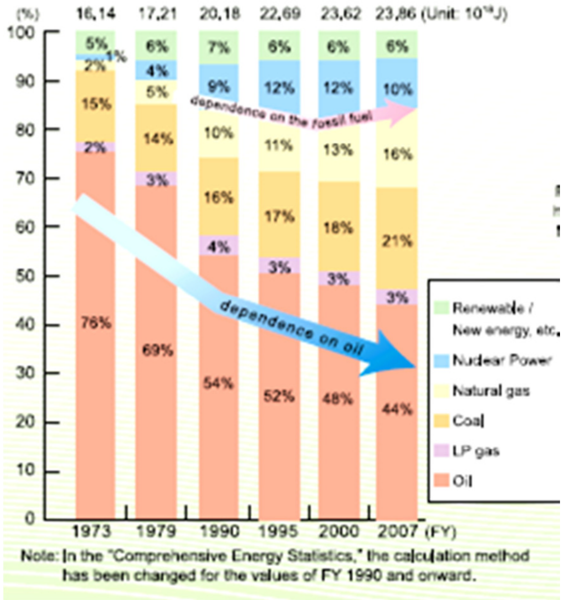


Figure 2: Trends in Japan's primary energy supply

(Source: Japan Agency for Natural Resources and Energy "Comprehensive Energy Statistics")

Currently 96% of natural gas supply depends on liquefied natural gas(LNG) procurement from overseas. LNG is used mostly for electric power generation or as feedstock for petrochemical manufacture. If the deep sea mining of methane hydrate becomes commercial viable in Japan, it is expected to reduce the reliance on imports of LNG. Diversification of energy supply sources is promoted to ensure stable supply and supply disruption, and increasingly crucial for Japan after the nuclear plant incident in Fukushima after the 11 March 2011 Great Eastern Japan Earthquake which is likely to disrupt Japan's nuclear energy plans. Hence methane hydrate could give hope of reducing dependence of fuel consumption on other country, and at the same time increase domestic consumer's surplus.

II. Framework of Cost and Benefit Analysis

In this section, we quantitatively investigate the benefit and cost of the project. We first see cost side and next, benefit side, and finally estimate the net present value: the profitability of the project. If we find NPV>0, then we can suggest MH project is at least profitable. Moreover, to make this assert more reliable, we carry out the sensitivity analysis: to be precise, we examine best and worst case.

a. Expected Costs

We try to investigate the cost part. Cost consists of three parts: production cost, R&D cost, and externality cost. Production cost includes almost all cost for construction and production such as construction of wells, machinery cost, wage, fuel cost and transportation cost. For the production cost, we use 46 (JPY/m3) from the MH21 web page. R&D cost is the cost to find the way to extraction, to investigate the potential amount of MH and so on. We apply the average cost in the phase one, 4.2 billion JPY, for the future R&D cost from 2011-2020. Externality cost is the CO2 emission cost from the MH production and since this is our main innovation, we scrutinize this point with

i. Yearly cost

Firstly, we calculate the production cost. We assume the yearly production cost is the average cost of total production:

- $yearly\ production\ cost = production\ cost \times production\ amount \times \frac{1}{duration}$

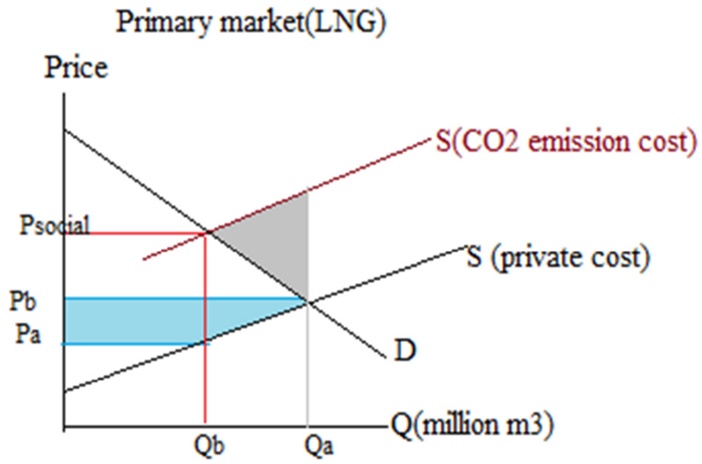
Then it is straightforward to get yearly cost = 2.10 trillion JPY. Since we already know the R&D cost, we skip it. And so we discuss environmental effect of MH.

ii. Externality costs from methane hydrate mining

Methane is the primary component of natural gas. Methane losses occur during the production, processing, storage, transmission, and distribution of natural gas. Methane is a greenhouse gas that remains in the atmosphere for approximately 9-15 years and it is over 20 times more effective in trapping heat in the atmosphere than carbon dioxide (CO_2). On the other hand, natural gas is the cleanest of the fossil fuels, and thus many applications can serve to decrease harmful pollution levels from all sectors, particularly when used together with or replacing other fossil fuels. The natural gas industry itself is also committed to ensuring that the process of producing natural gas is as environment-friendly as possible.

There can be two types of environmental risks can occur during production, first is human-induced environmental risks derived from mining of methane hydrate, and the second is natural global warming effect which is hard to proof and unforeseen effect of natural disaster. So we here count for the following external cost of man-made effect according to US survey.

- Global warming potential CO2 emission from production of methane hydrate is 1% production of natural gas from old method of production for natural gas.
- Global warming potential CH4- 1.4 % of production of natural gas, but the production method of depressurisation can mitigate those gas emissions.
- Value of coastal area-US$ 11-62/household/year(but it is too far from coast line and we assume it cannot affect)



Graph 1: Social costs in the primary market of LNG

Social cost of methane hydrate production is CO2 emission in production process[1].

- CO2 emission = 1% of production=0.82 ml m3/month (1% x82 mil m3/month)

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[1] To calculate the CO2 emissions from a gallon of fuel, the carbon emissions are multiplied by the ratio of the molecular weight of CO2 (m.w. 44) to the molecular weight of carbon (m.w.12): 44/12.

CO2 emissions from a gallon of gasoline = 2,421 grams x 0.99 x (44/12)= 8,788 grams = 8.8 kg/gallon = 19.4 pounds/gallon

CO2 emissions from a gallon of diesel = 2,778 grams x 0.99 x (44/12) =10,084 grams = 10.1 kg/gallon = 22.2 pounds/gallon. (1 m3 = 264.17gallon)

- CO_2 emission cost =1039 million Yen/month (0.82 ml m^3 x 264 gallon x 4.8Yen/gallon).

  With reference to the Japanese survey of CO_2 emission cost for petrol= 4.8Yen/ litter x 4= 19.2Yen/gallon, then for natural gas it will be 25% less = 4.8 Yen/ gallon.

- CO_2 emission cost /year =12.5bllion yen/year

Japan formulated ambitious climate protection targets in the early 1990s and continued to give attention to combating global warming throughout the decade. Japan has consistently supported international climate protection efforts under the UN Framework Convention on Climate Change (UNFCCC). The CO_2 intensity of the economy (kg CO_2/unit GDP) decreased by 1.8% during the 1990s to rank eighth among OECD countries. Japan has pursued fuel switching away from oil and towards gas and nuclear power. The latter is not so reliable in those days after the Fukushima nuclear power plant disaster.

So the production of MH can contribute to the reduction of using oil and can cause negative impact on global warming. However, MH extraction will use high technology of depressurisation method and can mitigate the risk of CO_2 emission and prevent the CH_4 emission.

Increased natural gas use in the electric generation sector, a shift to cleaner natural gas vehicles, or increased industrial natural gas use, could all serve to combat smog production, especially in urban centres where it is needed the most. Industrial plants and electric generators could use natural gas to fuel their operations instead of other, more polluting fossil fuels. This would effectively reduce the emissions of smog causing chemicals, and result in clearer, healthier air around urban centres.

iii. <u>Present value of cost</u>

- $present\ value\ of\ cost =$

  $$cost\ in\ 2011 + cost\ in\ 2012 \times \frac{1}{discount} + \cdots + cost\ in\ 2035 \times \left(\frac{1}{discount}\right)^{24}$$

We use R&D cost for cost from 2011- 2020 and use externality cost for cost from 2021-2035, and construction and operation cost from 2011-2035.

Thus we get, PVC =**32.61trillion JPY**

b. Benefits of the project:

Here we examine the benefit side. If we can develop the project as expected then the following benefits can be gained for the country.

- Revenue from MH
- Consumer Surplus (if this project can decreases the price of LNG)
- Reduction in dependency of oil imports from other countries,
- Savings in foreign exchange reserve for oil imports,
- Exploration and securing of safer energy sources.

For our analysis, we identify the main benefit of the project to be the production of MH in the LNG market. Although Consumer Surplus can be a major component of benefit, we do not include it here as we take the assumption that import price of LNG will not change by the project. Other points may also be important, but we do not regard them as the components of the benefit accounting in this analysis due to the difficulty of quantitative treatment and availability of data.

What we have to estimate is the yearly price with/without project, the yearly production with/ without project. Since we use Social Benefit and Social Cost to calculate the net value in this CBA, the yearly production boils down to the difference of production with and without project. The strategy for estimation is the following: First, we try to find yearly benefit of the benchmark case. We make assumptions on price and difference of quantity of MH so that we can obtain the merkmal. Later we relax the assumptions in order to investigate the sensitivity.

i. <u>Yearly benefit</u>

First, we estimate the difference of the quantity with/ without project. Here we assume the project produces the same amount through the production years. The key equations are the following:

- $production\ increase(per\ year) = total\ production \times \frac{1}{production\ duration}$
- $total\ production = potential\ amount \times technically\ possible\ mining\ rate$

The MH project has two uncertainties: the true potential amount of MH in the ocean bed is yet unknown, and there is no established method for deep-sea mining of MH. For the former problem, we use 1.14 trillion (m3) as the total production amount as a benchmark case, which is the production amount with probability 50% according to the MH21 project report. For the latter uncertainty, we use 1/3 because this is used in the MH21 report. The production years is from 2021 to2035, the duration is 15 year. Then with some mathematic extrapolation, we can find yearly production increase is 25.3 billion (m3).

Second, we estimate the MH price. Since MH has no own market yet, we apply the LNG price. We assume since the production of MH is so small relative to the total LNG production that it does not affect the price at all. In fact, the world gas production is 2.9 trillion in 2009 and the estimated yearly production is 25.3 billion, so that the influence of the project must be small. The difficulty comes from the estimation of future LNG price, because even in a shorter time span, the price fluctuates a lot. Here we tackle the difficulty with two assumptions: use recent highest, middle, low prices and introduce the constant growth. The former are 22, 46, and 63 respectively (lowest price in 2010, price at customs in May 2010, highest price in 2010). The latter can be assumed as 3.88 % per year as in the report. In the following, we use 46 Yen/m3 as a benchmark.

Since we estimate price and quantity, we can find yearly benefit. The equation is as follows:

- $benefit(per\ year) = yearly\ production \times\ yearly\ price$

ii. <u>Present value of benefit</u>

Finally, we can obtain the present value of benefit. The equation is:

- $present\ value\ of\ benefit = benefit\ in\ 2011 + benefit\ in\ 2012 \times \frac{1}{discount} + \cdots +$

$$benefit\ in\ 2035 \times \left(\frac{1}{discount}\right)^{24} + salvage\ value$$

We assume salvage value=0, for we cannot use the plant in any other way after the project. Discount factor is 1.04, usually used for the project in Japan. Taking the price growth into account, we get PVB=**17.14 trillion JPY**.

c. CBA of Primary Market i.e. Methane Hydrate

i. Net Present Value (NPV)

Referring to the values of PVC and PVB as derived in Section IIa and IIb, thus we get:

NPV= PVB-PVC = 17.13- 32.61=-(-)15.48 trillion JPY

In this case, the project is unprofitable.

ii. Sensitivity Analysis: best / worst case and cost-benefit correlation

Here we investigate the sensitivity, because several assumptions are assumed in the calculation of the NPV. First we try to examine the impact of price and production change on the benefit. The result is shown in the table below:

Price/Amount	**0.28 (prob 90%)**	**1.14(prob 50%)**	**2.34(prob 10%)**
22	2.01 trillion JPY	8.20 trillion JPY	16,84 trillion JPY
46	4.21 trillion JPY	17.14 trillion JPY	35.22trillion JPY
63	5.77 trillion JPY	23.47 trillion JPY	48.24 trillion JPY

Table 2: PVB with the different assumptions about price and production

Assuming the benefit and cost is mutually independent[2], we get the following graph for NPV:

[2] although it is quite strong an assumption, we introduce this for the simplicity.

Price/ amount	0.28 (prob 90%)	1.14(prob 50%)	2.34(prob 10%)
22	unprofitable (-32.33 trillion)	Unprofitable	unprofitable
46	unprofitable	Unprofitable	Profitable (2.61trillion JPY)
63	unprofitable	unprofitable	Profitable (15.63 trillion JPY)

Table 3: NPV with the different assumptions about price and production

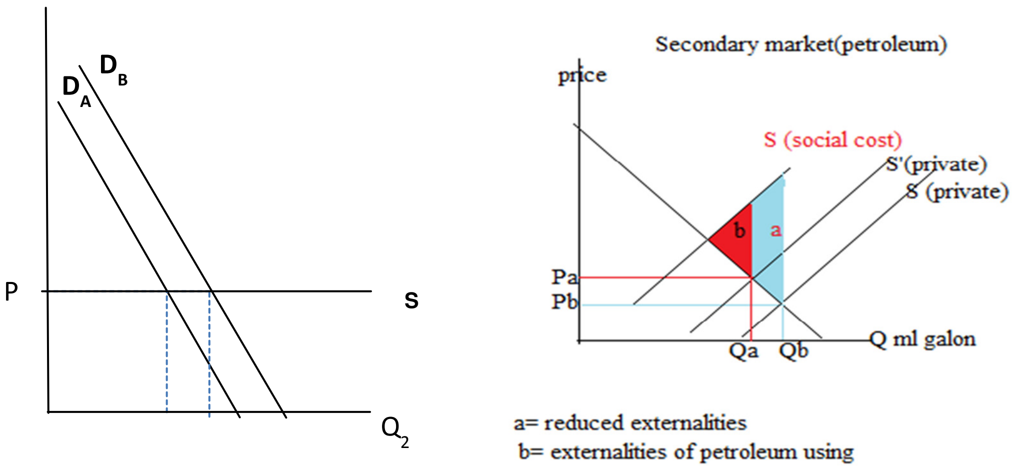
Hence from the above, we conclude that the project is profitable only when production probability is 10% and price at 46JPY and 63JPY, which would give profits of 2.61 trillion JPY and 15.63 million JPY respectively. From this, we can also analyse the best and worst case. In the best scenario, that is, when price of gas is very high and production amount is so large, the project provides 15.63 trillion JPY. However, in the worst case, the deficit amounts to 32.33 trillion JPY.

iii. CBA of Secondary Market i.e. Oil

We supposed secondary market only for oil (i.e gasoline, high grade fuel, liquefied petroleum gas etc) compare with energy price of methane hydrate and assuming that the demand of oil will be replaced with methane hydrate and import amount of oil will decline. Reduction of quantity demanded for oil usage will also lead to reduction of external costs of CO2 emission from oil burning.

- Total oil consumption= 29,000million litre/month = 7250 million gallon /month
  (price for petrol is 340 Yen/ gallon and price trend is also increasing which attracts consumer to change usage)

- CO2 emission cost from petrol= 19.2 Yen/gallon x 7250 million gallon= 13,920 million Yen/ month : NPC= 1.3 billion JPY



Graph 3 Demand, supply and social cost of oil (petroleum) usage reduction

Nowadays, the average oil price of Japan is increasing due to surges in global crude oil prices and relies heavily on imports of crude oil to power its economy. Rising crude prices forced Japanese oil wholesalers to raise petrol prices. So the production of methane hydrate become the natural source of energy and can encourage the consumer to change the usage of oil to LNG with cheaper price of energy. As a consequence, supply of oil will decrease and also CO2 emission from burning oil will be reduced regarding to the replacement of LNG as the emission from natural gas burning is 4 time less than other kinds of fuel burning.

III. Discussion of results and other factors

a. Energy Security issues

After the nuclear reactor incident in Fukushima since March 2011, the Japanese energy market is expecting more natural gas consumption, as well as other energy sources for electricity generation in replace of possible nationwide reduction of nuclear power supply.

The renewed focus on energy security is driven in part by an exceedingly tight oil market and by high oil prices, which have increased over the past 10 years. But it is also fuelled by the threat of terrorism, instability in some exporting nations, a nationalist backlash, fears of a scramble for supplies, geopolitical rivalries, and countries' fundamental need for energy to power their economic growth. In the developed world the usual definition of energy security is simply the availability of sufficient supplies at affordable prices.Multiplying one's supply sources reduces the impact of a disruption in supply from one source by providing alternatives, serving the interests of both consumers and producers, for whom stable markets are a prime concern.

A new range of vulnerabilities has become more evident, and the vulnerabilities are not limited to threats of terrorism, political turmoil, armed conflict, piracy and also get impact of rising demand of energy in China and emerging countries. Concerns over energy security are not limited to oil but also to power blackouts. Thus the possibility of commercial production of methane hydrate could address these energy security concerns and help to alleviate the dependency and energy costs, which include the following:

- 85 % of Japan's energy supply depends on imported energy
- National energy security cost = GDP x 85%= 4.308 trillion Yen(based on 2009 GDP)
- Production of MH =14 % of natural gas import= 2% of energy consumption
- Energy security cost of MH production= .02x4.308 trillion= 84 billion yen/ year which is far exceed the social cost of CO2 emission.

b. Environmental Benefits of Increased Technology

The exploration and production of natural gas can have a significant impact on the environment. However, innovative technologies have lessened the possible effect that natural gas exploration and production have on the environment. The benefits of technology are threefold: "Allow for More Efficient Natural Gas Recovery , Provide Cleaner Operations, and Allow for Smaller Drilling Footprints". The depressurization method using in production of methane hydrate is likely be efficient and the environmental risk of methane gas leakage from the seafloor during production is estimated to be minimal.

IV. Conclusion

We identified possible aspects, such as carbon emission, crude oil dependence, air pollution and environmental impact, in calculating external costs However, due to absence of relevant values applicable, we calculated only CO2 emission cost and oil dependence cost as energy security cost (see section II above).

We recognize that in the USA, there is estimation of cost for energy security by using i)profit reduction values of oil exporting countries,, ii) macroeconomic disruption values in the situation of oil exports cessation, and iii) relevant military costs for security of energy import[3]. However, no similar value is presently available to the situation of Japan, thus we calculated the security cost by utilizing different values as discussed in Section IIIb.

We are of the opinion that mining methane hydrate is worthwhile from the following overall social point of view:

- to reduce dependence of fuel consumption on other country;
- to find out stable energy source, domestic energy source;
- to save foreign exchange reserve for fuel import;
- to decrease harmful pollution levels from all sectors by using the cleanest fossil fuels; and
- to ensure that process of producing MH-depressurization method can mitigate emission of CO2 and CH4 at minimal level.

Given that the R&D of the MH 21 project is ongoing aimed at obtaining more precise values of costs and benefits for justification in near future, at this stage, in reality there is a great deal of uncertainty. We should encourage the ongoing R&D for efficient mining and production methods to accurately determine mining sites, to precisely assess/predict productivity and identify factors affecting the production. We also would like to encourage ongoing research projects to obtain comprehensive overall knowledge on the environmental impact so that they help minimize environmental risks and ensure accountability of the project.

[3] Please see page 7 of 金本良嗣 『道路特定財源制度の経済分析』第 1 章 (2007) (in Japanese).

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