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Techno-economic Assessment of Coal to SNG Power Plant in Kalimantan

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ABSTRACT

As the most abundant and widely distributed fossil fuel, coal has become a key component of energy sources in worldwide. However, air pollutants from coal power plants contribute carbon dioxide emissions. Therefore, understanding how to taking care coal in industrial point of view is important. This paper focused on the feasibility study, including process design and simulation, of a coal to SNG power plant in Kalimantan in order to fulfill its electricity demand. In 2019, it is estimated that Kalimantan will need 2446 MW of electricity and it reaches 2518 MW in 2024. This study allows a thorough evaluation both in technology and commercial point of view. The data for the model is gathered through literature survey from government institution reports and academic papers. Aspen HYSYS is used for modelling the power plant consists of two blocks which are SNG production block and power block. The economic evaluation is vary depends on the pay-back period, capital and operational cost which are coal price, and electricity cost. The results of this study can be used as support tool for energy development plan as well as policy-making in Indonesia.

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1. INTRODUCTION

Environmental issues and security of supply are the two main global problems relating to energy industry. Alternative source, which is transportable (flexibility in conversion and distribution network) is important to reduce the dependency on oil and natural gas. However, their reserves are limited to a range of 40–60 years. (Farobie & Nurhasanah, 2016) On the contrary, coalone of primary and old-generation of energy source has the reserves that will last for more than 150 years (Kopyscinski *et al.*, 2010), abundantly available in most area of the world, also locally in important energy markets, such as China, India, and the USA. (Asif & Muneer, 2007) However, air pollutants from coal power plants contribute more than 70% of carbon dioxide emissions that arise from power generation and more than 40% of global anthropomorphic carbon dioxide emissions. (Chen *et al.*, 2012) In coal plants, US is the top source of carbon dioxide (CO_2) emissions, the primary cause of global warming. (Davis *et al.*, 2010) Therefore, the coal environmental footprint needs to be reduced considerably using better technology to become a cleaner energy source in the near future. (Bose, 2010) The longer availability, the wish to improve the security of the energy supply, and the possibility to reduce the green-house gas emission by means of carbon capture and sequestration (CCS), are the main motivation to increase the use of coal. In addition, cheaper and more stable price of coal also supports synthetic natural gas as an attractive option to fulfill the need for clean energy from coal. (Kopyscinski *et al.*, 2010)

"Synthetic natural gas" or "substitute natural gas" (SNG) is an artificially produced version of natural gas mainly from coal, and also from biomass, petroleum coke, or solid waste (Higman & Tam, 2013). The carbon-containing mass can be gasified, then the resulting syngas can then be converted to methane, the major component of natural gas. (Balat *et al.*, 2009) Converting coal to natural gas could satisfy the demand for natural gas due to its inter-changeability with natural gas.

Table 1 reported the typical SNG specification (Kopyscinski *et al.*, 2010). As SNG can be extracted from low-rank coal, a cheaper and abundant feedstock, the industry anticipates that on top of shale gas, SNG will form one of the key axes in the future gas competition (Yu *et al.*, 2013).

Table 1. SNG typical specification.

Composition	Vol (%)
CH_4	94 – 96
CO_2	0.5 – 1
H_2	0.5 – 1
CO	Nil
N_2 + Ar	2 – 3
HHV, Kcal/Nm^3	8900 – 9100

Since its initial operation in 1984, The Dakota Gasification Company's (DGC) Great Plains Synfuels Plant (GPSP) located near Beulah, North Dakota, is the only coal-to-synthetic natural gas (SNG) gasification plant in operation worldwide, producing approximately 153 MM scf/day of SNG (56 billion scf/year) from 6 million tons/year of lignite (See http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html). However, recently, the energy industry has shown considerable interest in the coal-to-SNG concept. At least 15 coal-to-SNG plants are proposed in U.S., all in different stages of development. (Collot, 2006) In addition, China is embarking on the largest SNG investment in history. As of 2013, the central government has approved nine large-scale SNG plants with a total capacity of 37.1 billion m3 of natural gas per year (Yang & Jackson, 2013).

Main process of SNG plant is almost similar to other type of industrial process. (Putra, 2016) The plant basically consists of gasification, gas cleansing, methanation, and gas separator unit. As technology developed, there are several types of gasification, which impact the rest of the process. There are three types of processes used in coal to SNG plant, which are: steam-oxygen gasification, hydrogasification, and catalytic steam gasification (Puig-Arnavat *et al.*, 2010). The main differences among the three are:

1. In the steam-oxygen process, coal is gasified with steam and oxygen producing carbon monoxide, hydrogen, carbon dioxide, methane, and higher hydrocarbons such as ethane and propane (**Figure 1**).
2. The hydrogasification process uses hydrogen to gasify coal producing methane (**Figure 2**).
3. In the catalytic steam gasification, gasification and methanation occur in the same reactor in the presence of catalyst. Methane is then separated from carbon dioxide, carbon monoxide, and hydrogen (**Figure 3**).

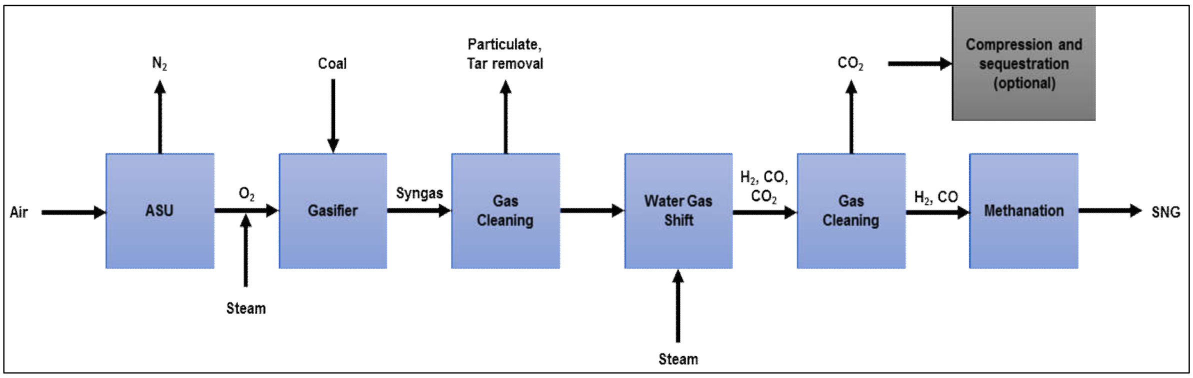

Figure 1. Steam-oxygen process.

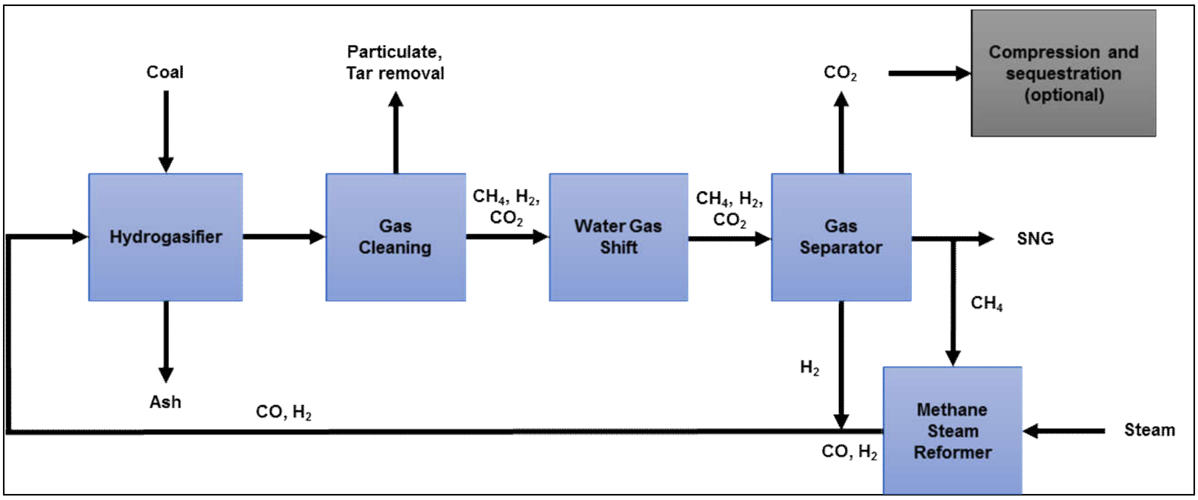

Figure 2. Hydrogasification process.

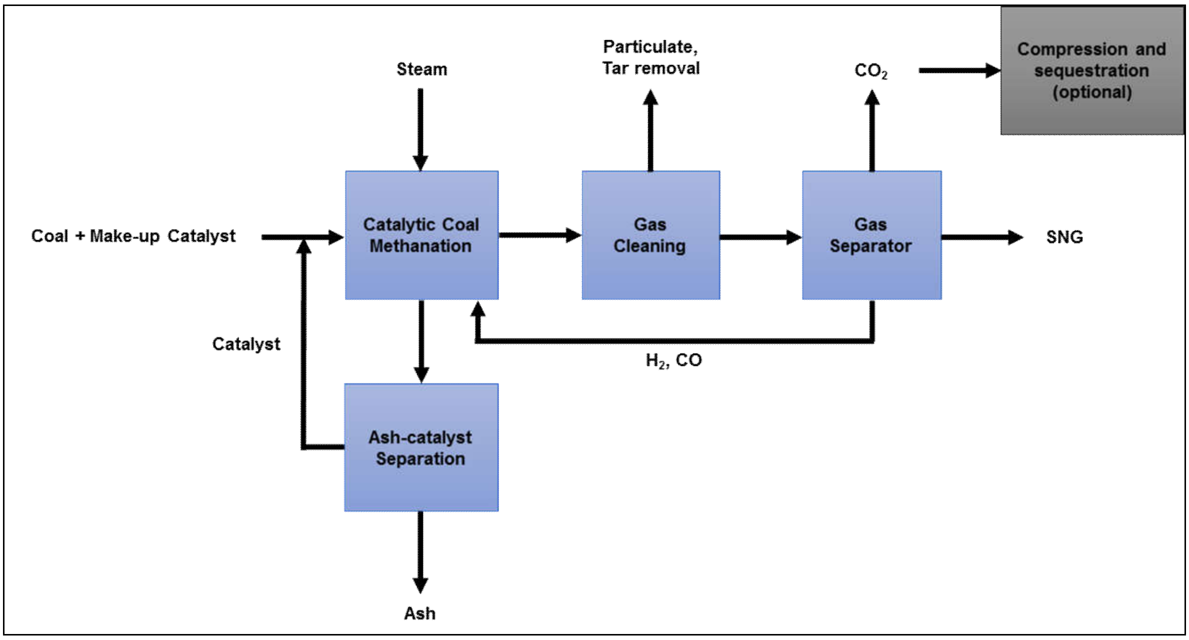

Figure 3. Catalytic steam gasification process.

The advantages of hydrogasification and catalytic steam gasification are that they don't require air separation unit; hence less energy for the process, also the cost are lower as the process occurs at lower temperature. However, both this method are still under development and not yet commercialized.

The proven and commercialized method of gasification for the coal-to-SNG process is the steam-oxygen gasification process. **Figure 1** shows a block diagram with major units of this SNG plant (Jensen *et al.*, 2011). The overall plant consists of the following key processing areas:

1. Gasification process, which includes coal handling and preparation: production of oxygen for the gasification process in an Air Separation Unit, gasification and heat recovery, slag handling, high-

temperature syngas cooling and particulate removal.

2. Syngas cleanup and conditioning, which includes scrubbing, low-temperature heat recovery, water-gas-shift to adjust the ratio between hydrogen and carbon monoxide, and sulfur recovery.
3. Gas treatment and SNG production section, which consists of AGR where carbon dioxide and hydrogen sulfide are removed in a washing process, methanation to convert carbon oxides and hydrogen to methane (SNG) followed by drying and possibly compression of the product SNG to pipeline conditions.

The currently known and commercialized methanation technology is called TREMP stands for Topsøe Recycle Energy-efficient Methanation Process. Methanation is the reaction of carbon oxides with hydrogen to form methane according to:

$CO + 3 H_2 \leftrightarrow CH_4 + H_2O$ ($H^{\circ}298 = -206$ kJ/mol)

$CO_2 + 4 H_2 \leftrightarrow CH_4 + 2 H_2O$ ($H^{\circ}298 = -165$ kJ/mol)

Both reactions are highly exothermic, releasing large amounts of reaction heat. Efficient recovery of the heat of reaction, which amounts to about 20% of the heating value of the synthesis gas, is essential for any industrial methanation technology. Energy Source in TREMP:

Syngas ↔ SNG + heat

Energy: 100% ↔ 80% + 20%

The TREMP technology addresses the essential question of heat recovery most efficiently by recovering the heat as high pressure superheated steam. This concept requires that thee reaction heat is recovered at a high temperature. A key challenge is therefore to manage the high heat of reaction by having a catalyst that has high activity at low temperature after long exposure to high temperatures. Some researchers have developed the proprietary catalysts MCR-2X and PK-7.

The MCR-2X catalyst, which is active at temperatures down to below 300°C and stable at the very high temperature in the first methanation reactor, where the outlet temperature may be as high as 700°C. The PK-7 catalyst is optimized for operation at low temperature and is always used in the last "clean-up" methanation reactor, which may operate at inlet temperatures as low as 200°C (Christian *et al.*, 2007). TREMP technology process layout and its heat recovery can be seen in **Figures 4, 5,** and **6**.

According to Ministry of Energy and Mineral Resources of Indonesia, coal reserved in Indonesia is amounted to 28.9 billion tons in 2012 and concentrated mostly in Kalimantan. Currently, 64% of national electricity demand is fulfilled by 80 million tons of coal, and by 2020 this number is projected to increase up to 126 million.

In 2019, it is estimated that Kalimantan will need 2446 MW of electricity, and this will be 2518 MW in 2024. Therefore, coal is considered as the primary source for electricity generation in Indonesia and SNG production for electricity will be a national strategic clean energy in Indonesia, especially Kalimantan, from the aspect of securing the country's energy. In 2013, KEPCO-Uhde, a joint venture company between Korea Electric Power Corporation (KEPCO) and Uhde, company based in Germany, announce its effort to pushing forward the SNG project near the bituminous coal mine of Bayan Resources located in Kalimantan, Indonesia. The bituminous coal mine of Bayan Resources is the eighth largest coal mine in Indonesia.

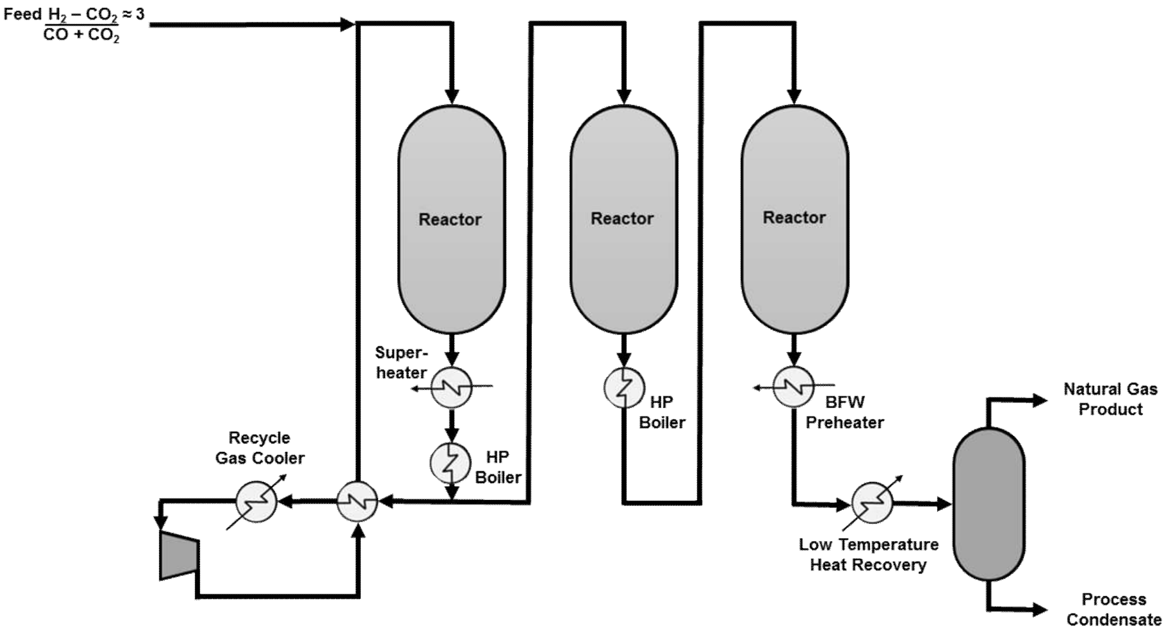

Figure 4. TREMP process scheme.

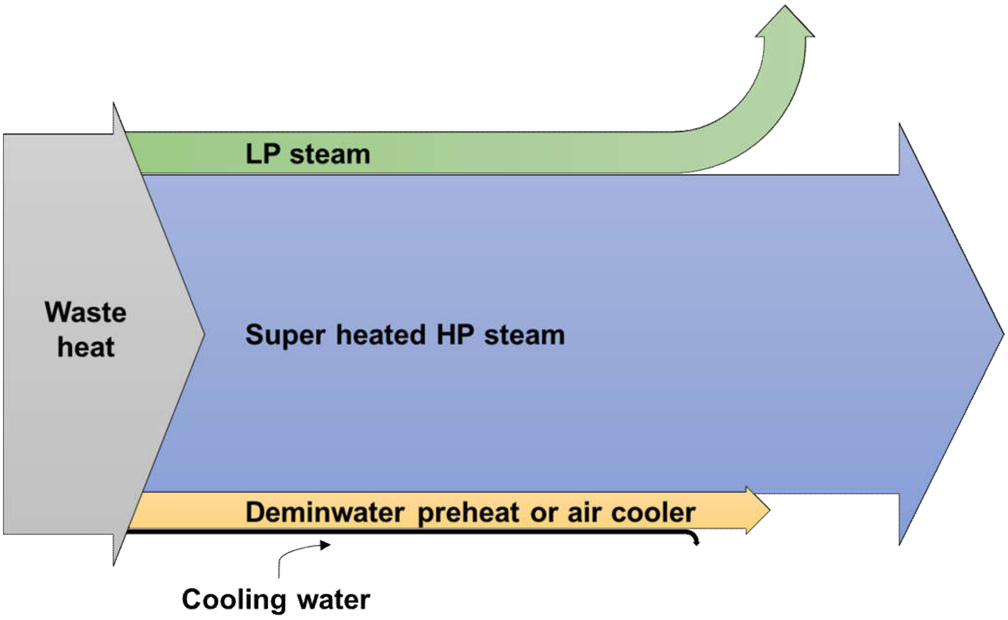

Figure 5. TREMP heat recovery.

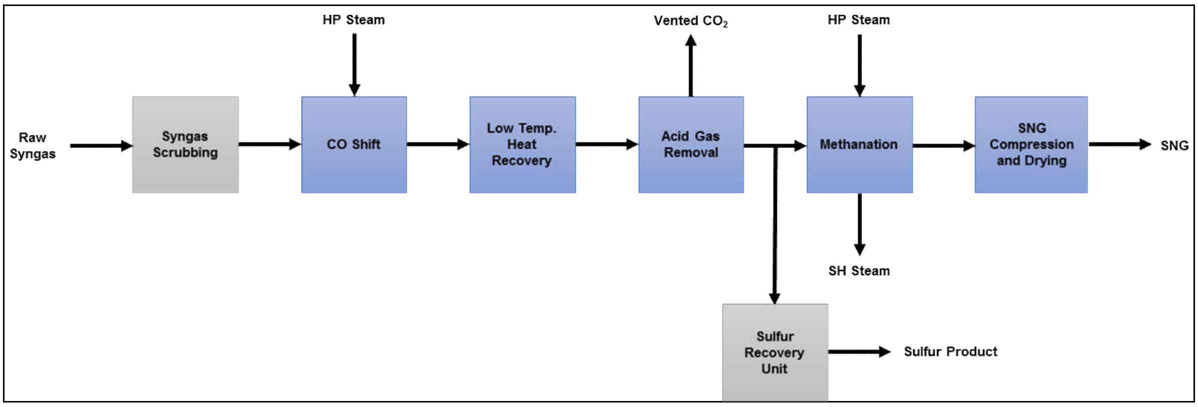

Figure 6. SNG process scheme.

This paper focused on the feasibility study, including process design and simulation. We focused on a coal to SNG power plant in Kalimantan in order to fulfill its electricity demand. This study allows a thorough evaluation both in technology and commercial point of view. The results of this study can be used as a support tool for energy development plan as well as policy-making in Indonesia.

2. EXPERIMENTAL METHOD

The data for the model is gathered through literature survey from government institution reports and academic papers. Aspen HYSYS 7.3 is used for modelling the power plant consists of two blocks which are SNG production block and power block. The economic evaluation is vary depends on the pay-back period, capital and operational cost which are coal price, and electricity cost.

3. PROCESS CONFIGURATION AND SIMULATION

The coal composition analysis done by some Universities from several coal companies in Kalimantan is shown in **Table 2**, which is used as a basis for this simulation. The process of the simulation will use integrated gasification combined cycle (IGCC) that converts fuel to syngas then to electricity in a combined cycle power block consisting of a gas turbine process and a steam turbine process that includes a heat recovery steam generator (HRSG).

The production of syngas in an IGCC power plant occurs in a gasifier through gasification. The main reactions of gasification are as follows (Sun *et al.*, 2011):

$C + \frac{1}{2} O_2 \rightarrow CO$ (exothermic - rapid)

$C + O_2 \rightarrow CO_2$ (exothermic - rapid)

$C + H_2O \leftrightarrow H_2 + CO$ (endothermic – slower than oxidation)

$C + CO_2 \leftrightarrow 2\ CO$ (endothermic – slower than oxidation)

$C + 2\ H_2 \leftrightarrow CH_4$ (exothermic)

$CO + H_2O \leftrightarrow H_2 + CO_2$ (slightly exothermic)

$CO + 3\ H_2 \leftrightarrow CH_4 + H_2O$ (exothermic)

Several commercial gasifier are available, including Shell, General Electric (GE, originally developed by Texaco), British Gas Lurgi (BGL), and Kellog-Rust-Westinghouse (KRW) gasifiers. These commercial gasifiers have different performances relating to their operating conditions.

Table 2. Kalimantan coal composition analysis.

Coal	Proximate Analysis							Ultimate Analysis							Heating Value	
	(as received basis, wt%)				(dry basis, wt%)			(dry basis, wt%)							(kcal/kg, dry basis)	
	I.M.	V.M.	F.C.	Ash	V.M.	F.C.	Ash	C	H	N	S	Cl	O (by diff.)	Ash	HHV	LHV
KPU* - Subbituminous	19.33	44.87	31.12	4.68	55.62	38.58	5.8	71.73	4.98	1.2	0.46	0.01	15.82	5.8	6570	6301
LG – Subbituminous	19.33	43.06	30.82	6.79	53.38	38.21	8.42	70.27	4.94	1.42	0.96	0.01	13.99	8.42	6539	6272
MSJ** - Subbituminous	13.66	44.28	36.97	5.1	51.29	42.82	5.91	71.13	5.04	1.68	1.38	0.01	14.58	5.91	6812	6540

*Kalimantan Prima Utama, **Mahakam Sumber Jaya

For example, Shell uses an entrained bed gasifier with a dry pulverized coal feeding system, whereas Texaco uses the same gasifier but with a water slurry feeding system. On the other hand, the BGL and KRW gasifiers employ a wet feeding system with a moving bed and fluidized bed, respectively (Zheng & Furinsky, 2005).

In this study, the syngas from an entrained bed gasifier with dry Kalimantan subbituminous coal as the feed was considered. This type of gasifier is made of two parts, which are the water cooled membrane wall as the inner part and the pressure vessel as the outer part. The gasification process begins when coal and oxygen enter the gasifier through a number of opposed burners at the bottom of the gasifier.

The syngas composition data from the existing IGCC plant in Taean, South Korea from this particular gasifier then is compared with simulation data. There are two simulation that compared with the plant data; first is raw syngas with small amount of impurity gas and second without the impurity. The comparison is shown in **Table 3**.

From the **Table 3**, the error from the gasifier simulation is big enough. To make the whole simulation result valid, the gasifier simulation is neglected. In addition, it gives the sensible value of gas composition compares to the simulation result where most of impurities are zero. Accordingly, plant data which has reasonably high CO and hydrogen is used as inlet data for syngas scrubbing unit.

To produce SNG, there are five units to build; syngas scrubbing unit, CO shift unit, low temperature heat recovery unit, acid gas removal unit, and methanation unit. To build the simulation syngas scrubbing unit from IGCC, power plant is used.

A scrubber is generally used as an air pollution control device with its main task being to remove the solid particle matter from the syngas. Single system and combined system are the scrubbers commonly used in industry. The single system is a system that uses one type of scrubber, while the combined system utilizes two single systems (two stage system). The single system is classified into two processing types, dry scrubbing and wet scrubbing. Dry scrubbing is a process when less or neither liquid or moisture is used to scrub the unwanted emission. Wet scrubbing, however, works in the opposite way. The combined system is used when the acid gas content is relatively high in the gas stream.

Table 3. Plant data and simulation result comparison.

Component	Plant Data	Simulation 1	Error	Simulation 2	Error
H_2O	1.47	0	100%	0	100%
Hydrogen	25.06	28.76	14.76%	29.32	17%
CO	61.77	70.09	13.47%	70.08	13.45%
CO_2	1.29	0	100%	0	100%
H_2S	0.23	0.1	56.52%	0.09	60.87%
Nitrogen	9.21	0	100%	0.51	94.46%
COS (ppm)	280	0	100%	N.A.	N.A.
CH_4 (ppm)	238	0.02	≈100%	N.A.	N.A.
HCl (ppm)	154	0	100%	N.A.	N.A.
NH_3 (ppm)	192	0	100%	N.A.	N.A.
HCN (ppm)	192	1.01	≈100%	N.A.	N.A.

In this study, the combined system was used because the acid gas content is relatively high in the gas stream. A combination of a venturi scrubber and packed tower were selected. The first stage, which is the venturi scrubber, can typically achieve 95% of acid gas removal. In the second stage, which is the packed tower, up to 99.9% of the acid gas can be removed. The two scrubbers selected belong to the wet scrubber type. The selection of those two scrubbers is related to the capability of the wet scrubber to simultaneously remove the particulate matter as well as various types of syngas pollutants from the gas stream. In addition, it is suitable for handling high temperature syngas. To simulate this unit, a valve and column were used to represent the venture scrubber and wet scrubber, respectively.

For CO shift unit, the reaction and kinetic data for CO shift reactor is acquired from open literature (See http://www.intechopen.com/books/petrochemicals/modeling-and-simulation-of-water-gas-shift-reactors-an-industrial-case):

$CO + H_2O \rightarrow CO_2 + H_2$

Catalyst: Fe_2O_3/ Cr_2O_3/ CuO Commercial type 1

K_o: 725

Ea: 110 kJ/mol

The number of reactor used in CO shift unit is two. One for CO shift to H_2 and the other is for COS hydrolysis. To model the CO shift reactor a CSTR reactor is used. While, for modelling COS hydrolysis reactor, a PFR reactor is used.

The low temperature heat recovery unit consists of two heat exchanger and one vessel to separate water. The acid gas process that used here is Rectisol process. This process is the earliest commercial process based on an organic physical solvent. Rectisol process uses methanol as a solvent and operates at a very low temperature. Methanol has higher selectivity for H_2S compared to CO_2 with ratio of H_2S and CO_2 about 4:1. At the same time, the selectivity of CO_2 is so high so that in Rectisol process, H_2S and CO_2 removal can be done with only one solvent. Besides that, it has superior ability to purified the syngas up to 5 ppmv to 5 mol% CO_2 content or less and 0.1 ppmv H_2S+COS content. In this work, to simulate the Rectisol process, some binary parameter is adjusted according to the latest version of HYSYS as can be seen in **Table 4**. The simulation of Rectisol process is shown in **Figure 7**.

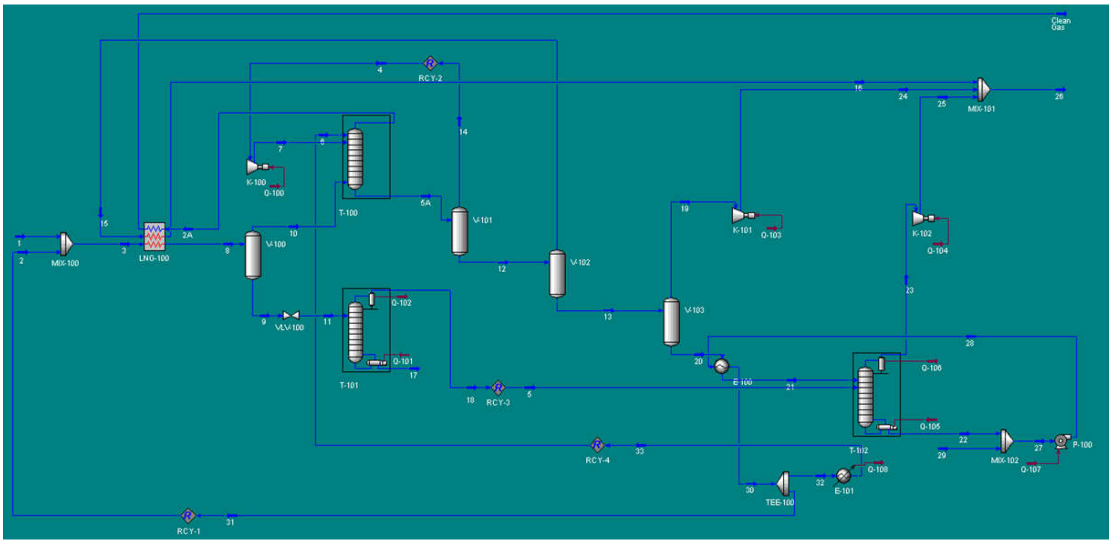

Figure 7. Simulation flowsheet of Rectisol process.

Table 4. Binary parameter adjustment value.

	CO_2	H_2O	Nitrogen	H_2S
CO_2		-0.12155		
H_2O	-0.12155		-0.69648	-0.03347
Nitrogen		-0.69648		
H_2S		-0.03347		

To simulate TREMP, three equilibrium reactors are used. The flowsheet of the simulation is shown in **Figure 8**. The kinetic data is acquired from open literature is shown in **Table 5**.

$$\mathrm{Ln}(K_a) = A+B/T \qquad (1)$$

In power block, this study considered two types of turbines, gas turbine and steam turbine. The gas turbine has its fuel from the SNG produced and steam turbine generated the steam using waste heat in gas turbine. Simulation of power block is shown in **Figure 9**. The integrated simulation of the whole process is shown in **Figure 10**.

Table 5. Kinetic data for TREMP.

Reaction	A	B
$CO + 3H_2 \leftrightarrow CH_4 + H_2O$	-29.3014	26248.4
$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O$	-4.3537	4593.2

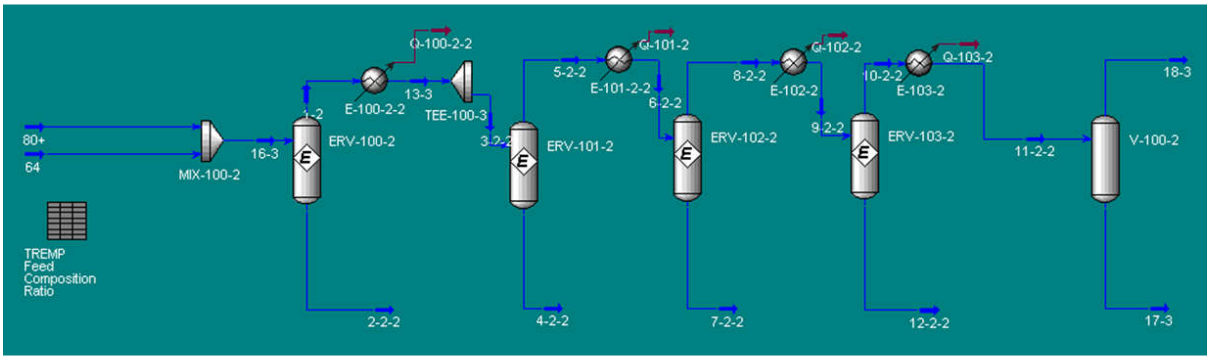

Figure 8. Simulation flowsheet of TREMP.

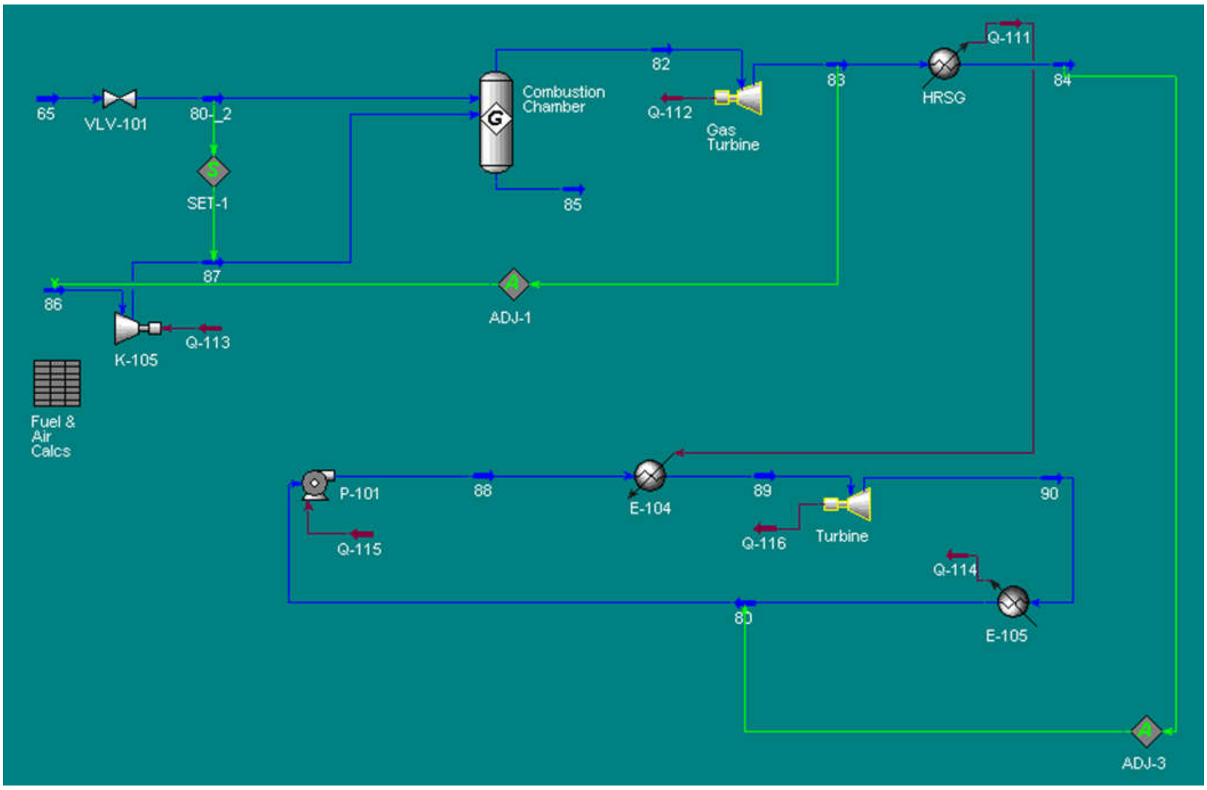

Figure 9. Simulation flowsheet of power block.

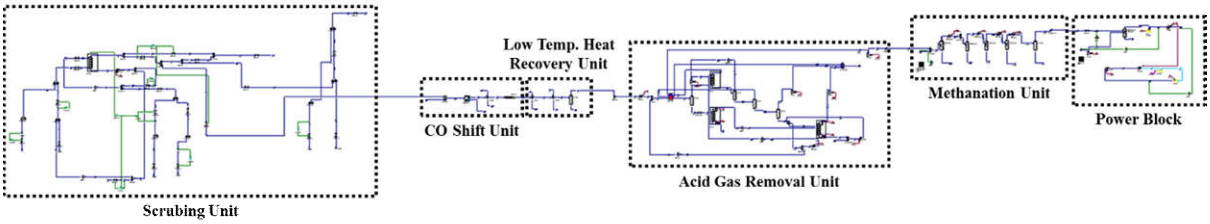

Figure 10. Simulation flowsheet of integrated process.

4. DISCUSSION

The benchmark of this SNG plant is the IGCC power plant in Taean, South Korea, which can generate electricity up to 300 MW with the pulverized coal flow to gasifier 113.6 ton/hour and O_2/steam to gasifier 89 ton/hour. This condition resulted in raw syngas flow to wet scrubber 201 ton/hour. The cost for establishing this power plant was 1.4 billion US$.

Thus, we compare the electricity generated from IGCC power plant and SNG power plant for Kalimantan. The capital cost of SNG plant compared to IGCC plant is 7:9. It means that the estimated SNG plant capital cost is 1.09 billion US$. With the assumption annual operational cost is 20% of the capital cost, operational cost value is 201.8 million US$. The simulation showed that SNG process generated 35 MW (excluding heat utilization from TREMP process).

The electricity cost can be adjusted by pay-back period. The summary of the electricity price is shown in **Table 6**.

Table 6. Electricity price according to pay-back period.

Pay-back Period (year)	Electricity Price (US$)
1	6.86
2	1.88
3	0.91
4	0.55
5	0.38
6	0.28
7	0.22
8	0.18
9	0.15
10	0.13

5. CONCLUSIONS

Electricity price in Indonesia for household is from Rp 415 to 1352, in which the price depends on capacity limit. Based on the above analysis, we found that the suitable period for SNG plant in Kalimantan is 10 years (0.13 US$/kWh or equal with Rp 1859; 1 US$ = Rp 14303.5). In the real implementation, this price could be reduced. This is because in this simulation, waste heat from TREMP process has not been utilized due to design limitation.

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7. AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

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