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Techno-Economic Assessment of Dimethyl Ether (DME) Production through Methanol Dehydration Process

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Abstrak

Dimethyl Ether (DME) merupakan gas tidak berwarna dan ramah lingkungan yang berpotensi menjadi pengganti Liquefied Petroleum Gas (LPG). Penelitian ini menyajikan kajian teknis dan ekonomi secara komprehensif terhadap produksi DME melalui proses dehidrasi metanol dengan kapasitas pabrik sebesar 20.000 ton per tahun. Proses ini menggunakan katalis alumina–silikat dalam reaktor multitube dengan kondisi operasi 300–350°C dan tekanan 30 bar. Hasil simulasi menunjukkan konversi metanol sebesar 85% per lintasan, dengan kemurnian produk DME mencapai lebih dari 99,5%. Total investasi modal (CAPEX) diperkirakan sebesar USD 12,8 juta, dan biaya operasi tahunan (OPEX) sekitar USD 13 juta. Hasil evaluasi ekonomi menunjukkan nilai Net Present Value (NPV) sebesar USD 5,2 juta, Internal Rate of Return (IRR) sebesar 14,5%, Return on Investment (ROI) antara 15–17%, dan periode pengembalian modal selama enam tahun. Titik impas (BEP) tercapai pada 60–65% kapasitas desain. Berdasarkan hasil tersebut, proses produksi DME dinyatakan layak secara teknis dan ekonomis untuk diterapkan di industri, serta mendukung transisi energi bersih dan pengurangan ketergantungan terhadap impor LPG di Indonesia.

Kata kunci: Dimethyl Ether, Metanol, Analisis Tekno-Ekonomi

Abstract

Dimethyl Ether (DME) is a clean, colorless gas that serves as a potential alternative to liquefied petroleum gas (LPG). This study presents a comprehensive techno-economic assessment of DME production via methanol dehydration with a plant capacity of 20,000 tons per year. The process utilizes an alumina–silicate catalyst in a multitube fixed-bed reactor operating at 300–350°C and 30 bar. Simulation results show a methanol conversion of 85% per pass, achieving a final DME purity exceeding 99.5%. The total capital investment (CAPEX) is estimated at USD 12.8 million, with annual operating costs (OPEX) of approximately USD 13 million. Economic indicators reveal a Net Present Value (NPV) of USD 5.2 million, an Internal Rate of Return (IRR) of 14.5%, a Return on Investment (ROI) between 15–17%, and a payback period of six years. The break-even point (BEP) is reached at 60–65% of design capacity. The findings indicate that the DME production process is technically feasible and economically attractive for industrial implementation, supporting Indonesia's clean energy transition and reduction of LPG imports.

Keywords: Dimethyl Ether, Methanol, Techno-Economic Analysis

1. Introduction

The decline of fossil energy resources and the growing awareness of environmental issues have driven the transition toward cleaner and more sustainable fuels. One promising alternative is Dimethyl Ether (DME), a colorless and non-toxic gas with combustion characteristics similar to Liquefied Petroleum Gas (LPG) and diesel fuel (Yaws, 1999). Unlike conventional fuels, DME burns cleanly—producing no soot and containing neither sulphur nor aromatic compounds—making it highly attractive for lowering emissions and improving air quality.

In Indonesia, the increasing dependence on imported LPG has become a serious challenge for national energy security. Domestic LPG demand continues to rise while local production remains insufficient (Ministry of Energy and Mineral Resources, 2022). This condition underscores the importance of developing domestic DME production as a strategy to strengthen energy resilience and support the government's commitment to achieving Net Zero Emissions by 2060 (Kompas.com, 2025).

DME can be synthesized through two main routes: direct synthesis from syngas and indirect synthesis via methanol dehydration. The methanol dehydration pathway is particularly suitable for medium-scale industries due to its moderate operating conditions (250–350°C, 1–2 MPa) and the widespread availability of methanol derived from natural gas, coal, or biomass (Fogler, 2004; Turton et al., 2012). The reaction is reversible and exothermic, expressed as:

$$2CH_3OH \leftrightarrow CH_3OCH_3 + H_2O$$

with acidic catalysts such as γ-Al_2O_3 and zeolites providing high selectivity toward DME formation (Perry & Green, 2019). Methanol

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adsorption onto acidic sites forms methoxy intermediates that subsequently convert into DME and water (Smith & Van Ness, 1993).

Recent techno-economic studies have provided stronger insight into DME's competitiveness. Dieterich et al. (2024) reported that renewable DME produced from green hydrogen and captured CO_2 can be cost-effective under low-cost renewable electricity. Muazzam et al. (2022) highlighted that despite hydrogen cost barriers, advanced electrolysis—particularly solid-oxide electrolysis—significantly improves overall process economics. Meanwhile, Kofler et al. (2024) demonstrated the techno-economic potential of producing DME from biomass-derived syngas using off-grid renewable electricity, while Ramadhan and Muthia (2025) emphasized that intensified distillation technologies can substantially lower energy demand and operating costs. In Indonesia, evaluations by Pamungkas et al. (2023) and Supriyadi et al. (2025) show that coal-based DME can serve as a viable LPG substitute, although its feasibility remains sensitive to coal prices, carbon regulations, and policy incentives.

Considering these developments, assessing the techno-economic feasibility of DME production through methanol dehydration is essential for determining its industrial relevance and economic viability in Indonesia. This study evaluates the technical and economic performance of a 20,000-ton-per-year DME plant, including process configuration, mass and energy balances, and key economic indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period (PBP) (Aries & Newton, 1955; Branan, 2005). The results are intended to provide insights into the potential role of DME as a sustainable alternative fuel in Indonesia's ongoing energy transition.

2. Methods

This section describes the processes modelling and simulation and the tools used for the calculation of the stream properties. The environmental, economic and thermodynamic performance indica- tors, suitable for carrying out the incremental comparative analysis, are also defined. Lastly, the optimization method, used to minimize the energy requirements, while maximizing the waste heat recovery, is also discussed.

2.1. Process Modelling and Simulation

The DME production process was modelled and simulated using a steady-state process simulator. Figure 1 presents the process flowsheet, which includes the key units such as the methanol preheating system, the fixed-bed reactor, separation columns, heat exchangers, and utility integrations.

Thermophysical properties for methanol, DME, and water were calculated using the software's property database and supported by values reported in standard literature. The methanol dehydration reaction was implemented as a reversible gas-phase reaction based on literature kinetics and equilibrium data.All unit operations were modeled under industrially relevant operating conditions, and mass–energy balances were generated to evaluate process performance. The simulation results served as the basis for subsequent environmental, thermodynamic, and economic assessments presented in the following sections.

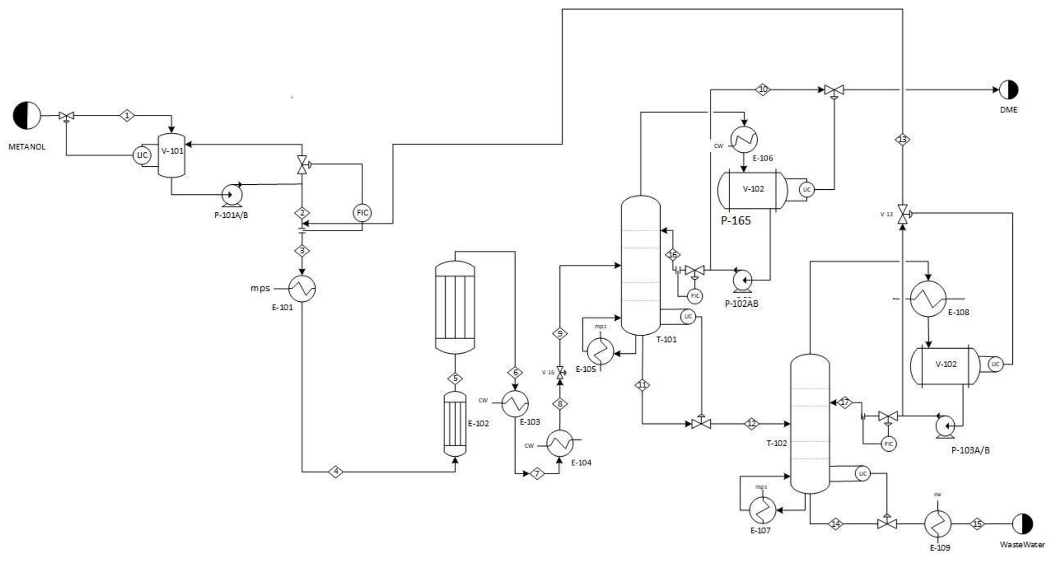

Figure 1. Process Flow Diagram for The DME Production Process Through Methanol Dehydration

2.1.1 Methanol Conditioning and Preheating Unit

The methanol feed is pumped, pressurized, and preheated to reach the vapor-phase conditions required for the catalytic dehydration reaction. Heat integration with hot process streams is applied to minimize external steam demand and stabilize the inlet temperature. This treatment ensures proper vapor–solid interaction in the reactor and supports efficient catalyst performance (Turton et al., 2012).

All thermophysical properties, including vaporization enthalpy and heat capacity, were sourced from validated literature databases (Perry & Green, 2019). The resulting conditioned feed reflects industrially relevant operating conditions and serves as the baseline for the reactor model.

2.1.2 Methanol Dehydration Reactor Unit

The conversion of methanol to DME follows the reversible reaction $2CH_3OH \leftrightarrow CH_3OCH_3 + H_2O$, simulated within a fixed-bed catalytic reactor modelled as a plug-flow system. Literature-based kinetic parameters for γ-Al_2O_3 catalysts were incorporated to represent realistic conversion behaviour and capture temperature rise due to the exothermic reaction (Fogler, 2004). This modelling approach provides accurate reactor performance predictions.

The simulation generates detailed profiles of temperature, conversion, and product distribution across the reactor length. The resulting effluent composition provides the basis for downstream separation, determining cooling needs and the capacity of purification units.

2.1.3 Product Separation and Purification Units

The hot reactor effluent is cooled through heat exchangers to condense water and unreacted methanol, followed by vapor–liquid separation. The condensed methanol is recovered for potential recycle, while the vapor stream—rich in DME—enters the purification section. This systematic treatment reduces the separation load and optimizes the use of process energy.

Purification is completed using a sequence of distillation steps. The first removes bulk water, while the second provides final DME purification to achieve the target product purity of ~99.5%. Vapor–liquid equilibrium models derived from standard literature (Perry & Green, 2019) ensure accuracy in representing column behaviour and energy requirements.

2.1.4 Dimethyl Ether Production

The DME production stage integrates the reactor and separation units to generate a high-purity DME stream. The dehydration reaction produces a mixture of DME, water, and residual methanol, which is subsequently treated through the multistage separation system. The combination of reactor conversion and distillation efficiency determines the final DME yield and process throughput.

Final product handling includes drying, vapor compression, and storage-conditioning to maintain product quality and pressure stability during transfer. These treatments simulate real industrial conditions commonly used in DME production facilities and ensure that the modelled process reflects practical operational behaviour (Peters & Timmerhaus, 1991).

2.1.5 Process Resources and Utility Units

Utilities such as steam, cooling water, electricity, and instrument air are included in the simulation to estimate total energy requirements. Steam is primarily used for preheating and distillation reboilers, while cooling water is used in condensers and heat exchangers. These utility demands are calculated based on heat duties from the simulation output and reflect typical industrial utility consumption patterns (Coulson et al., 1983).

Electrical power is required for pumps, compressors, and control systems, and is estimated using equipment efficiency and mechanical load data. The inclusion of utility units ensures a comprehensive energy profile for the process, enabling subsequent techno-economic and environmental evaluations.

2.2. Energi And Mass Balance

Material and energy balances were automatically generated from the process simulation. The energy balance was based on the first law of thermodynamics:

$$Q = \dot{m}(h_{out} - h_{in}) \tag{1}$$

where $Q$is the heat transfer rate (kW), $\dot{m}$is the mass flow rate (kg/s), and $h_{out} - h_{in}$is the enthalpy difference between outlet and inlet streams (Reklaitis, 1983). Energy integration was implemented to reduce steam and utility usage. The hot stream (reactor effluent) was used to preheat the cold feed stream (methanol vapor), thus minimizing the external heating requirement (Kern, 1965).

Mass balance was carried out to determine methanol conversion and product yield, calculated using the following relations (Fogler, 2004):

$$X_{MeOH} = \frac{F_{in,MeOH} - F_{out,MeOH}}{F_{in,MeOH}} \times 100\% \tag{2}$$

$$Y_{DME} = \frac{F_{out,DME}}{F_{in,MeOH}} \times 100\% \tag{3}$$

where X_{MeOH} is methanol conversion, and Y_{DME} is the yield of DME based on the methanol feed.

2.3 Economic Evaluation

Economic assessment was carried out using the factorial cost estimation method (Aries & Newton, 1955; Peters & Timmerhaus, 1991). The total fixed capital investment (TFCI) was estimated by summing the cost of purchased equipment multiplied by the installation factor:

$$TFCI = \sum(C_{eq} \times f_{inst}) \tag{4}$$

The total capital investment (TCI) includes working capital and start-up costs:

$$TCI = TFCI + WC + SC \tag{5}$$

Operating cost (OPEX) covers raw materials, utilities, labor, maintenance, and administrative expenses. The profitability indicators used are Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), Break-Even Point (BEP), and Return on Investment (ROI), calculated as follows:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} \tag{6}$$

$$IRR = i_1 + \frac{NPV_1}{NPV_1 - NPV_2}\,(i_2 - i_1) \tag{7}$$

$$PBP = \frac{I_0}{\text{Annual Net Cash In Flow}} \tag{8}$$

$$BEP = \frac{FC}{SP - VC} \tag{9}$$

$$ROI = \frac{\text{Annual Net Profit}}{TCI} \times 100\% \tag{10}$$

These equations were used to evaluate the economic feasibility of DME production at a design capacity of 20,000 tons per year (Branan, 2005; Turton et al., 2012).

3. Results and discussion

3.1. Process Simulation Results

The simulation of Dimethyl Ether (DME) production through methanol dehydration was successfully carried out using Aspen Plus. The process operates at 300–350°C and 10–30 bar pressure in a multitubular fixed-bed reactor with γ–Al_2O_3–SiO_2 catalyst. The simulation results show that the methanol conversion reached 85% per pass and over 90% after recycle, with a DME product purity of 99.5%.

The overall process was divided into four main sections: feed preparation, reaction, condensation, and purification. A summary of the main process parameters obtained from the simulation is shown in Table 1.

Table 1. Main Operating Conditions of DME Process

Unit Operation	Temperature (°C)	Pressure (bar)	Description
Preheater (E-101)	180	5	Methanol Preheating
Reactor (R-101)	250-300	10 → 15	Methanol Dehydration
Condenser (E-104)	40	10	Product Cooling
DME Column (T-101)	140	7.4	DME Purification
MeOH–H_2O Column (T-102)	126	15.5	Methanol Recovery

These conditions ensure that the process runs under optimal conversion and thermal stability while maintaining energy efficiency.

3.2. Material and Energy Balance

The overall mass and energy balance obtained from the process simulation is summarized in Table 2. The total methanol feed rate required to achieve 20,000 tons/year DME production is approximately 2,650 kg/h.

Table 2. Summary of Material Balance

Steam	Main Components	Flow Rate (kg/h)	Temperature (°C)	Pressure (bar)
1-Feed	Methanol	2,650	25	1
2-Reactor	$DME+H_2O+CH_3OH$	2,700	250	14,7
3-Product	DME (99.5%)	1,200	25	7,4

The process achieved 85% conversion per pass, increasing to over 90% after recycle. The presence of heat integration between the reactor effluent and feed preheater reduced the steam requirement by 15%.
The energy consumption and utility needs are presented in Table 3.

Table 3. Utility Requirements

Utility	Consumption	Main Use
Steam	1,800 kg.h	Feed Vaporization & Distillation
Cooling Water	55 m^3/h	Condensation & Temperature Control
Electricity	450 kW	Pumps, Instrumentation, and control

The results confirm that the process is energy efficient, with a low external heating load due to heat recovery between hot and cold streams.

3.3 Economic Performance

The economic assessment of DME production with a capacity of 20,000 tons per year was conducted to evaluate investment feasibility. The analysis used the factorial cost estimation method (Aries & Newton, 1955; Peters & Timmerhaus, 1991) based on data from the process simulation and equipment design.

The study assumed a plant lifetime of 20 years, discount rate of 10%, and operating time of 8,000 hours per year. The DME selling price was set at USD 800 per ton, while the methanol feedstock cost was USD 450 per ton. Other costs, including utilities, labor, and maintenance, were estimated according to industry standards.

The total capital investment (TCI) was estimated at USD 12.8 million, with the detailed cost distribution presented in Table 4. As shown in Table 4, equipment purchase represents the largest portion at 35%, followed by installation and piping at 25%. Civil and structural works contribute 10%, while indirect costs and contingency account for 15%. The remaining 6% corresponds to working capital requirements. This cost structure is typical for medium-scale chemical process plants and reflects the investment profile commonly reported in similar techno economic assessments.

Table 4. Summary of Capital and Operating Costs

Category	Value (USD million)	Percentage (%)
Equipment Purchase	4.50	35
Installation & piping	3.20	25
Civil & Structural Works	1.30	10
Indirect & Contingency	1.90	15
Working Capital	0.80	6
Total Capital Investment	12.80	100

Operating Cost Component	VAnnual Cost (USD million)	Contribution (%)
Methanol Feedstock	6.50	50
Utilities (Steam, Water, Power)	3.10	24
Labor & Maintanance	2.40	18
Overhead & Administration	1.00	8
Total Operating Cost (OPEX)	13.00	100

The economic evaluation of the DME production process was conducted to analyze its financial viability under the defined design parameters and market assumptions. This assessment included capital investment, operating expenses, revenue projections, and key financial indicators to determine the overall profitability of the proposed plant. The results of the economic indicators are summarized in Table 5, which provides a detailed overview of the project's performance metrics.

As shown in Table 5, the process is economically feasible, as the financial indicators exhibit favorable outcomes consistent with accepted industrial standards. The project demonstrates a positive Net Present Value (NPV), an Internal Rate of Return (IRR) that exceeds the discount rate, and a moderate payback period, all of which indicate a financially attractive investment. These results confirm that the DME plant can achieve sustainable profitability under the assumed market and cost conditions (Turton et al., 2012).

Table 5. Summary of Economic Evaluation Results

Indicator	Result	Unit	Description
Net Present Value (NPV)	5.2	Million USD	Represents the total project value over its lifetime
Internal Rate of Return (IRR)	14.5	%	Exceeds discount rate, indicating profitable investment
Payback Period (PBP)	6	Years	Duration required to recover initial capital
Break-Even Point (BEP)	62	% Capacity	Minimum operating rate for zero-profit condition
Return on Investment (ROI)	16	%	Annual return relative to total capital invested

The overall results confirm that the proposed DME plant can operate profitably with moderate investment levels. The incorporation of heat-recovery units and methanol recycle streams significantly reduces utility consumption, thereby improving both energy efficiency and operating economics. This finding aligns with recent techno-economic studies showing that process integration and energy optimization contribute to meaningful reductions in total operating cost for methanol-to-DME systems (Ramadhan and Muthia, 2025). Similar conclusions are reported in studies examining optimized DME production pathways, which show that financially viable performance can be achieved when heat management and feedstock availability are well-controlled (Dieterich et al., 2024).

Further evidence supporting the economic feasibility of DME production is provided by analyses demonstrating that DME plants can achieve competitive cost structures across various production scales when efficient separation and utility systems are applied (Kofler et al., 2024). These findings strengthen the conclusion that the proposed DME plant possesses strong economic potential under the assumed design and market conditions. Beyond financial viability, developing domestic DME production also provides strategic advantages, such as reducing dependence on imported LPG and supporting Indonesia's long-term clean-energy transition (Kompas.com, 2025).

Conclusions

The techno-economic analysis of DME production through methanol dehydration with a capacity of 20,000 tons per year shows that the process is technically and economically feasible. Simulation results confirm high methanol conversion and DME purity under moderate operating conditions using a γ–Al_2O_3–SiO_2 catalyst. Integration of heat recovery and methanol recycle reduces utility demand, improving overall energy efficiency. The economic evaluation indicates positive results with feasible investment returns, where NPV, IRR, and ROI values reflect profitable operation and a reasonable Payback Period.

The economic evaluation also demonstrates strong performance, with favorable NPV, IRR, ROI, and a reasonable Payback Period, indicating that the required investment can be recovered within an acceptable timeframe. Overall, the process design is robust, cost-effective, and competitive for medium-scale production. Therefore, DME production via methanol dehydration presents a viable alternative to LPG while supporting Indonesia's clean energy transition and long-term fuel diversification objectives.

References

Aries, R., & Newton, R. (1955). *Chemical Engineering Cost Estimation*. McGraw-Hill.

Branan, C. R. (2005). *Rules of Thumb for Chemical Engineers* (4th ed.). Elsevier.

Coulson, J. M., Richardson, J. F., Backhurst, J. R., & Harker, J. H. (1983). *Chemical Engineering: Volume 6 – Design*. Pergamon.

Dieterich, V., Neumann, K., Niederdränk, A., Spliethoff, H., & Fendt, S. (2024). Techno-economic assessment of renewable dimethyl ether production pathways. *Energy, 301*, 131688.

Fogler, H. S. (2004). *Elements of Chemical Reaction Engineering* (4th ed.). Prentice Hall.

Kirk-Othmer. (1998). *Encyclopedia of Chemical Technology* (Vol. 8). Wiley.

Kofler, R., Campion, N., Hillestad, M., Meesenburg, W., & Clausen, L. R. (2024). Techno-economic analysis of dimethyl ether production from biomass and off-grid renewable electricity. *Energy & Fuels, 38*(10), 8777–8803.

Kompas.com. (2025). Pemerintah targetkan Net Zero Emission 2060.

Ministry of Energy and Mineral Resources. (2022). *Statistik Energi Indonesia*.

Muazzam, Y., Yousaf, M., Zaman, M., Elkamel, A., Mahmood, A., Rizwan, M., & Adnan, M. (2022). Thermo-economic analysis of integrated hydrogen–methanol–DME production. *Resources, 11*(10), 85.

Pamungkas, W. A., Setyawati, R. B., Rifai, A. F., Setiawan, C. P., Budiman, A. W., & Inayati, I. (2023). Techno-economic study on DME as an LPG substitute.

Perry, R. H., & Green, D. W. (2019). *Perry's Chemical Engineers' Handbook* (9th ed.). McGraw-Hill.

Peters, M. S., & Timmerhaus, K. D. (1991). *Plant Design and Economics for Chemical Engineers* (4th ed.). McGraw-Hill.

Ramadhan, M. F., & Muthia, R. (2025). Advanced distillation technologies for DME production. *Korean Journal of Chemical Engineering, 42*, 505–527.

Smith, J. M., & Van Ness, H. C. (1993). *Introduction to Chemical Engineering Thermodynamics* (5th ed.). McGraw-Hill.

Supriyadi, F., Putra, I. A., Abriyant, R. Y., Sismartono, D., Wibowo, C. S., & Priyono, B. (2025). Techno-economic analysis of DME in Indonesia's household energy sector. *Scientific Contributions Oil and Gas, 48*(2), 259–277.

Turton, R., Bailie, R. C., Whiting, W. B., & Shaeiwitz, J. A. (2012). *Analysis, Synthesis, and Design of Chemical Processes* (4th ed.). Prentice Hall.

Yaws, C. L. (1999). *Chemical Properties Handbook*. McGraw-Hill.