Economic evaluation of thermochemical conversion for rice straw-based second-generation bioethanol production in West Java

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Abstract. Production of bioethanol through several routes from cheap materials such as agricultural solid waste is getting more interesting nowadays. Rice straw is one of the potential agricultural solid wastes that can be used as feedstock for bioethanol production due to a huge amount of availability, especially in South East Asia countries. In this study, the economics of rice straw-based bioethanol plant by thermochemical conversion was evaluated. The main processes involved in the plant are pretreatment, gasification, water-gas shift reaction, carbon dioxide removal, alcohol synthesis, and purification. The plant was planned to be located in Indramayu, West Java, Indonesia. The price of bioethanol set on this evaluation is US$ 0.61 per liter. The total capital expenditure (CAPEX) and operational expenditure (OPEX) of this plant were found to be US$ 122,614,000 and US$ 20,175,910, respectively. The return on investment (ROI) is 66.96%. The internal rate of return (IRR) is 24.08%. The net present value (NPV) is US$ 689,074,000. Finally, the payback period is 4.5 years. The result of this study shows that this bioethanol plant is feasible and very profitable to be implemented.

1. Introduction

The amount of fossil fuels as the global energy source keeps decreasing while the energy demands keep growing year by year. On the other hand, fossil fuel utilization is found to cause adverse effects on health and the environment [1]. These conditions lead researchers around the world to find alternative energy sources that should be more sustainable and environmentally friendly. The demand and supply of biofuels, including bioethanol, have been growing significantly nowadays as the production of biofuels increased substantially to the value of 118 million L in 2013 from 46 million L in 2006 [2]. Among all types of biofuels, bioethanol is the most produced biofuel, where about 73% of the 135.3 billion liters of produced biofuels in 2016 [3]. Utilization of bioethanol as the alternative energy source has many advantages, e.g., reducing the emission of CO₂ gas, greenhouse effect, and global warming [4]. The production of bioethanol is still limited to the utilization of edible crops as feedstock, where approximately 60% of global bioethanol production is always produced from sugarcane. This reality leads to significant pressure on arable land initially used for the production of crops as well as increasing the risk of food security issues [5].
The first generation of bioethanol production uses food, feed, or sugar, and starch-rich materials. The Second generation is characterized by the use of lignocellulosic materials, such as agricultural residues, forest materials and solid wastes [4, 6-9]. Thus, the second generation benefits from lower raw material prices, and they do not raise food security issues. Generally, the production of second-generation bioethanol by fermentation method includes four major steps: pretreatment to degrade the lignocellulosic structure of biomass into its fractions; hydrolysis/saccharification to obtain fermentable sugars; fermentation to convert sugars into ethanol, and purification to separate and purify ethanol from the fermentation broth [10]. This process applies hydrolytic enzymes to obtain fermentable sugars out of cellulose at the saccharification step, thus making this process quite expensive for commercial production [11]. On the other hand, the fermentation process by yeast sometimes produces other biochemicals, which will lead to some difficulties in the purification step. The second-generation of bioethanol production can be done through thermochemical conversion which uses heat and chemicals to break cellulose into syngas (CO and H₂) and reassembles it into ethanol [12]. The cellulose with lignin-rich parts cannot be easily converted biochemically. Other studies in this proceeding examine the technological selection as well as preliminary plant design of thermochemical conversion for rice straw-based second-generation bioethanol production. This study aims to evaluate the economic feasibility of rice straw-based bioethanol production by thermochemical conversion. Economic evaluations of bioethanol production from oil palm empty fruit bunch (OPEFB) have been widely studied by Indonesian researchers as the production of OPEFB is abundant in Indonesia [13]. The reason for using rice straw as the feedstock for bioethanol production is rice is a staple food for the Indonesia people and is cultivated in rice fields in every region of the country. The abundant production of rice as the main food for Indonesians lead to the production of abundant rice straw as its side products of harvesting rice on fields [10]. Indramayu Regency in West Java will be chosen as the location for this study as this area has high rice production in Indonesia which means producing high rice straw too. On the other hand, rice straw generally contains cellulose (32–47%), hemicellulose (19–27%), and lignin (5–24%), which means that this biomass has the potential to be used for bioethanol production [14].

2. Methods

Rice straw will be transported from the field to the plant by means of trucks. The rice straw will be fed into the hammer mill for size reduction to a uniform size of 0.1-0.3 mm. Straws are then ejected from the hammer mill directly to a conveyor belt. Before the straws are converted to syngas, the feedstocks are dried by a rotary dryer to reduce the moisture content to 10% using dry air.

The next step is the gasification process, where dried feedstocks will enter the gasification reactor to produce syngas. In this step, the medium is synthetic olivine (calcined magnesium silicate) consisting of Enstatite (MgSiO₃), forsterite (Mg₂SiO₄), and hematite (Fe₂O₃). A small amount of magnesium oxide (MgO) is added to the fresh olivine. The MgO rejects the potassium present in biomass as ash by forming a high melting (1300°C) ternary eutectic with the silica, thus sequestering it. The biomass ash is assumed to contain 0.2 % potassium. The MgO molar flow rate is set at two times the molar flow rate of potassium. With an expected potassium inlet flow rate of 0.087 lb moles per hour, the estimated MgO requirement is 0.174 lb-moles per hour or 7.0 lb per hour. The type of gasifier used is a fluidized flow gasifier because it has long residence time than an entrained flow gasifier and ensures high carbon conversion. In the gasifier, biomass will be converted into CO, H₂, and CH₄ by means of H₂O as the initial reactant. There is a water gas shift reaction on the gasifier, which functions to decrease CO and increase the amount of H. It is useful to get an H₂/CO ratio near 2. At the exit of the gasifier, there are cyclones that separate the char and olivine from the syngas. The solids flow to the char combustor, where the char is burned in the air in a fluidized bed, resulting in olivine temperatures greater than 982 °C.

After the water gas shift reaction, there is still more CO₂ in syngas. CO₂ must be removed from the syngas because CO₂ is not needed for the alcohol synthesis process. CO₂ is removed by the absorption mechanism that uses an amine solvent. This plant uses MDEA as an absorbent to remove CO₂. In
general, the amine absorption mechanism needs some equipment like the absorption column and the regenerator column. First, syngas will enter the absorption column and contact with lean MDEA. Then, the absorption will take place, and CO₂ dissolves in MDEA. Now MDEA contains a high amount of CO₂ and called rich amine streams. The rich amine will be regenerated by using heat energy to separate amine from CO₂. The regenerated amine can be used again to absorb CO₂ in the absorber column.

The next step is bioethanol synthesis. Cooled low-pressure syngas enters a four-stage centrifugal compressor system where the pressure is increased to approximately 2000 psi. The compressed fresh syngas is mixed with recycled syngas and methanol and then preheated to 313°C before entering the alcohol synthesis reactor. Then, reactions at above 300°C convert a portion of the syngas to oxygenate and hydrocarbon products. Light hydrocarbons, methyl esters, and aldehydes are produced in smaller quantities through similar chemical routes. Heat must be removed from the reactors because the synthetic reaction is extremely exothermic. The reactor effluent consisting of mixed alcohols, gaseous by-products (such as CO₂ and methane), and unconverted syngas is cooled through the heat exchanger with other process streams. As the reactor effluent cools, alcohol and water are condensed and sent to downstream separation and purification equipment.

Cooled crude alcohols are depressurized and degassed in a flash separator. Before it enters the flash separator, crude alcohol will be expanded by two series expanders to decrease its pressure. After that, the flash separator will separate the stream into the gas and liquid phase. The evolved gases are then collected as the side product, while the liquid phase will be pumped to the distillation column. The crude alcohols that enter the distillation column consist of ethanol, water, and a few methanols. The distillation column designed to separate ethanol and water by the difference of boiling point. Ethanol will exit the distillation column as top product and its pump to adsorption column to dehydrate water to reach purity until 99% mole.

The plant location selection has to consider several factors that affect the investors to build a plant such as capital and operational costs. Based on these criteria, it can be concluded that the area of Losarang, Indramayu, West Java is the most strategic location to build this plant. This district has the biggest rice production in Indonesia, which means produce the highest rice straw too. The plant was expected to run for 335 days per year with a continuous mode of operation (24 hours per day). The production capacity of this plant is set to produce 300 kL bioethanol per day. The cost evaluation includes the investigation of total capital investment (TCI) and operational cost (OPEX). The economic evaluation includes the investigation of internal rate of return (IRR), net present value (NPV), payback period (PBP), return on investment (ROI), and breakeven point (BEP). The sensitivity analysis is also examined. The main revenue of this plant is bioethanol, with the selling price set to be $0.61/L. For the basis of calculation, NPV and IRR are defined as Equation (1) and (2) below [15].

\[
\text{NPV} = \sum_{k=0}^{N} \frac{c_k}{(1 + i)^k}
\]

\[
\text{IRR} = \sum_{k=0}^{N} \frac{c_k}{(1 + i)^k} - c_0 = 0
\]

where \(c_k\) is the net income of the period of project exploitation, \(i\) is the discount rate, \(N\) is period of the project exploitation and \(c_0\) is the total investment costs.

3. Results and Discussions

3.1. Cost Analysis

In this plant, there is 45 equipment used in the process. Each equipment has a different way to determine the price of equipment. Cost Sites include land cost, construction labor, fire protection equipment, grading, landscaping, parking, railroad track, security systems, sewers, site preparation, and yard
lighting. A plant and its office must provide decent facilities for its worker so that they can work optimally and accelerate the production process. The amount of this supporting facility is determined by the number of employees and their needs. This includes all sorts of facilities that essential for an office like furniture, office equipment, stationary, and vehicle. The additional cost includes overhead plant costs for some installations such as water, telephone, electricity, internet, and hydrants. The TCI of this plant is $122,614,000, as can be seen in Table 1 below.

| Component                      | Cost ($)                  |
|--------------------------------|---------------------------|
| Equipment                      | 31,088,000                |
| Installation                   | 17,751,248                |
| Engineering expenses           | 9,202,048                 |
| Piping & instrumentation       | 12,592,000                |
| Site development               | 9,354,350                 |
| Building                       | 14,246,700                |
| Offsite facility               | 16,079,700                |
| Contingency                    | 4,663,200                 |
| Contractor fee                 | 932,600                   |
| Working capital                | 11,576,000                |
| Supporting facility            | 109,710                   |
| Additional                     | 14,230                    |
| **TCI**                        | **122,614,000**           |

The huge amount of TCI will be fulfilled from both bank loans (40%) and investors (60%). The interest rate for both bank loans and investors is 11% and 13%, respectively. The lifetime of this plant was set to be around 20 years, where it is needed to pay the loan investment in 5 years. From the calculation, the amount of loan interest each year is then accumulated over the five years debt of $43,773,198 with the annual average of financial interest for $8,754,639.60. The total amount of payment for five years was US$ 166,387,198.

There are only two raw materials needed for bioethanol production in this plant. The costs of raw materials are shown in Table 2 below. The costs of utilities are shown in Table 3.

| Raw Material   | Demand (MT/year) | Price ($/MT) | Total price ($) |
|----------------|------------------|--------------|-----------------|
| Rice straw     | 125,000          | 18.25        | 2,281,021       |
| CuO/ZnO        | 530              | 167.88       | 88,978          |
| **Total annual raw material cost** |                 |              | **2,370,000**   |

| Utility       | Needs            | Price (IDR) | Daily Cost ($) | Annual Cost ($) |
|---------------|------------------|-------------|----------------|-----------------|
| Steam         | 137 ton          | 140,000 /ton| 1400           | 315,000         |
| Electricity   | 4,703 kWh        | 1,385 /kWh  | 475            | 106,976         |
| Water         | 53 m³/day        | 10,000 /m³  | 38             | 8,540           |
| Fuel          | 170 kg           | 11,500 /kg  | 143            | 32,107          |
| **Total Utility Cost** |               |             | **462,623**    |

Labor cost is classified into direct labor cost and indirect labor costs. Each direct and indirect Cost will be classified again into fixed Cost and variable Cost. Fixed Cost is a cost that has not escalated equally over the years, or its value remains still throughout the year. On the other hand, variable Cost is a cost that value does not remain still. Labor cost is the total of every employee fee. Wage paid to
employees should be above the regional minimum wage in Losarang, Indramayu, which is Rp 1,465,000 or $106 per month. The total labor cost from the amount of direct and indirect labor costs is $ 1,113,140.

The maintenance cost is issued to ensure the production line can run smoothly without encounter any failure along the line of production in the factory, and also this Cost was expensed to extend the age of the equipment (primarily the main production equipment) to run as long as possible. The total annual maintenance cost for this plant is $ 613,070.

3.2. Economic Analysis
The unit cost for the bioethanol product is $ 0.17 /L. The calculated unit cost is cheaper than the selling price of our product, which reaches $ 0.61 /L, which means that there will be a positive margin. Annual net profit is the Net Profit After Tax that is resulted from the cash flow. According to the cash flow, the annual net profit of this plant is $ 92,253,000, and the invested capital is $ 137,762,000. So, the ROI of this plant is 66.96 %. From the ROI calculation, it can be seen that this plant is attractive to investors because it has high enough ROI value. The payback period for this plant is 4.50 years. The PBP matches the rule of thumb. In the rule of thumb where the tolerable payback period is about ten years and should be done after all the loans are fully paid. A product design project will be feasible if the payback period is still in the period of the operation being evaluated at the time of making the feasibility analysis of the amount of net profit after a significant payback period. This result is reasonable because this plant has large production capacity, so it needs many years to get back the investment. In accordance with the PBP, the BEP of this plant is 450,508,000 L bioethanol. The obtained IRR for this plant is 24.08%. IRR of this plant is larger than the minimum acceptable rate of return (MARR) of 11.9 %, which means that this plant is attractive for investors.

The obtained IRR value of this plant is a little bit higher than the bioethanol production plant by fermentation method, which is 17.89% [4]. The NPV that value of this plant is $ 689,074,000. The NPV is positive and high, which means that the project can be implemented. The summary of the economic parameters for this plant can be seen in Table 4 below.

| Table 4. Summary of economic parameters |
|-----------------------------------------|
| Return on investment (ROI)              | 66.96%     |
| Payback period (PBP)                    | 4.5 years  |
| Internal rate of return (IRR)           | 24.08%     |
| Net present value (NPV)                 | $ 689,074,000 |
| Breakeven Point (BEP)                   | 450,508,000 L |

A plant is not always stable. There is a time of plant instability. This instability is due to the changes experienced by plants and is caused by various factors. These changes can affect beneficial or even detrimental to a plant; thus, a sensitivity analysis was carried out. Effect of changes on product price, raw material price, and labor wage on IRR and PBP were analyzed, as shown in Figure 1 below.
It can be seen from Figure 1 above that product price has a significant effect both on IRR and PBP of this plant. Increasing the bioethanol selling price to $0.797/L will increase IRR to 33.3% and decrease PBP to 3.25 years. While decreasing ethanol selling price to $0.429/L will decrease IRR to 13.91% and increase the payback period to 6.86 years. From Figure 1, it also can be seen that both changes in raw material price and labor wage will not have a significant effect on both IRR and the payback period. It is suggested to find alternatives application of the produced bioethanol in order to increase its economic values as previous techno-economic study of hand sanitizer production from second generation bioethanol was found to increase its economic values [16].

4. Conclusion

The total capital investment of this plant is found to be $122,614,000, with a production capacity of 300 kL bioethanol per day and 20 years of plant lifetime. The total annual operating cost of this plant is only $21,000,000, which is lower if compared with the fermentation method even with higher production capacity. The ROI and IRR of this plant are 66.96 and 24.08%, respectively, which means that this plant is economically feasible and attractive for the investors. Sensitivity analysis shows that the economic condition of the plant highly depends on the bioethanol selling price.

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