Techno-economic evaluation of integrated levulinic acid-bioethanol plant design based on oil palm empty fruit bunches

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Abstract. Currently, renewable energy started to become a focus of the world as it can be an alternative to fossil energy. Bioethanol is the result of glucose fermentation derived from lignocellulosic raw material (second-generation bioethanol). As one of the countries with the most significant biomass resources globally, Indonesia has a huge opportunity to develop the bioethanol industry. Oil Palm Empty Fruit Bunch (OPEFB) is the most significant solid waste generated by oil palm plantations. Levulinic acid can be used as a chemical platform for biodiesel production, which has a higher selling price than bioethanol. In this research, techno-economic evaluation of integrated levulinic acid-bioethanol plant based on OPEFB was conducted. Optimization of production capacity is done to determine the suitable plant capacity so that the integrated levulinic acid-bioethanol plant is feasible to be developed. Based on simulation results with SuperPro Design 9.5 and analysis of the economic value, Net Present Value (NPV), Internal Return Rate (IRR), and the payback period is 53.939.000 USD; 29.77%; and 4.52 years, respectively. In conclusion, an integrated levulinic acid-bioethanol plant based on OPEFB has fulfilled the economic parameters of a chemical plant.

1. Introduction
The Indonesian government has planned to increase bioethanol utilization as a substitute for fossil fuel in 2016-2025, providing bioethanol with at least 20% fuel consumption. Indonesia has 14 first-generation ethanol plants with a total capacity of 408 thousand KL per year. Only 3 of 14 factories produce fuel-grade ethanol (FGE) with a total capacity of 100 thousand KL per year [1]. As one of the world's largest biomass resources, Indonesia has an excellent opportunity to develop the bioethanol industry. Especialy lignocellulosic, which are the second generation of bioethanol.

Besides bioethanol, lignocellulose biomass can be converted to formic acid [2], furfural [3], and levulinic acid [4]. Levulinic acid can be used as a chemical platform for biodiesel additives [5, 6]. The need for levulinic acid continues to increase every year. The global demand for levulinic acid in 2013 is 2,606.2 tons, and by 2020 it is predicted to reach 3,820 with an annual rate of 5.7% [7]. Levulinic acid is produced by degrading the C6 (hexose) sugar group.
The initial step from converting biomass to high-value chemical products must be through pretreatment. Various pretreatment processes have been studied [8-10]. Alkaline delignification is the most recommended option [11-13]. These processes lead to high costs.

The development of bioethanol plants needs to be considered to fulfil the government's target of fuel-grade ethanol (FGE). However, the economic feasibility of integrating bioethanol, levulinic acid and furfural manufacturing processes has not been widely studied. This research aims to evaluate the economic feasibility of integrated levulinic acid and bioethanol plant development based on OPEFB to determine the production capacity and determine the economic value of the integrated levulinic acid and bioethanol plant development includes IRR, PBP, and NPV.

2. Methods
2.1. Biomass
Oil Palm Empty Fruit Bunches is a potential feedstock for biofuel production due to high cellulose content. The following characteristics of OPEFB used are in Table 1.

| Component        | Composition (%) |
|------------------|-----------------|
| Ash              | 2               |
| Lignin           | 23.2            |
| Cellulose (Alfa) | 40.3            |
| Hemicellulose    | 31.18           |

2.2. Model development
The process models were developed using SuperPro Designer 9.5 for integrated levulinic acid-bioethanol plant with the processing capacity of 118.800 metric ton biomass/year (15 metric ton biomass/a). The production process was divided into three sections: pretreatment, levulinic acid production, and bioethanol production. After the pretreatment process, 50% biomass will be distributed to levulinic acid production and bioethanol production, respectively. Tanjung Buton Industrial Area, Riau Province, was chosen as the factory's location because it has advantages in terms of availability of raw materials of OPEFB that is equal to 1.7 million tons per year or about 200 tons/hour. Besides, the area is very strategic, close to the Port of Tanjung Buton, a national port. There is also a big company that is expected to absorb levulinic acid.

2.3. Pretreatment of biomass
The pretreatment stage is needed to break the structure of OPEFB to facilitate enzyme access in the enzyme hydrolysis stage. The main objective of the pretreatment step is to remove lignin, reduce cellulose crystallinity, modify lignin structure and increase surface area and porosity of lignocellulose material [14]. Pretreatment stages of OPEFB are done by size reduction of biomass using hammer-milled to produce OPEFB fibre with 1-3 mm size [15, 16]. Followed by washing using tap water to reduce ash and other minerals at room temperature (25-28°C) for 30 minutes (100g OPEFB: 5L water) [17]. The process conditions for the delignification process will adopt a method based on Jeon et al. [18] that uses dilute alkali pretreatment to damage the lignin structure because it has some advantages solubilization. Pretreatment using dilute alkali is also known to cause swelling in the fibre structure, enlarging the internal cellulose surface and decreasing the polymerization and cellulose crystallization rate [14].

2.4. Levulinic acid production
This study adopted the technology and operating conditions from Farone and Cuzens [19] on the primary process of hydrolysis of biomass into levulinic acid using Plug-Flow Reactor (PFR) reactor and continued with Continuous Stirred Tank Reactor (CSTR) reactor type. The feed mixture consisting of levulinic acid, furfural, formic acid, and water was fed to the distillation column to produce 98%
levulinic acid product and furfural byproducts (98%), formic acid (85%) adjusted to commercial product standards in general.

2.5. Bioethanol production

Hydrolysis and fermentation are two essential stages in bioethanol production. Saccharification or hydrolysis is the process of converting cellulose into glucose. Ethanol production from lignocellulose can be done by hydrolysis technology using sulfuric acid (H₂SO₄) or hydrochloric acid (HCl). However, this way produces a small ethanol yield [20]. In addition, hydrolysis also requires a large amount of acid and can cause corrosion of the appliance. Acid hydrolysis produces hydrolysates, which inhibit the later fermentation process. The resulting glucose yield is also limited to about 60% in the batch process due to kinetic reasons [21]. The enzymatic hydrolysis causes a higher conversion of cellulose to glucose that produces greater ethanol yield. The fermented glucose is then fermented using microorganisms to produce bioethanol.

The process of enzymatic hydrolysis and fermentation of OPEFB was conducted by the Simultaneous Saccharification and Fermentation (SSF) method. SSF technology is considered more advantageous than SHF technology [22], for several reasons: they reduce stages of the process, reducing the inhibitor products because the conversion of glucose to ethanol by yeasts is done rapidly and directly, and reduces the contaminant microorganisms that do not look desirable due to the presence of ethanol. SSF process does not need separated glucose from the lignin fraction to avoiding the potential of sugar loss [23-25]. Furthermore, the combination of hydrolysis and fermentation can decrease the number of vessels used and lower the investment cost. The decline in the value of the capital investment has been estimated at more than 20% [15]. OPEFB in 0.05 M buffer citrate pH 4.8 with a ratio of 15% (g/ml) [26] will go through the sterilization stage at 121 °C for 20 minutes. The enzyme activity required for 15 % of cellulose is 40 FPU/g and uses dry yeast as much as 1% (g/ml), so it is unnecessary through the breeding stage [26].

The fermentation product is fed to the continuous distillation column for ethanol purification. The first distillation column is called the mash column, this concentration process produces 35-50% ethanol, and a second distillation column or a rectification column will increase the ethanol concentration to 90-92%, which will then enter the dehydration stage to produce anhydrous ethanol (99.5%). Combining the SSF process followed by two-stage distillation and dehydration process with membrane-based is more economical than using dehydration technology with molecular sieve [17].

2.6. Economic calculation

The currency used during the calculation is US dollars (USD). Estimate the cost of each piece of equipment using the Chemical Engineering Plant Cost Index. The cost of equipment was calculated based on Seider [27] calculation. Factory equipment was purchased in 2018, and the factory started production in early 2020. The cost of heat exchanger equipment and some other equipment is estimated using a database of SuperPro. The plant operates for 330 days in 1 year, with 24 hours a day working hours. Construction of the factory is carried out for 24 months with a start-up time of 4 months, and the plant will start operating in early 2020. Plants lifetime is 15 years, and no production capacity is increased during the plant's productive life. The depreciation period for 13 years and depreciation calculation using declining balance method with 5% salvage value. Direct fixed costs are distributed in the first three years of the plant (30%, 40%, 30% in the first, second, and third-year respectively). The income tax rate used in cash flow was calculation at 25%.

3. Result and Discussion

3.1. Total capital investment

Capital cost includes piping, insulation, building, and other indirect cost other than installed equipment costs. The breakdown of capital investment is shown in Table 2.
Table 2. Total Capital Investment

| Total Capital Investment (TCI) | Total Cost (USD) |
|-------------------------------|------------------|
| Equipment Purchase Cost       | 14,463,000       |
| Installation                  | 5,270,000        |
| Process Piping                | 5,062,000        |
| Instrumentation               | 5,785,000        |
| Insulation                    | 434,000          |
| Electrical                    | 1,446,000        |
| **Total Bare-Module Cost**    | 34,460,000       |
| Buildings                     | 6,508,000        |
| Yard Improvement              | 2,169,000        |
| Auxiliary Facilities          | 5,785,000        |
| **Total Direct Permanent**    | 14,462,000       |
| Investment (DPI)              |                  |
| Engineer                      | 11,731,000       |
| Construction                  | 16,423,000       |
| **Total Indirect Cost (TIC)** | 28,154,000       |
| Cost of Contingency and       |                  |
| Contractor Fee                | 11,262,000       |
| **Total Depreciable Capital** | 86,338,000       |
| (TDC)                         |                  |
| Cost of Plant Start-up        | 4,317,000        |
| **Total Permanent Investment**| 90,655,000       |
| (TPI)                         |                  |
| Working Capital               | 13,122,000       |
| **Total Capital Investment**  | 103,777,000      |

3.2. Operating cost
Operating costs included facility-dependent costs, raw material costs, utility costs, labour costs, and waste treatment costs. The total operating cost was USD 158.996.000, as illustrated in Figure 1.

![Operating Cost Breakdown](image)

**Figure 1.** Cost-breakdown Operating Cost per Year

3.3. Profitability analysis
The selling price and market for selling levulinic acid, furfural, formic acid, and bioethanol products are as follows.
- Levulinic Acid
  The selling price of levulinic acid products is 8000 USD/ton. The selling price of levulinic acid on an industrial scale is around 5-8 USD/kg [7].
- Furfural
  The selling price of furfural products is 1100 USD/ton, marketed to meet the furfural needs in Indonesia of 2,087 tons/year, and 19,401 tons/year will be exported to Asia-Pacific countries [7].
Formic Acid
The selling price of a formic acid product is 780 USD/ton [7].

Bioethanol
The selling price of bioethanol products is Rp. 8000, or 0.6 USD/litre [7]. The bioethanol products will be marketed locally to meet domestic demand and increase bioethanol production in Indonesia. Based on the selling price, obtained IRR value of 29.77% (Table 3). A project is considered feasible if the IRR value is greater than the Minimum Attractive Rate Return (MARR). Where in the calculation of the economic value of MARR equal to Weighted Average Cost of Capital (WACC). From the calculation, results obtained a WACC value of 11%. Based on this, it can be concluded that the design of integrated levulinic acid and bioethanol plant can be said economically feasible where the IRR value > MARR. In addition, the margin generated is quite large (12.24%), thus reinforcing the conclusion that the design of this plant is economically feasible.

Table 3. Profitability Analysis

| Production Capacity   |   |
|-----------------------|---|
| Formic Acid           | 8,584 ton/year |
| Furfural             | 21,488 ton/year |
| Levulinic Acid       | 18,831 ton/year |
| Bioethanol           | 286 ton/year |

| Income               |   |
|----------------------|---|
| Formic Acid          | 780 USD/ton |
| Furfural             | 1,100 USD/ton |
| Levulinic Acid       | 8,000 USD/ton |
| Bioethanol           | 672.97 USD/ton |

| Profitability Analysis |   |
|------------------------|---|
| CAPEX                  | 103,777,000 USD |
| Gross Margin           | 12.24 % |
| Return On Investment   | 22.11 % |
| Internal Rate of Return| 29.77 % |
| Net Present Value      | 53,939,000 USD |
| Payback Period         | 4.52 years |

A project is declared viable if NPV ≥ 0 for indicating a project will benefit during its productive life. The NVP value on designing this factory is worth > 0, which is 53,939,000USD. This indicates a factory worthy of investment. The payback period of 4.52 years, which is less than half the age of the factory, can attract investors to invest in the integrated levulinic acid plant to be built. The economic parameters (IRR, NPV, and PBP) show that the design of this plant is economically feasible. Another study is comparable to the plant design of levulinic acid without bioethanol [28].

4. Conclusion
This study showed that the production capacity was 18.831 tons/year for levulinic acid and 286 tons/year of bioethanol with feed input of 15 ton/h and levulinic acid feed ratio with bioethanol is 50%. The selling prices of levulinic acid, furfural, formic acid, and bioethanol products are 8000, 1100, 780, and 672.97 USD/ton. The IRR is 29.77%, NPV is 53,939,000 USD, and PBP is 4.52 years.

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