Investigation of Potential Cases to Produce Substitute Natural Gas from Low Grade Coal

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1. Background

The demand for LNG in Europe, the United State and Asia is expected to increase in the long term. That will cause tightness of the supply and increase of the price. The amount of Japanese importing LNG is the most in the world. In addition, more than 90% of city gas feedstock is imported LNG in Japan. Consequently, they are very important to examine the possibility of using Substitute Natural Gas (SNG) as city gas feedstock except for Natural Gas. It is important in this examination that agendas and requirements for commercialization are clarified in terms of increasing diversification and security of energy resource in the future.

2. Objective

Coal is more abundant in fossil resources and widely distributed in the world. Especially, low grade coals such as sub-bituminous coal and lignite accounts for more than 50% of the amount of coal resources. Additionally, they are low price because they are almost unused. Therefore they are suitable for SNG feedstock. Meanwhile they cannot be transported over a long distance by ship because the coals in which much water and volatile components have evaporated become igniting easily. Accordingly, it was designed that SNG was produced from low grade coals by a suitable combination of recent technologies related to coal gasification and methanation with capturing by-product CO_2. Furthermore, it was assumed that SNG was transported as LNG to the points of demand. In terms of two aims, it was studied the feasibility of producing SNG from unused low grade coals on the basis of the above scheme. The one aim was that the supply of city gas made more stable to ensure security of energy resources. The other was that the undeveloped resources in coal mining countries were used effectively.

3. Concept of producing LNG from low grade coal

The outline of concept that LNG is produced from low grade coal is shown in Figure 3-1. At first, synthesis gas is produced by coal gasifier near a mine mouth in a coal mining country.

Impurities such as CO_2 and sulphur are removed from the synthesis gas by removal equipment. Following that, the synthesis gas is converted to methane by methanation after adjusting CO/H_2 ratio by shift reaction. Produced methane is transported to the points of demand after liquefied at LNG plants or injected into gas pipelines.

The SNG process is ready for Carbon Capture and Storage (CCS) because it has normally an equipment removing and capturing CO_2 in concentrated amounts. Captured CO_2 has to be stored in the ground. In terms of economy, it is better that captured CO_2 is able to be utilised in Enhanced Oil Recovery (EOR) instead of be stored.

The key of this concept is that the coal is used effectively emitting as little CO_2 as natural gas by means of producing clean methane with capturing CO_2.

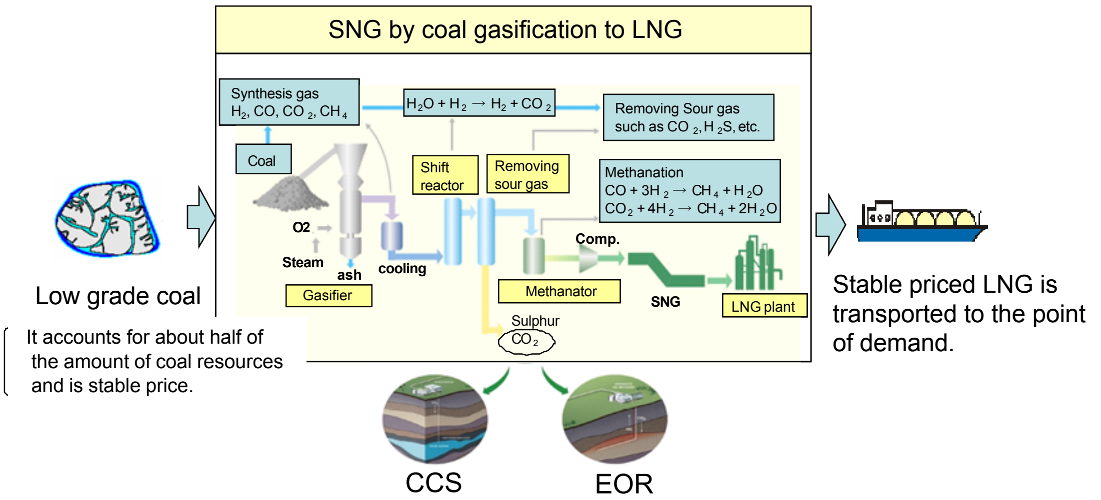


Figure 3-1 Outline of concept that LNG is produced from low grade coal

4. Investigation item

The Japan Gas Association had carried out the study in FY2007 to FY2009, commissioned by the Ministry of Economy, Trade and Industry. In this study, feasibility of the process producing LNG from low grade coal was estimated and questions to solve in the future was extracted by means of the following investigations.

1) Domestic and foreign leading-edge technologies of coal gasification
2) Technologies of methanation, CO shift reaction and gas purification
3) Technologies of pretreating low grade coal
4) Geographical situations of specific areas hopeful for producing SNG
5) Cost of SNG produced in specific operation areas

5. Result of investigations

5.1 Coal gasification technology

Information about operating, maintenance and others that was not acquired from only published one was collected and compared by means of visiting coal gasifier users in the U.S., Europe and China. There are mainly three different types of coal gasification technologies; fixed-bed, fluidised bed and entrained-bed. These types of gasifiers have been operated on a commercial scale. Therefore, it was clarified conventional technologies were applied to producing SNG from coal.

The hopeful gasifiers were picked out by the following three points, based on information related to feasibility and requirements of SNG production business.

1) The commercial gasifiers by coal throughput of 1000 to 2000 ton per day can be operated within ten years.

The gasifiers commercially operated are Shell, GSP, Prenflo and IGC which are entrained-bed with dry coal feed, GE and E-GAS which are entrained-bed with slurry coal feed, Lurgi and BG-Lurgi which are fixed-bed, and U-GAS which is fluidised bed.

2) Low-grade coal can be used.

Low grade coal is used as tests by many types of gasifier. GE and E-GAS gasifier with slurry coal feed are not suitable for sub-bituminous coal and lignite containing much water. Coal types suitable for the selected gasifiers are shown in Figure 5-1. Finally, the gasifier has to be chosen according to the coal type in the candidate site.

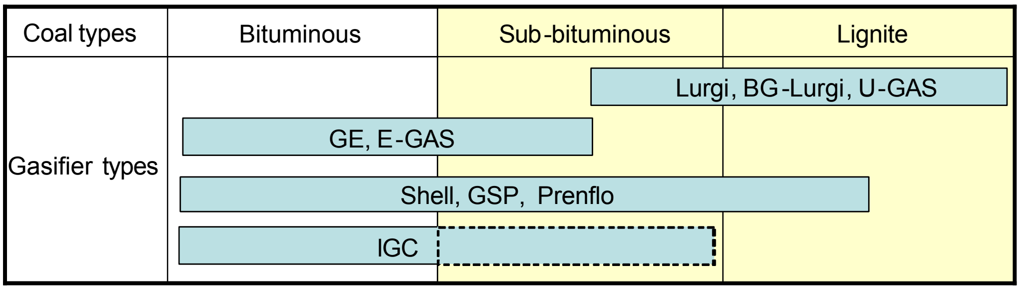


Figure 5-1 Coal types suitable for the selected gasifiers

3) The outlet gas from the gasifier is suitable for SNG production.

The fixed-bed and fluidised-bed gasifiers which can be operated at low temperature (less or equal than 1000℃) emit methane rich gas being favorable for SNG production. But these gasifiers have disadvantages of low gasification efficiency, tar generation and ash disposal. On the other hand the entrained-bed gasifiers operated at high temperature have advantages of high gasification efficiency, no tar generation and easy ash disposal. But these emitting gas are low-concentrated methane and methanation load increases. Consequently, the gasifier has to be chosen also considering entire heat efficiency of the process and cost.

5.2 Methanation technology

Recent technology trend related to commercialised methanation technologies were investigated. Following that, methanation conditions of efficient production with a coal gasification technology were made clear.

Because methanation is exothermic reaction, high methanation load can't prevent the reactor's temperature from going up uncontrollably. As an example of methanation technology, Lurgi process is shown in Figure 5-2. It prevents temperature from rising by means of dividing reactor into three series parts and recycling a part of the first reactor's outlet gas to the same reactor's inlet in order to lower CO that is reaction component. The process also inhibits the reduction in heat efficiency by recovering reaction heat.

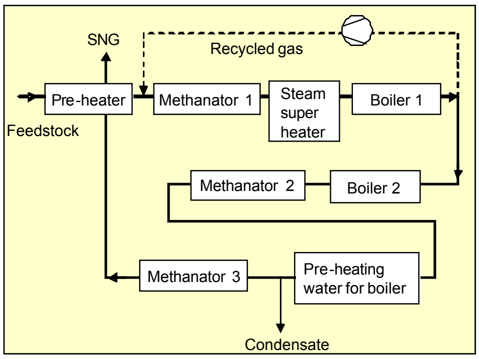


Figure 5-2 Schematic of Lurgi process

Methanation concentration of gasifier's outlet gas varies 0 to more than 10% according to the type of a gasifier. Relative methanation load depending on methane concentration of each gasifier's outlet gas calculated by process simulation is shown in Figure 5-3.

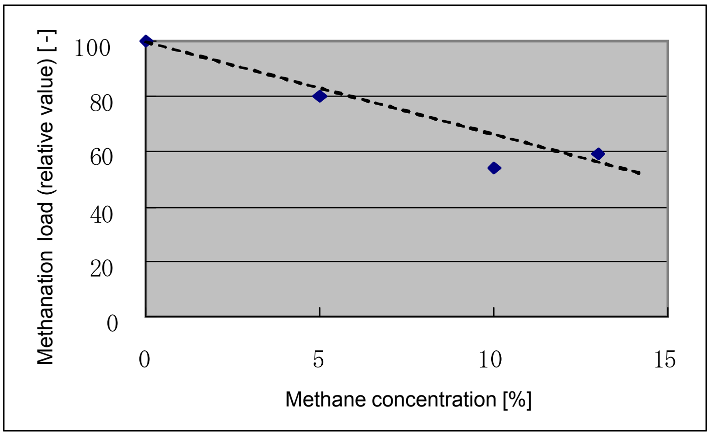


Figure 5-3 Methanation load corresponding to methane concentration

Gasification temperature needs to be lowered in order to decrease methanation load. But it is considered how tar and unreacted char that are generated along with lowering gasification temperature have an affect on process operation. An evaluation considering heat recovery is also needed, because steam can be utilised effectively by means of heat recovery in case of high methanation load.

5.3 CO shift reaction process

CO shift reaction process adjusts H_2/CO molar ratio of synthesis gas to suitable ratio for methanation. There are two types of CO shift reaction processes; sweet gas shift and sour gas shift. In sweet gas shift, the synthesis gas from which H_2S is removed is introduced to a shift reactor. On the other hand, in sour gas shift the synthesis gas containing H_2S is directly introduced to a shift reactor. The outlines of both processes are shown in Figure 5-3 and Table 5-1. Although sour gas shift with less heat loss is more energy-efficient than sweet gas shift, an evaluation considering equipment cost and catalyst life is also needed.

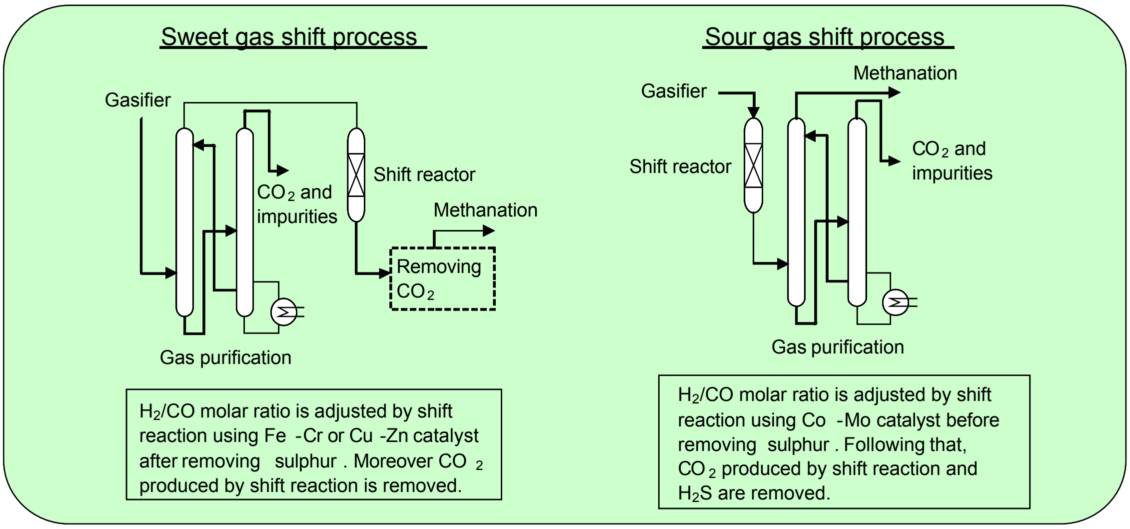


Figure 5-3 Schematics of CO shift reaction processes

Table 5-1 Outlines of CO shift reaction processes

	Sweet gas shift process	Sour gas shift process
Process Composition	Capturing sulphur Shift reaction Capturing CO_2 Methanation	Shift reaction Capturing sulphur and CO_2 Methanation
Catalyst	High temperature(320-450℃) Fe_2O_3-Cr_2O_3@CO<70 vol%, S< dozens ppm Low Temperature(150-300℃) CuO-(ZnO)-Cr_2O_3@CO<2-4 vol%, S<1 ppm Calatysts for High and low temp. are fitted together as usage.	250-500℃ Co-Mo@CO< 70 vol%, S>100 ppm Two or three reactors are fitted together ordinarily.
Applied gas	Removed sulphur	Containing sulphur
Catalyst quantity Catalyst cost	1 (basis) 1 (basis)	About 1-2 About 1.5
Outlet gas composition	CO descends to around 0.2% using low temperature catalyst because of shift reaction progress in equilibrium.	Unreacted CO remains at around 1% generally, because lower limit of outlet gas temperature is around 300℃.
Advantage Disadvantage	Advantage: It is suitable for producing hydrogen because CO concentration descends to lower. Remaining CO is no problem for SNG production. Disadvantage: More energy for heating gas is needed, because of using two reactors in removing sour gas.	Advantage: less energy for heating gas is needed, because of using one reactor in removing sour gas.

5.4 Gas purification process

There are mainly two types of gas purification processes; Rectisol and Selexol. Rectisol process is operated at coal gasification and SNG production plant in North Dakota, the US. Selexol process has been tested many times at Integrated Gasification Combined Cycle (IGCC) plants using coal. Applicability of these processes for coal-to-SNG process was compared and evaluated. The outlines of both processes are shown in Table 5-2. In SNG process H_2S concentration of synthesis gas introducing methanation reactor has to be decreased to less than 0.1 ppm order considering resistance property against H_2S of Ni catalyst packed in mathanation reactor. If CO_2 concentration in supplied gas is more than 4%, its combustion quality could be influenced. Consequently Rectisol process is better for SNG process because it is superior in desulphurisation performance and ability of removing CO_2.

Table 5-2 Outlines of gas purification processes

	Rectisol process	Selexsol process
Licenser	Linde Co.	UOP Co.
Delivery record	100	50
Delivery case	North Dakota SNG	Pretreatment of PSA Removing CO_2 from natural gas
CO_2 removal efficiency	100 %	50 %
Desulphurisation performance	Less than 1 ppm	Around 4 ppm
Equipment cost	1.3	1 (basis)
Operational cost	0.8	1 (basis)
Absorbent	Methanol	Dimethyl ether of polyethylene glycol
Operational condition	High pressure and low temperature	Lower pressure and higher temperature than Rectisol process
Signature	Removal ability of H_2S and COS	Removal ability of H_2S
Harmful substance	HCN, NH_3, carbonyl, H_2O	COS (needed to be hydrolysed)

5.5 Pretreatment technology of low grade coal

It is efficient that water in low grade coal is removed as much as possible before gasifying coal. If the coal is fed into gasifier, more oxygen will be necessary fed to make up for evaporative latent and sensible heat of water than with little water. Increasing the amount of oxygen requires scaling up an air separation equipment. It also increases CO_2 concentration of synthesis gas and reduces cold gas efficiency. On the other hand, moderate water is desirable because additional oxygen effect enlarging H_2/CO molar ratio. It is considered that amount of water contained in low grade coal adequate to SNG production process, depending on the type of gasifier and the variety of coal, is around 10 to 20 % (Detailed conditions have to be shown by licensers of gasifiers and methanation process). There is a variety of drying technologies depending on the types of gasifiers. In the gasifiers with dry coal feed, candidate technologies are Steam Tube Dryer, Upgrading of Brown Coal in oil (called "UBC" of Kobe Steel, Ltd., Japan) and fluidised bed drying with internal waste heat utilisation (called "WTA" of Rheinbraun, Germany). On the other hand, in slurry coal feed they are Hot Water Treating (called "HWT" of JGC Corporation, Japan), Coal Water Mixture with kneading and so on. In this feasibility study Steam Tube Dryer was adopted assuming utilisation of by-product steam from SNG production process.

5.6 Specific areas hopeful for producing SNG

Geographical situations suitable for producing SNG

Two cases were assumed in selecting site for coal-to-SNG process in mine mouth. Case 1 was that SNG produced in mine mouth was liquefied at nearby existing LNG plant and LNG was transported to the point of demand. Case 2 was that SNG in mine mouth was injected into gas pipeline to be consumed on the site and LNG was transported in stead of SNG.

Conditions considered suitable for producing SNG are shown in Table 5-3. First requirement is that there is gas infrastructure; LNG plant or pipeline. Second is that there is sufficient quantities of reasonable low grade coal which can be easily gasified. For example, 3 million to 6 million ton of low grade coal is needed to produce 600,000 ton of SNG per a year. Third is that there is EOR or CCS site where CO_2 from SNG plant can be injected into. Forth is that there are sufficient quantities of water which can be used for gasification. Specifically, 10 million to 15 million ton of water is needed for 600,000 ton / y of SNG. Though there are candidate sites satisfied with above requirements in Indonesia, Australia and the US. Especially, Bontang area in East Kalimantan of Indonesia was focused on as an example of case 1 and investigated in detail.

Table 5-3 Conditions suitable for SNG production

	Case 1	Case 2
Requirement 1: Gas infrastructure	LNG plant which has enough capacity to liquefy SNG	Gas pipeline which has enough capacity to transport SNG
Requirement 2: Low grade coal	Sufficient quantities of reasonable low grade coal which can be easily gasified (sub-bituminous or lignite: 3-6M ton/y for 20-25 years)	
Requirement 3: CO_2 management	EOR/CCS site into which CO2 from SNG plant can be injected	
Requirement 4: Other	Sufficient quantities of water which can be used for gasification (10-15M ton/y)	
Candidate site	Bontang (Indonesia)	Midland of Sumatra (Indonesia) Queensland (Australia)

Investigation of east Bontang area in Indonesia

LNG production at Bontang LNG plant tends to decrease recently and could further reduce in the future, though it was about 20 million ton per a year at the peak. That is to say, it was made out that Bontang LNG plant had sufficient room to receive SNG from coal. There are gas field, oilfield and gas pipelines in the area between Bontang LNG plant and Mahakam River downstream, hence these gas infrastructures is possible to be utilised. It has been clarified that there is sufficient amount of low grade coal in some coal mines which are Bhakti Energi Persada (BEP), Anugerah Bara Kaltim (ABK) and Ilthabi Bara Utama (IBU) inland about 100 km from the coast. These low grade coals can be transported and used by means of utilising the coal road or Mahakam River. On the basis of above information two sites, which are shown in Figure 5-4, were assumed as candidates for constructing SNG production plant. One site is the circumference of Bontang LNG plant. In this case low grade coal can be transported by the coal road and a barge. Product gas can be received by Bontang LNG plant immediately. Another site is the circumference of Samarinda which is located in Mahakam River downstream area. There are some small coal mines along Mahakam River, therefore low grade coal can be transported by a barge from upper stream. Product gas can be delivered to Bontang LNG plant by gas pipelines. CO_2 from SNG plant could be disposed of by storage in the ground, because there are gas field and oilfield near this area. Though the feasibility study of CO_2-EOR had been estimated once, an additional detailed investigation is needed for applying CCS or EOR.

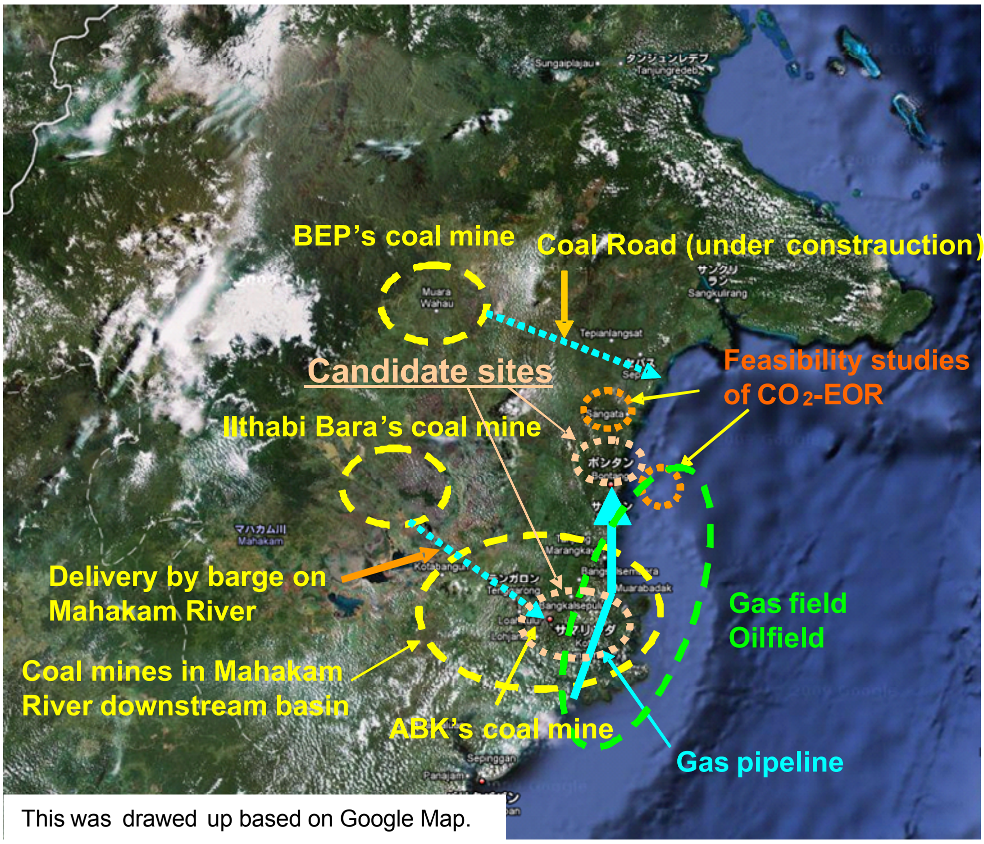


Figure 5-4 Candidate sites for SNG production

5.7 Level of SNG production cost

Assuming SNG liquefied in coal mine country is transported to Japan, LNG production cost containing liquefaction and transportation was estimated. It was supposed that production scale was 600,000 ton per year as methane. It is presumed that this scale doesn't have a significant influence on an operation of LNG plant in coal mine country because it is less than around 10% of most LNG plant's liquefaction ability which is 6 millions to 20 millions ton/y. corresponding amount of feedstock coal is about 6,000 ton/day as dry basis. SNG production cost was estimated by the following procedure.

1) Calculation of material and heat balance by simulation

Material and heat balances SNG production process adopting fixed-bed and entrained-bed were calculated by simulation using published data of coal gasification and methanation processes. Low grade coal's characteristics that were found by analysing coal acquired at mines nearby Bontang were also used in simulation. The characteristics are shown in Table 5-4.

Table 5-4 Characteristics of coals

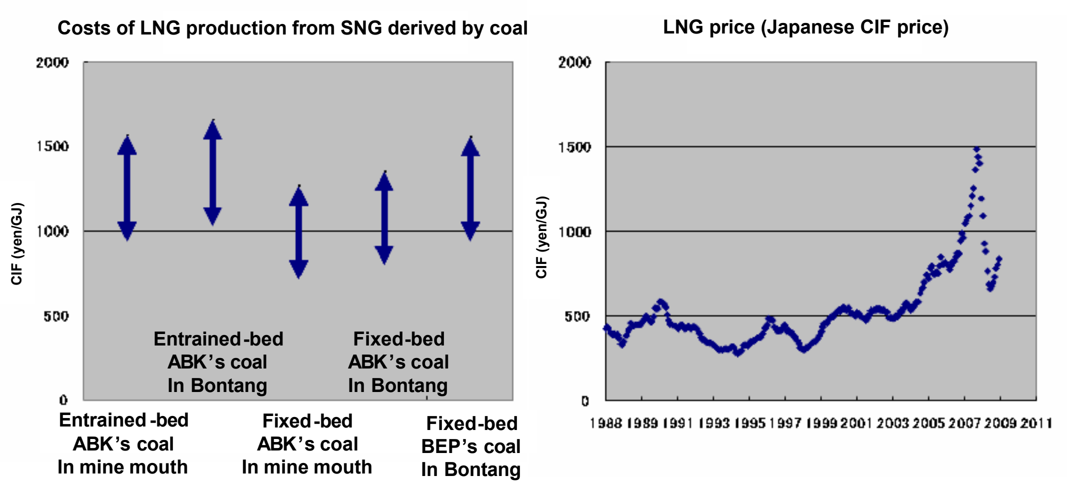
	ABK's coal	BEP's coal
Calorific value [kcal/kg]	4,520	3,300
Total moisture [%]	30.6	49.4
Ash content [%]	2.5	21.9
Ash melting point [℃]	1,395	> 1,600
Coal types	Sub-bituminous	Lignite

2) Estimation of SNG plant cost and production cost

SNG plant cost was estimated by published data and material balance. Off-site facilities cost was also estimated, assuming suitable developing sites, coal deliveries, utilities and pipelines in cases of SNG production in nearby LNG plant and mine mouth. On that basis, SNG production cost was estimated considering the postulates of SNG production and economic efficiency.

3) Estimation of SNG to LNG production cost

Assuming SNG liquefied in coal mine country is transported to Japan, LNG production cost containing liquefaction and transportation was estimated. Some of results are shown in Figure 5-6.



<u>Precondition for liquefying</u>

The upper and the lower limit of coal price and plant's cost by sensitivity analysis were adopted as SNG production costs.

It was supposed that liquefying cost to LNG was $ 0.2/MMBTU and transportation cost was $ 0.5/MMBTU.
(It was assumed that SNG was liquefied by Bontang LNG plant not considering heat increment.)

Figure 5-6 Estimated costs of LNG from SNG and Japanese LNG price

In consequence it was clarified that SNG to LNG production became effective depending on future energy resource price because the estimated costs were the same level as the Japanese CIF (cost, insurance and freight) price on which was very high in 2007 to 2008.

6. Conclusion

It was clarified that there were some hopeful processes of producing SNG and LNG from low grade coal in consequence of investigations related to developing or commercialised technologies of coal gasification, methanation, gas purification and so on.

The area between Bontang LNG plant and Mahakam River downstream was selected as hopeful candidate site by field study to investigate specific site suitable for SNG production business. It was found that there were gas pipeline and sufficient unused low grade coal in East Kalimantan of Indonesia. ABK, BEP, IBU coal and so on were selected as candidate coals. It was also marshalled how these coal were delivered to SNG plant.

As the result of considering information about specific sites and coal brands in estimating cost, it was clarified that SNG to LNG production could become effective depending on future energy resource price because the estimated costs were the same level as the Japanese CIF (cost, insurance and freight) price on which was very high in 2007 to 2008.

It was found that low grade coal could be utilised efficiently without problems of ignition and substantial transport cost if low grade coal is not transported for long distance but obtained from mines near LNG plant or converted to SNG in mine mouth

7. Future subject

Three factors that have large influence on SNG production cost are coal cost, plant cost and CO_2 storage cost. The condition which makes total cost minimum has to be found in feasibility study of SNG production business.

1) Coal cost

Though low grade coals obtained from commercialised or developing mines were selected as candidates in this study, possibility of acquiring coal with no market value at low cost has to be investigated for the reason that coal has market value can be higher priced despite low grade

2) Plant cost

In this study the plant cost was estimated on the basis of literature information, therefore plant maker’s feasibility study that contains judgement of suitable coal brand and cost estimation on the basis of performance forecast is needed.

3) CO_2 storage cost

Though there are depleted oilfields to which applied CO_2-EOR or CCS in the circumference of candidate sites investigated in this study, information about CO_2 storage and economic potentials (amount of recovering oil in EOR) has not been acquired. In serious study not only this information but also movement of regulation related to CCS and EOR in Indonesia has to be investigated.

Beside costs it has to be estimated feasibility of the concept that SNG produced by coal gasification is liquefied at LNG plant and transported to the point of demand, considering supposed operator and domain and the possibility of applying to existing contract establishment.