

# Achieving Sustainable Energy Security in Indonesia Through Substitution of Liquefied Petroleum Gas with Dimethyl Ether as Household Fuel

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**Abstract.** Indonesia has been facing an energy security issue regarding Liquefied Petroleum Gas (LPG) consumption. The rapid increase of LPG consumption and huge import have driven the Indonesian government to develop the alternative for LPG in the household sector. Dimethyl ether (DME) is the well-fit candidate to substitute LPG because of its properties similarities. However, discrepancies in the properties, such as combustion enthalpy and corrosivity, lead to adjustments in the application. Coal is a potential raw material to produce DME, especially in Indonesia, known as the fourth-largest coal producer globally. However, the gasification of coal into DME brings a problem in its sustainability. To compensate for the emission, co-processing of DME with biomass, especially from agricultural residue, has been discovered. Recently, carbon dioxide (CO<sub>2</sub>) captured from the gasification process has also been developed as the raw material to produce DME. The utilization of CO<sub>2</sub> recycling into DME consists of two approaches, methanol synthesis and dehydration reactions (indirect synthesis) and direct hydrogenation of CO<sub>2</sub> to DME (direct synthesis). The reactions are supported by the catalytic activity that strongly depends on the metal dispersion, use of dopants and the support choice. Direct synthesis can increase the efficiency of catalysts used for both methanol synthesis and dehydration. This paper intended to summarize the recent advancements in sustainable DME processing. Moreover, an analysis of DME's impact and feasibility in Indonesia was conducted based on the resources, processes, environmental and economic aspects.

Keywords: coal gasification, DME, energy security, LPG, sustainable

## 1. Introduction

Liquefied Petroleum Gas (LPG) is a by-product of the refinery process that mainly consists of propane and butane (Huth & Heilos, 2013). According to Indonesia's Handbook of Energy & Economic Statistics of Indonesia (HEESI), in 2018, Indonesia's LPG consumption reached 63.7 million barrels of oil equivalent (MBOE), with a 5.2% increase from 2017, of which the household sector contributed to 96% of the consumption. Despite its high consumption, according to Indonesia's Ministry of Energy and Mineral Resources, in 2015 alone, 60% of LPG in Indonesia came from imports. Moreover, Indonesia's oil and gas production has been decreasing with a reserve to production ratio (RPR) at around 55%, which means for every 1 barrel of oil produced, the industry could only find 0.55 barrel new oil source. This, in fact, has put Indonesia in an energy security problem. Therefore, a race for a new alternative to LPG has been going on for decades.

A well fit candidate to substitute LPG usage is dimethyl ether (DME) due to their similarity. Both LPG and DME are non-toxic properties, produce colored fire and the same vapor pressure range (Parbowo et al., 2019). However, several property discrepancies, such as heat enthalpy and corrosivity can impact the feasibility of DME usage. DME is mainly used as an 'ozone-friendly' propellant in spray cans. Usually, DME is derived from natural gas (NG) or methanol (Nieuwenhuis & Wells, 2003).

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DME can also be synthesized through the gasification of coal. Indonesia has a tremendous amount of coal with a national reserve of 26.2 billion tons, the fourth largest coal producer globally. Coal gasification into DME is not a new thing. Korea, which is known for its NG-based DME producer, has been researching to substitute NG with coal to cut the dependence on imported crude oil (Kim et al., 2012). The utilization of DME can decrease the import of LPG in Indonesia (Boedoyo, 2016). To reduce greenhouse gas (GHG) emissions of the DME production, biomass can be integrated with coal through co-gasification process (Howaniec & Smoliński, 2014). Biomass is a potential energy resource for its abundance in Indonesia, especially from agricultural waste, but most of the resources were underutilized. Therefore, DME can also increase the domestic usage of coal and support Indonesia's development of energy.

Using coal as a feedstock still posed a threat to the environment. Coal gasification to DME even contributed to GHG emission of up to 5.5 kg CO<sub>2</sub>eq per kg DME (Lecksiwilai et al., 2016). To fulfill national demand, around 6.37 Mt of DME is needed, which emits 35.04 Mt of CO<sub>2</sub>eq per year. Therefore, to achieve a lower carbon footprint, advancements have to be made in producing the DME. Some advancements include using biomass, removing CO<sub>2</sub> and more recently utilizing CO<sub>2</sub> as the material to produce DME. A more detailed explanation of the processes will be presented in this work.

Given its potential, there are some essential points regarding DME sustainability. First, it does not come from renewable resources. Even though the Ministry of Energy and Mineral Resources Republic of Indonesia (ESDM) projected that coal reserves' age is still 56 years, other sustainable resources have to be discovered for national energy security. Second, DME processing and application have to be environmentally safe, both in DME production chain and emissions. Third, DME implementation has to be economically feasible at the industrial level.

Therefore, this work aims to analyze DME's potential in Indonesia based on the resources, processes, environmental and economic aspects and explain the long-term sustainability of DME production. In this paper, some scenarios in which DME utilization can lessen LPG consumption was analyzed to better understand its feasibility and impact.

## **2. DME potency to substitute LPG**

### *2.1 LPG in Indonesia*

The discussion of household fuel in Indonesia will always remind the national program, known as the *Zero Kero* program, to convert domestic kerosene users to liquefied petroleum gas (LPG) for cooking in 2007. Kerosene was the primary cooking fuel for 37% of households in that era (MEMR, 2016a). However, the amount of government subsidy on household kerosene became burdensome. In 2008, the total subsidy escalated for more than twice in 2005, reaching up to USD 5.24 billion due to the weakening in domestic supply and increase in oil prices (Budya & Yasir Arofah, 2011). Therefore, LPG was chosen by the government as the substitute for kerosene because LPG's higher calorific value would make it cheaper to subsidize (MEMR, 2007). The other reason was the easier supply chain because LPG with storage tanks and filling plants was easy to distribute even to remote populations.

The *Zero Kero* program gained enormous success to make Indonesian households shift to LPG as kerosene consumption shrank 92% from 10 million kiloliters (kl) in 2006 to 0.8 million kl in 2015. On the other side, LPG consumption rose convincingly from 1.1 million tons (Mt) to 6.3 Mt in 2015, so that Indonesia became at the same level as mature LPG markets like Brazil in LPG consumption per capita (Thoday et al., 2018). This program made the government save until IDR 216,4 trillion compared to subsidizing kerosene (MEMR, 2016b). However, the booming demand for LPG has become another problem. The *Zero Kero* program penetrated the LPG consumption increase annually even though the program has ended. In 2018, 63.7 million Barrel Oil Equivalent (MBOE) of LPG were consumed, and 96% by the household sector (Sekretariat Jendral Dewan Energi Nasional, 2019). Indonesia has been a net-importer oil country since 2004. Therefore, the government had to import LPG to fulfill demand. The *Zero Kero* program drove the LPG import to reach 64% of the total demand in 2015 (MEMR,

2016a). It increases annually until 5.5 million tons of LPG were imported in 2018 (Sekretariat Jendral Dewan Energi Nasional, 2019). Thus, to control the increasing of LPG import, Indonesia government is developing an alternative energy, which is DME produced from coal gasification. To solve the weak local LPG production, Indonesia government is developing gasification of coal, which is abundant in Indonesia, to produce DME.

## 2.2 DME as the LPG Substitution

DME with the chemical formula  $\text{CH}_3\text{OCH}_3$  is the simplest ether with the lowest carbon to hydrogen ratio. Under standard atmospheric conditions (1 atm, 298 K), DME is in the gaseous state. It is a colorless, non-toxic and environmentally safe gas. DME is condensable by pressurization above 5 atm. Given its fuel characteristic, DME produces visible blue flame while burning, comparable with LPG. DME is the potential candidate to substitute LPG because of its physical properties similarity, and it is possibly produced from many sources, such as coal, natural gas and biomass (Larson & Yang, 2004). In some properties, DME is approximately the average of propane and n-butane, two primary LPG components. However, there are still discrepancies in the physical properties caused by the different chemical structures between DME and LPG. The most contrasting differences are combustion enthalpy and corrosivity. DME has a lower combustion enthalpy compared to LPG as it is an oxygenated fuel. Therefore, to substitute LPG, a larger DME volume should be injected into the larger tank (Constantine, 2008). Stronger corrosivity on rubber material also brings adjustment on DME application. Rubber material in the stove, like seals, gasket and pressure regulator, will dissolve and harm the safety aspect if no modifications are done (N. Wu et al., 2008). Hence, it is compulsory to consider those different properties in the DME application (Ohno, 2007). Table 1 contains physical properties information of DME, propane and n-butane.

**Table 1.** Physical properties data of DME, propane and n-butane (Arya et al., 2016).

Properties	Unit	DME	Propane	n-Butane
Molecular weight	g/mol	46.07	44.10	58.12
Liquid density	g/cm <sup>3</sup>	0.67	0.49	0.599
Gas density	g/cm <sup>3</sup>	2.057	1.969	2.595
Melting point	°C	-141.5	-189.69	-138.32
Boiling point	°C	-24.8	-42	-11.7
Flash point	°C	-41.11	-104	-72
Adiabatic flame temperature	°C	1954	1977	1982
Vapour pressure	MPa @293 K	0.530	0.9119	0.21
Liquid viscosity	cP	0.15	0.099	2.074
Gas viscosity	10 <sup>-6</sup> P	9.160	7.99	7.36
Cetane number	-	55-60	5	-
High Heating Value (HHV)	MJ/kg	31.7	50.34	49.49
Low Heating Value (LHV)	MJ/kg	28.8	46.4	48
Wobbe index	MJ/m <sup>3</sup>	52	81	91
Combustion enthalpy	kJ/mol	-1460.4	-2220	-2877.5
Copper Corrosivity	ASTM D-1838	1a	1b	1b

Some discrepancies in properties and the current stove design have led DME-LPG blend fuel to be more feasible. A study by (Matsumoto et al., 2004) found that pure DME was applicable in the methane stove with minor modification. It is supported by the DME's Wobbe Index that is closer to methane than propane and butane. The improbability of using pure DME to substitute LPG entirely has triggered the study by researchers to find the proper portion of DME and investigate its heating performance. Marchionna et al. (2008) used five conventional LPG cooking stoves with three different burners to find that DME's optimum volume concentration in LPG mixtures was 15–20%.

Makmool and Jugjai (2013) also confirmed the same optimum concentration. They tested DME-LPG blend up to 30% in the conventional burner (CB) and porous radiant burner (PRB). In general, up to 30% of DME can be used in the LPG burner, but 20% of DME is the best portion. Blending DME with

LPG improved the combustion efficiency as it can significantly reduce the CO and NO<sub>x</sub> emission. However, the limitation was the decreased thermal efficiency due to increased DME concentration at the fixed fuel supply pressure.

Moreover, at higher than 20% DME, thermal efficiency significantly decreases because of reduced radiation efficiency. Anggarani et al. (2014) did another investigation that used up to 50% DME in 6 commercial stoves in Indonesia. The experiment referred to SNI 7368:2007 method investigated the heat consumption, fuel efficiency and flame stability of DME-LPG blend fuel. Heat consumption and fuel efficiency stove decreased as the DME concentration increased. These tendencies were explainable respectively by the DME's calorific value that is nearly half of LPG's, and the design of current stoves was more compatible with pure LPG. All stoves produced good flame stability when fuelled with a DME-LPG blend.

The Research and Development Center for Oil and Gas Technology of Indonesia (LEMIGAS) has developed the DME stove to utilize 100% DME (ESDM, 2020). The evaluation using SNI 7368:2011 method showed that the DME stove's efficiency was 64.7–68.9 %, better than the conventional LPG stove with 53.75–59.13 % efficiency. Implementation test of DME stove conducted in Palembang and Jakarta cities on 255 households. From the test, the conclusion was that DME stove usage was feasible and had a comparable performance as LPG stove with a drawback of 1.1–1.2 longer cooking time.

### 3. Advancements in DME Production Towards Sustainability

#### 3.1 Co-processing of DME from Low-rank Coal and Biomass

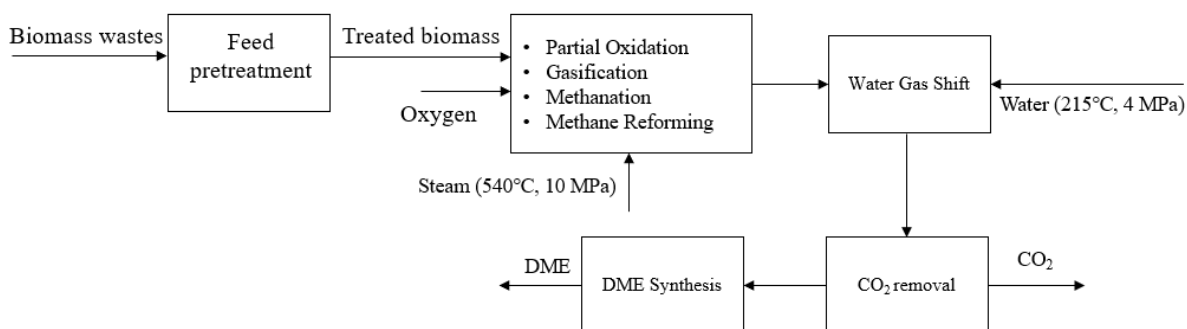
Biomass has been appealing alternative resources to produce DME, especially in Indonesia as an agricultural country. Using biomass as the resource for the gasification of DME could reduce the greenhouse gas (GHG) emissions of the process. Table 2 summarizes GHG emissions from DME utilization from various agricultural residue and coal as a comparison.

**Table 2.** GHG emissions of DME utilization from various feedstocks (Lecksiwilai et al., 2016).

Feedstocks	GHG emission (kg CO <sub>2</sub> e per kg DME)
Sugarcane tops and leaves	0.89
Empty fruit bunches	1.75
Rice straw	1.24
Cassava rhizome	2.11
Maize straw	0.93
Coal	5.50

It can be seen that the utilization of agricultural residue has a significant impact in lowering GHG emissions of DME than coal up to 4.61 kg CO<sub>2</sub>e per kg DME. However, to ensure the carbon neutrality of biomass gasification to DME, more thorough research is needed, including the source of energy required to process and transport biomass. The effect of deforestation as biomass comes from the plantation (Johnson, 2009).

A simplified block flow diagram (BFD) of biomass gasification into DME can be seen in Figure 1.



**Figure 1.** BFD of DME Gasification from biomass (Inayat et al., 2017).

The processing of biomass into DME is not distinct from the gasification process of coal. However, pretreatment steps are needed to screen from unwanted impurities and dry biomass until a specific moisture level to achieve an optimum feedstock condition. The difference between biomass and coal gasification are listed in Table 3.

**Table 3.** Difference between coal and biomass gasification.

Parameter	Coal Gasification	Biomass Gasification	References
Pretreatment	Drying and size reduction	Drying, Torrefaction, and size reduction	(Mamvura & Danha, 2020)
Optimum Gasification Temperature	782 °C	1668 °C	(Prins et al., 2007)
Hydrogen/Carbon Ratio	Low	High	(Burnham, 2018)
Oxygen/Carbon Ratio	High	Low	(Burnham, 2018)

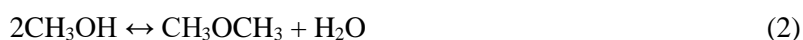
As biomass needs to be pretreated through torrefaction, a conventional coal gasification reactor is not suitable for the task (Basu, 2013). Moreover, torrefaction of biomass accounted for a large sum of energy in the gasification process, making it less economically attractive than coal gasification (Howaniec & Smoliński, 2014).

A more viable approach is to co-process biomass and low-rank coal into DME. In a co-gasification study, Howaniec and Smoliński (2014) reported an increase in gasification efficiency when using several biomass types, such as basket willow (*Salix Viminalis*) and big bluestem grass (*Andropogon Gerardi*), at a fuel blend ranging from 40–60% of the biomass. Moreover, they reported higher hydrogen yield ranging from 7–15% when using 40% biomass. A similar result on higher hydrogen yield with co-gasification has also been achieved by Li et al. (2010). In their study, Li et al. (2010) used pine sawdust and rice husk as biomass sources. They reported an increase of hydrogen yield from 17.66% to 19.30% when the biomass ratio was increased from 20% to 33% (Li et al., 2010).

An increase in hydrogen composition could lead to a higher DME yield as it promotes methanol forming, which is a crucial intermediate-product in DME gasification (Shim et al., 2009). As a result, an increase in hydrogen yield will subsequently increase DME production. The reaction taking up from the production of methanol from the hydrogenation of carbon dioxide, according to the following reaction:



Then, DME is formed from alcohol dehydration:



In the reverse water shift reaction, carbon dioxide reacts with hydrogen to be carbon monoxide:



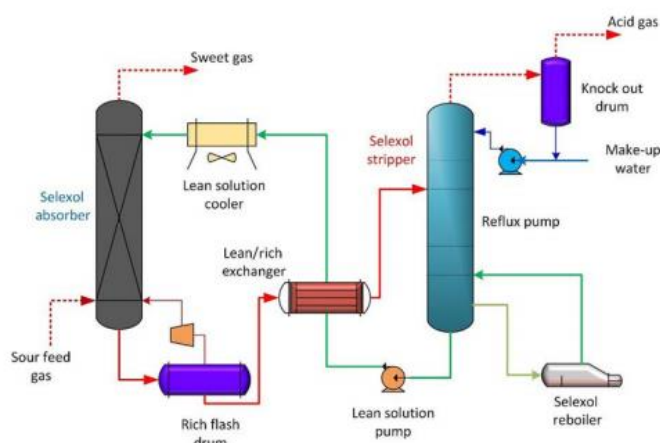
Then, the final reaction leading to the formation of DME as below:



### 3.2 CO<sub>2</sub> Capture in Coal Gasification

The current trend of energy production is shifting to less CO<sub>2</sub> emission. One step in the DME synthesis process is the water-gas shift reaction, which reacted with CO in syngas with steam to produce H<sub>2</sub> and a by-product of CO<sub>2</sub>. During the next process, CO<sub>2</sub> needs to be removed before DME synthesis to avoid a decrease in DME yield (Kabir & Bhattacharya, 2011). The decrease in DME yield happened due to CO<sub>2</sub> competing for hydrogenation and acidic sited of the bi-functional catalyst, thus reducing the methanol dehydration rate (Brown et al., 1991).

Without proper handling, this CO<sub>2</sub> could end up in the atmosphere as emissions. Some methods are available in capturing CO<sub>2</sub> in this process, such as physical and chemical adsorption. Physical adsorption is widely used due to its advantages, with an example of Selexol absorbent method. The Selexol absorbent method was innovated by Union Carbide, which utilizes dimethyl ether of polyethylene glycol (DMPEG) as a physical absorbent (B. Miller, 2015). The advantages of this method are using a small amount of energy to regenerate solvent, utilizing inert gas for solvent stripping and flexibility of utilization with or without refrigeration (Ghasem, 2020). The small amount of energy required to regenerate the solvent is due to no chemical reaction is involved in the process (Fahim et al., 2010). The process flow diagram of this process can be seen in Figure 2.



**Figure 2.** Schematic diagram of a typical Selexol process (B. G. Miller, 2011).

The captured CO<sub>2</sub> can then be stored and utilized further. One example of CO<sub>2</sub> utilization is mineral carbonation. Mineral carbonation involves reacting CO<sub>2</sub> with metal oxides to form carbonates. Furthermore, mineral carbonation is more economically attractive than storage in geological formation as carbonates can be utilized in the construction industry (von der Assen et al., 2013). More promising advancement has been made to utilize this CO<sub>2</sub>, which is through recycling into DME. A detailed discussion about this technology is presented in the following subsection.

### 3.3 Alternatives in the Utilization of CO<sub>2</sub> to DME

Utilization of CO<sub>2</sub> recycling into DME consists of two approaches: 1) Methanol synthesis and dehydration reactions (indirect synthesis), and 2) Direct hydrogenation of CO<sub>2</sub> to DME (direct synthesis) (Centi et al., 2013). Overall economic merits of the direct synthesis can reduce their capital cost. However, most Chinese companies decided to use indirect synthesis to minimize technology risks

and diversify methanol marketing options. The direct synthesis has not yet been proven in large scale commercial plants (Fleisch et al., 2012).

Both of the approaches need hydrogen as one of the reactants. Ensuring the process can be a reliable option, hydrogen needs to be produced using renewable energy sources. There are several ways to produce renewable hydrogen: 1) hydrogen production from cyanobacteria (Tamagnini et al., 2002), 2) biomass thermochemical process (Kalinci et al., 2009), 3) photoelectrolysis to split water into hydrogen (Takanabe, 2017), 4) water electrolysis using fuel cells (Centi et al., 2013). Photoelectrolysis using an anion exchange membrane (AEM) is used more than other alternatives. Enapter, the leader of AEM technology has built the first mass production facility at Germany (Hannovermesse, 2020). Other than that, photoelectrolysis can be done by integrating with the other renewable electricity production that has been increasing over years (Armijo & Philibert, 2020).

### 3.3.1 Indirect Synthesis: Methanol Synthesis and Dehydration reactions

Production steps of DME shown in Equation (1) and (2) requires the usage of catalysts. The most active for the activation of carbon dioxide is Cu or copper-based systems (Sugawa et al., 1995). The catalytic activity strongly depends on the metal dispersion, use of dopants and the support choice (Wambach et al., 1999). Table 4 lists the best-performing catalysts and preparation methods for the methanol synthesis.

**Table 4.** Catalytic properties of M/ZrO<sub>2</sub> catalysts.

Catalyst M/ZrO <sub>2</sub>	Preparation	Product Selectivity (CH <sub>4</sub> (%))	Ref.
Ni	Alloy	100	(Haryanto et al., 2005)
Rh	Impregnation	100	(Palo et al., 2007)
Ru	Impregnation	100	(Vicente et al., 2013)
Rh-Mo	Impregnation	100	(Semelsberger, Ott, et al., 2006)

Most studies have used Cu-based support on ZnO for CO<sub>2</sub> hydrogenation. The nature of the carrier oxide can influence the activity of copper. Zn gives compelling advantages compared to other oxides like Cr<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub> and MnO. Geometrical spacer in the Cu nanoparticles is needed and Cu metal need to be active with ZnO in the CuZnO catalyst. It provides a high number of active sites exposed to gaseous reactants (Aguayo et al., 2007). Moreover, the addition of trivalent ions to the catalyst can improve stability, Cu dispersion and metal surface area. One of the catalyst used for methanol synthesis is Cu/ZnO/Al<sub>2</sub>O<sub>3</sub> (CZA) catalyst. It operates at pressure from 50–100 bar and temperature of 250 °C (Jeong et al., 2013). There are some studies of the unique features of various metals added as the promoters of Cu-Zn based catalysts such as Al (Samei et al., 2012), Cr (Fujiwara et al., 1994), Si (Batyrev et al., 2005) and carbon (Fan & Wu, 2016).

Methanol dehydration can be carried out in both vapour and liquid phase with temperature in of 100–300 °C and pressure up to 20 bar. A high surface area with good thermal and mechanical stability but still affordable can be acquired using  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>. It has a high selectivity to DME due to the presence of weak Lewis acid that cannot promote side reactions (Azizi et al., 2014). These acid characteristics need to be reacted at a temperature higher than 250 °C to achieve the high methanol conversion which aligned with the catalyst ability to achieve high selectivity at temperature up to 400 °C. Moreover, the catalyst activity can enhance their performance with silica, aluminium-phosphates, titanium, boron and other species (Liu et al., 2011). The downsides of using this catalyst is that it absorbs water produced during the reaction causing deactivation. So,  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> is not reliable for the methanol dehydration.

### 3.3.2 Direct Synthesis: Direct Hydrogenation CO<sub>2</sub> to DME

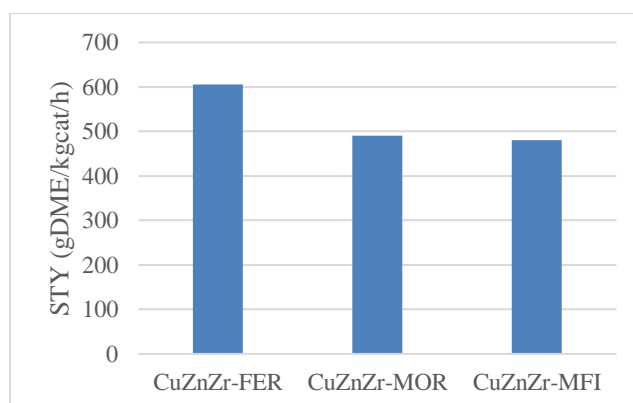
Direct synthesis is a single-step process to produce DME from CO<sub>2</sub> using a hybrid catalyst (Frusteri et al., 2017). It can increase the efficiency of catalysts used for both methanol synthesis and dehydration.

Efficiency can be achieved by minimizing the yield of CO from the Reverse Water Gas Shift (rWGS) side reaction, also hydrocarbons from methanol conversion. It is caused by the water formed from CO<sub>2</sub> hydrogenation to DME caused to lower the DME yield from both formation and dehydration of methanol (Azizi et al., 2014). Some alternatives to the catalyst for the direct synthesis shown in Table 5.

**Table 5.** The alternative catalyst for CO<sub>2</sub> to DME hydrogenation. X<sub>CO<sub>2</sub></sub>: conversion of CO<sub>2</sub>, Y<sub>DME</sub>: yield of DME-product.

Catalyst	Preparation Method	X <sub>CO<sub>2</sub></sub> (%)	Y <sub>DME</sub> (%)	Ref.
Cu/Zn/Al HZSM5	Physical Mixing	31	19	(Naik et al., 2011)
Cu/Zn/Zr/V ZSM5	Co-Precipitation	9.1	19.1	(Zhang et al., 2014)
Cu/Zn/Al/La ZSM5	Physical Mixing	43.8	31.2	(GAO et al., 2013)
Cu/Zn/Al ZSM5+CNTs	Physical Mixing	46.2	21	(Zha et al., 2013)
Cu/Zn/Al Amorphous silica-alumina	Co-Precipitation	28.4	20.1	(Zha et al., 2012)

Direct synthesis can also be done by gel-oxalate co-precipitation of CuZnZr precursors in a slurry solution of three homemade hybrid systems zeolite, which are MOR, FER and MFI. MOR structure was synthesized with structure-directing agents (SDA) from the molar composition of 0.20 Na<sub>2</sub>O - 0.02 Al<sub>2</sub>O<sub>3</sub> - 1.0 SiO<sub>2</sub> - 20 H<sub>2</sub>O. FER structure was prepared from the following gel, the molar composition of 0.12 NaO - 1.30 C<sub>2</sub>DN - 0.07 Al<sub>2</sub>O<sub>3</sub> - 1.0 SiO<sub>2</sub> - 39.0 H<sub>2</sub>O. MFI was prepared following the synthesis gel, the molar composition of 0.10 NaO - 0.02 Al<sub>2</sub>O<sub>3</sub> - 0.08 TPABr - 1.0 SiO<sub>2</sub> - 20 H<sub>2</sub>O (Migliori et al., 2014). The activity selectivity pattern of the catalyst in the CO<sub>2</sub> to DME hydrogenation reaction showed the CZZ-FER system's best performance reaching a CO<sub>2</sub> conversion of 28% at 280 °C with a selectivity of DME/MeOH to 70%. At 260 °C and 5.0 MPa, the CuZnZr-FER system reached the highest final space time yield (STY) for about 600 gDME/kgcat/h compared to other hybrid systems at around 450–500 gDME/kgcat/h on Figure 3. This was able to be done because of the active sites' progressive blockage due to the formation of water during the catalytic experiments as it was the primary effect of the catalyst stability (Frusteri et al., 2017).



**Figure 3.** DME productivity in physical mixtures and hybrid catalyst. P: 5.0 MPa, T: 260 °C, CO<sub>2</sub>/H<sub>2</sub>/N<sub>2</sub>:3/9/1. (Frusteri et al., 2017).



#### 4. Feasibility and Impacts of DME-LPG Blend Fuel in Indonesia

##### 4.1 Feasibility

Indonesia's coal production is predicted to increase (Figure 4) (DEN, 2018). In 2018, the total production of coal in Indonesia was about 492 Mt, only 24.6% used for domestic demands (Dirjen, 2018). The rest, 75.4%, were exported as one of the highest Indonesia's economic income (Dirjen, 2018). The National Energy Policy (KEN) stated that energy should support national development. Therefore, General Planning of National Energy (RUEN) was made to realize the new allocation of energy resources in national development. Figure 5 showed the RUEN of coal in Indonesia (Government's Regulation No. 22/2017).

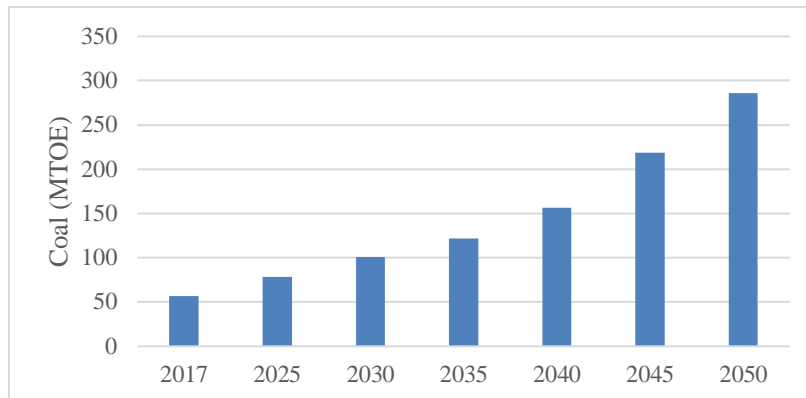


Figure 4. Data Modelling of coal as primary energy resources (DEN, 2018).

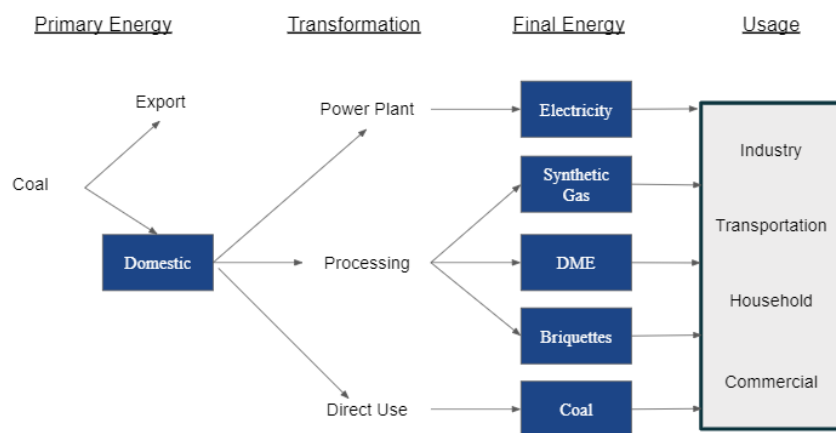


Figure 5. RUEN illustration of the optimization of coal usage (RUEN, 2017).

On the other side, biomass brings more advantages for sustainability. The processing of biomass waste can provide energy, especially to be DME resources. To ensure technical and economical feasibility of biomass utilization in gasification, the ideal mix of biomass can be up to 40%. Above 40%, the energy needed to process biomass would be too high which resulted in lower yield of DME (Howaniec & Smoliński, 2014). The abundance of biomass has triggered the government to maximize the opportunity to produce renewable energy planned in the national energy mix target. Table 6 summarized the biomass potential in Indonesia.

**Table 6.** Biomass Potential in Indonesia (ESDM, 2016).

No	Potency Source	Total (MW)
1	Palm Oil	12,654
2	Sugar Cane	1,295
3	Rubber	2,781
4	Coconut	177
5	Paddy	9,808
6	Corn	1,733
7	Cassava	271
8	Wood	1,335
9	Cows and Buffalo	535
10	Municipal Solid Waste	2,066
Total Potential		32,654

The system's techno-economic efficiency between coal and biomass is taking some aspects to be considered, such as the blending ratio of biomass and coal, loan ratio, electricity price and fuel price. The influence of biomass blending ratio on the economic indicators was nonlinear. So, the highest internal rate of return (IRR) for about 12–13% achieved with a 20–40% biomass ratio (Z. Wu & OuYang, 2017). Moreover, techno-economic analysis for bio-DME (DME production using oil palm empty fruit bunches) in Riau, Indonesia, also economically feasible with a 10.08% IRR generated. The data was generated from the simulation of 4.1 empty fruit bunches/DME and 1,090 tpd of DME produced with a selling price of IDR145,000/12-kg-LPG-equivalent (Parbowo et al., 2019). This enable to give the customer a cheaper alternative compared to LPG with a selling price of IDR150,000/12-kg-LPG in 2021.

## 4.2 Impacts

### 4.2.1 Environmental Impact

DME is an environmentally friendly fuel with less harmful emissions than other fuels such as coal and LPG. The combustion of DME results in low CO, NO<sub>x</sub>, SO<sub>x</sub>, HC (hydrocarbon) and PM (particulate matter). Increasing the DME's concentration in the DME-LPG blend decreases both the CO and NO<sub>x</sub> emission (Makmool & Jugjai, 2013). CO emissions dropped from over 1,000 ppm to less than 200 ppm at 5% DME and zero CO emissions at 20% DME. NO<sub>x</sub> reduced to its minimum at 15% DME. Furthermore, DME produces much lower solids, only 0.026%, due to the high oxygen content and absence of direct C-C bonds (Makoś et al., 2019).

DME is a volatile organic compound that is non-carcinogenic and non-toxic. The compound itself is environmentally and global warming safe. DME atmospheric lifetime is 5.1 days with global warming potentials of 1.2 in a 20-year time horizon and 0.3 in a 100-year time horizon (Semelsberger, Borup, et al., 2006). Hence, DME is significantly less global warming potential than greenhouse gases. With its environmental benefits, DME can be used as a clean-efficient fuel. The implementation secures the environment aspect as one of the three pillars of sustainability.

Considering the environmental aspect of DME production, a life cycle assessment was done for a coal DME plant in South Korea (Kim et al., 2012). The assessment's scope started from coal mining, transportation and coal conversion into DME. For 1,000 tons of DME produced, 1,956 tons of coal were required. The CO<sub>2</sub> emission factor was 1.46 kg CO<sub>2</sub>e per kg DME. In comparison, LPG production emission factor is 5 times lower than DME at 0.3 kg CO<sub>2</sub>e per kg LPG (AEER, 2020; Shahrier et al., 2020) It is rational enough as DME production involve more chemical reaction and energy extensive. However, the DME emission can be reduced by utilizing biomass in co-processing (Lecksiwilai et al., 2016). Another advancement like CO<sub>2</sub> capture also potentially to utilized for less carbon emitted.

4.2 Energy Security

Based on General Planning of National (RUEN) 2017, DME is one of the Indonesian government concern to reduce LPG import. Primarily, the raw material resource is an essential aspect of producing DME. Crude oil, natural gas, coal and biomass are appropriate raw materials to produce DME. However, the decreasing oil reserve led to oil import and natural gas production barely enough for domestic demand, making coal and biomass the potential resources. Indonesia has a surplus of coal. Therefore, the allocation of coal for DME production will vary the energy distribution and suppress the LPG import.

There were two proposed scenarios on the DME implementation to substitute LPG to achieve energy security (Boedoyo, 2016). The scenarios were made considering the energy supply, available potency and DME application on related sectors. Scenario 1 was targeted to reduce 20% of LPG consumption by 2030, which was rated as the most feasible scenario. Scenario 2 with a 40% reduction target in 2030 rated as the most optimum scenario. Figure 6 shows LPG and DME's consumption in Million Barrel Oil Equivalent (MBOE) under each scenario and basic condition (without scenario). Moreover, Table 7 presents the requirement of natural gas, biomass and coal needed to run each scenario.

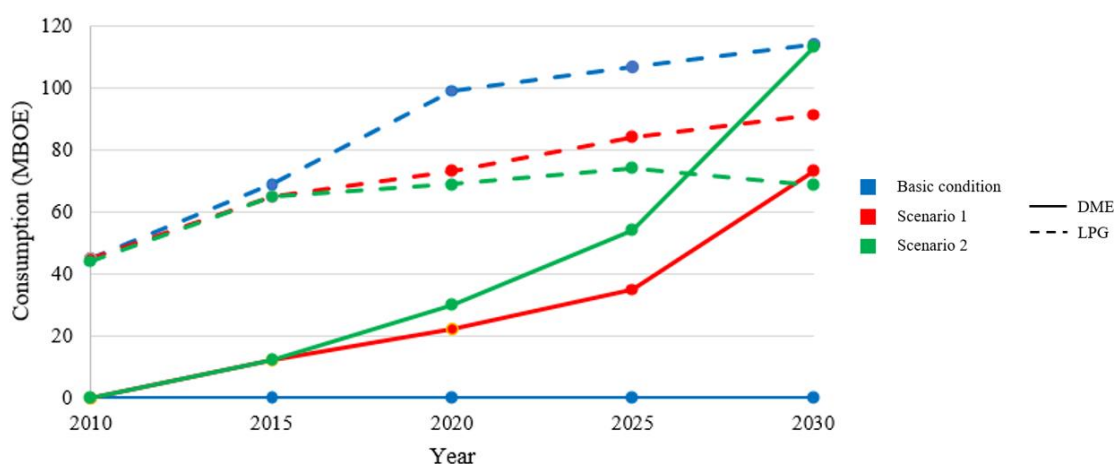


Figure 6. LPG and DME consumption on each scenario (Boedoyo, 2016).

Table 7. The requirement of natural gas, biomass and coal for each scenario (Boedoyo, 2016).

Resources	Scenario	Year									
		2010		2015		2020		2025		2030	
		%	MBOE	%	MBOE	%	MBOE	%	MBOE	%	MBOE
Natural gas	1	0	0	40	4.62	20	4.34	0	0	0	0
	2	0	0	40	4.62	20	6.06	0	0	0	0
Biomass	1	0	0	20	2.31	30	6.51	40	13.80	40	29.37
	2	0	0	20	2.31	30	9.08	40	21.69	40	45.25
Coal	1	0	0	40	4.62	50	10.85	60	20.69	60	44.05
	2	0	0	40	4.62	50	15.14	60	32.53	60	67.87

In both scenarios, natural gas is only used until 2020 as its downtrend production. This is due to natural gas is also demanded by the industrial and power plant sector, make it limited to utilize. Therefore, by 2020 resources are supplied by coal and biomass. Biomass is utilized up to 40% of the total resources, after considered its availability and technology. Coal is projected to the dominant resource for DME production. This is aligned with the positive trend of Indonesia's coal production.

Achieving LPG energy security in Indonesia has to follow by the synergy of many sectors. In raw material resources, the coal export should be allocated for DME production. A more in-depth exploration of biomass is an essential task for the government to maximize the granted nature potential. Infrastructure, policy and technology are also crucial considerations for the fruitful DME. Although it

seems out of reach to completely zero the LPG import, this study has confirmed that it is promising and feasible to cut the enormous import amount. Innovation like DME 100% stove by LEMIGAS has to be considered to accelerate Indonesia to achieve LPG energy security.

## 5. Conclusion and Suggestion

Along with the weakened oil and gas production, an alternative fuel such as DME is needed to cover the massive LPG import amount. DME is proven suitable to substitute LPG. However, some property discrepancies between DME and LPG lead DME-LPG blend fuel to be the most feasible in this current state. By the optimum composition of 15–20% DME, combustion efficiency was increased. The flame remained stable when tested in commercial LPG stoves, concluding that DME-LPG blend fuel is advantageous in households. In the raw material resources aspect, Indonesia, with a high abundance of coal reserves, can achieve its energy security by cutting LPG imports and producing its DME through coal gasification. The coal gasification process could be modified by co-processing with biomass, capturing the CO<sub>2</sub> emission and utilizing the produced CO<sub>2</sub> as the feedstock for the gasification process to reduce DME carbon footprint. The usage of coal and biomass to produce DME for LPG substitution can positively impact both economically and environmentally. It is projected with an IRR within 10–13%. Increasing the DME's concentration in the DME-LPG blend can decrease the CO for 80–100% and NO<sub>x</sub> emission to its minimum. Moreover, a study has evaluated the potential of LPG to save Indonesia's energy security by cutting LPG imports up to 40%.

More studies on feedstocks quality and supply need to be done before the direct implementation of DME. The quality of feedstocks could significantly affect the syngas produced, which will then be used as DME. Moreover, an integrated system regarding the DME synthesis plant and its distribution needs to be developed. More advances on the DME stove are also required to increase DME composition and burning efficiency before being commercially sold to consumers. In this study, the usage of DME to complement or substitute has been analyzed with result of slight modification on gas stove to comply with DME fuel. A sustainability study was also done regarding the usage of DME and its potential to be produced through co-gasification with biomass. To further reduce the environment impact of this process, carbon capture system can be implemented into the coal gasification system and the development of more effective catalyst is needed. Lastly, the government would have to convince households to shift their LPG usage into DME or DME-LPG blend fuel.

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