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Research Article

State of the Art of Global Dimethyl Ether Production and It's Potentional Application in Indonesia

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Abstract: Dimethyl ether (DME) is a flammable gas that changes to liquid phase when applied a relatively mild pressure to it, i.e., 0.5 MPa. Therefore, DME has a special advantage to be utilized as both the gas and liquid fuels. Moreover, DME can be produced from various feedstock, including natural gas, residual oil, coal and biomass. On account of these features, DME might be a suitable form of intermediate fuel for Indonesia, which has abundant and unutilized energy resource but in other hand still highly relies on the import of energy commodities, particularly liquefied petroleum gas (LPG) and diesel oil. This paper summarized the state of art of worldwide DME development and application, as well as discussed the potential application of DME in Indonesia. DME properties, production process and brief development history were first introduced. Then, state of the art of the global DME application and commercial market along with the available technology providers were summarized. Economic analysis and challenges for global DME application were subsequently discussed. Finally, the analysis of driving factor, potential benefit, and current state of DME application in Indonesia were presented. This paper could be an initial guide for the development of DME industry and application in Indonesia.

Keywords: Application, DME, Indonesia, LPG, review, energy, fuel

1. INTRODUCTION

1.1 Introduction of DME and it's Benefit

Dimethyl ether (DME) is an organic compound with the formula of CH_3OCH_3. It is a highly flammable gas at ambient conditions which forms liquid phase when it is pressurized above 0.5 MPa. Therefore, DME is commonly handled and stored as liquid. As shown in Table 1, the calorific value of DME in liquid form, 4 620 kcal · L^{-1}, is about 85 % of liquefied petroleum gas (LPG); while in gaseous form, 14 200 kcal · Nm^{-3}, is about 1.6 times of natural gas. Moreover, its cetane number, 55 to 60, is 1 to 1.5 times of diesel oil. Owing to these properties, DME has the special advantage to be penetrable to the gas and liquid fuel market [1]. The potential major uses of dimethyl ether are either as a propane substitute in LPG for residential cooking, or as a fuel in gas turbine power generator, and as a transportation fuel in diesel engines or petrol

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Table 1. Properties of DME and other fuels [1, 2].

Properties	DME	Propane (LPG)	Methane (Nat.gas)	Diesel fuel
Chemical formula	CH_3OCH_3	C_3H_8	CH_4	
Boiling Point (˚C)	-25.1	-42.0	-161.5	180 to 370
Liquid density (g cm^{-3} at 20 ˚C)	0.67	0.49	0.42	0.84
Liquid viscosity (kg m^{-1} s^{-1} at 25 ˚C)	0.12 to 0.15	0.2	-	2 to 4
Specific gravity of gas (vs. air)	1.59	1.52	0.55	-
Vapor pressure (MPa at 25 ˚C)	0.61	0.93	-	-
Explosion limit (%)	3.4 to 17	2.1 to 9.4	5 to15	0.6 to 6.5
Cetane number	55 to 60	5	0	40 to 55
Net calorific value (kcal Nm^{-3})	14 200	21 800	8 600	-
Net calorific value (kcal L^{-1})	4 620	5 440	5 040	8 400
Net calorific value (kcal kg^{-1})	6 900	11 100	12 000	10 000

engines (30 % DME / 70 % LPG) [1–3].

Furthermore, DME is known to be a clean and valuable alternative energy [2, 3] for several reasons:

- It can be safely stored and handled, as it does not produce explosive peroxides
- It's combustion products, such as carbon monoxide and unburned hydrocarbon emissions, are less than those of natural gas since DME only has C-H and C-O bond, but no C-C bond, and since it contains about 35 % oxygen
- Owing to its high cetane number, DME is considered to be an excellent alternative to the present transportation fuel with no emission of particulate matter and toxic gases such as NO_x at burning
- It has a similar vapor pressure to that of LPG, and hence can be used in the existing infrastructures for transportation and storage.
- DME is degradable in the atmosphere and is not a greenhouse gas

Another advantage of DME is that it can be produced from a variety of feedstock including natural gas, crude oil, residual oil, coal, biomass and waste products. Fig. 1 shows illustrate the beneficial "Multi-Source and Multi-Use" feature of DME. This feature is favorable for providing a flexibility and sustainability not only on resource supply but also subsequently on the product marketing.

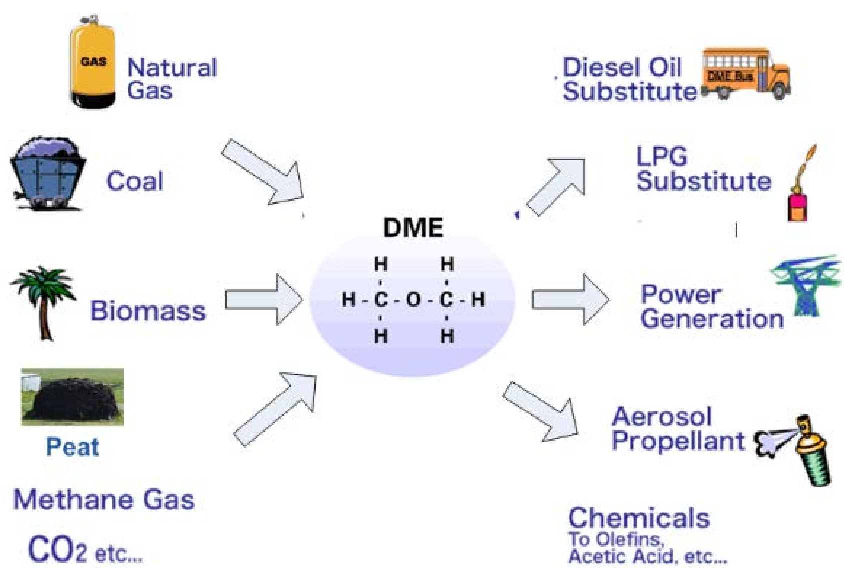

Fig. 1. "Multi-source and multi-use" feature of DME.

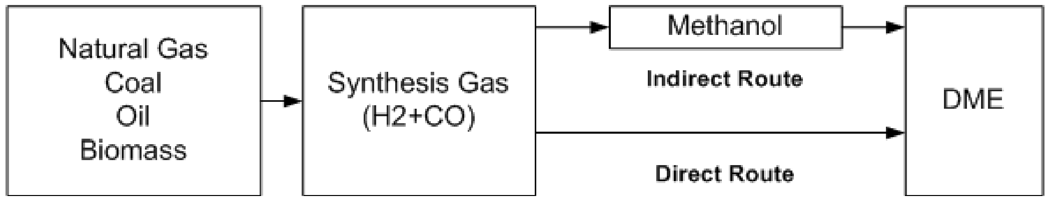

Fig. 2. DME production pathways.

Fig. 2 shows the routes of DME production in two distinct ways: The first way, called as the indirect route, is through the synthesis of methanol which then followed by its dehydration to DME (involving reaction shown in Eq.1 and Eq. 2); the second way, called as the direct route, is through a single stage of DME synthesis using bi-functional catalyst (shown in Eq. 3). As shown in Eq. 1 and Eq. 3, all of the process routes are involving synthesis gas (syngas: the mixture of H_2 and CO) as the intermediate feedstock. Meanwhile, syngas composition could be highly varied depend on the utilized feedstock and it will subsequently affect the selection of the suitable DME synthesis route. Coal or biomass derived syngas, obtained through a high temperature gasification process, has a composition of H_2/CO = 0.5 to 1. Therefore, the direct route through Eq. 3 is appropriate since the required H_2/CO = 1. In contrary, natural gas derived syngas, obtained through a methane reforming process, has a composition of H_2/CO = 1 to 3. Therefore, the indirect route through Eq. 1 is appropriate since the desired H_2/CO = 2. However, the adjustment of H_2/CO ratio for each syngas is possible by utilizing water gas shift reaction (Eq. 4) [2]. In addition, it is studied that the direct route is potentially more efficient than the indirect [4, 2]. That is related to a cost saving by process simplification and an occurrence of high CO conversion due to the prompt consumption of the "produced methanol [4, 5]."

Methanol synthesis:

$$2CO+4H_2 \leftrightarrow 2CH_3OH \quad (1)$$

Methanol dehydration:

$$2CH_3OH \leftrightarrow CH_3OCH_3+H_2O \quad (2)$$

DME Synthesis:

$$3CO+3H_2 \leftrightarrow CH_3OCH_3+CO_2 \quad (3)$$

Water gas shift reaction:

$$CO+H_2O \leftrightarrow H_2+CO_2 \quad (4)$$

Catalyst is utilized for obtaining a higher selectivity towards DME formation and a lower tendency on hydrocarbons and coke generations. In the indirect process, metallic catalyst is employed in the methanol synthesis then solid-acid catalyst is employed in the methanol dehydration to DME. While for the direct process, bi-functional catalysts, composed of a metallic synthesis and a solid-acid function, is employed. The metallic function is mainly composed of such oxides as CuO, ZnO, Al_2O_3, and Cr_2O_3 with the compound of CuO-ZnO-Al_2O_3 (CZA) being the mostly applied [6, 2]. The solid-acid function includes γ-Al_2O_3 and zeolites such as H-ZSM-5, HY, SAPO, MCM, and Ferrierite with H-ZSM-5 being the mostly applied [2, 5]. As methanol synthesis is the rate limiting step in DME synthesis, research works for improving metallic catalyst activity have been widely reported [2, 5, 6]. Those were aimed to maximize Cu active site on Cu-ZnO interface by altering blending ratio [2, 5] and preparation method [2, 6] of Cu and ZnO. Improvement of bi-functional catalyst activity and selectivity by altering the composition and blending method of metallic and acid function also become the emerging focus on DME catalyst development [2, 5, 6].

DME reactor typically operated at the temperature of (200 to 350) °C with the pressure of (30 to 50) bar [2]; (1 bar = 100 kPa). This resulted in the syngas conversion thermal efficiency of around 80 % to 90 % and DME purity of more than 99.5 %. Combined with the efficiency of the upstream process for syngas production (gasification or methane reforming), the overall DME production process thermal efficiency can be around 53 % to 66 % for coal/biomass based process [7, 8], and 70 % for natural gas based process [1]. These efficiencies are relatively high compared with other synthetic fuel production through Fischer-Tropsch reaction, e.g. syn-diesel, gasoline, etc., that produced thermal efficiency of around 30 % to 50 % for coal/biomass based process and 53 % to 63 % for natural gas based process [9]. Therefore, DME can be manufactured at a lower cost than Fischer-Tropsch fuel [8].

1.2 Brief History of DME Development

- ***1970s to 1980s***

The research and development of the novel fuels including DME was motivated by the increasing of oil prices due to the oil embargos. On the other hand, the remarkable growth in stranded gas also led to an effort to utilize these gas resources by converting them into some easily transportable liquid fuels. Amoco (now BP) was named as a pioneer in this novel fuels development [1]. In the 1980s preliminary engine tests were performed at the National Institute for Petroleum and Energy Research laboratories at Bartlesville in Oklahoma (US) addressing chances and challenges in the use of DME as a fuel in diesel vehicles [3].

- ***1990s***

In 1995, collaborative research on DME among Amoco, Haldor Topsoe and Navistar International Corp showed that DME could be a novel, low-emissions alternative fuel for diesel engines and could be manufactured at large-scale from a simple methanol with dehydration technology [1, 3]. However, the development of the DME diesel market was challenging because of the prerequisite adjustment of the fuel distribution infrastructure and the modifications to the engines themselves. Meanwhile, the obvious primary market of DME was the blending with LPG up to 20 volume % (similar to the blends in automotive applications). This blend worked well in standard cooking and heating applications without any significant adjustment to existing LPG infrastructure [1], except 20 % to 35 % increase in the storage capacity or more frequent delivery of the LPG container [3].

In the mid-to late 1990s, Amoco with the General Electric Co. and Electric Power Development Corporation of Japan (EPDC) tested DME as a gas turbine fuel. The results showed excellent performance with a significant improvement in efficiency and the same low emissions as natural gas [1]. DME as a new multi-purpose fuel was introduced to the world through press releases, press conferences and publications in 1995. About fifteen companies and agencies from around the world expressed interest in sharing in work aimed at the commercialization of DME.

In 1998, Amoco formed a joint venture with both the India Oil Company (IOC) and the Gas Authority of India (GAIL). The India joint venture identified the power market as the primary market because of its ease of entry and lower market risk. The LPG blending and diesel market were targeted for future DME trains after the appropriate technical demonstrations, regulatory work and development of standards were completed. Supply agreements were signed with several Indian power producers. For gas access, the joint venture held talks with several countries with large gas resources, particularly Qatar. However, in 2001, the DME project was terminated by BP (the merger company of British Petroleum and Amoco) due to other more favorable gas-related ventures.

- ***2000's***

Despite the project termination, a global interest in DME had been awakened. The International DME Association (IDA) was formed in 2001. In the next few years, The Japan DME Forum (JDF), the Korea DME Forum (KDF) and the China DME Association (CDA) were formed. Information was shared in both regional Asian meetings and in international DME meetings. The significant results on commercialization of DME were produced by CDA in the past decades due several reasons:

- The presence of a large demand for additional home cooking and heating fuel in China. DME positively contributed to this issue since their distribution was relatively simple through LPG blending using the existing infrastructure and marketing channels
- A clear government direction to use the domestic coal resource as a feedstock for chemicals and fuels. On the other hand, the established coal-to-methanol plants had resulting in a large oversupply of methanol. Therefore, the DME manufacturing was lead to near-term profit.
- History have shown that Chinese authorities and business are quick in adapting new technologies and products

2. STATE OF THE ART OF GLOBAL DME APPLICATION AND INDUSTRY

2.1 State of the Art of the Application and Market of DME

In 2011, the global DME demand is estimated about 3 000 000 metric t yr^{-1} and it is growing at 32 % year-over-year. The demand is expected to rise to over 7 000 000 metric t yr^{-1} by 2015 while the global capacity ranges between 10 000 000 and 12 000 000 metric t yr^{-1}. In summary, China, a late-comer in DME, has been the unmatched player in DME production and consumption. Nearly all of the commercial DME plants for fuel applications have been built in China and about 90 % of the global DME demand is in China [1].

2.1.1 LPG Blend Stock in Residential Cooking/ Heating Sector

The largest market for the use of DME is as a blend fuel with LPG for residential cooking and heating, particularly in China [1]. This is related to the fact that, the use of (15 to 20) volume % of DME in LPG/DME blends would not require any modification either in the existing distribution infrastructure or in the users' appliances. More than 90 % of DME produced in China is blended with LPG. Various regulations and industry standards for the use of DME in such applications have been or are being implemented in China. In South Korea, DME-LPG Blended Fuel Field Test was performed for household and commercial use since Aug 2010 to Oct 2011 (15 mo). In the U.S., the LPG industry still require additional experimental studies to determine the safe limits for DME in LPG/DME blends as a prerequisite to commercialization using existing appliances for residential and restaurant applications [1].

2.1.2 Transportation Fuel Alternatives

DME offers many other advantages such as significantly reduces engine noise, absence of cold-start problems and the likelihood of light-weight, low-cost DME diesel engines because of the very low ignition pressure of DME. Despite the promising properties of DME and significant progress of DME-engine development in many countries, the utilization of DME as an alternative transportation fuel is still in the early step of commercialization. This is because some adjustment of the fuel distribution infrastructure and the modifications to the engines are required to able to accommodate the DME feed.

- **Diesel Fuel Alternative**

The Amoco consortium work conducted around 1994 showed for the first time that DME is an ultra-clean alternative fuel for diesel engines with emissions levels that could meet the 1995 ULEV (the California Ultra Low Emissions Vehicle) regulations for medium duty vehicles [1].

In Europe, Haldor Topsoe (Denmark) developed the first DME-fueled vehicles in 1996. Volvo (Sweden) developed the first DME-fueled bus in 1999 which had a fuel consumption of 1.17 km L^{-1}. Then, a second generation of DME vehicle with a 224-kW engine launched in 2005 and, a third generation DME truck (displacement: 13 L) with 343 kW (max.) engine power and 2732.56 Nm of torque has been scheduled for release in 2015 [10]. Moreover, for biomass-derived DME (Bio-DME), ten Volvo Bio-DME trucks have been operated in Sweden and the first of these passed the 100 000 km [1].

In the USA between 1999 and 2001, a consortium under the Department of Energy (DOE) with some companies developed a project to convert diesel buses to DME-diesel blended fuels (14 % DME and 25 % DME) buses. They suggested optimization of the injection strategy and engine control logic for DME blended diesel fuels, and emphasized the need for an oxidation catalyst [10].

In Japan, between 1998 and 2001, a consortium led by the National Traffic Safety and Environment Laboratory (NTSEL) developed a heavy-duty DME bus operated by a mechanical injection device with Nissan diesel motors and Bosch Japan. Then the National Institute of Advanced Industrial Science and Technology (AIST) developed a medium-duty DME-fuelled truck with 7.1 L of displacement and showed that this truck had very low emission levels with its average fuel consumption was 2.61 km L^{-1} (diesel equivalent fuel consumption: 4.93 km L^{-1}). Nissan diesel motors developed an in-line, 6-cylinder truck operated by DME fuel with NTSEL. Isuzu Motors is also developing light- and medium-duty DME engines with a common-rail injection system. They reported based on field test that light-duty and medium-duty DME-fuelled vehicles had fuel consumption rates of 2.83 km L^{-1} and 3.81 km L^{-1}, respectively [10].

In China, 10 DME-fueled buses with a mechanical fuel supply system along with the filling station were developed by a consortium of the Shanghai Motor Company, Shanghai Jiao Tong University (SJTU), and Shanghai Coking & Chemical Corporation in 2005. These vehicles were successfully tested in a commercial operation for more than 220 000 km. Since then, second and third generation DME vehicles have been developed to satisfy the Euro-5 emission standards by a common-rail injection system and after-treatment devices. Shanghai has examined the extension of DME as vehicle fuel for trucks, taxis, and buses in order to reduce PM 2.5 pollution in the city (Park SH & Lee CS, 2014). As of 2009, there were three DME city buses with commercial license plates in use in Shanghai [1].

In Korea, the Korea Institute of Energy Research (KIER) manufactured a proto-type DME truck with 3.0 L of displacement in 2003. In addition, they undertook a project to convert diesel bus with 8.1 L of displacement to a DME-fuelled bus in 2005. KIER successfully developed a proto-type DME bus for 33 passengers which was successfully driven on the road in 2010. Hanyang University (HYU) developed a DME engine for passenger car with 1.6 L of displacement based on a common-rail injection system and it has been successfully driven on the road. Korea Automotive Technology Institute (KATEC) modified a sports utility vehicle (SUV) with 2.0 L of displacement to a DME-fuelled vehicle in 2009. They also studied a 2.9 L DME-fuelled light-duty truck with a common-rail injection system in 2012 which emission levels satisfy the Euro-5 emission standard [10].

- **LPG/DME Blends as Transportation Fuel Using Spark Ignition (SI) Engines**

In the U.S., LPG is the leading alternative transportation fuel, after gasoline and diesel, primarily for marine applications that use SI engines. There are over 10 000 000 LPG-fuelled vehicles in the world, including about 270 000 in the U.S. where LPG is facing severe competition and new stricter emission regulations [1]. For this market sector, DME, especially, bio-DME produced via biomass gasification, may find a niche application in the future as a blend fuel, at about (15 to 20) vol. %. Preliminary research by Amoco in 1997 indicated that, a DME-Propane blend of about (10 to 25) wt. % DME can be used in specific SI engines due to the relatively high Octane Numbers of LPG [1].

2.1.3 Gas Turbine Fuel

In 2001, Amoco conducted a pressurized combustion tests to evaluate the suitability of DME as a gas turbine fuel. The test results demonstrated that the fuel-grade DME, can be successfully used in all modes of turbine operation with emission properties, specifically, NOx, CO and UHC-Unburned hydrocarbons, comparable to natural gas [1]. Based on those tests results, General Electric (GE) was to pursue commercial offers of DME-fired E class and F class heavy duty gas turbines. Amoco had also worked with GE and Fluor to estimate the comparative performance of nominal 1000-MWe 50-cycle grid Combined Cycle Power Plants fuelled with natural gas and Amoco's fuel-grade DME using GE 9FA gas turbines. Around 1.5 % higher power generation efficiency than that of the natural gas fuelled power plant can be expected from the DME fuelled power plants (55.9 % with DME compared to 55.4 % with natural gas) [1]. Various DME-fuelled gas turbine related test programs have also been carried out in Japan (e.g., TEPCO/JFE and Mitsubishi Chemicals GT tests) and South Korea.

2.1.4 Chemical Intermediate for Producing Olefins

China is significantly interested to produce propylene and ethylene from coal, primarily via various methanol-to-olefins (MTO) processes, such as Honeywell UOP's Advanced MTO process and Lurgi's methanol-to-propylene (MTP) process. In 2010, more than 20 such coal-to-olefins projects are currently at the planning stage in China while three such demonstration plants, owned by Shenhua Baotou, Datang (Duolun) and Shenghua Ningxia Coal Inc, have been operated. UOP announced that they would license their MTO process technology to China's Wison (Nanjing Clean Energy Co.) to produce about 295 000 metric t yr^{-1} of ethylene plus propylene from coal-derived methanol. Dow Chemical and the Shenhua Group also announced their plans to build a USD 10 000 000 000 coal-to-olefins complex, which is scheduled to start operating around 2016, in China. Key Chinese and Japanese groups have also developed similar technologies: (i) Dalian Institute of Chemicals Physics, under the Chinese Academy of Sciences, has demonstrated technology to convert a mixture of methanol/DME to olefins with very high selectivity to ethylene and propylene, and (ii) Japan Gas Chemical Company has also pursued a process to produce olefins from DME [1].

2.2 DME Industry

2.2.1 Technology Provider

The first-generation processes for the synthesis of DME are based on dehydration of methanol. For this relatively mature indirect route technology there are several licensors including Haldor Tospoe, Linde/Lurgi, Toyo Engineering, Uhde, Mitsubishi Gas Chemical Company, China Southwestern Research Institute of Chemical Industry and China Energy (Jiutai Group). Meanwhile for the relatively new but arguably more efficient direct route technology, several companies: Haldor Topsoe, Japan JFE Holdings Company, and Korea Gas Corporation, have developed their DME synthesis technologies.

2.2.2 Established and Projected DME Plants

- ***China***

Nearly all of the commercial DME plants for fuel applications have been built in China. During 2011, there were 60 DME producers in 18 provinces, of which 17 have capacities of at least 200 000 metric t yr^{-1} [1]. Five companies represent 60 % of total capacity; namely, Jiutai Energy Group (aka China Energy), XinAo Group (aka ENN Group), Lutianhua, Tianmao and Lanhua Kechuan. The Jiutai Group and SWI (China Southwestern Research & Design Institute of Chemical Industry) of China have also developed their own DME technologies [2].

- ***Japan***

Three groups have been studying DME production; namely, Japan DME, Ltd. Group, DME International Ltd. Group and Mitsui &Co., Ltd. Group. These studies focused on the feasibility of commercial DME production in gas-producing regions such as the Middle East, Southeast Asia and Oceania. In 2009, the Japan DME Ltd. Group build an 80 000 metric t · yr^{-1} DME plant using imported methanol, in the Mitsubishi Gas Chemical Factory in Niigata, Japan [1].

- ***Korea***

Some important step of development and commercialization of DME are actively conducted by KOGAS especially for catalyst invention, reactor design and process intensification. 50 kg · d^{-1} pilot plant was built in 2003 and 3 000 metric t · yr^{-1} demo plant in operation since 2008. DME-LPG Blended Fuel Field Test was performed for 15 mo for household and commercial use since Aug 2010 to Oct 2011. KOGAS also provides 300 000 metric t · yr^{-1} basic engineering package.

- **Other Countries** [1]

i. Saudi Arabia: 300 000 metric t yr^{-1} planned by KOGAS, with Unitel Technologies chosen to do frontend engineering design for the plant
ii. Sweden: world's first 4 metric t · d^{-1} bio-DME plant operational by Chemrec. Chemrec is planning a 300 metric t d^{-1} commercial-scale bio-DME plant
iii. Egypt: 200 000 metric t yr^{-1} planned
iv. Indonesia: 800 000 metric t yr^{-1} planned
v. India: 265 000 metric t yr^{-1} planned
vi. Vietnam: project announced in 2010
vii. Uzbekistan: 100 000 metric t yr^{-1} planned
viii. KOGAS has announced plans to form joint ventures to build commercial DME plants in Oman, Mongolia, Myanmar and Australia.

3. ECONOMIC ANALYSIS AND CHALLENGE FOR GLOBAL DME APPLICATION

3.1 Economic Analysis of General DME Production

The business prospect of DME as a new fuel is determined by the economics for the supply chain including the feedstock resource, production cost, and transportation to the destined market. An economic analysis for DME supply chain to China has been conducted previously. For the case of DME produced from integrated plants in the Middle East from natural gas; that cost USD 1.50 per MMBtu (LHV) (1 MMBtu = 28.263 682 m^3) it is estimated that DME to be deliverable to China at USD 368 per MT. The bases for these estimates are shown in Table 2. These economics show that DME can be competitive with conventional petroleum-derived products, on an energy equivalent basis, when crude oil costs at least (USD 70 to USD 80) bbl^{-1} (1 bbl = 159 L), depending if DME is valued as LPG or as higher-valued diesel, on an energy equivalent basis.

Coal-derived DME is more expensive than natural gas-derived DME due to: (i) higher capital investment, (ii) higher feedstock cost on an energy equivalent basis, and (iii) lower plant thermal efficiency. Therefore, the key assumption for coal-to-DME plant is that the capital investment costs is 50 % more than plants using natural gas per annual metric ton produced. For the case of DME produced from integrated plants in China from coal, costing USD 100 per MT, it is estimated that

Table 2. Bases for DME cost analysis [1]

Cost component	DME resource	
	Natural gas	**Coal**
Plant capacity, MT/day	3 520	35 20
Plant capital cost/CAPEX, ($ million)	1 110	1 508
Feedstock consumption, ((MMBtu or MT)/ MT-DME)	38 MMBtu	2.05 MT
Feedstock cost (USD/MMBtu or USD/MT)	1.5/MMBtu	22.7/MT
Plant overall thermal efficiency (% LHV basis)	71	58
Operating expenses: non-feedstock (% Capex/yr)	6	6
Capital costs @ 12 % DCF ROR (% Capex/yr)	20	20
Plant availability (%)	94	85
Shipping distance	6 200 nautical miles	1 000 km inland
Shipping cost (USD/MT-DME)	47	53

DME to be deliverable to East China at USD 644 per MT. The bases for these estimates are shown in Table 2. This economic analysis show that coal-derived DME can be competitive with conventional petroleum-derived products, on an energy equivalent basis, when crude oil costs at least (USD 30 to USD 140) bbl^{-1}., depending if DME is valued as LPG or as higher-valued diesel, on an energy equivalent basis.

However, it should be noted that these economics analyses are for illustrative purposes only, since the DME economic are strongly case sensitive to some factors. Those factors are, among others, government policy, incentives, capacity, construction cost, environment, availability of supporting infrastructure, technology, feedstock cost, the degree of process integration, and product specifications and pricing. These analysis is conducted based on the two-step/indirect synthesis that has been commercialized. The commercial one-step/direct synthesis plant, that is theoretically more efficient than the two-step plant, is still not presence to best of our knowledge.

The case sensitivity can be seen from the successful application of DME in China which is produced from the expensive coal-derived methanol at around 2009. Some supporting specifics are [1]:

- DME is sold at a higher price than its energy equivalent basis. IDA reported that DME sold as an LPG blend stock was sold at 75 % to 90 % of LPG price whereas the DME energy value is about 62 % of LPG on a weight basis.
- LPG prices in China are higher than parity with crude oil due to increased demand in winter and when domestic refineries, which produce LPG, were shut down for maintenance (Oct and Nov 2009, and in Jul and Aug 2009)
- Plants once-built are yielding a lower DCF ROR on the capital investment than 12 %,
- Government support and incentives to encourage production from domestic resources for strategic reasons.

3.2 Challenge and Opportunity for DME Application

The commercialization of DME were challenging, primarily due to competition from not only established conventional fuels with distribution and marketing infrastructures but also other alternative fuels. A significant challenge involves the risks in building commercial-scale production and distribution facilities before the market is fully developed. However, in some extent as shown in the case of China, DME has been able to overcome this challenge due the relative simplicity of (i) making DME from methanol, which already has an established market, and (ii) marketing DME as an LPG blend stock, using the established local LPG distribution infrastructure: the cylinder filling facility, the cylinder, and household combustion appliance, with minor modifications.

The development of the DME diesel market was more challenging because of the prerequisite adjustment of the fuel distribution infrastructure and the modifications to the engines themselves. However, DME-fuelled engines and vehicles is necessary due to soot-free combustion and the potential of a high EGR to reduce NOx emissions. In addition, development and application of DME for transportation vehicles can address the shortage of resources including fossil fuel because DME is a synthetic fuel. Therefore, institutes and car-making companies around the world are extending their research from bench-level engine testing to modification and development of DME-fuelled vehicles.

Process intensification is likely required to make DME economically competitive to the conventional fossil fuel. In this case, one-step/direct synthesis shows a potential since it is theoretically produced higher efficiency than the mature two-step process. However, research work encompassing optimization and scaling up of the one-step synthesis of DME and furthermore its economic aspects of the process was hardly been reported. This should be the focus of DME development in the near future.

Finally, government support is still be the most important factor for the massive implementation of DME as energy source. This is since some relatively significant adjustment on the conventional energy infrastructure and management is required. Direction, regulation, and incentives need to be issued in order to get the optimum benefit of DME as flexible (considering the "multi-source and multi-use" feature), clean and efficient fuel.

4. DRIVING FACTOR, POTENTIONAL BENEFIT AND STATE THE ART OF DME APPLICATION IN INDONESIA

Similar to the case of China, Indonesia could be the specific place where domestic DME production and consumption can be beneficial. This is related to following driving factors and potential benefits that might specifically belong Indonesia.

- ***Driving Factors***:

i. Plenteous availability of any kind of DME resource, namely: natural gas, coal, peat, and biomass

ii. Huge demands on DME target market, namely: LPG, diesel oil, and power generation fuel, where the most of those demands are fulfilled by import.

iii. The overall cost of DME production in Indonesia can be lower from the general case shown in section 3.1 since the distance of the DME resource and demand could be much closer. Sea transportation, that is cheaper than land transportation, also could be optimized since Indonesia is highly inter-connected by ocean.

iv. The above mentioned factors have been attracting some technology providers to build DME production facility and infrastructure in Indonesia.

- ***Potential Benefits***:

i. Domestic DME production from local resource can reduce the dependence of Indonesia's energy supply from other countries.

ii. The easily-transportable feature of DME can lead to the better exploitation of the unutilized resources in Indonesia, particularly which is problematic due to its distant location from the energy demand.

iii. The transportability of DME also can lead to its wider and deeper distribution, especially to the remote area which is difficult to serve.

iv. DME synthesis has a potential to increase the added value of the low rank and low commercial value energy resource, e.g. peat, lignite, wasted biomass, etc. However a deeper feasibility study must be performed with this feedstock since the utilization of low rank resource will result in the lower process efficiency.

Despite the described driving factors and potential benefits of DME application, only limited case of commercial utilization can be found in Indonesia. To the best of our knowledge, only PT. Bumi Tangerang Industry can be tracked as a commercial DME supplier. The company is a relatively small-scale DME distributor (65 kg to 700 kg pack unit) which supply DME for aerosol-related purposes. Research works on DME recently performed by Anggarani et al., [11, 12] from the Research and Development Center for Oil and Gas Technology (Lemigas). This research group examined the DME application as replacement of LPG for household stove [11] and as a gasoline alternative for SI engine [12]. Some important findings were produced from their research and worth for further trail for the smooth application of DME in current commercial appliances. From the production side, Priyanto [13] from the Agency for Assessment and Application of Technology (BPPT) presented the proposed DME project in West Java (840 000 TPA) and in West Papua (200 000 TPA) in 2011. Information about the recent status of the West Java project, which was scheduled operated in 2012, is hardly accessible and the projects might possibly had been cancelled. The West Papua project, targeted to monetize LNG from Tangguh Plant, was likely shifted for the production of other chemicals such as methanol, propylene and polypropylene [14].

5. CONCLUSIONS

DME has the special advantage to penetrate the gas and liquid fuel market. DME can be produced from a wide range feedstock grade including natural gas, crude oil, residual oil, coal and waste products. The development of DME was started in USA and Europe since the late 1970's but the significant results on commercialization of DME were done by China in the past decades. In 2011, the global DME demand is estimated about 3 000 000 metric $t \cdot yr^{-1}$, 90 % of which is in China. The utilization of DME is mostly for a fuel blend with LPG for residential cooking and heating. Research and development of DME has been conducted by technology providers in some specific countries namely USA, Sweden, Denmark, Japan, Korea, and China. However, almost all of the commercial DME plants have been built in China. A clear government direction to utilize the domestic coal resource and the presence of a large demand for additional home cooking and heating fuel were among the determinant of the success application of DME in China. Similar to the case of China, Indonesia could be the specific place where domestic DME production can be advantageous. Widespread availability of DME resource and huge demands on DME target market which are still fulfilled by import were among the driving factors for DME application. However, at the current state, commercial utilization as well as the R&D activity for DME application hardly can be found in Indonesia.

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