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A Comparison of EFB to Ethanol Production by Integrating Between RBD Palm Oil and EFB Pulping Plant: An Assessment for Energy, Environmental and Economical Advantages

Arief Ameir Rahman Setiawan[1,5], Ary Mauliva Hada Putri[2], Teuku Beuna Bardant[2*], Roni Maryana[2], Yanni Sudiyani[2], Muryanto[2], Eka Triwahyuni[2], Deliana Dahnum[2], Nino Rinaldi[2], Yan Irawan[2], Tofael Ahamed[3], Ryozo Noguchi[4]

[1]*Graduate School of Science and Technology, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, 305-8572, Japan*
[2]*Research Centre for Chemistry, National Research and Innovation Agency, 452 Bldg, Puspiptek, Tangerang Selatan, 15314, Indonesia*
[3]*Faculty of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, 305-8572, Japan*
[4]*Graduate School of Agriculture, Kyoto University, Kitashirakawa Oiwake-cho, Sakyo-ku, Kyoto 606-8502, Japan*
[5]*Research Centre for Sustainable Production System and Life Cycle Assessment, National Research and Innovation Agency, 720 Bldg, Puspiptek, Tangerang Selatan, 15314, Indonesia*

Abstract. A comparative evaluation between two scenarios to utilize Empty Fruit Bunch (EFB) biomass residue for producing bioethanol was performed. The simulations included EFB-to Ethanol integrated into the Refined, Bleached & Deodorized (RBD) palm oil scenario as the first archetype and EFB-to-ethanol integrated with the pulping plant scenario as the second archetype. Literature reviews for each archetype were conducted to accomplish data for definitions, assumptions, and simulation analysis of each production stage. Ethanol production capacity was set at 255.55 kg as the basic calculation for mass and energy balances. The energy preference focused on energy efficiency and the environmental preference focused on consumed water and wastewater load. The simulation showed that excess energy from the Refined, Bleached & Deodorized Palm Oil (RBDPO) plant, which processes 5 tons of Fresh Fruit Bunch (FFB) equals to 82% of the required energy for producing 255.55 kg of ethanol. This required energy could also be supplied by excess energy from the combustion of 14.9 tons of dried black liquor in EFB pulping plant with 10.5 tons production capacity. The additional wastewater from the EFB-to-ethanol unit in the second archetype was only 2% of the wastewater from the EFB pulping plant with only a 5% increase in water consumption but it required a large production capacity. The first archetype could use 58.4% of the EFB waste. However, the required water increased from 5.3 m^3 to 20.88 m^3 for this archetype and required additional water treatment plant due to the different pollutant components from the additional installation units. The first archetype could gain additional income, which equals 18.5% of RBDPO sales. However, investment for integration of the first archetype was larger than the second archetype due to different types of additional installation units. Integration as in the second archetype required small modification and installation, with 2% additional income in 10.5 tons of pulp daily sales.

Keywords: Black liquor combustion; Cellulose hydrolysis; Energy effectiveness; Utilization

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[*] Corresponding author's email: qaismajnun@gmail.com, Tel.: +62-21-7560929; Fax: +62-21-756-0549

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1. Introduction

In commercial scale best practice, as also simulated in this paper, the fiber and shell were simulated to be burned as an energy source. Empty Fruit Bunch (EFB) becomes the rest challenging waste to deal with. Utilization of EFB ash for fertilizer is no longer an interesting option since many Crude Palm Oil (CPO) producing countries not allowing EFB burning in plantation sites (Walker *et al.,* 2018; Van-Dam, 2012). Thus, a special incinerator was required for converting EFB into ash. Mulching EFB to the plantation land was the second cheapest practice and claimed to improve soil deterioration management by avoiding run-off and erosion (Afandi *et al.,* 2017). Along with global concern for the environmental impact of the production process, the Global Warming Potential (GWP) of the process becomes a challenging issue. The GWP per ton of EFB, if stockpiled on land surfaces as the open lagoon-like mulching practice, is 180.90 kg CO_2 equivalent (Nasution *et al.,* 2020).

Converting EFB into ethanol is one of the promising options due to its potential availability, as acknowledged in a previous review (Hossain *et al.,* 2017). The conversion path proposed by this review was similar to this study, which is through *Saccharomyces cerevisiae* fermentation. The review also briefly introduced commercializing other fermentation products as a co-product, xylitol. Selling dried yeast is also a co-product option. A preliminary study utilizing EFB hydrolysate for producing dried *Saccharomyces cerevisiae* yeast gave promising results. The production cost per kilogram of dried yeast was less than Rp 20,000.00 or US$ 1.27 (Hermansyah *et al.,* 2015). The potential profit from co-product is an advantage for covering the extra cost in EFB-to-ethanol conversion. The extra cost came from the lignocellulose pre-treatment requirement. Some studies even observed the utilization of advanced physical process assistance for pre-treatment, such as microwaves (Harahap *et al.,* 2019) and ultrasound (Hermansyah *et al.,* 2019). However, the production cost is still challenging compared to starch-based raw materials.

A previous study used tofu waste as raw material and *Aspergillus niger* as hydrolyzing agent (Febrianti *et al.,* 2017). The study reported that substrate conversion efficiency was up to 88%, but the obtained bioethanol was 7.69 g/L. Bioethanol production through fermentation other than yeast was reported using *Clostridium ljungdahlii* (Anggraini *et al.,* 2019). The bacteria used synthetic gas as a feed, but the obtained ethanol concentration was 1.09 g/L. Similar to the previous study, the obtained ethanol concentration was considered low, which led to a great challenge in it is refinery feasibility.

EFB-to-ethanol conversion, as proposed in this study, similar to other waste-to-energy conversions, is still having economic feasibility as the main challenge. Other waste, such as municipal solid waste, had its advantages due to its main component being plastics. Thus, it has a high calorific value, 8970 MJ/kg, and is very competitive as fuel for electric power plants. The economic feasibility of converting municipal waste to energy has been reported using South Tangerang, Banten, Indonesia, as the case study (Prabowo *et al.,* 2019). In the case of EFB, its availability is in wet condition and with a low C/H ratio, which also makes a low EFB calorific value. This is leading to high transportation costs per produced calorie energy from EFB.

This research proposed integrating EFB-to-ethanol conversion units into other production plants to avoid transportation costs. The obtained ethanol can be self-utilized for gasoline substitutes in their transporting unit as previously proposed for biodiesel utilization in Refined, Bleached & Deodorized Palm Oil (RBDPO) production plant (Battle *et al.*, 2021). This is one of the circular economy approaches at the enterprise management level. According to a previous review, the greatest innovative activity which can affect the diffusion of "circular" innovations is manifested at this level (Zaytsev *et al.,* 2021). These substitutions will reduce overall GHG emissions. Transportation as one of the contributors to GHG emissions was confirmed by a preliminary assessment of GHG emission trends in food production and consumption in Malaysia (Petersen *et al.*, 2014; Padfield *et al.*, 2012).

This research proposed a simulation for the integration of EFB into an ethanol conversion unit. A comparative evaluation between two ways of integrating the conversion process was conducted. Whether the EFB–to-Ethanol plant is integrated into a pulping plant or integrated into an RBD palm oil production plant. The evaluation was based on their potential energy-environment benefits. This is a step further from the Multi Criteria Decision Making (MCDM) technique applied in the assessment of composting for organic waste management in the previous study (Shukor *et al.*, 2018). More calculated results based on reliable data from the existing pilot plant were provided in this study to make it more credible and traceable for validation.

2. Methods

2.1. The evaluated scenarios

Reviews of background literature and description of each proposed scenario were conducted in order to accomplish the data survey and simulation analysis of each production stage. Definition and assumptions limitations were established for the observed multi-product system. This establishment helps much in characterizing the mass and energy balance of the studied processes.

The compared simulations in this study were EFB-to Ethanol integrated into the RBD Palm oil scenario and EFB-to-ethanol integrated with pulping plant scenario. The comparison analysis for energy preference was focused on utilizing energy effectiveness. The environmental preference was focused on consumed water and produced wastewater. The investment requirement and potential profit from ethanol sales were also calculated.

The simulation was adjusted to comply with the Indonesian situation and circumstances. Potential profits from selling excess electricity to the grid were beyond the scope of this paper. This is because the national or local policy for selling excess electricity by a third party is still unavailable. Indonesian territory as an archipelago country also becomes a main challenge to transfer electricity across the sea. Thus, waste-to-energy conversion in terms of electricity becomes a very site-specific and definite case study region required for meaningful assessment as a previous study in South Tangerang (Prabowo *et al.*, 2019).

2.1.1. EFB-to-ethanol Integrated into RBD Palm Oil plant scenario

This scenario was simulated by integrating five production units as a plant, as shown in Figure 1. They are the RBD palm oil unit, the 2nd generation bioethanol unit, the reboiler and soda regeneration unit, the lignin production unit, and the syn-gas production unit. The RBD palm oil unit was adopted from eight traditional RBD palm oil plants and palm oil mills in Kalimantan and Sumatera, Indonesia (Harsono *et al.*, 2012). Data in this article had methodologically reviewed for reference in life cycle studies and were categorized as acceptable by other research groups (Archer *et al.*, 2018). The 2nd generation bioethanol unit, according to the pilot plant operated by Research Center for Chemistry, National Research and Innovation Agency (BRIN) (Jeon *et al.*, 2014). Soda regeneration and black liquor reboiler unit referred to the commercial Kraft Pulping process, which was also previously used as a reference by the LignoBoost process. The lignin production refers to the LignoBoost process, established in the Metso Pilot plant in Bäckhammar, Sweden (Tomani *et al.*, 2011; Tomani, 2010). The syn-gas production unit adopted a pilot plant operated by the University Technology of Petronas, Malaysia (Hussain *et al.*, 2021a; Hussain *et al.,* 2021b).

Due to operating simulation at the most efficient condition, the amount of EFB being processed was adjusted according to the available energy (in steam and electricity) from the combustion of total palm oil kernel and fiber. In this scenario, the RBD palm oil capacity set as calculation basis was 5 tons of Fresh Fruit Bunch (FFB) input. This small-scale choice was inspired by the previous assessment of pellet production in Russia (Smirnova *et al.,* 2021) to make it viable for micro-business conditions.

References for the FFB component were carefully selected from literature originating from South East Asia as the region of interest (Ahmad *et al.,* 2019; Aditiya *et al.,* 2016). Their quoted data were traced from The Compendium of Environment Statistics Malaysia 2013. Based on this literature, 20%w of FFB converted to CPO was used as the basic data platform for calculation in this review. Along with this main product, there were also Crude Palm Kernel Oil - CPKO (1.5%), palm kernel cake - PKC (2.5%), empty fruit bunches - EFB (22%), fiber (13%) and shells (7%) as the side product in FFB percentages. The rest of the processed FFB became wastewater mixed with condensed steam from the sterilization process, which is called Palm Oil Mill Effluent (POME).

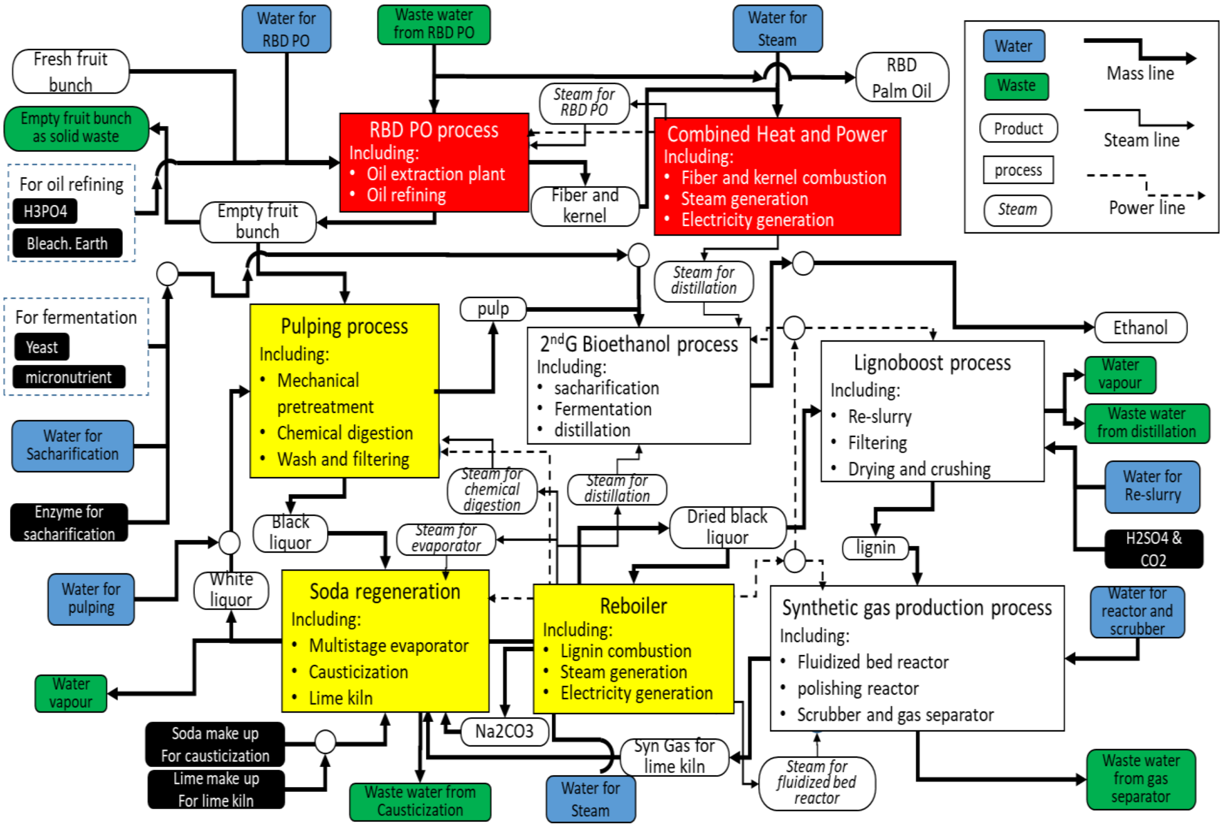

Figure 1 Brief scheme for the first archetype, when 2nd G Bioethanol integrated into RBD palm oil plant. Yellow boxes were units for pulping process. Red boxes were units for the RBD palm oil process

The water, steam, and electricity requirement in the oil extraction was then calculated. The oil needs to be refined to meet the commercial requirement by eliminating free fatty acids and fruit wax. The chemical and energy requirement was also calculated. The process adopted in this research was the physical process with phosphoric acid as a wax coagulant and the color adjustment by using bleaching earth. The physical process has a higher global yield, uses fewer chemicals, and produces less effluent. Most big companies where the data originated use certified seedlings from the Indonesian Oil Palm Research Institute (IOPRI).

Only a small amount of plantations use seedling private seedling companies in Indonesia or certified imports from Malaysia and other parts of the world (Harsono *et al.*, 2012). Thus, the amount of wax in palm oil fruit in the observed CPO plant is almost equal. Only small deviations were reported for the required energy and required phosphoric acid and bleaching earth for the RBD palm oil process.

The required energy for operating RBD palm oil plant supplies was simulated using a cogeneration system based on a back-pressure steam turbine (BPT). This cogeneration system uses fiber and shell as fuel, which comes from the oil extraction process. Furthermore, the plant adopted in this study was calculated to meet energetically self-sufficient so that the electricity produced could feed both the mills (considered electrified mills) and the process equipment such as pumps, agitators, and conveyors, among others and in addition to lighting installations.

2.1.2. EFB-to-ethanol integrated with EFB pulping plant scenario

In this simulation scenario, all four aforementioned units were applied in EFB-to-ethanol integrated with EFB pulping plant, except the RBD palm oil unit. The scheme can be observed in Figure 2. In this scheme, the energy supply was solely from the black liquor combustion. The main difference in energy supply can be seen in energy lines which only came from the reboiler.

The amount of lignin production was adjusted to the amount of lignin converted into syn-gas. The produced syn-gas was calculated to equal the required syn-gas for the lime kiln. Through a series of iteration calculations, energetically self-sufficient design can be achieved. The setting value for iteration was to meet a similar amount of ethanol produced from the first scenario. Thus, the performance of both scenarios can easily be compared. The calculation required energy included electricity for both the pulping mills (considered electrified mills) and the process equipment, i.e, pumps, agitators, and conveyors, among others and in addition to lighting installations.

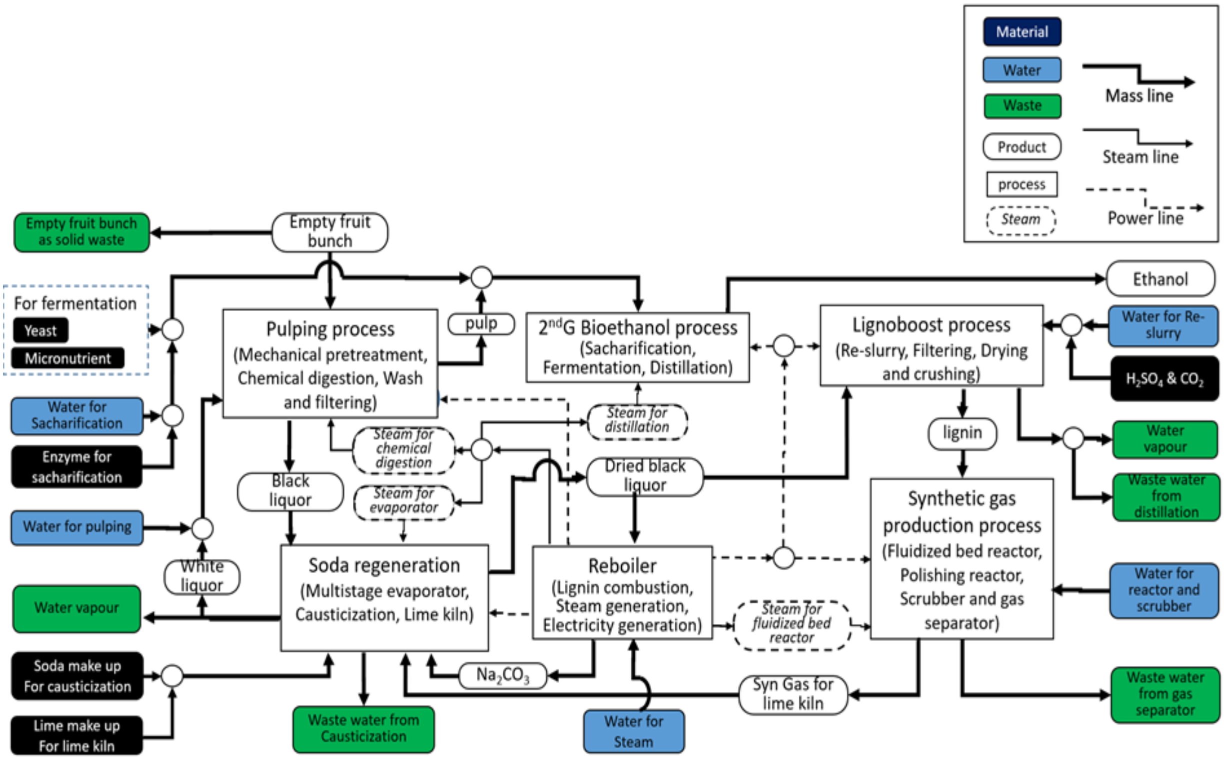

Figure 2 The brief scheme for the second archetype, where the 2nd Generation Bioethanol is integrated into EFB pulping plant

3. Results and Discussion

3.1. General simulation comparison

The total required energy as steam and electricity for producing 255.6 kg ethanol was 1.293 MW, as shown in Table 2. This amount of energy can be supplied from the excess energy produced by the RBD Palm oil plant with a capacity of 5 tons FFB or pulping plant with a capacity of 22.15 tons EFB. This excess energy was sufficient without any additional fuel required (zero net energy). EFB-to-ethanol plant integrated into RBD palm oil plant scenario was preferable in energy analysis. This is due to the flexibility of energy supply from fiber and kernel combustion. The excess energy from these combustions was 1.06 MW, or equal to 82% of the required energy for ethanol production. The other 18% of energy came from dried black liquor combustion from the pulping unit. This dried black liquor needs to be completely burned for soda regeneration.

Table 1 General comparison of EFB-to-ethanol when integrated into RBD palm oil plant or pulping plant

Parameters	Unit	RBD palm oil	Pulp
Material input			
Fresh fruit bunch	kg	5000	0
Wet EFB available (Moist 73%)	kg	2632.81	22,151.01
Fraction of EFB used for ethanol	%	58.42	2.64
EFB used for ethanol	kg	1538.20	1538.20
Fraction of BL to lignin then syn-gas	%	2.55	2.55
Product output			
Wet EFB excess (Moist 73%) (back to the farm)		1,094.62	0
RBD palm oil	kg	1,126.92	0
	liter	1,444.77	0
Wet Pulp (Moist 40%)	kg	0	17,379.43
Pulp (Atmospheric dried)	kg	0	10,427.65
Ethanol fuel grade (97%v)	kg	255.55	255.55
	liter	319.44	319.44
Additional chemical requirement			
Water	m^3	20.88	191,32
Bleaching earth	kg	10.76	0
H_3PO_4	kg	0.57	0
Yeast	kg	7.179	7.179
Micronutrient (urea + NPK)	kg	13.04	13.04
Enzyme and additives (buffer & surfactant)	liter	170.08	170.08
Soda make up	kg	29.83	429.55
Lime makeup	kg	40.93	630.34
H_2SO_4 and CO_2	kg	4.37	62.86

3.2. Energy preference analysis

The total required energy as steam and electricity for producing 255.6 kg ethanol was 1.293 MW, as shown in Table 2. EFB-to-ethanol plant integrated into RBD palm oil plant scenario was preferable in energy analysis. This is due to the flexibility of energy supply from fiber and kernel combustion. The excess energy from the combustion was 1.06 MW, or equal to 82% of the required energy for ethanol production. The other 18% of energy came from dried black liquor combustion from the pulping unit. This dried black liquor needs to be completely burned for soda regeneration.

On the other hand, EFB-to-ethanol integrated with EFB pulping plant scenario used energy supply solely from dried black liquor combustion. Due to the large amount of energy for black liquor evaporation, the excess energy was only 0.1 MW per ton of dried black liquor. Thus, for supplying the aforementioned EFB-to-ethanol required energy, excess energy from the combustion of 14.9 tons of required dried black liquor. This black liquor obtained from EFB pulping plant capacity was 22.15 tons of EFB feed or 10.5 tons of produced pulp.

Both scenarios had options for selling their energy potency as side products. RBD palm oil plant can directly sell its excess kernel as solid fuel. The main customers were small and medium-sized enterprises (SMEs), and no literature was found about this market. Pulping plant had the option to sell the excess dried black liquor to the cement plant. An Indonesian case study, PT. Pindo Deli Pulp and Paper Mills in Ciampel-Karawang, West-Java, selling it as kiln fuel in cement plants. The selling prices were not reported, but it was stated the cost of USD 5/t for transporting (Mikkilä *et al.*, 2021). These options were highly dependent on the market demand and transportation costs. The market availability was less preferable compared to the availability of ethanol market as fuel or industrial chemical.

Table 2 Energy Utilization Comparison of EFB-to-ethanol when integrated into RBD palm oil plant or pulping plant (basic calculation: 255.6 kg of ethanol production capacity)

Parameters	Unit	RBD Palm Oil	Pulp
Required electricity for EFB-to-ethanol plant	MW	0.14	
Required steam for EFB-to-ethanol plant	MW	1.153	
Total excess power from black liquor combustion in the boiler (after excluding power consumed for pulping plat), per ton of dried black liquor	MW/tons	0.1	0.1
Required EFB to be processed for zero net energy	tons EFB	2.6	22.15
Total produced dried black liquor	tons	1.00	14.90
Total excess power from fiber and kernel combustion in the boiler (after excluding power consumed for RBD Palm Oil plant) per ton of combined fiber and kernel.	MW/tons	1.06	0
Total produced fiber and kernel	tons	1.033	0

3.3. *Environmental preference analysis*

RBD palm oil plant required an additional water treatment plant when integrated into the EFB-to-ethanol unit. Not only because the amount of wastewater tripled but also because the pollutant component from the EFB-to-ethanol unit and pulping unit significantly differed from the pollutant from the RBD palm oil unit. On the other hand, ideal pulp plants need to have their own water treatment due to the massive wastewater produced. The additional wastewater from the ethanol unit was only 1% of the wastewater derived from pulping plant, so the pulping plant does not need the additional water treatment.

Table 3 Pollutant comparison of EFB-to-ethanol when integrated into RBD palm oil plant or pulping plant. Basic calculation: 255.6 kg ethanol production capacity

Pollutant component	Source	Amount (kg)	
		RBD Palm Oil	Pulp
	To water treatment plant		
Spent bleaching earth, PFDA and Palm Oil Mill Effluent (POME)	Palm oil extraction plant & oil refining	5,418.67	
Lignin and spent yeast	Distillation bottom.	2,847.35	2,847.35
$CaCO_3$, NaOH	Causticization lime kiln, scrubber and gas separator	1,491.98	22,890.71
Lignin and NaOH	Pulp washing	7,647.26	94,303.02
	To environment/gas treatment		
Multi-stage evaporator and lignin drier	water vapor	5,198.64	77,543.36
Causticization and lime kiln	CO_2 and SO_x	6.43	177.40

3.4. Additional investment for integration schemes

RBD palm oil market price used in this study was US$ 752 per ton (Battle *et al.,* 2021), the pulp price was US$ 790 per ton (Mikkilä *et al.,* 2021), and the ethanol price was US$ 490 per kl in 2021. According to simulation results in Table.3. The basic income for the RBD palm oil plant with 5 tons FFB process capacity was US$ 847.44 from selling 1.13 tons of their RBDPO product. Integration with EFB-to-ethanol unit gives extra income of US$ 156.53 from selling 319.5 liters of ethanol. Additional income for the RBD palm oil plant was 18.47% by implanting this integration. For other scenarios, the basic income for EFB pulping plant with 22.15 tons EFB processing capacity was US$ 8237.9 from selling 10.5 tons of their pulp. Thus, the additional income from selling ethanol was only 1.9%.

However, if the EFB pulping plant had already been established, the additional required installation for integration with the EFB-to-ethanol-only distillation unit and saccharification fermentation tank was required. The other requirement can use the existing unit in pulping plant with a 2-5% increasing load. This includes the water treatment plant unit. RBD palm oil plant required more investment for the required additional installations.

Production capacity is another issue for economic performance. The small capacity of RBD palm oil, with 5 tons FFB processed daily, had met the feasibility of integrating with the EFB-to-ethanol unit. The comparable EFB pulping plant capacity was 22.15 tons of EFB processed daily. This large capacity then definitely required large initial investment and large depreciation as its consequences. Pulp market availability for this large production needs to be carefully considered. However, the proposed scenario for EFB pulp integrated with an EFB-to-ethanol unit was still comparable to the proposed action for a sustainable circular bio-economy (Mikkilä *et al.,* 2021). Recycling nutrients into the farm or forest where the biomass is produced was proposed. This can be done only if the farm or the forest is under the same management as a pulping plant. A large initial investment is also required to manage upstream and downstream processes.

4. Conclusions

The 2nd generation bioethanol production process has its own appeal since its product is used as a gasoline substitute and industrial chemicals on one end and utilizes cheap, abundant, non-food raw material at the other end. In this context, this study aimed to analyze EFB utilization as ethanol raw material and as the possibility of converting the potential excess energy in RBD palm oil production or pulping process into financial profit and reduce waste simultaneously. This would encourage a reduction in dependence on fossil fuels (consequently reducing GHG emissions) and improve the system's energy performance. Integrating an EFB-to-ethanol unit into the RBD palm oil plant with a capacity of 5 tons FFB processed daily could recycle 58.4% of EFB waste, increasing income 18.47% of the basic income from selling RBD palm oil solely. This was achieved by utilizing all the energy potency stored in fiber and kernel to supply the required energy. To implement the integration, the RBD palm oil plant required almost fourfold processed water and dealing with threefold wastewater with different pollutants. The types of operation unit that needed to be installed was also more miscellaneous compared to the integration of the EFB-to-ethanol unit into the EFB pulping plant. The integration of the EFB-to-ethanol unit into the EFB pulping plant only required an additional distillation unit and saccharification-fermentation tank to be installed. The required process water, the pulping process, and the wastewater treatment unit only had an increasing workload of 2-5 % which is usually compromised in the original pulping plant design. This small additional investment gave extra income of 1.9% of the pulp sales. However, the pulping production capacity needs to be 22.15 tons of processed EFB daily for the ethanol to be comparable with the aforementioned RBD palm oil integration. This is due to the small amount of potential excess energy in dried black liquor. The results outlined in this paper are based on the integration of technological considerations adopted in each scenario. Therefore, limitations of the present research would be economical and feasibility, especially in economic comparison for selling kernel or dried black liquor as a side product, and logistic aspects regarding the cost of sending EFB and/or black liquor to farms, industrial users, or municipalities. Once these limitations have been overcome with data survey and market study, plants like both proposed scenarios might reach a feasible economic stage and play an important role in transitioning towards a circular economy that promotes sustainability. Thus, it is recommended that a more detailed socio-economic analysis should as well be considered in a future study. The study's main conclusion may be presented in a short conclusions section, which may stand alone. It should not repeat the results but provide significant findings and contributions to the study.

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References

Aditiya, H.B., Mahlia, T.M.I., Chong, W.T., Nur, H., Sebayang, A.H., 2016. Second Generation Bioethanol Production: A Critical Review. *Renewable and Sustainable Energy Reviews*, Volume 66, pp. 631–653

Afandi, A.M., Zuraidah, Y., Nurzuhaili, H.A.Z.A., Zulkifli, H., Yaqin, M., 2017. Managing Soil Deterioration and Erosion under Oil Palm. *Oil Palm Bulletin*, Volume 75, pp. 1–10

Ahmad, F.B., Zhang, Z., Doherty, W.O.S., O'Hara, I.M., 2019. The Outlook of The Production of Advanced Fuels And Chemicals From Integrated Oil Palm Biomass Biorefinery. *Renewable and Sustainable Energy Reviews*, Volume 109, pp. 386–411

Anggraini, I.D., Keryanti, Kresnowati, M.T.A.P., Purwadi, R., Noda, R., Watanabe, T., Setiadi, T., 2019. Bioethanol Production via Syngas Fermentation of Clostridium Ljungdahlii in a Hollow Fiber Membrane Supported Bioreactor*. International Journal of Technology*, Volume 10(3), pp. 481–490

Archer, S.A., Murphy, R.J., Steinberger-Wilckensa, R., 2018. Methodological Analysis of Palm Oil Biodiesel Life Cycle Studies. *Renewable and Sustainable Energy Reviews*, Volume 94, pp. 694–704

Febrianti, F., Syamsu, K., Rahayuningsih, M., 2017. Bioethanol Production from Tofu Waste by Simultaneous Saccharification and Fermentation (SSF) using Microbial Consortium. *International Journal of Technology*, Volume 8(5), pp. 898–908

Harahap, A.F.P., Rahman, A.A., Sadrina, I.N., Gozan, M., 2019. Optimization of Pretreatment Conditions for Microwaveassisted Alkaline Delignification of Empty Fruit Bunch by Response Surface Methodology. *International Journal of Technology*, 10(8), pp. 1479–1487

Harsono, S.S., Prochnow, A., Grundmann, P., Hansen, A., Hallmann, C., 2012. Energy Balances and Greenhouse Gas Emissions of Palm Oil Biodiesel in Indonesia. *GCB Bioenergy*, Volume 4(2), pp. 213–228

Hermansyah, H., Wisman, A.P., Firdaus, D., Arbianti, R., Utami, T.S., Kurnia, A., 2015. Effect of Aeration and Nutrients on Saccharomyces Cerevisiae Cultivation using Lignocellulosic Hydrolysate from Empty Fruit Bunch. *International Journal of Technology*, Volume 6(7), pp. 1110–1118

Hermansyah, H., Putri, D.N., Prasetyanto, A., Chairuddin, Z.B., Perdani, M.S., Sahlan, M., Yohda, M., 2019. Delignification of Oil Palm Empty Fruit Bunch using Peracetic Acid and Alkaline Peroxide Combined with the Ultrasound. *International Journal of Technology*, Volume 10(8), pp. 1523–1532

Hossain, N., Zaini, J.H., Mahlia, T.M.I., 2017. A Review of Bioethanol Production from Plant-based Waste Biomass by Yeast Fermentation. *International Journal of Technology*, Volume 8(1), pp. 5–18

Hussain, M., Zabiri, H., Uddin, F., Yusup, S., Tufa, L.D., 2021. Pilot-scale Biomass Gasification System for Hydrogen Production from Palm Kernel Shell (part A): Steady-state Simulation. *Biomass Conversion and Biorefinery*, pp. 1–14

Hussain, M., Zabiri, H., Uddin, F., Yusup, S., Tufa, L.D., 2021. Pilot-scale Biomass Gasification System for Hydrogen Production from Palm Kernel Shell (part B): Dynamic and Control Studies. *Biomass Conversion and Biorefinery*, pp. 1–23

Jeon, H., Kang, K.E., Jeong, J.S., Gong, G., Choi, J.W., , Abimanyu, H., Ahn, B.S., Suh, D.J., Choi, G.W., 2014. Production of Anhydrous Ethanol using Oil Palm Empty Fruit Bunch in a Pilot Plant, *Biomass and Bioenergy*, Volume 67, pp. 99–107

Mikkilä, M., Utanun, P., Luhas, J., Horttanainen, M., Linnanen, L., 2021. Sustainable Circular Bioeconomy-feasibility of Recycled Nutrients for Biomass Production within a Pulp and Paper Integration in Indonesia, Southeast Asia. *Sustainability 2021*, Volume 13(18), pp. 10169

Nasution, M.A., Erwinsyah, Wulandari, A., Lydiasari, H., 2020. Reducing the Greenhouse Gas Emission from Palm Oil Industry. *Ecology, Environment and Conservation Paper.* Volume 26, pp. 89–94

Batlle, E.A.O, Palacio, J.C.E., Lora, E.E.S., Bortoni, E.D.C., Nogueira, L.A.H., Caballero, G.E.C., Julio, A.A.V., Escorcia, Y.C., 2021. Energy, Economic, and Environmental Assessment of the Integrated Production of Palm Oil Biodiesel and Sugarcane Ethanol. *Journal of Cleaner Production*, Volume 311, p. 127638

Prabowo, B., Simanjuntak, F.S.H., Saldi, Z.S., Samyudia, Y., Widjojo, I.J., 2019. Assessment of Waste to Energy Technology in Indonesia: A Techno-economical Perspective on a 1000 Ton/Day Scenario. *International Journal of Technology*, Volume 10(6), pp. 1228–1234

Padfield, R., Papargyropoulou, E., Preece, C., 2012. A Preliminary Assessment of Greenhouse Gas Emission Trends in the Production and Consumption of Food in Malaysia. *International Journal of Technology*, Volume 3(1), pp. 56–66

Petersen, A.M., Haigh, K., Görgens, J.F., 2014. Techno-economics of Integrating Bioethanol Production from Spent Sulfite Liquor for Reduction of Greenhouse Gas Emissions from Sulfite Pulping Mills. *Biotechnology for Biofuels*, Volume 7(1), pp. 1–14

Shukor, J.A., Omar, M.F., Kasim, M.M., Jamaludin, M.H., Naim, M.A., 2018. Assessment of Composting Technologies for Organic Waste Management. *International Journal of Technology*, Volume 9(8), pp. 1579–1587

Smirnova, O., Kharitonova, E., Babkin, I., Pulyaeva, V., Haikin, M., 2021. Small-scale Biofuel Production: Assessment of Efficiency. *International Journal of Technology*, Volume 12(7), pp. 1417–1426

Tomani, P.E.R, 2010. The Lignoboost Process. *Cellulose Chemistry and Technology*, Volume 44(1–3), pp. 53–58

Tomani, P., Axegård, P., Berglin, N., Lovell, A., Nordgren, D., 2011. Integration of Lignin Removal Into a Kraft Pulp Mill and use of Lignin as a Biofuel. *Cellulose Chemistry and Technology*, Volume 45 (7–8), pp. 533–540

Van-Dam, J.E.G., 2012. *Options for Sustainability Improvement and Biomass use in Malaysia: Palm Oil Production Chain and Biorefineries for Non-food use of Residues and by-products Including other Agricultural Crops*. AGRIS, Food and Agriculture Organization of United Nations 2012, Extent 37

Walker, SM., McMurray, A., Rinaldy, F., Brown, K., Karsiwulan, D., 2018. Compilation of Best Management Practices to Reduce Total Emissions from Palm Oil Production. Winrock International. In: *Roundtable on Sustainable Palm Oil (RSPO)*

Zaytsev, A., Dmitriev, N., Rodionov, D., Magradze, T., 2021. Assessment of the Innovative Potential of Alternative Energy in the Context of the Transition to the Circular Economy. *International Journal of Technology,* Volume 12(7), pp. 1328–1338