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Techno-Economic Study on the Potential of Dimethyl Ether as a Substitute for LPG

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Abstract**—**The increase in LPG consumption in Indonesia is not balanced with the amount of supply. The high demand for LPG due to the success of the government's kerosene-to-LPG conversion program and the COVID-19 pandemic in 2020 led to an increase in LPG consumption in the household sector and caused Indonesia's trade balance to experience a deficit. The high consumption of LPG encourages the need for alternative fuels which aims to substitute LPG. Dimethyl Ether (DME) is an organic compound with the chemical formula CH_3OCH_3, has a high cetane number and has characteristics similar to LPG. DME can be produced from various sources such as coal, biomass and natural gas. Based on the economic analysis conducted at 10% Internal Rate of Return (IRR), coal has the largest Net Present Value (NPV) of Rp. 20,034,837,497,241 with a payback period of 3.86 years, then biomass with an NPV of Rp. 10,401,526,072,850 and payback period of 5.16. The latter is natural gas with an NPV of IDR 7,401,272,559,191 and a payback period of 6.17 years. Of the three sources of raw materials used, if the sensitivity is calculated using the selling price of DME equal to the selling price of LPG, it will get an NPV value that is greater than the NPV value when using the current DME price. The advantages of coal as a raw material for DME are profitableness, low price and abundant resources, but it has high greenhouse gas emission.

Keywords**—**LPG, DME, coal, biomass, natural gas.

I. Preliminary

POPULATION growth in Indonesia has increased quite large from year to year so that it has a very large influence on energy consumption in Indonesia directly as well as its impact on the country's economy indirectly [1], where there is a correlation between the amount of final energy consumption and the population in Indonesia is called the final energy consumption intensity per capita. The intensity of final per capita energy consumption in Indonesia has increased until 2019 and then decreased in 2020 which is likely due to several reasons, one of which is the COVID-19 pandemic (Fig. 1) [2]. But unfortunately, the rate of increase in energy consumption in Indonesia for Liquified Petroleum Gas (LPG) is experiencing an imbalance with the amount of supply. Fig. 2 shows the supply and demand for LPG in Indonesia from 2018 to 2020 [2]. Since 2007, the Government has started implementing the program conversion of kerosene to LPG, therefore LPG consumption continues to show improvement. To meet this need, LPG imports have grown significantly since 2008 at an average growth rate 2008-2020 of 8.1% [3].

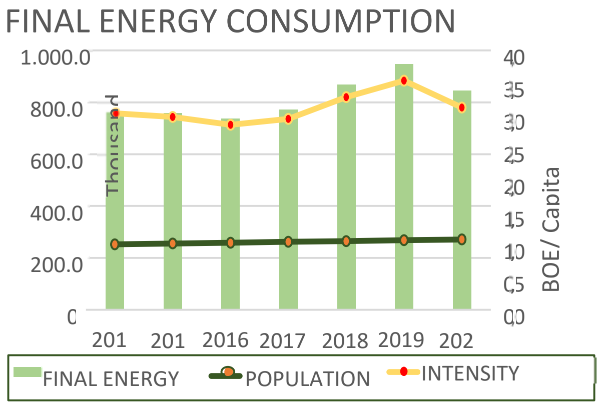

Fig. 1 Final energy consumption intensity per capita

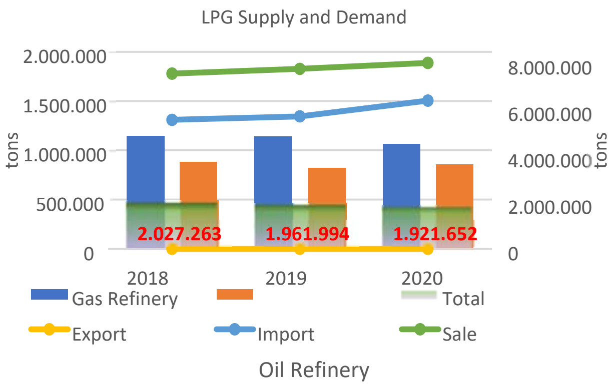

Fig. 2 LPG supply and demand in Indonesia [2]

At present, LPG is the most imported energy by Indonesia because of the increasing demand; until 2020 the amount of LPG imported is almost 6.4 million tons, as shown in Fig. 2. The increase in LPG demand, especially in the household sector, was influenced by several things, namely the success of the kerosene to LPG conversion program and the COVID-19 pandemic with the Enforcement of Restrictions on Community Activities (ERCA) policy, the need for LPG has increased compared to the previous year. The increase in LPG imports was so burdensome for the government that it caused Indonesia's trade balance to become a deficit [3].

The high demand for LPG consumption in Indonesia encourages the need for alternative fuels intended to substitute LPG, one that can be used is DME. It is an organic compound with a chemical formula CH_3OCH_3 which can be produced

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from various sources of raw materials such as natural gas, coal and biomass. DME has a high cetane number and has characteristics resembling LPG, the characteristics of DME and LPG are listed in Table I. The use of DME as an alternative material to replace LPG is expected to be able to reduce the amount of LPG imports which increase each year to meet domestic needs [4].

TABLE I
CHARACTERISTICS OF LPG AND DME [5]

Physical Properties	DME	LPG
Boiling point (°C)	-25	-42
Steam pressure (kPa)	530	520
Density (kg/m³)	0.66	0.49
Viscosity at 40°C (cP)	0.18	0.1
Low Heating Value (MJ/kg)	28,8	46

II. METHOD

The method used in this study is a literature study which is divided into four parts, namely the first regarding energy supply and energy demand projections, the second regarding DME which includes a study of raw materials and their availability in the manufacture of DME and the technology of the DME manufacturing process, the third is an analysis of DME economic studies as substitute for LPG, and the last is a recommendation that comes from a summary of the previous literature review.

III. RESULTS AND DISCUSSION

A. Energy Supply and Energy Demand Projection

The basis for the analysis of the development of alternative energy needed is to look at the projection of future energy needs and energy supply to explore energy potential that has not been optimally utilized. The use of LPG has continued to increase from year to year, while its production has decreased (Fig. 2).

From several energy sources in Indonesia, there are 3 types of energy sources that can be further utilized as raw materials for DME production, including: coal, natural gas and biomass. The availability and potential reserves of the three types of energy sources encourage their development and utilization so that they can be processed into DME which can later be used as a substitute for LPG.

The potential and energy reserves in Indonesia listed in Table II show that biomass has enormous potential to be utilized and can pollute the environment if it is not utilized optimally.

TABLE II
POTENTIAL AND ENERGY RESERVES [6]

Type	Resource	Reserve	Production	Reserve/Prod
	Total			(Year)
Coal (Million tonnes)	110,069	36,279	614	59
Natural Gas (TSCF)	67,42	60,61	2,4	25
	Installed		Reserve	
Biomass (MW)	151.52		1969.64	

B. Production of DME

i. Based on Raw Materials

a. Coal

Coal is a fossil energy whose price is relatively cheaper compared to other types of energy [6] (Table III). Coal is globally used for power generation, cement industry, fertilizer, iron, steel, briquettes etc. [7] and is divided into four classes, namely lignite, sub-bituminous, bituminous and anthracite [8].

TABLE III
ENERGY PRICES IN INDONESIA [6]

USD/BOE	2018	2019	2020	2021
Gasoline RON 88	79	80	79	78
Avtur	122	120	118	117
Kerosene	30	30	30	30
Gasoline CN 48	57	57	56	56
LPG 3kg	36	36	35	35
LPG 12kg	104	105	103	102
LPG 50kg	115	116	114	113
Coal	13	13	15	13
Household Electricity	128	129	115	117
Industrial Electricity	126	129	126	124
Commercial Electricity	145	148	143	141

DME production from coal requires low production costs [5], with Indonesia's capacity as the third largest brick exporting country in the world [9] and coal reserves in Indonesia that can be produced for the next 59 years, it is certain that DME production from coal can run continuously.

In the process of converting coal to DME, a gasification process is required to produce syngas, a process of cleaning the gas from sulfur and CO_2, in the process of removing CO_2, methanol is used as a solvent. After the gas cleaning process, further DME synthesis and DME purification processes are needed [10]. A diagram of the DME production process from coal can be seen in Fig. 3.

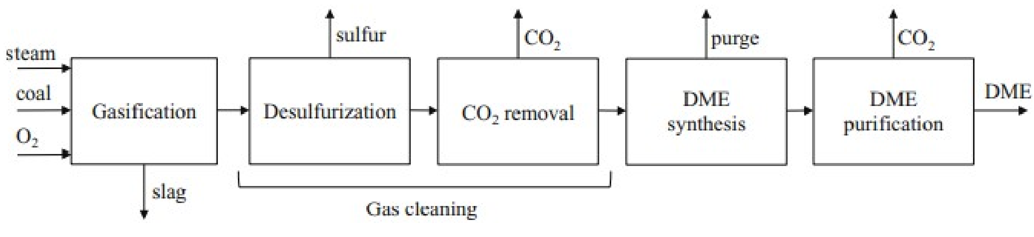

Fig. 3 Diagram of the DME production process from coal [10]

The process of gasification of coal and biomass into DME is generally grouped into three: fixed bed gasifier; fluidized bed gasifiers; and entrained flow gasifiers.

- Fixed bed gasifier: consists of two process parts namely gas process producer and water gas process, both process stages play an important role in the initial process of syngas formation. Coal which has a size of 6-50 mm is fed through the top of the reactor and will accumulate due to gravity and weight. Meanwhile, steam and air (O_2) will be fed from the bottom of the reactor. With the opposite direction of entry, there will be a reaction to form syngas (synthetic gas) [11].
- Fluidized bed gasifier: uses coal with a smaller size compared to the coal used in the fixed bed gasifier, which is 6-10 mm in size. Powdered coal is fed from the side of the gasifier and then moves turbulently because the flow velocity of the gasification medium, namely steam and air (O_2), is relatively high from below. Because the force of gravity and the weight of the coal are in balance with the thrust of the steam and O_2, the coal will be in a floating state when the gasification process occurs. The operating conditions for this gasifier have a temperature of 800-1100 °C and a pressure of 10-30 bar [11]
- Entrained flow gasifier: steam and air (O_2) come in contact with the coal powder rapidly. The type of flow that enters this gasifier is -co-current- i.e., the steam and air feeds are entered from the same direction as the coal. The bait used for coal can be in the form of slurry feed or dry feed. The incoming coal size is less than 100 µm. The operating conditions for this gasifier have a temperature of 1250-1600 °C and a pressure of 20-85 bar [11]

Although there are many coal gasification technologies, none of them have been used commercially and sustainably in Indonesia. This causes doubts for investors and stakeholders in terms of determining gasification technology [12].

Syngas production with a large capacity can be fulfilled with one unit of entrained flow gasifier, while using a fluidized bed gasifier and a fixed bed gasifier in a series of DME production processes, several gasifiers may be required. The number of gasifiers used will affect the investment value and also the whole process [12].

b. Biomass

Biomass is a material that comes from plantation, agricultural and forestry plants which can be processed directly or by the residue/waste from the processing of these plants [1]. Indonesia has large biomass reserves of nearly 2,000 MW of which only 151 MW have been installed (Table III). The largest composition of biomass in Indonesia is biomass from oil palm: shells; fiber; palm fronds and empty fruit bunches (EFB) [12], this is because only 10% of 1 oil palm tree produces oil, while the rest becomes biomass [1]. This abundance of biomass underlies the production of DME from very potential biomass. Fig. 4 shows the flow of the process for making DME from biomass.

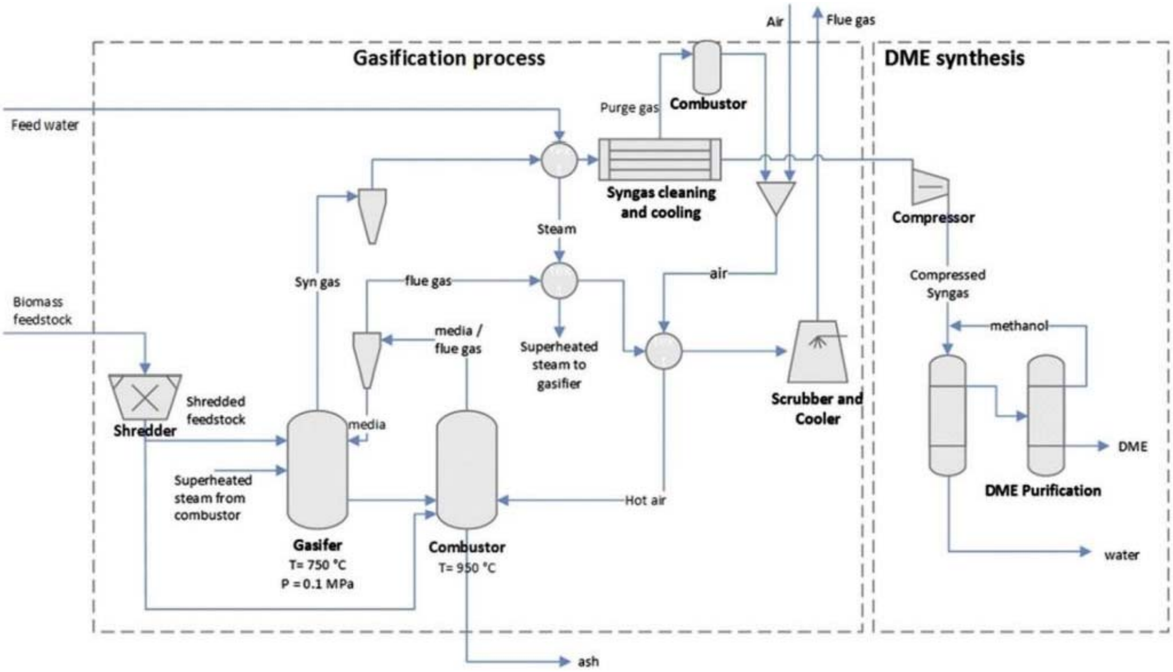

Fig. 4 Diagram of the process for making DME from biomass [13]

There are several biomass gasification technologies, including: downdraft, updraft, circulating fluidized bed, entrained flow bed and twin fluidized bed [1]. The choice of gasification technology used in the DME manufacturing process depends on the conditions and characteristics of the biomass; the main things to consider in determining the gasification technology of biomass include: proximate levels (water, ash, volatile matter, fixed carbon), ultimate analysis (grade C, H, O, N and S), ash fusion temperature, HGI (hardgrove Grindability Index)/abrasive properties and caking/ swelling index [12]. For example, if you use biomass from empty oil palm fruit bunches (EFB) which is still wet and has a moisture content of 67%, then use updraft gasification technology, but if EFB has a low water content because it has gone through the pretreatment process, the gasification technology that can be used is twin fluidized bed [1]. At present, the most suitable type of gasification technology to be applied in Indonesia is a down-draft fixed bed gasifier because biomass in Indonesia is generally collected in relatively small amounts [12].

c. Natural Gas

DME can be produced from the synthesis of natural gas/natural gas into syngas first through the reforming section process, which is classified into three types, namely steam reforming, autothermal reforming, and partial oxidation [14]. Steam reforming is a syngas formation reaction with the main formation reaction being the reaction between natural gas and water vapor, the reaction is endothermic. Autothermal reforming is a reaction where natural gas meets oxygen and water vapor in one reactor. Partial oxidation is the process of forming syngas by reacting natural gas with oxygen and is exothermic. The stages of the DME production process from natural gas/natural gas can be seen in Fig. 5.

Broadly speaking, the process of making DME is divided into three main stages, namely reforming (converting DME into syngas), methanol synthesis (converting syngas into methanol) and the last is converting methanol into DME. The stages of the DME synthesis process are divided into two, namely direct and indirect [15]. Fig. 5 shows the stages of the DME production process using the indirect method [4]. DME synthesis has been carried out commercially by several industries. The technology used by the industry is guaranteed by the licensor, where the licensor can grant licenses to one party or another party according to an agreement made together [14].

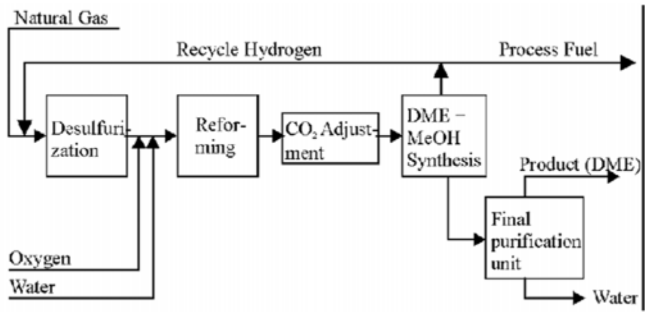

Fig. 5 Diagram of the process for making DME from natural gas [4]

The synthesis of DME from natural gas needs further consideration, bearing in mind that natural gas production has decreased in recent years (Fig. 6) due to decreased production in several wells and several undeveloped proven gas reserves, one of the largest being the Natuna D-block. Alpha, which is predicted to have reserves of 46 TSCF, aside from the natural gas production factor which continues to decline from year to year, the gas reserves in Indonesia are estimated to be depleted in the next 25 years (Table III) so that the government stops gas exports to Singapore in 2023 and then natural gas production is prioritized for domestic needs and directly distributed to several related sectors [3].

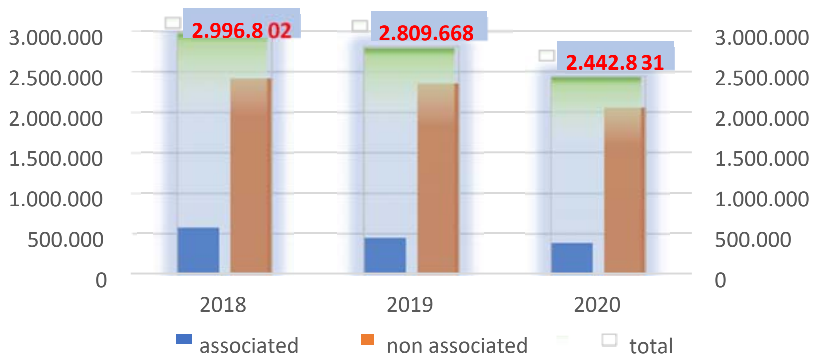

Fig. 6 Gas production in Indonesia [2]

ii. Based on Process

a. Indirect Process

The process of forming DME through an indirect process consists of three stages, namely: formation of syngas from methane, synthesis of methanol from syngas and then dehydration of methanol to become DME [4]. The indirect process of forming DME can be seen in Fig. 7.

The DME synthesis process indirectly requires two reactors: a methanol reactor and a DME reactor [17], thus requiring high investment and low conversion of syngas to methanol [7]. The reaction to the indirect *process* is as follows:

Reaction in methanol reactor:

(a) $2CO + 4H_2 \rightarrow 2CH_3OH$ ΔHo 298 = -182 kJ/mol

Reaction in DME reactor:

(b) $2CH_3OH \rightarrow CH_3OCH_3 + H_2O$ ΔHo 298 = -23 kJ/mol

(c) $CO + H_2O \rightarrow CO_2 + H_2$ ΔHo 298 = -41 kJ/mol

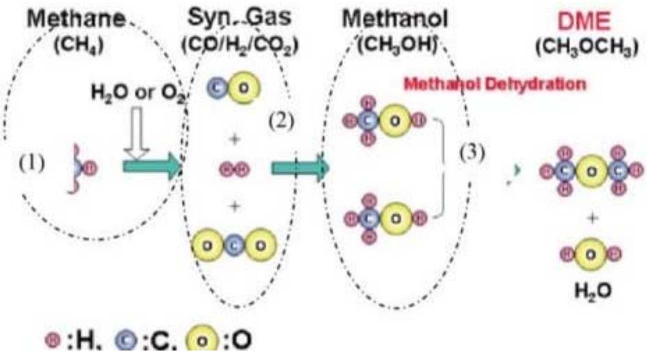

Fig. 7 Indirect DME formation process [16]

b. Direct Process

The process of directly forming DME is a combination of stages in the indirect process but it occurs in one reactor [18]. In the process of making DME through a direct process, dual catalysts system is used in methanol synthesis [4]. The reaction in the direct process is as follows:

- $3CO + 3H_2 \rightarrow CH_3OCH_3 + CO_2$ ΔHO 298 = -246 kJ/mol

In the direct process there are several advantages, including: more efficient, high CO conversion, and high DME selectivity [7]

iii. Economic Study of DME as a Substitute for LPG

a. DME from Coal

Using assumptions based on [19]:

- DME production per year: 500,000 tons
- Coal used: 1,150,000 tons
- Factory age: 20 years
- Working days per year: 330 days (24 hours/ day)
- Coal price: 192,000 (Rp/BOE) = 958,084 (Rp/Ton) [6]
- Economic Analysis: (1 BOE of coal = 0.2004 tons) [20]
- NPV: IDR 20,034,837,497,241
- IRR: 10%
- Payback Period (PP): 3.86 years

TABLE IV
SENSITIVITY OF DME SELLING PRICE

Scenario	DME price = LPG price [21]			DME price = 3850 yuan [22]		
	NPV	pp	IRR	NPV	pp	IRR
-20%	36,137,974,499,957	2.68	37%	12,698,645,885,284	4.83	37%
-10%	42,735,986,382,770	2.39	31%	16,366,741,691,262	4,29	31%
10%	55,932,010,148,396	1.95	22%	23,702,933,303,219	3.51	22%
20%	62,530,022,031,209	1.79	18%	27,371,029,109,198	3,22	18%

b. DME from Biomass

Using assumptions based on [23]:

- DME production per year: 1090 tons/day = 359,700 tons/year
- Biomass used (EFB): 4.1 tons/ton DME = 1,474,770/year
- Factory age: 20 years
- Working days per year: 330 days (24 hours/ day)
- Price of biomass (EFB): IDR 300/kg = IDR 300,000/ton [23]
- Economic Analysis: IDR 300/kg = IDR 300,000/ton [23]
- NPV: IDR 10,401,526,072,850
- IRR: 10%
- Payback Period (PP): 5.16 years

TABLE V
SENSITIVITY OF DME SELLING PRICE

Scenario	DME price = LPG price [21]			DME price = 3850 yuan [22]		
	NPV	pp	IRR	NPV	pp	IRR
-20%	22,999,822,832,605	3.58	37%	5,123,869,827,208	6,45	37%
-10%	26,732,732,581,100	3,19	31%	7,762,697,950,029	5,73	31%
10%	36,225,952,078,092	2.61	22%	13,040,354,195,671	4.69	22%
20%	40,972,561,826,587	2.39	18%	15,679,182,318,492	4.30	18%

c. DME from Natural Gas

Using assumptions based on [17]:

- DME production per year: 240,000 tons/year
- Natural Gas: 265,843 tons/year
- Factory age: 20 years
- Working days per year: 330 days (24 hours/ day)
- Natural gas price: IDR 108,409/ MMBTU [24]
- Economic Analysis: IDR 430,213/ton [25]
- NPV: IDR 7,401,272,559,191
- IRR: 10%
- Payback Period (PP): 6.17 years

TABLE VI
SENSITIVITY OF DME SELLING PRICE

Scenario	DME Price = LPG Price			DME price = 3850 yuan		
	NPV	pp	IRR	NPV	pp	IRR
-20%	15,130,778,320,496	3,43	37%	3,879,900,585,452	6,17	37%
-10%	18,297,824,024,246	3.05	31%	5,640,586,572,322	5,48	31%
10%	24,631,915,431,746	2.49	22%	9,161,958,546,061	4.49	22%
20%	27,798,961,135,496	2,29	18%	10,922,644,532,931	4,11	18%

d. Strengths and Weaknesses

The strengths and weaknesses of each raw material used can be seen in Table VII.

TABLE VII
OPPORTUNITIES AND CHALLENGES IN DME PRODUCTION FROM VARIOUS RAW MATERIALS

Coal	Biomass	Natural gas
The price of raw materials is more expensive than other materials (depending on the type used)	Cheapest raw material prices	Cheap raw material prices
Abundant resources	Abundant resources	Less resources (decreases)
Increasing greenhouse gas emissions [26]	Low greenhouse gas emissions (biomass, *carbon neutral category)*	Increase greenhouse gas emissions
The assumption of the ratio of coal: DME produced is ≈ 2: 1 [19]	The assumption of the ratio of biomass : DME produced is ≈ 4 : 1 [27]	The assumption of the ratio of natural gas: DME produced is ≈ 1: 1 [17]

IV. Conclusion

Based on the economic analysis calculation data, the use of coal as a raw material for making DME is considered the most profitable compared to the other two types of raw material sources. With the current selling price of DME and the projected age of the factory as 20 years with 330 working days/ year for 24 hours a day, it will get an NPV > 0, which is IDR 20,034,837,497,241, and will experience a *payback period* in year 3 with an IRR of 10%; then the second profitable raw material source is biomass which has an NPV value of IDR 10,401,526,072,850, PP in the fifth year with an IRR of 10%, then finally natural gas with an NPV value of IDR 7,401,272,559,191, PP in year 6 with an IRR of 10%. Of the three raw material sources used as references, the sensitivity is calculated using the selling price of DME the same as the selling price of LPG, then one will get a higher NPV value compared to the NPV value when using the current DME price.

There are several reasons that can make the production of DME from coal very profitable, apart from the cheap price of coal, the availability of coal in Indonesia is also very abundant and it can produce DME with an ingredient : yield DME ratio of ≈ 2 : 1. However, from an environmental point of view the use of coal as a source of raw material in the production of DME will increase the resulting greenhouse gas emissions by 5x compared to the resulting gas emissions from the manufacture of LPG with the same tonnage.

The source of raw material for making DME which is also considered to have the potential to be developed in Indonesia is biomass, the raw material for biomass has the cheapest price compared to other sources of raw materials. In addition to the relatively cheap price, the availability of biomass in Indonesia is very abundant, and the resulting emissions are less than other fossil-based raw materials. Biomass is included in the category of carbon neutral where carbon from combustion is not disposed directly into the environment, but is used by plants for photosynthesis. However, the drawback of DME production from biomass is the need for a lot of material (biomass) to produce DME yields with a ratio of ≈ 4 : 1. The use of natural gas as a source of raw material for making DME is not recommended, apart from being unprofitable in terms of economic analysis, natural gas resources in Indonesia are also decreasing from year to year due to the number of wells that are old and have not yet developed new wells/drilling reserves of new natural gas sources.

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