

Techno-economic Analysis of Dimethyl Ether Production Using Oil Palm Empty Fruit Bunches As Feedstock – A Case Study for Riau

Herdadi Supriyo Parbowo, Aisyah Ardy, Herri Susanto*

*Department of Chemical Engineering
Institut Teknologi Bandung, Bandung 40132, Indonesia*

*Corresponding author: herri@che.itb.ac.id

Abstract. The increase of Liquid Petroleum Gas (LPG) import in Indonesia made the government promote Dimethyl Ether (DME) as partial substitution of LPG as written in the General Planning of National Energy (RUEN) 2017. DME can be produced from biomass which abundantly exists in Indonesia. Such biomass is especially oil palm empty fruit bunches (EFB) that consist of 49.07% C, 6.48% H, 0.70% N, 38.29% O, and 5.36% Ash. Techno-economic analysis of this bio-DME production plant was conducted based on literature data. The direct synthesis of DME was applied in this study, instead of using methanol as an intermediate product. Result calculated from mass and energy balance simulation was 4.1 EFB/DME. Thus, 1,090 ton per day of DME can be produced from EFB with a collecting radius of 100 km in Riau Province. Assuming 20 years plant operation with DME selling price of IDR 145,000/12-kg-LPG-equivalent and EFB price of 300 IDR/kg, economic evaluation showed that this business was economically feasible with 10.08% IRR generated. The CAPEX of this plant was 990.4 million USD and the OPEX was IDR 7,143 IDR/kg-LPG-equivalent. DME production from EFB will give the positive economics and environmental effects. Therefore, support and synergy from government, industries, and academics are needed to realize this business.

Keywords: oil palm biomass, biomass to DME, renewable energy, business plan.

INTRODUCTION

The use of DME is one of government scenarios to reduce LPG import, as already written in RUEN 2017. LPG's partial substitution with DME can be implemented because of the similar characteristic between LPG and DME. The main identical characteristics of theirs are (1) both substances identify as non-toxic, (2) having colored fire, and (3) DME vapor pressure lies within the range of LPG vapor pressure. Those similar characteristics between them will minimize the change of infrastructure. The results of testing conducted by BPPT and Lemigas concluded that a mixture of maximum 20% DME in LPG can be applied in household stoves without modification. Pertamina has also conducted the market trial for the utilization of DME as household fuel in North Jakarta with satisfying result.

DME can be produced from natural gas, methanol, coal, and biomass. The utilization of biomass as feedstock is suitable to be applied in Indonesia, having the abundance of biomass. Biomass potential energy is approximately 30,000 MW_e, while only 800 MW_e of it that has already been utilized [1] whereas biomass has a potential to produce energy that economically feasible [2]. From that biomass potential, the largest proportion is oil palm biomass (39.3 %).

Oil palm biomass consists of palm trunk, palm frond, empty fruit bunch (EFB), palm kernel, and palm fiber. EFB is chosen as raw material for DME production because of its abundance in Indonesia, it not being widely utilized yet, and its localized existence in palm oil plant.

This research has been carried out with aiming to provide a preliminary techno-economical data and to propose a business plan of DME production from EFB. The results of this research are expected to be an initial reference to promote the development of DME production from EFB in Indonesia.

METHODS

This research consisted of four major steps: determination of EFB potential, mass and energy balance calculation, economical evaluation, and business plan preparation. Overall, the steps of this research were performed based on literature study and computer aided simulation.

Determination of EFB Potential

Determination of EFB potential was implemented by creating an imaginary circle in biomass collecting area with radius of 100 km from proposed DME plant in Riau Province. The imaginary circle of biomass collecting area is illustrated in Fig. 1. The center of biomass collection is the selected plant location (District of Kampar, Riau Province). The EFB potential from this collection area was referred as the production scale of EFB to DME plant in this research.

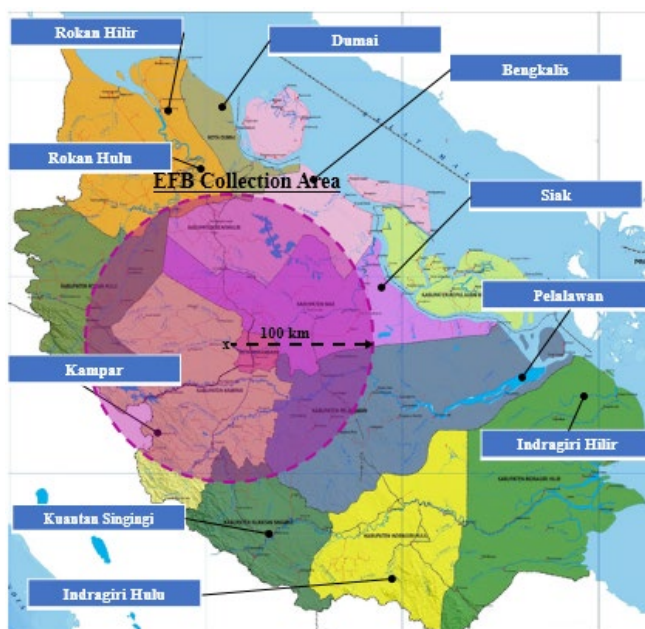
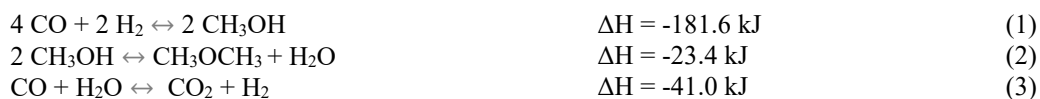


FIGURE 1. Selected EFB collecting area in this research

Mass and Energy Balance

The main reactions of this process are shown on Reaction (1), (2), and (3). This process uses the direct synthesis of DME instead of producing methanol and then dehydrated it on the separate reactor. The main purpose of this selection is to minimize the energy consumption. The catalysts for conducting these reactions are dual catalysts with Cu and $\gamma\text{-Al}_2\text{O}_3$ based [3].



Simplified process diagram of the biomass conversion to DME is presented in Fig. 2. Calculation with Aspen Plus V8.8 and Aspen Hysys V8.8 were used to solve energy and mass balance problem. The main process parameter used in the mass and energy balance is presented in Table 1.

TABLE 1. Process design parameter used in this research

Feedstock	EFB with dry composition (%-mass) [5]: 49.07% C, 6.48% H, 0.70% N, 0.10% S, 38.29% O, 5.36% Ash, HHV 17.08 MJ/kg (dry basis), and 9%-mass of moisture content (wet basis).
Gasification	Equilibrium reaction at P 4 bar and T = 900°C. Heat loss is 5% of thermal input (dry basis).
Air Separation Unit	Electricity consumption 1 MJ/kg-O ₂ [4].
DME Synthesis Reactor	Equilibrium reaction for reactions (1), (2), and (3) with approach to equilibrium 15°C for reaction (1), (2), and 100 °C for reaction (3) [5]. Operating P = 50 bar and T = 250°C.
Rotating equipments	Isentropic efficiency = 80%
Pinch temperature	10°C
Export/import heat or electricity	Zero
Fluid package	PRSV (Peng-Robinson Stryjek Vera)

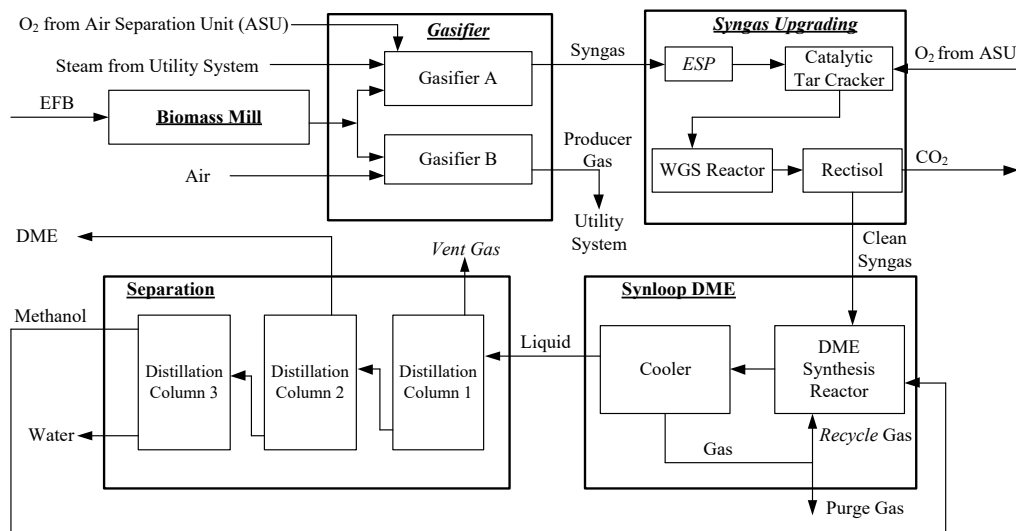


FIGURE 2. Simplified block diagram of EFB to DME Plant

Economic Evaluation

In order to estimate CAPEX, the assistance of APEA (Aspen Process Economic Analyzer) was employed. Values from APEA, based on 2015 data, were extrapolated using CEPCI (Chemical Engineering Plant Cost Index) to predict CAPEX of the plant in 2018. Major assumptions used in economic evaluation are presented in Table 2.

Business Plan

The result of techno-economic evaluation was then used to develop the business plan. The author's experience of interaction with some of the biomass industry practitioners had also been considered to complete the proposed business plan.

TABLE 2. Economic evaluation assumptions

Plant's economic age	20 years
Duration of construction	3 years
EFB cost	IDR 300/kg (plant gate)
DME selling price	IDR 145,000/12-kg-LPG-equivalent (retail)
Capital Structure	40% equity and 60% debt
Interest rate	5% per year
Depreciation Model	Linear with salvage value 0
Tax	15% from earning
Exchange Rate	13,500 IDR/USD
Internal Rate of Return (IRR) Criteria	≥8%

RESULT AND DISCUSSION

EFB Potential in Biomass Collecting Area

EFB potential collected from selected collection area mentioned in Fig. 1 was obtained using following approximation and the result is presented in Table 3.

$$P = \sum_{i=1}^6 \left(\frac{C_i}{A_i} P_i . t . eff . fr \right)$$

P = EFB potential in the selected collection area shown in Fig. 1 (ton per day)

C_i = collection area covered in district i (m²)

A_i = area of district i (m²)

P_i = palm oil mill installed capacity in district i (ton per day) [6]

t = average operation time factor of palm oil mill, assumed 0,69 [6]

eff = collection efficiency of EFB, assumed 80%

fr = mass fraction of EFB in palm fruit, assumed 21%-mass

i = six districts in Riau covered by biomass collection area

TABLE 3. EFB potential in the selected collection area

No	District	EFB potential on selected collection area (ton/day)	
		As received (41.8% moisture content)	Air dried (9% moisture content)
1	Kampar	3,802	2,433
2	Rokan Hulu	1,158	741
3	Siak	1,808	1,157
4	Bengkalis	856	548
5	Rokan Hilir	263	168
6	Dumai	17	11
Total EFB potential in collection area		7,904	5,058

With a yield of 4.1 ton-biomass-air-dried/ton-DME based on our calculation on mass and heat balance (see Table 4), the estimated production capacity of this plant was 1,090 ton/day-DME. Thus, DME production from EFB with collecting radius of 100 km in Riau Province could replace about 7% of LPG import in Indonesia.

Selection of Kampar District in Riau Province as plant location had several advantages. The first, EFB cost could be minimized since abundant EFB was available on its surrounding and road infrastructure was available for EFB transportation. Furthermore, Kampar River was available as utility source and also enabling the ship transportation of DME to ocean.

The Mass and Heat Balance

The mass and energy balance was calculated by taking a heat integration using the pinch technology into account. So, minimum energy consumption could be expected. The summary result of heat and mass balance simulation is presented in Table 4. The process simulation has included heat integration to ensure energy utilization within the process.

TABLE 4. Summary result of process simulation

No	Parameter	Value	Unit
1	Production rate	1,090	ton-DME/day
2	Overall thermal efficiency	45.5	% (LHV basis)
3	Energy consumption		
3a	As feed	46.7	MMBTU/ton-DME (LHV basis)
3b	As fuel	13.1	
3c	Total	59.8	
4	Feedstocks and utilities		
4a	EFB (MC 9%)	4.1	ton/ton-DME
4b	Water	7.6	ton/ton-DME
4c	Air	17.4	ton/ton-DME
5	Side products		
5a	Nitrogen	4.7	ton/ton-DME
5b	Argon	0.1	ton/ton-DME
6	Waste		
6a	Ash	0.1	ton/ton-DME
6b	Waste Water	0.3	ton/ton-DME

Economic Evaluation

Contributions of CAPEX of each unit process and operation are presented in Table 5. It is understandable that the investment cost of the gasification unit contributed up to 17%. Moreover, to produce the synthesis gas, this process required O₂ which in turn it costed the Air Separation Unit. A twin bed gasifier without requiring O₂ is being developed for production of synthesis gas.

To validate our assessment, comparisons to other study are presented in Table 6. Result of our feasibility study was with in the range of other studies. It was surprising that the study by Clausen (2011) gave an extremely low investment cost [4]. It was because Clausen (2011) applied the biggest scale compared to others hence the advantage from the plant economies of scale can be obtained. Furthermore, Clausen (2011) used semi-processed biomass as feedstock that can reduce the equipment needed inside the plant.

Levelized cost calculation of DME production was calculated with assumption in Table 2 and the result is shown in Table 7. Operating cost needed to produce DME was 7,143 IDR/kg-LPG-equivalent. With DME selling price similar with LPG (12,083 IDR/kg-LPG-equivalent or 145,000 IDR/12-kg-LPG-equivalent), an IRR of 10.08% would be obtained, this was above IRR criterion of 8%.

TABLE 5. Summary of CAPEX calculation

Parameter	Cost (million USD ₂₀₁₈)	
Gasification Island: biomass mill, gasifier, and cyclone.	169.5	17.1%
ASU	116.5	11.8%
Syngas Upgrading: ESP, tar cracker, WGS reactor, CO ₂ removal.	128.9	13.0%
Synloop DME	121.2	12.2%
Power Plant: Gas Turbine, HRSG, Steam Turbine, etc.	159.0	16.1%
Separation and Purification	35.1	3.5%
Miscellaneous Utility	25.1	2.5%
Total Installed Cost (TIC)	755.3	
Land development (4% TIC)	30.2	3.0%
Total Direct Cost (TDC)	785.5	
Indirect Cost (20% TDC)	157.1	15.9%
Fixed Capital Investment (FCI)	942.6	
Land	0.62	0.1%
Working Capital (5% FCI)	47.1	4.8%
Total CAPEX	990.4	100%
Specific CAPEX (per MW_{th} product)	2.74	
Specific CAPEX (per ton/day product)	0.93	

TABLE 6. Techno-economic result comparison of biomass to DME process from various study

Parameter	[4]	[7]	[8]	[9]	This study
Feedstock	Torrefied woodchips	Switchgrass	Switchgrass	Woody biomass	EFB
Input Rate (MW_{th} LHV)	2302	893	601	430	795
CAPEX Specific (mil USD₂₀₁₈/MW_{th} product)	1.17	2.91	2.97	2.68	2.74

TABLE 7. Levelized cost calculation of DME production from EFB

No	Cost Component	Cost (IDR/kg-LPG-eq)	
1	Capital charge	2,814	23.3%
2	EFB	2,026	16.8%
3	Fixed manufacturing cost	1,876	15.5%
4	Others feedstock, waste, catalyst	206	1.7%
5	Tax	221	1.8%
	OPEX	7,143	
6	Distribution and selling	540	4.5%
7	Internal return minimum ^{*)}	3,688	30.5%
	Minimum economic selling price	11,371	
8	Additional internal return ^{**)}	712	5.9%
	Selling price	12,083	100%

^{*)} resulting minimum IRR (8%)

^{**)} resulting the same selling price with LPG

CAPEX and the exchange rate of dollar were the most sensitive variable. On the other hand, if N₂ and Ar as side products can be sold, the minimum economic selling price might be reduced significantly. Therefore, in the feasibility study of this project in the future, the possibility of side products selling should be investigated further.

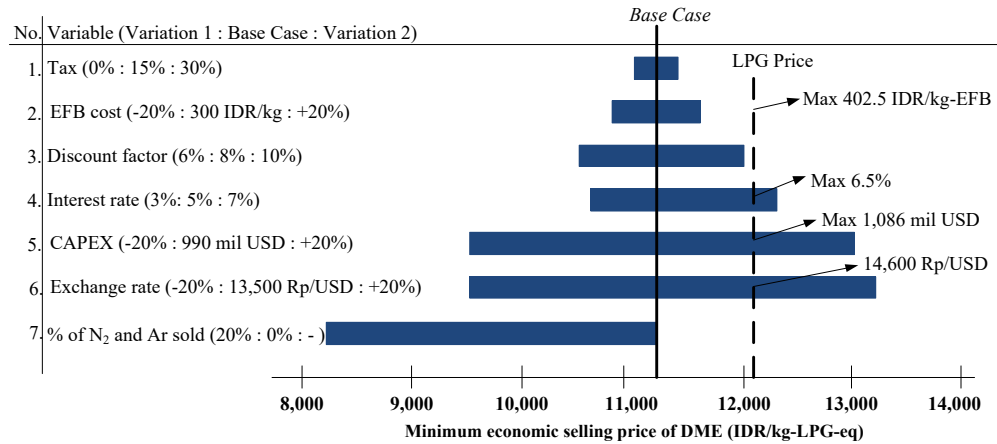


FIGURE 3. Sensitivity analysis result

Business Plan

The comprehensive business plan with several key points for this business is shown in Fig. 4. The first key point, EFB transportation shall be integrated with existing fresh fruit bunch (FFB) transportation to keep the EFB price on the allowable level. The integration can be performed by optimizing the FFB trucks, so that after finishing the FFB delivery to palm oil mill, the truck is then filled with EFB. The truck then returned to the plantation with twisting the route slightly to deliver EFB to the DME plant.

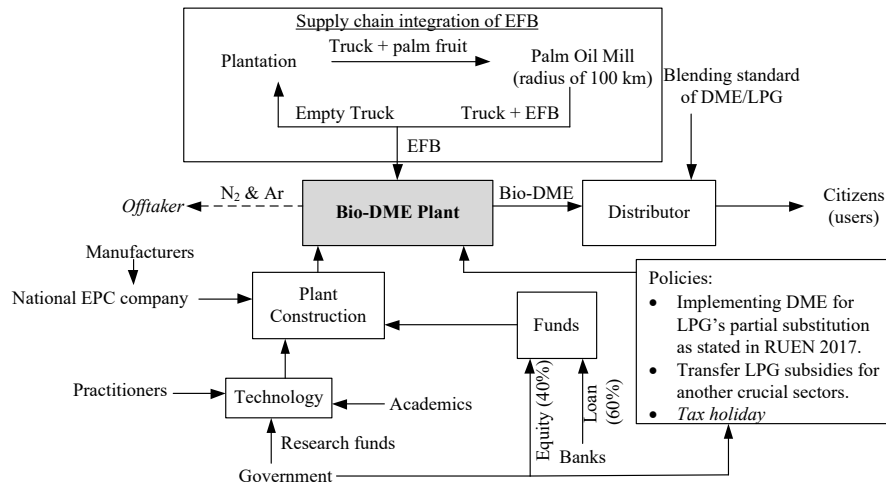


FIGURE 4. Proposed business plan of DME plant from EFB in Indonesia

The second key point, the possibility to sell N₂ and Argon as side products, shall be explored during the feasibility study of this plant since it can increase the business competitiveness dramatically as shown in Fig. 3. Argon is an inert gas that is commonly used for titanium manufacturing, healthcare industries, lighting industries, and food industries. Similar with Argon, Nitrogen is also commonly used for food packaging, lighting industries, and also electricity industries. Thus, this DME plant may initiate an integrated business with these industries in order to improve each business performance.

The third key point, local content shall be maximized on this project to reduce CAPEX, decrease the linkage with the fluctuation of exchange rate, and maximize the positive domino effect for national economic growth. To maximize the local content, synergies between academics, practitioners, and government are needed to produce patents related

to DME process technology from EFB and or patents related process equipment especially static equipment. Gasifier is a static equipment that is very likely to be designed and produced locally. If the gasifier can be produced locally, the CAPEX will decrease significantly since investment in the gasification island is the biggest portion of CAPEX.

The fourth key point, government support is needed by issuing policies that assure and regulate the DME utilization as LPG's partial substitution. If the policies to encourage DME application are fixed, the investment will get more trust from banks and any other investors. Government's support is also needed by providing the fund for the related research and development.

Implementing bio-DME as LPG's partial substitution may give positive effects. For instance, it can save the Indonesia foreign exchange and also increase the national energy security by reducing the dependency with LPG import. It will reduce GHG (Green House Gas) emission due to the use of fossil fuel and increase the renewable portion on Indonesia energy mix. Last but not least, it will solve the environmental problem caused by EFB pile in the surrounding of palm oil mills and also give the added value for EFB.

CONCLUSION

DME production from EFB was theoretically feasible with yield of 4.1 ton-EPB/ton-DME and total thermal efficiency of 45.5% (LHV basis). Commercialization of DME production from EFB will be more feasible if it is sold with the same price to LPG. DME production from EFB will give the positive economics and environmental effects. This result gave an intuition that DME production process from EFB was decent to be developed further starting from pilot scale to commercial scale. Support and synergy from government, practitioner, and academics are needed to realize this business.

ACKNOWLEDGMENTS

This study was a part of Master's Program Thesis at Department of Chemical Engineering, ITB. The authors would like to thank to *the Indonesian Palm Oil Estate Fund* (BPD PKS) for funding our research on *Biomass to Methanol/DME*, in Fiscal Year of 2018.

REFERENCES

1. Tajalli, Arief. 2015. Panduan Penilaian Potensi Biomassa Sebagai Sumber Energi Alternatif di Indonesia. Jakarta: *Penabulu Alliance*, 16.
2. Susanto, H., T. Suria, S.H. Pranolo. Economic Analysis of Biomass Gasification for Generating Electricity in Rural Area in Indonesia. *IOP Conf. Ser.: Mater. Sci. Eng.* 334 012012, 2018.
3. Ardy, A., M. Laniwati, J. Rizqiana., H. Susanto. 2018. Synthesis of Dimethyl Ether Using Dual Catalyst Fixed Bed for Methanol Synthesis and Its Dehydration. 25th Regional Symposium on Chemical Engineering. Manila. 2018.
4. Claussen, R.A. 2011. Design of Novel DME/Methanol Synthesis Plant Based on Gasification of Biomass. DCAMM Special Report No S123. Technical University of Denmark. 41, 55, 86, 97, 253
5. Ginting, Agus S., Tambunan A.H., Setiawan R.P.A. 2014. Karakteristik Gas-Gas Hasil Pirolisis Tandan Kosong Kelapa Sawit, *Jurnal Teknologi Industri Pertanian* **25**(2). Institut Pertanian Bogor. 158-163.
6. Syahza, A., Rosnita, Suwondo, Nasrul, B. 2013. Potential Oil Palm Industry Development in Riau. *International Research Journal of Business Studies Vol. 6 No.2*. 142.
7. Larson E.D., Jin H., Celik F.E. 2009. Large-scale Gasification-based Coproduction of Fuels and Electricity from Switchgrass. *Biofuels, Biorprod. Bioref.* 2009;**3**.174–194.
8. Kreutz T.G., Larson E.D., Liu G., Williams R.H. 2008. Fischer-Tropsch Fuels from Coal and Biomass, Report. Princeton, New Jersey: Princeton Environmental Institute. Princeton University.
9. National Renewable Energy Laboratory. Process Design and Economics for The Conversion of Lignocellulosic Biomass to Hydrocarbons via Indirect Liquefaction – Thermochemical Research Pathway to High-Octane Gasoline Blendstock Through Methanol/Dimethyl Ether Intermediates. 2015.