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Economic Assessment of the Sugarcane-based Bio-refinery in Indonesia

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Implementing sustainability in the industry is a challenge for the scientist as well as for the engineer. It is essential as it ensures the continuation of the fulfillment of human's basic needs. This paper focuses on the application of sustainability concept in the sugar industry in Indonesia. The utilization of waste and side product of sugar production was endeavored by the integration of the sugar milling process with chemical production. Sugarcane bagasse which has a low production value was employed for producing levulinic acid, furfural, and formic acid. While the side product, molasses, was used as the feedstock of bioethanol and lactic acid production. Lactic acid was produced by fermentation of molasses with *Lactobacillus delbrueckii* for 21 hours with the yield of 90%. On the other hand, levulinic acid was produced by hydrolysis in the two-stage reactor with the minimum yield of 70% and residence time between 25 to 30 minutes. The engineering economic assessment was applied for assessing the feasibility of the integration process. Based on the calculation, the rate of return value is higher than the loan interest. This result implied that the investment in the integration of sugar production and bio-refinery is very promising.

Keywords: sustainability, sugar industry, biorefineries, Levulinic acid, Lactic acid.

1. Introduction

1.1. Sustainability concept in industry

Sustainability concept is known as a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional changes are made consistent with future as well as presents needs.[1)] The sustainability in industry, therefore, is essential in the increasing demand for fuels and chemicals for ensuring the future security of the said commodity needs. Since the available fuel and chemical are fossil-based that known to be non-renewable, finding a new resource which is independent of the fossil is more desirable. Lignocellulosic biomass, such as agricultural residue, herbaceous crops, forestry wastes, wood, waste paper and other types of lignocellulosic biomass is a promising alternative for fuel and chemical sources.[2)] Not only lignocellulosic biomass but other derivatives such as glucose or sugar can also be utilized as feedstock for biofuel production. The chemical or fuel production from biomass is known as bio-refinery.[3)] Bio-refinery offers benefit such as to save fossil fuel and to reduce carbon footprint, energy recovery, valuable resources (e.g., metal, mineral) recovery, environmental/health protection, and promoting industrial sustainability while enhancing public image.[4)]

The production in the sugar industry in Indonesia has been limited only to produce sugar. However, as the technology developed and research has advanced, a lot more potential of this industry has revealed. In the sugar production process, approximately from 1 ton of sugarcane, 55 kg of molasses and 280 kg of bagasse also produced.[5)] Sugarcane molasses is a by-product of the production of sugar which is a sugar solution that separated from the sugar crystal. It formed as thick black viscous liquid and contains simple carbohydrates which have been further utilized as a feedstock for fermentation-based products such as ethanol, yeast, etc.[6)] On the other hand, bagasse is a squeezed fibrous residue that remained after the sugar juice has extracted from the sugarcane. This bagasse is usually burned as fuel in the boilers to generate steam.[7)] Sugarcane bagasse composed of cellulose (38-40%), hemicellulose (25-28%) and lignin (20-22%).[8)] It can be utilized directly as fuel for electricity and heat generation, charcoal, chemical source of methane fermentation and methanol production through gasification and syngas production. It is also suggested to be converted to levulinic acid, furfural, and formic acid production via bio-refinery.[9)] Currently, there have been studies revealing the potential of sugar industries that focused on bio-ethanol but few addresses on other valuable chemicals.[6,10-12)]

1.2. Renewable policy in Indonesia

Based on the national energy policy 2014, it was targeted by 2025 that non-renewable energy (NRE) share in Indonesia energy mix will increase to 23%. Amongst the targeted renewables, biomass contributes a significant portion to the energy mix both in electricity generation and as fuel in the transport sector. The NRE is not only benefiting the approach of reducing greenhouse gases (GHG), but it also offers advantages in social and economic aspects, including creating job opportunities, improvement on the quality of life in the rural area, and poverty alleviation.[13,14]

The Government of Indonesia issued the presidential decree no.1 in 2006 in order to create the executive team for the development of biofuel in Indonesia. This committee was taking the responsibility to create a master plan as well as a guideline for a national biofuel development program and regulations for all aspects includes in the biofuels supply chain which covers from the upstream to the downstream. This committee also taking the measure to counsel the regional governments on the chances of raising the economic growth through biofuel programs.[13,15]

The Government of Indonesia was further revised their regulation on the transport biofuels by adding new subsidies in September 2013. Prices were set for the bioethanol at IDR 3500 or USD 0.26 per liter and biodiesel at IDR 3000 or USD 0.22 per liter. The subsidized volume is limited to 48 million kiloliters and 51 million kiloliters for bioethanol and biodiesel respectively. Besides, according to the Ministry Regulation No. 25 of 2013, the biofuel blending target was set to 10% by 2014, and it will be further increased to 25% in 2025.[13,16] Based on the description above, it can be concluded that biofuel still has an opportunities and market in Indonesia.

1.3. Biomass-based chemicals from molasses

As mentioned in the section 1.1., molasses, as well as sugarcane bagasse can be the promising feedstock for bio-refinery industry. Although research and development in bio-ethanol have been increasing thoroughly, there are few studies on lactic acid from molasses. Lactic acid or 2-hydroxypropanoic acid ($CH_3CHOHCOOH$) is the chemical which widely used in varied industry. For example, preservatives and pH adjusting agent in food and beverage industry are common usages of lactic acid. It is also often used as a solvent and starting materials for lactate esters. In addition, lactic acid also commonly found in the pharmaceutical industry as solidifying and encapsulating agent.[17,18] Lactic acid also can be a starting material for more chemicals such as propylene glycol, 2,3-pentadione, propanoic acid, acrylic acid, acetaldehyde, *etc.* The consumption of lactic acid has increased that the worldwide demand for this chemical may be expected to reach 130,000 to 150,000 (metric) tons per year.[19-21]

The market of lactic acid in Indonesia is predicted to increase from time to time. However, in spite of having a significant demand, it is quite surprising that there is no production unit available inside the country. It has to be noticed that Indonesia has been importing a large quantity of lactic acid from China, Belgium, Brazil, Japan, Spanish, Singapore, India, and other countries to meet the needs of the chemical. This import amount was getting higher from year to year and reach a total of 3,159 tons in 2012 and will continue to rise at an average rate of 12%. It is true that Indonesia has been exporting, but it is due to the excess of importing supplies.[22]

Lactic acid can be produced through fermentation with fungi and bacteria. The most common fungi used in the fermentation is the *Rhizopus* species such as *R. oryzae* and *R. arrhizus*. The utilization of this kind of fungi is benefitted to direct conversion of L(+)-lactic acid due to amylolytic enzyme activity. However, the production rate of these fungi is meager because of mass transfer limitation.[23-24] On the other hand, some bacteria commonly used for producing lactic acid are *Lactobacillus rhamnosus*, *Lactobacillus helveticus*, *Lactobacillus bulgaricus*, *Lactobacillus casei*, *Lactobacillus plantarum*, *Lactobacillus pentosus*, *Lactobacillus brevis*, and *Lactobacillus delbrueckii*. The bacteria mentioned the latter is the typical bacteria appeared in many studies and has a relatively high yield and production rate.[25-29]

1.4. Biomass-based chemicals from sugarcane bagasse

Levulinic acid or 4-oxopentaonic acid ($CH_3CCH_2CH_2CO_2H$) is one of the chemical platforms which is valuable for the production and development of alternative energy. In the production of biodiesel, using levulinic acid as an additive is known to improve the engine efficiency. This chemical also significantly used as the building block or starting material for a vast number of compounds. For example, it is useful for production of other derivatives such as 5-Bromolevulinic acid, Valeric acid, Methyl tetrahydrofuran (MTHF), Methyl pyrrolidone, *etc*.[30]

Currently, levulinic acid has been produced in North America, Europe, and China achieves the Asia Pacific with the highest production. It is predicted that the global demand for levulinic acid will increase at a rate of 5.7% per year with the current market demand of 2,606 tons per year. With the continuing growth, it was predicted that the demand would reach over 5,000 tons per year in 2030. In Indonesia itself, currently there's no manufacturing place available, and therefore, it is very reasonable to consider to build a production plant of levulinic acid using bagasse as feedstock.[31]

During the production of levulinic acid, furfural also can be obtained as a side product. Furfural has a broad application in different types of industry.[32,33] Furfural is a bio-based chemical that shows a lot of potential due to its broad application. It has been manufactured from the hemicellulose fraction of biomass, and its production has increased in the past few years to around 430,000 tons per year with the retail price around 1.0 – 1.7

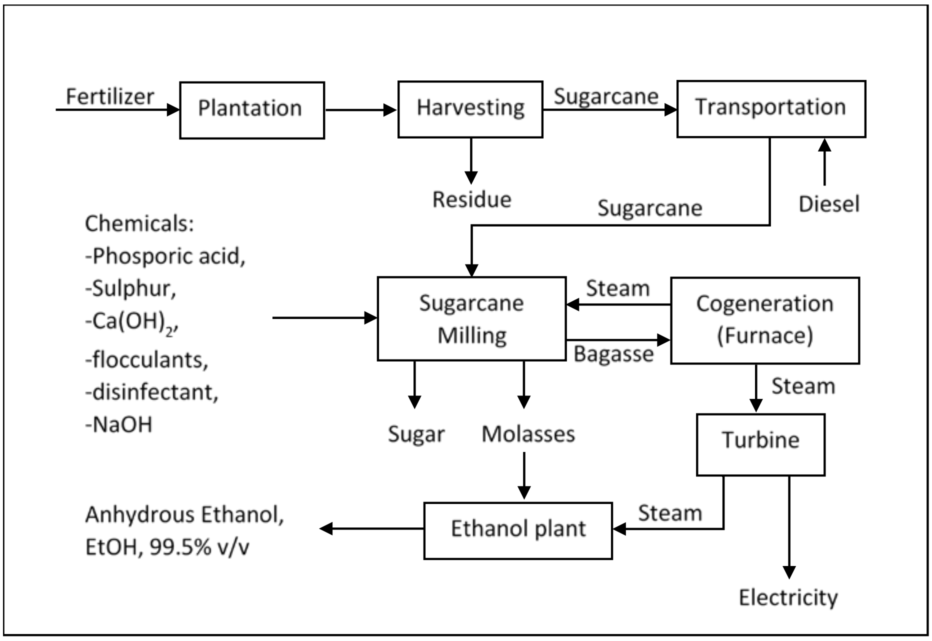


Fig 1: The sugar production process of sugar plantation in Indonesia.[6)]

USD/kg. [34,35)]

To produce furfural, recently, sugarcane bagasse is known to be one of the favorable feedstock due to its high xylans content.[36)] In the bio-refinery approach, the conversion to furfural will not be limited to the hemicellulose, but to take advantages of each content of biomass in a single process.[34)]

Formic acid can also be obtained from the production process of levulinic acid. Having chemical formula of HCOOH, formic acid is known for its use as a preservative and disinfectant in livestock feed. It is also applicable in the leather production, where it is used in tanning, dyeing and finishing processes.[37)] Formic acid also can be found in various cleaning products and recently is gaining its popularity amongst researchers due to its promising utilization in fuel cells.[38-40)]

1.5. The objective of this study

The sugar industry in Indonesia has a potential for the development of bio-refinery from its wastes and side product. Therefore, this work is aimed to evaluate the feasibility of bio-refinery production based on the sugar milling process with the new chemical output of lactic acid, furfural, formic acid, and levulinic acid. Considering the market prospect of lactic acid and levulinic acid in future which was expected to reach over 5,000 tons per year by 2030, a model for the chemical production process was developed with the target production as much as 5,000 tons per year. This capacity also considered being fitted to be a model plant for future development or scale up. While the feasibility of the process is assessed by economic estimation of the capital cost, as well as the payback period and the break even point.

2. Methods

2.1. Sugar Production Process

Sugar production process, in general, is consist of harvesting from the plantation, followed by the transportation of sugarcane to the sugar mill, process of sugarcane milling, wherein this process, the steam generator provides the steam. Molasses coming from sugarcane milling is processed in the ethanol plant to produce anhydrous ethanol 99.5%v/v. The scheme of the whole process can be seen in figure 1, and detailed process is summarized below.[6)]

2.1.1. Harvesting and transportation

The cultivation activities include the land preparation, sugarcane farming, fertilizing, and harvesting. The irrigation of the sugarcane crop is sustained by the monsoon rain that diesel pumping is not required. After being harvested, the sugarcane is transported by the truck or trains (although may uncommon) to the sugar milling unit. The harvesting period usually between May and October.

2.1.2. Sugar juice extraction system

Sugarcane is composed mainly of fiber and juice (a sugar-water solution), in which sucrose is dissolved. In the extraction system, sugar juice is extracted as much as possible which also considers producing bagasse in an appropriate condition for rapid combustion in boilers. The sugar juice extraction happens in the milling process, and it requires knives and shredder to crush the cane and separate the solid bagasse from the cane pulp. Bagasse

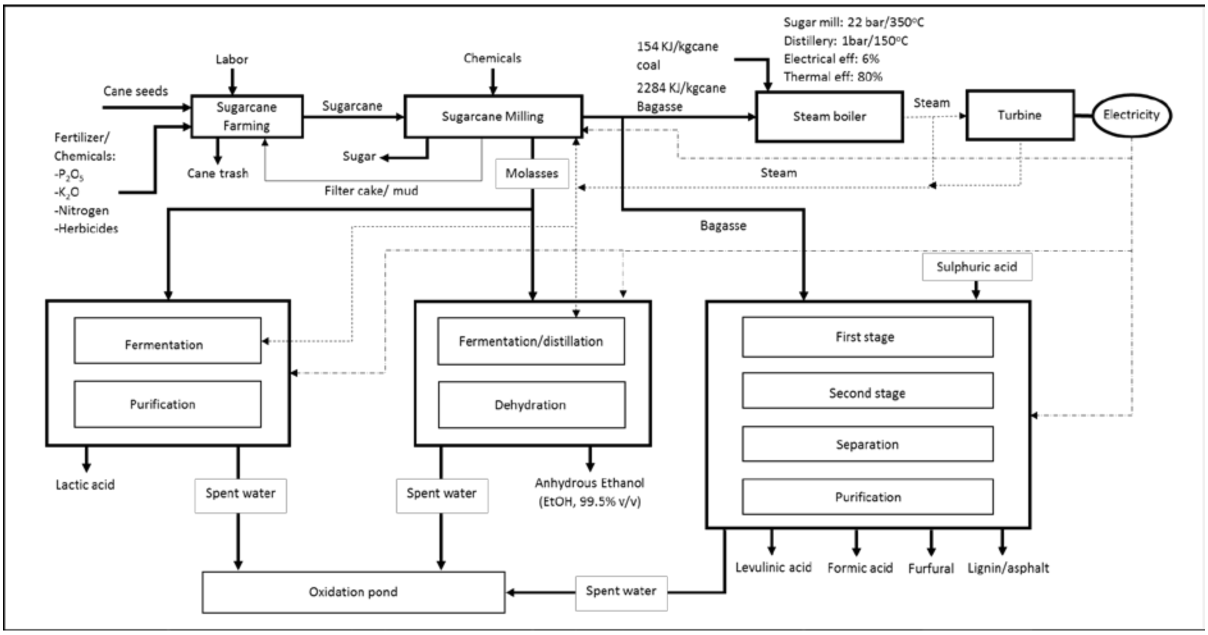


Fig 2: The proposed integration of sugar production process. *Adapted from literature[6] with several additions.*

then transported to the boiler as the fuel for the furnace, and the rest goes to the open storage.

2.1.3. Juice treatment

The sugar juice is separated from the solid impurities by passing through strainers, and then it is continued by clarifying process using sulfuric acid in a rotary drum. The impurities are collected in the form of filter cake which defined as the by-product and then it is separated from the clarified juice with filter screens. In the sugarcane field, the filter cake can be applied for fertilizer. Finally, the sugar juice which has cleaned from impurities is then purified, while the pH is adjusted for to the appropriate condition for the next process.

2.1.4. Sugar production

The clarified sugar juice is passed through a sequence of evaporators until the cane syrup concentration reaches 80% (w/w). This evaporation procedure is followed by crystallization of the concentrated syrup at low temperature under partial vacuum in which crystal seeds are added to trigger the crystal sugar formation which is the main desired product (raw sugar). This process is repeated several times until no more crystals formation observed. The raw sugar crystals are then processed in a different unit to get the final sugar product where it is packed and distributed to the customer. The molasses which remain after the multiple-crystallization is continuing to the ethanol production unit.

2.1.5. Ethanol production

The molasses is concentrated and further processed in the ethanol distillery. The molasses preparation prior to the fermentation is carried out with 4% (w/w) sulfuric acid (H_2SO_4). After the condition of molasses is achieved, the fermentation is started by introducing *Saccharomyces cerevisiae*. This kind of bacteria is useful for producing ethanol with the concentration of 7-10% (w/w), and it can be further distilled to 96% (v/v) of pure ethanol. The distillation process will leave spent wash or residual liquid waste. This wastewater is returned to the farm for irrigation.

2.2. The Scenario of Integrated Chemical-Sugar Production Process

As explained in the previous section, this report briefly introduces an integration process of sugar production with bio-refinery. The challenge of this integration is to ensure the operation of sugar production itself is not disturbed. Bio-refinery in this study is focusing on a limited number of chemicals including ethanol, lactic acid, levulinic acid and formic acid. The thorough step-by-step explanation of the process shown in figure 2 will be explained in the following segment.

2.3. Lactic Acid Production

In this process, lactic acid production is by the fermentation of molasses. The molasses (represented by glucose and fructose in figure 3) from sugar mill is diluted to a concentration of 12% prior to fermentation by *Lactobacillus delbrueckii* bacteria. The fermentation takes place in the fermenter tank with the temperature of 46°C, atmospheric pressure, pH 5 – 6 with the addition of nutrition (malt sprouts) and $CaCO_3$ as the pH stabilizer. Fermentation takes about 21 hours and will give lactic acid with yields of 90%. During the process, some of the calcium lactate, carbon dioxide, and water also produced. Carbon dioxide will be released into the atmosphere,

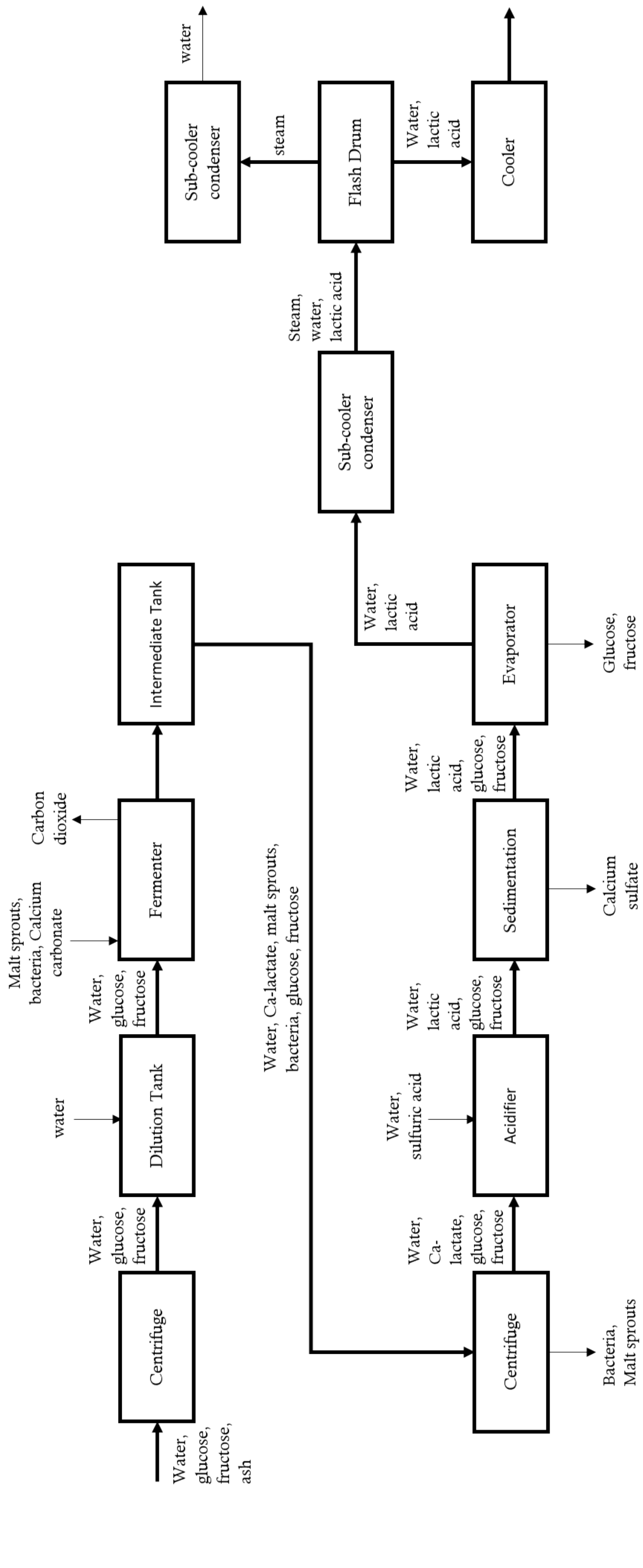
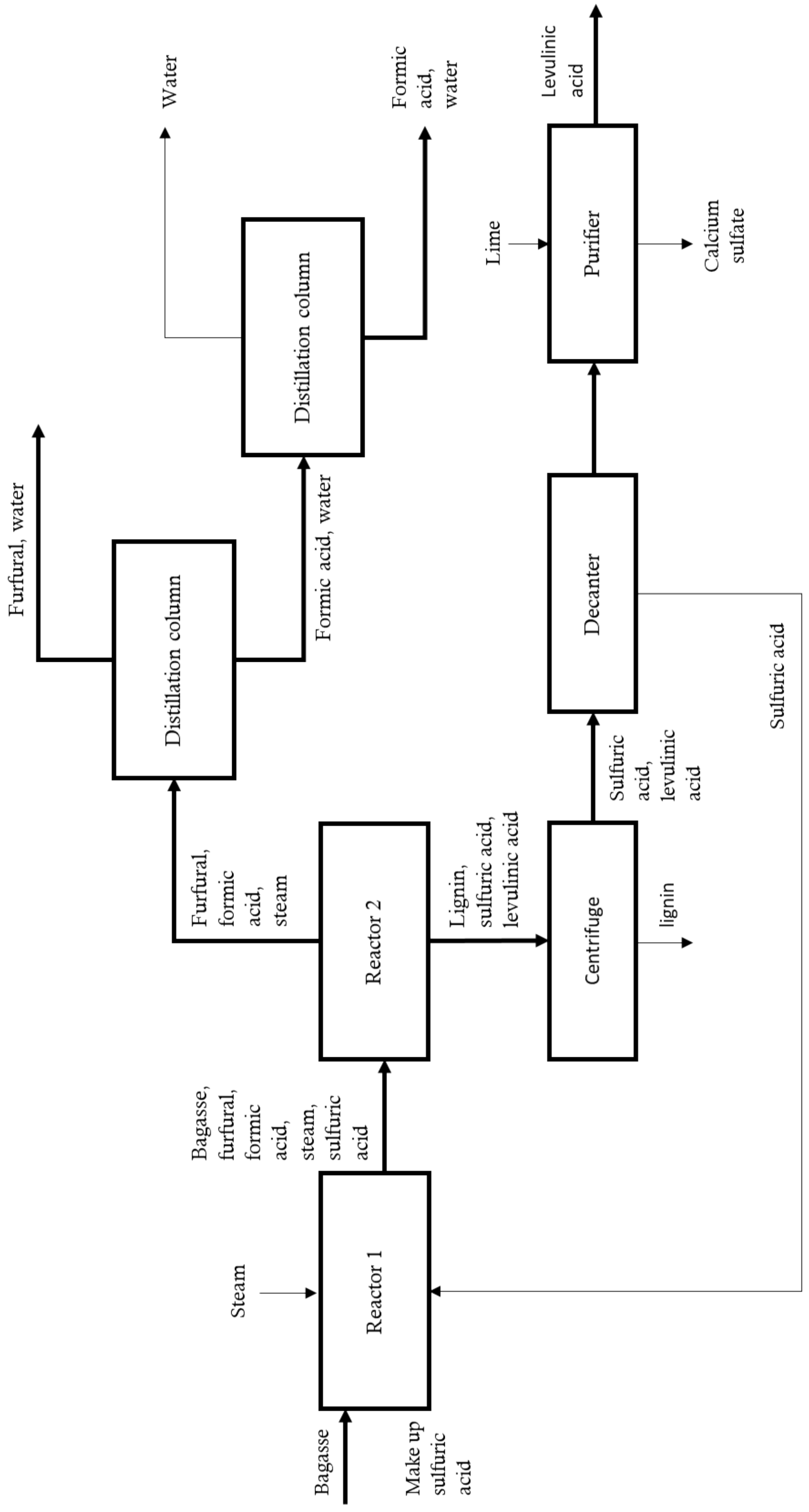


Fig 3: The Detailed Process of Lactic Acid Production from Molasses.

Fig 4: The Detailed Process of Levulinic Acid Production from Bagasse.



while the water phase will be transported to intermediate tank before the purification process.[41)]

The centrifuge unit in this process is practical for separating the product from the unreacted portion. This separation is important to remove the product from the contaminant like bacteria and malt sprouts. The water phase which is the outcome of centrifugation is acidified with sulfuric acid so that lactic acid and sediment of $CaSO_4$ is formed. Afterward, the calcium sulfate is removed by sedimentation. Lactic acid solution separated from the deposit is purified to get high concentrated lactic acid approximately 80%v/v. First, the glucose and fructose are separated using evaporator; lactic acid and water vapor will be exited in the vapor phase, and then it separated using partial sub-cooled condensation. Finally, lactic acid and a small part of the water will be cooled and stored in the storage tank. The detailed process of lactic acid production can be seen in figure 3.

2.4. Levulinic Acid, Furfural, and Formic Acid Production

First, bagasse is fed to a reactive extruder with operating pressure of 21 atm and temperature of 215°C to react with sulfuric acid. The process then continued to the second reactor (CSTR) with operating pressure of 16 atm and temperature of 195°C. After the reaction, furfural and formic acid are coming out from CSTR in the vapor phase and is separated using distillation column. Both furfural and formic acid are purified and stored in the storage tank. On the other hand, lignin is being separated from levulinic acid using a centrifuge. Sulfuric acid is recovered using a decanter and returned to the reactive extruder. Finally, levulinic acid is purified with lime to create sedimentation of calcium sulfate which can be separated using a centrifuge. The detailed process of levulinic acid production can be seen in figure 4.[42,43)]

2.5. Mass balance, energy balance, and economic analysis

The mass and energy balances calculation was applied to the main streams (ex. raw material, chemical reagent, water) as well as the side stream of the different process. The flow of some output stream which affected by the reaction was calculated according to the methods established in the literature. The estimation of energy consumption was calculated from the required energy to maintain the heat of the reaction on some processes.

The economic analysis was performed by the calculation methods established in the chemical engineering for plant design and economics analysis.[44-48)] The cost of equipment, feedstock and products were collected from journals, books, or websites while the direct and indirect investment costs were estimated.

3. Results and Discussion

3.1. Mass and energy balance

For achieving the target production of lactic for as much as 5000 tons per year, it needs 275 kg per hour of sulfuric acid, 3,367 kg per hour of malt sprouts, and 1,900 kg per hour of bacteria. For pH stabilizer agent, $CaCO_3$ is required with the amount of 6,734 kilograms per hour. For the process, it needs an additional of 6,500 kilograms per hour of steam.

On the other hand, to meet the target production of levulinic acid for 5,000 tons per year, formic acid as much as 2,000 tons per year and furfural as much as 3,250 tons per year, it requires 5,250 kilograms of bagasse per hour and 670 kg of sulfuric acid per hour for the start-up process. As the process runs continuously, the recovered sulfuric acid is recycled, thus left only a few amounts as much as 3.5 kg per hour of sulfuric acid. The required steam for this process is 1,053 kg per hour.

Water is, therefore, necessary to generate the steam. But not only has the water for the steam, but the process also needs water for cooling and utility. The total water required for the whole process is 8,830 kg per hour which is supplied by the local water supplier (PAM).

Energy is required for maintaining the temperature of some reaction and as well as to generate the utility steam. The unit like reactor, evaporator, and distillation column are energy intensive operations because of the high temperature and a significant amount of water involved. The total energy required for the process is about 662 kW per hour, and this energy is supplied by the local electric company (PLN). For the future consideration and improvement, it is necessary to self-generate the electricity using IGCC system.

3.2. Economic evaluation

Economic analysis is conducted to obtain a clear picture of the economic benefit that can be derived from this process. This analysis includes the approximation of capital cost, revenue, break-even point and other related information. The calculation is performed using the steady estimation, in which the fixed capital investment is applied to calculate the process equipment. Equipment cost can be obtained from the Perry's Chemical Engineering Handbook and trusted sites.

3.2.1 Total Capital Investment (TCI)

Total Capital Investment is combination amount of fixed capital investment and working capital investment that being invested in building and operating the factory.

3.2.2 Fixed Capital Investment (FCI)

Fixed capital investment is an investment which required for purchasing equipment and the construction. This investment can be distinguished into two type of investment, including direct and indirect fixed capital investment.

3.2.3 Direct Fixed Capital Investment (DFCI)

This type of investment is including; purchasing the equipment, the equipment installation, instrumentation and control, piping, land, building and layout, facility, etc.

3.2.4 Indirect Fixed Capital Investment (IFCI)

IFCI including construction cost, planning, and design cost, trial run, survey cost, feasibility study and the authorization, etc.

3.2.5 Working Capital Investment

Working capital is the amount of money which required for starting up the plant, and it also signifies the amounts of production cost for a month of operation before revenues from the process start. The working capital is needed to ensure that the manufacturing process is carried out smoothly.

3.2.6 Total Production Cost (TPC)

The critical part of complete cost estimation is the estimation of the total budget to the plant operation and selling out the products. While the capital expenditure only occurs once during the life of a project, the operating expenses are regular expenditures. Therefore it significantly influences the cash flow and the viability of a project.

The total production cost can be divided into two categories;

A. Manufacturing Cost

The manufacturing cost can be described as all expenses required to make a product until ready for shipment. These expenses include direct production costs, fixed manufacturing cost, and plant overhead cost.

B. General Expenses

General expense includes the administrative expenses, distribution expenses, research and development expenses, and financing expenses.[49)]

The estimation of overall total annual production cost is described in Table 1 and Table 2.

Table 1. The Annual Production Cost for Lactic Acid Production.

Cost Type		**USD (IDR)/year**	
Production Cost		**Fixed Cost**	**Variable Cost**
A	**Manufacturing Cost**		
1	**Direct**		
a	Raw materials	-	13,726,381 (194,681,271,908)
b	Supporting facilities	9,982 (141,570,000)	6,609,470 (93,742,112,994)
c	Shipping and packaging	-	274,527 (3,893,625,438)
d	Labor cost	539,010 (7,644,780,000)	-
e	Maintenance	440,153 (6,242,693,004)	-
f	Royalties and Patent	-	191,955 (2,722,500,000)
g	Laboratory	-	68632 (973,406,360)
2	**Plant Overhead**	195,832 (2,777,494,601)	-
3	**Depreciation**	2,851,436 (40,441,927,485)	-
a	Tax	211,014 (2,992,817,131)	-
b	Insurance	120,767 (1,712,847,740)	-
B	**General Expenses**		
1	administration	26,950 (382,239,000)	-
2	distribution & sales	-	27,453 (389,362,544)
3	interest	274,977 (3,900,000,000)	-
Total Production Cost		25,568,541 (362,638,648,205)	

Table 2. The Annual Production Cost for Levulinic Acid Production.

Cost Type		USD (IDR)/year	
Production Cost		Fixed Cost	Variable Cost
A	**Manufacturing Cost**		
1	**Direct**		
a	Raw materials	-	9,696,000 (137,651,681,619)
b	Miscellaneous materials	7,800 (110,632,442)	5,165,090 (73,256,472,853)
c	Shipping and packaging	-	238,165 (3,381,168,730)
d	Labor cost	434,000 (6,161,389,214)	-
e	Maintenance	499,792 (7,095,420,045)	-
f	Royalties and Patent	-	158,880 (2,255,574,808)
g	Laboratory	-	65,000 (922,788,707)
2	**Plant Overhead**	211,492 (3,002,497,524)	-
3	**Depreciation**	3,569,667 (50,677,662,694)	-
a	Tax	2,251 (31,953,976)	-
b	Insurance	124,948 (1,773,855,011)	-
B	**General Expenses**		
1	administration	27,883 (395,853,378)	-
2	distribution & sales	-	23,427 (332,584,516)
3	interest	688,479 (9,774,157,504)	-
Total Production Cost		20,928,130 (296,823,693,020)	

The total capital investment of each production was calculated from the fixed capital investment and the working capital investment. The TCI for lactic acid production was estimated to cost around IDR 466,998,587,947 or USD 32,876,700.59. On the other hand, the TCI for levulinic acid production was predicted to be *c.a.* IDR 132,583,442,104 or USD 9,339,000.

With the economic calculation, the number of minimum payback period (MPP), Internal Rate of Return (IRR), Net Present Value can be known. Minimum payback period is the minimum time to get back the investment. From the calculation, it needs four years to obtain the money as much as the expenses. The internal rate of return is used to assess the attractiveness of a business or a project. It is the discount rate that sets the net present value of all cash flows (both positive and negative) from the investment equal to zero. Equivalently, it is the discount rate at which the net present value of future cash flows is similar to the initial investment, and it is also the discount rate at which the total present value costs (negative cash flows) equals the total present value of the benefits (positive cash flows).[46] In this calculation, the IRR is 34.9%, and this value is more significant than the interest rate. Therefore it can be defined as an attractive project. Break even point is the production capacity where the amount of revenue is equal to the total cost. In this process, the break event point at first round was found to be at the 38% capacity. Moreover, the net cash flow present value shows the positive value after ten years which strengthen the argument that this project is feasible.

4. Conclusion

The outgrowing population and issue of global warming have triggered the movement for sustainable development to ensure the energy and basic commodity security in the future. The United Nation, together with the countries under the organization initiated the sustainable development goal in order to tackle those problems as well as to decrease the poverty. In Indonesia, the green industry policy has been used to ensure the energy security, feedstock sustainability and protecting the environment. With this policy, the government can control the industry that develops their business in Indonesia to perform an excellent industrial practice to achieve the sustainable development goals.

One of the idea to create a sustainable in the industry is by utilizing the side product or waste to obtain a more valuable commodity. In this report, the proposal of bio-refinery based on sugar industry has already briefly explained. The process is aiming for utilizing molasses for production of lactic acid and bio-ethanol as well as to use bagasse for producing levulinic acid. Lactic acid is produced by fermentation of molasses with *Lactobacillus delbrueckii* for 21 hours with a yield of 90%. On the other hand, levulinic acid is produced by hydrolysis in the two-stage reactor with a minimum yield of 70% and residence time between 25 to 30 minutes. The economic feasibility calculation showed proof that this project can be judged as feasible. This because the rate of return value is higher than the loan interest and this argument was strengthened by the positive number of the net cash flow present value. In the meantime, it can be concluded that the investment in the integration of sugar production and bio-refinery is promising.

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