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Techno-economic Analysis of Bioethanol Production from Palm Oil Empty Fruit bunch

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Abstract. Bioethanol has become more attractive as an alternative to fossil-based fuel: a biofuel and fuel additive to gasoline. Therefore, people are interested in ethanol from a feedstock that does not compete with the food supply. Oil palm empty fruit bunch (EFB) are major biomass by-products from the palm oil industry. This study proposes commercial-scale bioethanol production from EFB of 99.5 wt.% at 10,000 L/day ethanol. This bioethanol production was formulated using the commercial simulator and divided into four stages: pre-treatment, Hydrolysis, fermentation, and purification. EFB is pretreated using hot water, hot-compressed water, and alkaline hydrogen peroxide approaches. Simultaneous Saccharification and fermentation are chosen to produce the target of ethanol. At optimum conditions, it can conclude that the ethanol production rate was 13,950 litter per day by using an empty fruit bunch of 47,208 kg per day. Finally, the economic feasibility is also evaluated under techno-economic analysis. From the economic perspective, the net present value (NPV), internal rate of return (IRR), and payback period (PBP) equate to 9.016 M USD, 15%, and seven years, respectively, based on 20 years of life and a total capital investment of 12.32 M USD. The results show that bioethanol production is profitable.

Keywords: Bioethanol production; Empty fruit bunch; Process simulation; Techno-economic analysis

1. Introduction

Nowadays, humankind has more concerned about global warming and the global petroleum crisis. Many countries worldwide are accelerating the development of alternative fuel technologies to reduce dependence on petroleum. Bioethanol has become more attractive as an alternative to fossil-based fuels. It can be used as a biofuel and fuel additive to gasoline. Pure ethanol has an energy content of around 57% of gasoline's specific energy estimated (Sugiarto, 2021; Mukherjee & Sovacool, 2014; Chen & Khanna, 2012; Karimi & Christi, 2007). Blending ethanol with gasoline can improve the octane number of fuels. Almost ethanol production is produced by the fermentation of food crops such as rice, wheat, corn, and sugarcane, which contain starch and sugar (Wibowo et al., 2020; Bateni et al., 2014; Balat, 2011; Galbe et al., 2007). Starch and sugar-based feedstock are defined as the first generation of biofuels. It is limited because feedstock also leads to food supply and land utilization problems.

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The feedstock named the second generation of biofuels includes lignocellulosic biomass such as non-food crops, forest residue, woody biomass, and municipal waste (Halder et al., 2019; Galbe & Zacchi, 2007). Oil palm wastes are an attractive lignocellulose source outside the human food chain that makes these materials inexpensive feedstock for ethanol production and no conflict with the food supply. This study focuses on the simulation model of bioethanol production from palm empty fruit bunch. Consequently, a techno-economic analysis is performed (Stoklosa et al., 2017; Do et al., 2014; Shafiei et al., 2013; Gnansounou & Dauriat, 2011; Tao et al., 2011). The aim is to express the economic viewpoints, especially in Thailand, to address the waste utilization of the palm oil industry.

2. Methods

The empty fruit bunch (EFB) is used as raw material for bioethanol production (Singh et al., 2014). The ethanol production from palm empty fruit bunches is 10,000 liters per day at a concentration of 99.5% wt. This section describes the process of modeling ethanol production in the Aspen suite simulator, which has been described as using the proper equipment for simulating ethanol production (Suwajittanon et al., 2022). Four main sections function as Pretreatment (to digest Lino-cellulosic to smaller molecules), Hydrolysis (to convert small molecules to sugars), Fermentation (to produce ethanol from sugars), and Purification (to purify ethanol to 99.5%).

2.1. *Process Overview*

The bioethanol production process from empty oil palm fruit bunches includes nine steps: hot compressed water, hot water extraction, alkaline hydrogen peroxide, neutralization (Chin et al., 2013; Balan et al., 2021), mixing, autoclave, simultaneous Saccharification (Hossain et al., 2020; 2018; Choedkiatsakul et al., 2015a; 2015b; Li et al., 2010), and fermentation process (SSF), autoclave again, and purification. Figure 1 describes various condition information used in the actual experiment and the results derived from the experiment.

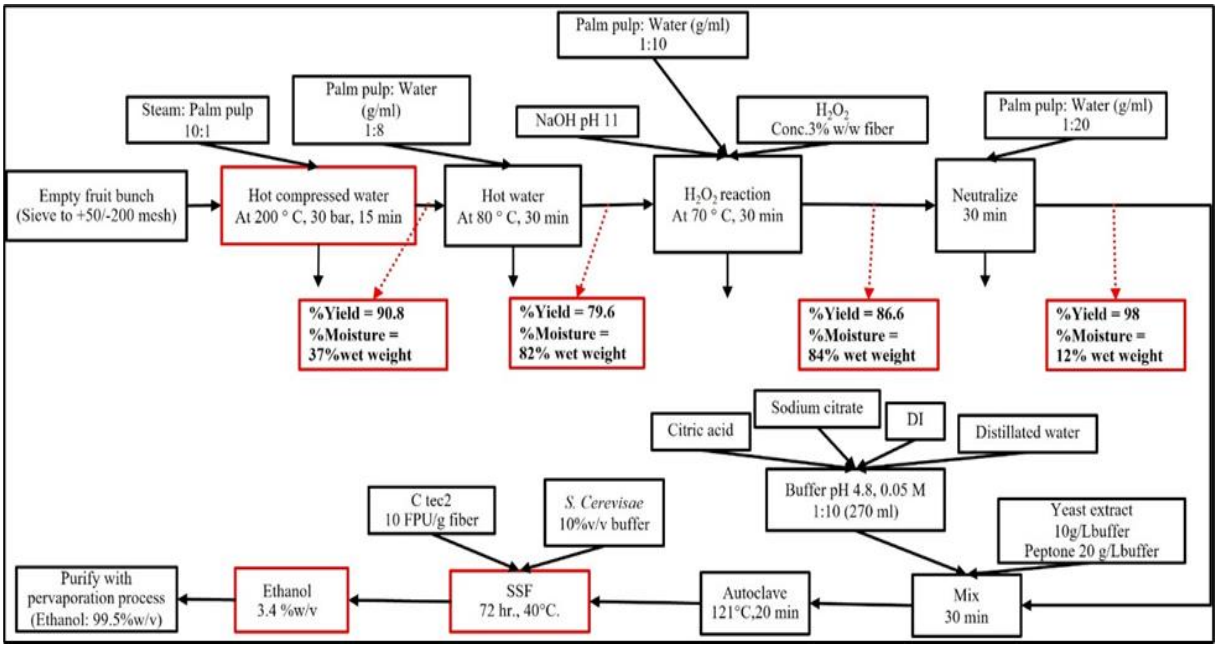

Figure 1 Overall process of bioethanol production from oil palm empty fruit bunch

2.2. *Composition of raw material*

The composition of the oil palm empty fruit bunch is experimented with and available on our laboratory website under permission.

2.3. *Process description*

Figure 2 depicts the bioethanol production process from oil palm empty fruit bunch flowsheet in Aspen plus. The first steps of substances are added to the FEED1-line, and steam is added to the STEAM1-line. They then begin the pre-treatment process. The objective of the hot compressed water unit is to dissolve and remove hemicellulose into a liquid phase. When a hot compressed water process has already been completed, the second sub-pretreatment is the hot water extraction process. This unit eliminates hemicellulose and lignin, which uses the WATER1-line to add water, and the final pre-treatment is an alkaline hydrogen peroxide treatment process. When the process is completed, sodium hydroxide (NaOH) is added by the NaOH-line, the H_2O_2-line adds hydrogen peroxide (H_2O_2), and lignin is delignification by H_2O_2. After that, all substances are neutralized, and this step introduces water into the process via the WATER3-line. The mixing process has the following steps combining yeast, peptone, and buffers in a mixing tank. The next step is to sterilize contamination with the substance using the autoclave process. After sterilization, the substances are stored in the STORAG1-tank for simultaneous Saccharification and fermentation. This process needs a 72-hour operation time and incorporates yeast and enzyme (Ctec2) into the cycle. At the completion of the process, all substances are separated from solid waste before being collected in the liquid phase in the STORAGE tank. Next, the purification process that uses pervaporation is used to purify ethanol for the next cycle. A comparison of the proposed purification is available elsewhere (Suwajittanon et al., 2022). Finally, it achieves 99.5 %wt. ethanol or Anhydrous ethanol for fuel blending as a customer requirement.

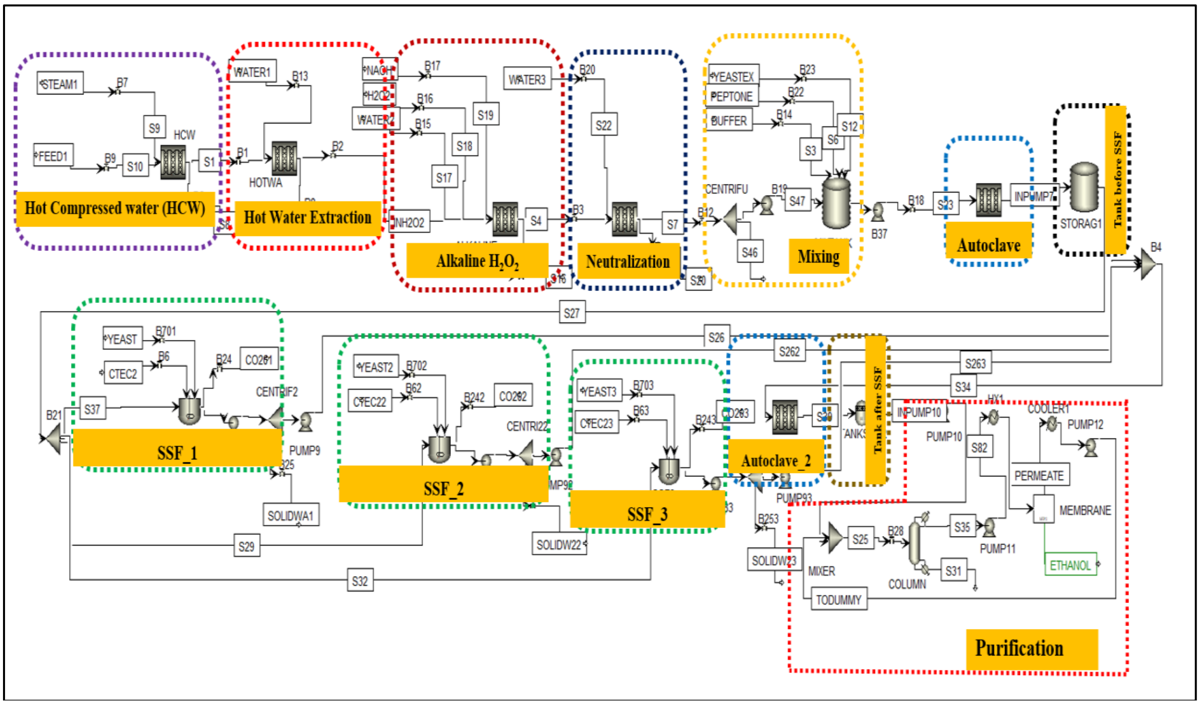

Figure 2 The completed flowsheet of bioethanol production from oil palm empty fruit bunch

2.4. Economic Evaluation

The maximization of financial indicators such as the gross operating margin (GOM) or the net present value (NPV) is a common objective in investment projects and process optimization. In such cases, the project evaluator will use the NPV (Net Present Value) as a basic decision. In capital budgeting, NPV assesses a project's or investment's profitability. It is calculated by subtracting the present value of cash inflows from the current value of cash outflows over time. As a result, one of the project's objectives is to maximize net present value to determine the profitability of developing an EFB ethanol production process. The GOM determines the cash flow associated with gross profits or income and annual operating expenses (OPEX). Net present value is calculated as the difference between annual gross profits and total capital expenditure (CAPEX).

CAPEX is for major purchases that will be used in the future. Because these costs can only be recovered through depreciation, companies ordinarily budget for CAPEX purchases separately from preparing an operational budget. CAPEX refers to the costs of constructing a new plant or changing an existing chemical manufacturing plant. Fixed capital investment (FCI) refers to the capital required to supply the necessary manufacturing and plant facilities, whereas working capital refers to the capital required to operate the plant. The total capital investment is the sum of the fixed capital investment and the working capital. The fixed-capital investment represents the direct cost of the installed process equipment and auxiliaries required for complete process operation. These plant components include the land, processing buildings, administrative and other offices, warehouses, laboratories, transportation, shipping and receiving facilities, and other permanent parts of the plant. The raw-materials inventory included in working capital usually amounts to a first-month supply of the raw materials valued at delivered prices. The ratio of working capital to total capital investment varies with different companies. Still, most chemical plants use an initial working capital amounting to 10-20% of the total capital investment. This project uses working capital at 15% of the total capital investment. As mentioned, CAPEX cost includes the purchased equipment cost and the direct and indirect capital investment. This study utilized the fractionated calculation (Peters et al., 2003). CAPEX can be calculated by estimating the cost based on equipment cost. Therefore, the purchase of equipment cost is a key for CAPEX estimation. In this work, only the purchased equipment cost of the base case is calculated using APEA (Aspen Process Economic Analyzer) as a supportive tool to evaluate the industrial equipment price mainly. The estimation of the equipment price is based on the 1st Qtr of 2017. As a result, all of the prices exported from APEA should be recalculated to the cost in the current year, 2020. The chosen cost index utilized in this work is the Marshall & Swift Equipment Cost Index (M&S Index). Therefore, the M&S index value used to advance the purchased equipment cost should be in 2017 and the present index in 2020 following equation (1).

$$\text{Equipment cost}_{2020} = \text{Equipment cost}_{2017} \times \left(\frac{\text{M\&S Index 2020}}{\text{M\&S Index 2017}}\right) \quad (1)$$

In other cases, the equipment cost is estimated by the scaling equation, which shows in equation (2)

$$\text{Estimated cost} = \text{Base case equipment cost} \times \left(\frac{\text{The capacity of estimated equipment}}{\text{The capacity of base case equipment}}\right)^{n} \quad (2)$$

Where n is the exponential value depending on the specific type of equipment

OPEX can be estimated from the summation of direct costs, fixed costs, and general expenses. This study utilized the fractionated OPEX calculation (Peters et al., 2003); the other relevant economic metric should be considered in addition to the benefit and expense aspects. The discounted flow rate is to apply an adjustment factor to the net present value. The adjustment factor derived from the accepted time value of money is the so-called "discounting rate." WACC (Weighted Average of Capital Cost) has been considered as most investors rely on discounting the future cash flow for new investments. The WACC in this work for new plant investment is 7%. For the ethanol production operation, the operating hours each year were assumed for 7,200 hours. The summary of all related economic analyses is illustrated in Table 1.

Table 1 The additional information for economic evaluation

Description	Value
Number of operating weeks	52 weeks/period
Number of periods for analysis	20 years
Number of operating hours	7200 hours/period
Plant lifetime	20 years
Required Rate of Return (r)	10%
TAX	10%
Working capital	5%
Depreciation method	Straight line
Salvage value	10% of the Purchased equipment cost
WACC	7%

3. Results and Discussion

At the designed conditions, bioethanol from an empty fruit bunch can produce ethanol of 13,950 litter per day by using an empty fruit bunch of 47,208 kg per day.

The economic evaluation was performed for selling ethanol as the main product. The equipment size was calculated in the first step, and the purchase cost was estimated. The major equipment, such as the pump, heat exchanger, reactor, and distillation column, was sized, and estimated the purchased cost with APEA. However, the batch units were sized using a mass flow through the units at a cycle time. The purchased costs were estimated for the equipment that Aspen Process Economy Analyzer was not provided (Seider et al., 2009). The characteristic is represented by the unit's capacity, which was used to estimate the purchased cost.

Total capital investment (TCI) or Total capital expenditure (CAPEX) was then estimated; it was associated with the plant's construction. The fixed-capital investment (FCI) and working capital (WC) results are calculated using critical assumptions for a solid-fluid process. However, the total equipment cost from APEA estimated the price based on the 1st Qtr of 2017. Marshall & Swift Equipment Cost Index (M&S Index) converts total equipment costs from 2017 to 2020. CAPEX of bioethanol production is 29,014,831.77 USD. The purchase of equipment cost is directly used for CAPEX calculation by ratio factor (Peters et al., 2003). The detail of the CAPEX parameter of the base case is illustrated in Table 2.

Figure 3 illustrates the CAPEX distribution in each section. It can be noticed that the highest capital costs are the saccharification and fermentation section (SSF), followed by the purification section and pre-treatment section. The SSF section is the core of the ethanol production process to convert sugar into ethanol. The distillation process is highly complex, nonlinear, and high order. It has many constraints that are frequently encountered by the operation. The equipment with this unique characteristic of operation requires a high construction cost. The pre-treatment section operates at high temperatures, making the building cost very high.

Bioethanol production process from empty fruit bunch must work under high pressure (30 bar) in the first pre-treatment process. It results in the requirement of high equipment purchasing costs in a hot compress water process (HCW).

Table 2 Total capital investment in bioethanol production

Estimating capital investment items based on delivered-equipment cost		
Cost parameter	Solid-Fluid processing	Cost ($)
Direct costs		
Purchased equipment delivered	100	2,597,000
Purchased-equipment installation	39	1,013,000
Instrumentation and controls (installed)	13	338,000
Piping (installed)	31	805,000
Electrical systems (installed)	10	260,0000
Buildings (including services)	29	753,0000
Yard improvement	10	260,000
Service facilities (installed)	55	1,428,000
Land	6	156,000
Total direct plant cost	302	**7,610,000**
Indirect costs		
Engineering and supervision	32	831,000
Construction expenses	34	883,000
Contractor's fee	18	467,000
Contingency	36	935,000
Total indirect plant cost	120	3,116,000
Fixed-capital investment (FCI)	422	10,726,000
Working capital (15% of total capital investment)	74	1,596,000
Total capital expenditure (CAPEX)	496	**12,322,000**

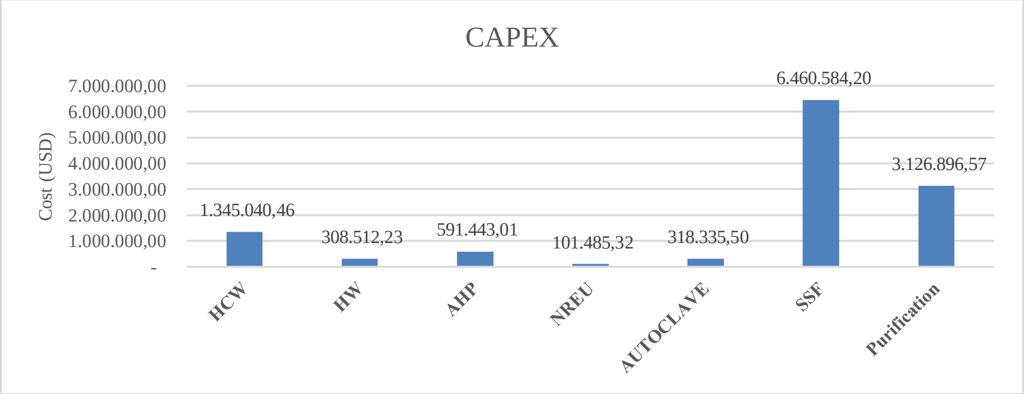

Figure 3 CAPEX distribution based on process section

Total product cost (TPC) was estimated from direct manufacturing cost, fixed manufacturing cost, and general expense. The distribution of the operating cost of the base case is illustrated in Figure 4, which introduces the essential impact parameters. It can be noticed that the raw material is the highest portion of the OPEX, followed by utility cost and operating labor cost subsequently. The raw material is the most increased cost due to the large requirement of EFB in the ethanol pr process. For utility, the cost is second for large portions. Because the utility cost is directly manufacturing cost based on process capacity, the labor cost is the third large portion because various operating processes within ethanol production require many workers and specific technical positions. The base case's annual OPEX (Table 3) is 3,154,350.53 USD.

The net present value is calculated based on CAPEX and OPEX, which were calculated previously. Wat the same time, the income of this process came from selling ethanol. Net present value (NPV) is calculated by the assumption of weighted average cost of capital (WACC) which is 10% of profit and a plant lifetime of 20 years. From the calculation, the NPV of the base case is 9,016,964 USD. The process is worth investment because the net present is a positive value. In addition, the base case's internal rate of return (IRR) is 15%, which is greater than WAC and the payback period (PB) is around 7 years as in Table 4.

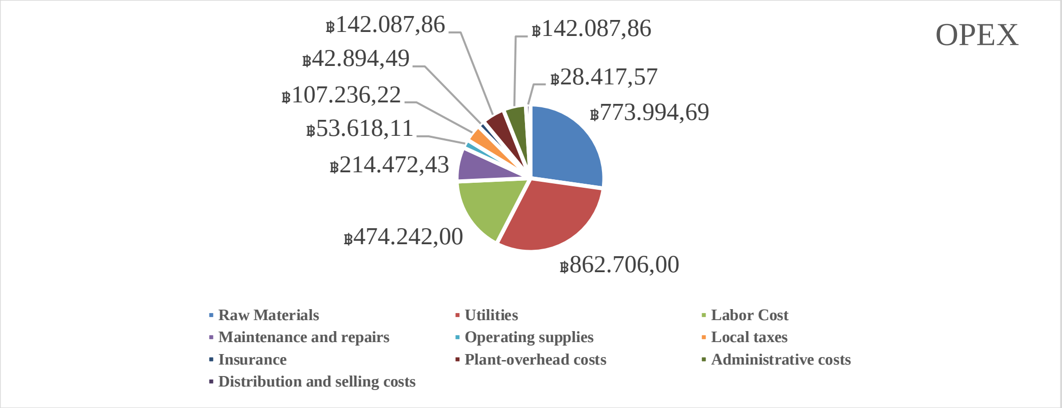

Figure 4 CAPEX distribution based on process section

Table 3 Estimating total product cost

Estimating the total product cost		
Manufacturing cost		
Direct product cost		Cost ($)
	Raw materials	774,000
	Utility	863,000
	Labor cost	474,000
	Maintenance and repair	214,000
	Operating supply	54,000
Fix charges		
	Local taxes	107,000
	Insurances	43,000
	Plant overhead cost	142,000
General expense		
Administrative cost		142,000
Distribution and selling cost		29,000
Total production cost (OPEX)		**2,869,000**

Table 4 Economic result summary of the base case

Economic parameter	Value
Total capital cost (CAPEX)	12,322,000 USD
Total production cost (OPEX)	2,869,000 USD
Total annual income	5,006,486 USD
Net present value (*NPV*)	9,016,964 USD
Internal rate of return (*IRR*)	15%
Payback period (PB)	7 years

4. Conclusions

The design of bioethanol production was simulated by using empty fruit bunch as feedstocks. The process was separated into four sections: pre-treatment, Hydrolysis, fermentation, and purification. Pervaporation technologies were proposed as ethanol dehydration technologies. The empty fruit bunch was treated with hot-compressed water and hot water techniques for the pre-treatment section. Then, the alkaline hydrogen peroxide technique was used to treat the raw materials. After sterilizing and feeding into the fermenter, the raw materials were converted into ethanol using simultaneous Saccharification and fermentation. In the purification process, 99.5% wt. Ethanol was produced by using pervaporation technologies. The ethanol production rate was 13,950 litter per day by using an empty fruit bunch of 47,208 kg per day. Next, the techno-economic analysis was performed. The net present value (NPV) is calculated by the assumption of weighted average cost of capital (WACC) which is set as 7%, tax which is set fit, and a designated lifetime of 20 years. From the calculation, the NPV of the base case is 9,016,964 USD. The process is worth investment because the net present is a positive value. In addition, the rate of return (IRR) is 15%, which is greater than WACC, and paid back period (PB) is around seven years.

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References

Balan, W.S., Janaun, J., Chung, C.H., Semilin, V., Zhu, Z., Haywood, S.K., Touhami, D., Chong, K.P., Yaser, A.Z., Lee, P.C., Zein, S.H., 2021. Esterification of Residual Palm Oil Using Solid Acid Catalyst Derived from Rice Husk. *Journal of Hazardous Materials*, Volume 404, p. 124092

Balat, M., 2011. Production of Bioethanol from Lignocellulosic Materials via the Biochemical Pathway: A Review. *Energy Conversion and Management*, Volume 52, pp. 858–875

Bateni, H., Karimi, K., Zamani, A., Benakashani, F., 2014. Castor Plant for Biodiesel, Biogas, and Ethanol Production with a Biorefinery Processing Perspective. *Applied Energy,* Volume 136, pp. 14–22

Chen, X., Khanna, M., 2012. Food vs. Fuel: The Effect of Biofuel Policies. *American Journal of Agricultural Economics,* Volume 95(2), pp. 289–295

Chin, S.X., Chia, C.H., Zakaria, S., 2013. Production of Reducing Sugar from Oil Palm Empty Fruit Bunch (EFB) Cellulose Fibers via Acid Hydrolysis, *BioResources,* Volume 8(1), pp. 447–460

Choedkiatsakul, I., Ngaosuwan, K., Assabumrungrat, S., Mantegna, S., Cravotto, G., 2015a. Biodiesel Production in a Novel Continuous Flow Microwave Reactor. *Renewable Energy,* Volume 83, pp. 25–29

Choedkiatsakul, I., Ngaosuwan, K., Assabumrungrat, S., Tabasso, S., Cravotto, G., 2015b. Integrated Flow Reactor That Combines High-Shear Mixing and Microwave Irradiation for Biodiesel Production. *Biomass and Bioenergy,* Volume 77, pp.186–191

Do, T.X., Lim, Y.I., Yeo, H., 2014. Techno-Economic Analysis of Biooil Production Process from Palm Empty Fruit Bunches. *Energy Conversion and Management,* Volume 80, pp. 525–534

Galbe, M., Sassner, P., Wingren, A., Zacchi, G., 2007. Process Engineering Economics of Bioethanol Production. American Journal of Agricultural Economic, Volume 2007, pp. 289–295

Galbe, M., Zacchi, G., 2007*. Pre-Treatment of Lignocellulosic Materials or Efficient Bioethanol Production.* Biofuels. Berlin: Springer

Gnansounou, E., Dauriat, A., 2011. Techno-economic Analysis of Lignocellulosic Ethanol: A Review. *Bioresource Technology,* Volume 101(13), pp. 4980–4991

Halder, P., Azad, K., Shah, S., Sarker, E., 2019. *Advances in Eco-Fuels for a Sustainable Environment*. Cambridge, USA: Woodhead Publishing

Hossain, N., Zaini, J., Jalil, R., Mahlia, T.M.I., 2018. The Efficacy of The Period of Saccharification on Oil Palm (Elaeis Guineensis) Trunk Sap Hydrolysis. *International Journal of Technology,* Volume 9 (6), pp. 652–662

Karimi, K., Christi, Y., 2007. *Encyclopedia of Sustainable Technologies.* Cambridge: Elsevier

Li, X., Kim, T.H., Nghiem, N.P., 2010. Bioethanol Production from Corn Stover Using Aqueous Ammonia Pre-Treatment and Two-Phase Simultaneous Saccharification and Fermentation (TPSSF). *Bioresource Technology,* Volume 101(15), pp. 5910–5916

Mukherjee, I., Sovacool, B.K., 2014. Palm Oil-Based Biofuels and Sustainability in Southeast Asia: A Review of Indonesia, Malaysia, and Thailand. *Renewable and Sustainable Energy Reviews,* Volume 37, pp. 1–12

Peters, M.S., Timmerhaus, K.D., West, R.E., 2003. *Plant Design and Economics for Chemical Engineers.* USA: McGraw-Hill

Seider, W.D., Seader, J.D., Lewin, D.R., Widagdo, S., 2009. *Product and Process Design Principles Synthesis, Analysis, and Evaluation.* New Jersey, USA: Wiley-Interscience, John Wiley & Sons

Shafiei, M., Kabir, M.M., Zilouei, H., Horváth, I.S., Karimi, K., 2013. Techno-Economical Study of Biogas Production Improved by Steam Explosion Pre-Treatment. *Bioresource Technology,* Volume 148, pp. 53–60

Singh, R., Shukla, A., Tiwari, S., Srivastava, M., 2014. A Review on Delignification of Lignocellulosic Biomass for Enhancement of Ethanol Production Potential. *Renewable and Sustainable Energy Review,* Volume 32, pp. 713–728

Stoklosa, R.J., del-Pilar, O.A., da-Costa, S.L., Uppugundla, N., Williams, D.L., Dale, B.E., Hodge, D.B., Balan, V. 2017. Techno-Economic Comparison of Centralized Versus Decentralized Biorefineries for Two Alkaline Pre-Treatment Processes. *Bioresource Technology,* Volume 226, pp. 9–17

Sugiarto, B., Dwinanda, M.F., Auliady, D., Andito, R.N., Mokhtar, Simanjuntak, C.R.M., 2021. Investigation on Cyclohexanol as an Oxygenated Additives for Gasoline – Bioethanol Mixture on The Combustion and Emission Characteristic of Spark Ignition Engine. *International Journal of Technology,* Volume 12(5), pp. 1071–1080

Suwajittanon, P., Thongrak, P., Srinophakun, T.R., 2022. Techno-Economic Analysis of Commercial-Scale Bioethanol Production from Oil Palm Trunk and Empty Fruit Bunch. *Agriculture and Natural Resources,* Volume 56(4), pp. 825–836

Tao, L., Aden, A., Elander, R.T., Pallapolu, V.R., Lee, Y.Y., Garlock, R.J., Balan, V., Dale, B.E., Kim, Y., Mosier, N.S., 2011. Process and Techno-Economic Analysis of Leading Pre-Treatment Technologies for Lignocellulosic Ethanol Production Using Switchgrass. *Bioresource Technology,* Volume 102, pp. 11105–11114

Wibowo, C.S., Setiady, N.I., Masuku, M., Hamzah, A., Fedori, I., Maymuchar, Nugroho, Y.S., Sugiarto, B., 2020. The Performance of a Spark Ignition Engine using 92 RON Gasoline with Varying Blends of Bioethanol (E40, E50, E60) Measured using a Dynamometer Test. *International Journal of Technology,* Volume 11(7), pp. 1380-1387