Techno-economic analysis study of coal gasification plant into various strategic chemicals

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Abstract. The abundant amount of coal reserves in Indonesia has a great potential to be used as a source of raw materials and energy for industry. However, the use of coal in meeting domestic needs is not optimally utilized, as indicated by the high number of raw coal exports abroad. In addition, the low quality of coal is also one of the reasons for its low utilization. The processing of coal into synthetic gas (syngas) opens the way downstream of coal-derived chemical products, namely dimethyl ether (DME), methanol, ammonia and synthetic natural gas (SNG). The integration of various chemical products is expected to maximize the potential of Indonesian coal. The plant capacity was 11540 tpd (tons per day) low-rank wet coal producing DME 2000 tpd, methanol 2500 tpd, ammonia 600 tpd and SNG 25 MMSCFD (million standard cubic feet per day). These chemical production technologies have been proven and are commercially available. Based on the results of the process and economic simulations, it is found that the establishment of a coal gasification plant into various integrated chemicals is feasible to be established with an internal rate of return (IRR) of 12.46% and a payback period of 6 years and 5 months.

1. Introduction

Coal is the largest energy resources in the world which is roughly three times compared to oil and gas resources. Indonesia’s coal reserves are mostly found in Kalimantan and Sumatra islands. Coal sustainability is important because it will support energy security of the world [1]. This is supported by the maximum potential for coal production to reach 4.9 Gtoe per year [2]. The high amount of coal reserves is not supported by the quality of the coal. Mostly Indonesian coal is low-rank coal. Low-rank coal has a high moisture content, high volatile substance content, low calorific value and high oxygen content [3].

Domestic market obligation (DMO) makes coal mining companies legally obliged to support Indonesia’s energy securities. The use for domestic needs must be prioritized based on Government Regulation No. 23/2010. Therefore, the use of coal must support domestic needs before being exported as raw coal.

Based on the above discussion it is necessary to have a specific strategy in the utilization of Indonesia’s coal resources. This is due to the low quality of Indonesian coal, so it requires a process and production scheme that can utilize all the potential chemicals that are formed in the utilization of the coal. The figure below is the proposed scheme of coal gasification to various chemical and energy products.
From Figure 1, coal derivatives product are dimethyl ether (DME), methanol, ammonia, and synthetic natural gas (SNG). Dimethyl ether (DME) is a colorless mono-structure gas at ambient temperature. DME can be one of the candidates to substitute LPG due to its similarity with LPG in physical properties [4,5]. With the proposed DME production capacity of 600,000 tons per year, it is expected to solve Indonesia’s LPG deficit. Methanol is one of the high-value product targets targeted at this plant process scheme. Methanol is now used commercially in China as a feedstock to make ethylene and propylene via catalysis, also known as methanol-to-olefins (MTO) [6]. Similar to MTO, methanol can be catalyzed to yield hydrocarbon streams with high percentages of gasoline. The versatility of methanol and its derivatives indicates that many commercial routes leading to modern-day consumer goods rely on the existence of methanol [7]. Ammonia is a chemical that produces a strong-smelling odor in liquid and gas form. It is used in various industries such as fertilizing of plants. Synthetic natural gas is variety of natural gas that its composition and properties similar to natural gas. From the previous description, this plant product are strategic chemicals.

The various product targets aim to get an integrated plant that can utilize the potential of low-quality Indonesian coal. If the process of utilizing low-quality coal is only targeting one main product, then in terms of industrial business does not have good potential. Due to the complexity of the processes involved and a large number of product targets, a comprehensive feasibility techno-economics study is needed. This work aims to evaluate the techno-economic feasibility each of utilization of coal to various chemical products and its sensitivity. This study provides proven and commercially available technology for coal gasification, synthesis DME, methanol and ammonia from syngas, and methanation reactor for SNG production.

2. Materials and methods

The simulation of the gasification process and the production of chemical products in this study is based on the coal composition of the ultimate and proximate analysis shown in Table 1. Simulation of the production process is divided into five main sections namely coal gasification and production of DME, methanol, ammonia and SNG. Many technologies that have been proven in the production process have been widely developed and applied to industry. Hence, it is necessary to select the appropriate technology. The following is an explanation of the types of technology and method of financial analysis used in this study.
2.1. Coal gasification technology
The gasification processes can be classified basically in two general ways, by the Btu content of the product gas and by the type of the reactor hardware configuration, as well as by whether the reactor system is operated under pressure or not. Based on the reactor configuration and each phase contacting method, gasification processes can also be categorized into the following four types are moving bed, fluidized bed, entrained flow and transport [8]. In this study, the gasification process was using an entrained-flow type gasifier was chosen with Shell Gasification technology because of high conversion and efficient heat recovery through the production of high-pressure superheated steam [9].

Table 1. Coal composition of the ultimate and proximate analysis.

| Composition | Ultimate analysis | Proximate analysis |
|-------------|-------------------|--------------------|
|             | Mass fraction     | Parameter          | Unit  | arb (as received base) | adb (air dried basis) |
| Coal        | C 0.596           | Moisture in analysis | %     | -                     | 14.0               |
|             | H 0.039           | Ash content        | %     | 4.1                   | 5.4                |
|             | O 0.300           | Volatile matter    | %     | 31.7                  | 42.0               |
|             | N 0.007           | Fixed carbon       | %     | 29.1                  | 38.6               |
|             | S 0.003           | Total sulfur       | %     | 0.25                  | 0.33               |
| Ash         | 0.054             | Gross calorific value | Kcal/kg | 4194                | 5558               |
|             |                   | Hard grove grindability index | -     | 100                |

2.2. DME production technology
There are two method options that can be done to get DME from syngas, namely direct synthesis and indirect synthesis [10,11]. The main advantage of using the indirect method is that the reaction is separated into two reactors, namely the reactor for methanol formation and the DME formation reactor. Thus, it is easy to control the optimum operating conditions for each reaction. In addition, the indirect method produces less heat reaction than the direct method. However, economically indirect synthesis requires a more significant cost than direct because it requires two reactors. In addition, because syngas is first converted into methanol and then DME, there is a possibility that DME will be produced less because not all syngas and methanol are converted. Based on the things that have been described, the direct synthesis from JFE Company technology is considered more suitable for obtaining DME from syngas [12]. Considering the DME market as a substitute for LPG in Indonesia, the DME price will not be much different from the LPG price set by the government. Therefore if using the indirect method will be an uneconomic process because the price of methanol is higher than the price of LPG and DME in Indonesia.

2.3. Methanol production technology
The most important section of the methanol synthesis process is the reactor or converter. As the methanol synthesis reaction is exothermic, the primary task of all the reactors is to control the reaction temperature. The reactor technologies that have been used extensively in commercial settings fall into two categories, gas phase and liquid phases technologies [13]. Liquid phase technologies were representing the future of the methanol industry because they allow efficiently removing the heat of reaction and enforcing tight temperature control. Unfortunately, liquid phase technologies have not been used for commercial methanol production so far because of both modeling and scale-up issues. Therefore, liquid phase technologies are still under development. Gas-phase reactors can be operated as adiabatic or isothermal reactor. From various methanol reactors technologies, the Isothermal
Methanol Converter (IMC) Casale technology is considered more suitable for obtaining methanol from syngas. The IMC Casale design cope with the conservative drawback of size, hence it can produce higher rates in a single converter. The gas flow in the catalyst can be axial-radial, and the catalyst bed cooling can be achieved with a combination of water and gas, leading to the lowest temperature at converter exit, improving the conversion per pass [14].

2.4. Ammonia production technology
Various improvements were made in ammonia plant technology. It has advantage for existing plant to increase the production rates and new plants to be built with larger capacities. Competition between technology suppliers is quite fierce. Three technology licensors - KBR (Kellogg Brown and Root), Haldor Topsøe, and ThyssenKrupp Industrial Solutions (TKIS) - currently dominate the market [15]. Ammonia Casale offers an axial-radial catalyst bed design which make it to be a market head in convert of existing plants [16]. From the comparison of various technologies, Ammonia Casale is considered more suitable for obtaining ammonia from syngas in this study. It is because Ammonia Casale's technology has low pressure drop and higher efficiency because of its axial-radial technology [17].

2.5. SNG production technology
Methanation processes aim to produce methane from hydrogen and carbon oxides. Methanation has been used for years as the final purification step in ammonia plants, but methanation for SNG production is at a different level due to the higher content of carbon monoxide (CO) and carbon dioxide (CO2). CO and CO2 are hydrogenated according to the methanation reactions, both favored by low water content and high pressure. The methanation technologies were an adiabatic fixed bed, cooled fixed bed and fluidized bed methanation [18]. From the comparison of various technologies Topsoe recycle energy-efficient methanation adiabatic fixed bed reactors are considered more suitable for SNG Plant. The technology solves the important problem about the lowest recycle and heat recovery cost by heat recovery of superheated steam.

2.6. Method of financial analysis
Financial feasibility analysis is conducted by simulating financial projections as the basis for calculating feasibility indicators. The source of funding will be using a combination of funding from third parties and equity. The project's weighted average cost of capital (WACC) is calculated based on assumptions as shown in Table 2 below, with a funding structure of 85% from loan and 15% equity. The investment is carried out with project duration will last for 4 years. The source of funding will be using a combination of funding from third parties and equity. Loan repayments are assumed to be made for 10 years with an interest of 6% per year. Production and sales within projection are assumed to remain flat with an escalation in price of 3% per year.

| Item                     | Value     | Remarks                      |
|--------------------------|-----------|------------------------------|
| Beta                     | 1.21      | Category Chemical (Diversified) |
| Risk Free                | 6.665%    | Government Bond Yield        |
| Market Return            | 9.56%     | IHSG Return 2009 – 2019      |
| Company Specific Risk    | 2%        |                              |
| Cost of Equity           | 12.17%    | CAPM                         |
| Interest rate            | 5%        | Credit investment in IDR     |
| Tax                      | 25%       |                              |
| Cost of Debt             | 4.5%      |                              |
| Equity : Debt            | 15 : 85   |                              |
| WACC                     | 5.65%     |                              |
3. Results and discussion

3.1. Basis design

The plant capacity design in this study is 11540 tpd (low rank-wet coal) which produces 2000 tpd of DME, 2500 tpd of methanol, 600 tpd of ammonia and 25 MMSCFD SNG. In general, the plant process is described in the following Figure 2. Coal is gasified to produce syngas. The produced syngas will be split into several plants to produce the chemicals. Some of the syngas is converted into methanol at the methanol plant. Some others will pass water gas shift (WGS) reactor and acid gas removal unit (AGRU) to increase the H₂/CO ratio to 1:1 and eliminated the acid gas content. Syngas was then converted to DME, Ammonia and SNG at each plant. At the same time, the sulfur-containing gas is further processed into solid sulfur in future processing. CO₂ can be used as a raw material in future processing such as dimethyl carbonate (DMC) production plant.

![Figure 2. Coal gasification, DME, methanol, ammonia, and SNG plant block diagram.](image)

3.2. Financial feasibility and sensitivity analysis

The coal gasification plant project will cost approximately US $ 2.5 billion not including initial working capital and IDC. Total production cost per product and feasibility indicators can be seen in the Table 3 below.

| Total production cost per product | Feasibility indicators |
|----------------------------------|-----------------------|
| Item                             | Value     | Item           | Value              |
| Methanol production cost         | US$ 227/ton | Investment     | US$ 2,540,600,444  |
| DME production cost              | US$ 390/ton | WACC           | 5.65%              |
| Ammonia production cost          | US$ 245/ton | IRR            | 12.46%             |
| DMC production cost              | US$ 463/ton | NPV            | US$ 2,455,881,679  |
| LNG production cost              | US$ 9.32/MMBTU| Payback period | 6 years 5 months  |

Based on the feasibility indicators as shown in the table above, can be concluded that this project is feasible to be implemented because its IRR value is 12.46%, which is higher than the weighted average cost of capital (WACC) value (5.65%), its net present value (NPV) is also higher than zero. The project payback period is estimated to take 6 years and 5 months.
Sensitivity analysis is carried out to determine the impact of changing an assumption on the overall project feasibility. Sensitivity analysis are shown in Figures 3-6. The assumptions used in the sensitivity analysis are product price, production costs, investment and syngas production costs. Figure 3 shows that if the product selling price drops 30% from base scenario used in the financial projection, then the project would not be feasible, because its IRR will be lower than the project’s WACC. The sensitivity diagram on Figure 4 shows that the project’s IRR will drop and become lower than project’s IRR if its production cost rises up higher than 80% from the base scenario. The investment sensitivity analysis (Figure 5) shows that if the project’s sensitivity could not be feasible even if its investment requirement doubles up to US$ 5 Billion. Figure 6 shows that if syngas production cost is higher than US$ 123 / ton then the project will not be feasible to run, because its IRR will be lower than the project’s WACC.

4. Conclusions
The coal gasification plant into DME, ammonia, methanol and SNG products is a solution in the utilization of Indonesian low-grade coal for domestic needs. The plant's capacity to process 11540 tpd of low rank-wet coal to produce 2000 tpd, of DME, 2500 tpd of methanol, 600 tpd of ammonia and 25 MMSCFD SNG can use commercially proven production process technology so that it can support the establishment of this integrated plant. The technologies used in this study were Shell Gasification technology, direct DME synthesis from JFE Company technology, IMC Casale technology, Ammonia Casale technology and Topsoe adiabatic fix-bed reactor technology. Based on the results of economic analysis, it was found that the feasibility parameter was an IRR of 12.46% with a payback period of 6 years and 5 months. Based on the results of the process and economic simulations, it is found that the establishment of a coal gasification plant into various integrated chemicals is feasible. By utilizing
carbon dioxide as a by-product, it has the potential to be used as one of the raw materials for products with high selling value, thereby increasing economic potential and being environmentally friendly. This research was limited to the utilization of carbon dioxide and sulfur by-products, hence further research should be optimising these chemicals potential.

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