GREEN HYDROGEN PRODUCTION FROM PALM BIOMASS: A REVIEW ON POTENTIALS AND CHALLENGES

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ABSTRACT: T*his review aims to unlock information on the hydrogen production potential of carbon emission potential palm biomass and its related challenges. The for conducting this study, 100 journals were studied published between the years 2010 to 2022. for this paper is the literature review. Journal papers studied for this review published on the energy potential of EFB and technologies used for green hydrogen production from that biomass. The calorific value of EFB varies between 17 to 21 MJ (kg-EFB)$^{-1}$ on a dry basis with 0.24 kgCO_2eq emission. Experiments on pyrolysis and gasification demonstrated that at optimum operating conditions, the H_2 yield was 127 gH_2 (kg-EFB)$^{-1}$. The caloric value of hydrogen is about 150MJ (Kg-H_2)$^{-1}$. Information published in this paper on hydrogen production from palm biomass would be a reference for researchers in preparing a methodology for green hydrogen production. This information would also attract government agencies and industries to implement a palm biomass-based hydrogen economy. This study concludes that a palm biomass-based hydrogen economy may empower Southeast Asian countries to achieve economic (SDG 8) and environmental sustainability (SDG 13) for reducing climate change effects.*

Keywords: Green Hydrogen. Palm Biomass, Advanced Technology, Production Performance, Economic Sustainability, Environmental Sustainability, Climate Change

1.0 BACKGROUND OF THE STUDY

Southeast Asian counties produce more than 90% of global pump oil. In 2020, the Fresh Fruit Bunches (FFB) production in this region was about 200 million tons [1, 2]. The average yield of crude palm oil (CPO) outputs from FEB is 22 percent, and 78 % is waste [3–5]. The waste part of Empty Fruit Bunch (EFB) is about 160 million tons a year [6]. EFB is renewable biomass and renewable energy source [7, 8].

Traditionally, EFB dumps into the environment, and a small part is used for producing steam and energy. When EFB degrades in the atmosphere, this biomass emits 60 kgCO_2eq.(ton)$^{-1}$ carbon. When EFB burns for steam, the emission rate from this biomass is about 29 CO_2eq(kWh)$^{-1}$ [9–11]. This information indicates that it either dumps into the environment or burns for steam, in both ways this biomass emits carbon. The carbon emission from EFB contains about 64% methane (CH_4) and 34% carbon dioxide (CO_2); and this information demonstrates that EFB is a potential source of hydrogen [11, 12].

With this background, the current study aims to answer whether "**is palm biomass a green hydrogen source**?" This study aims to review related journals to answer the question. Answering that question, 100 journals were studied that were published between the years 2010 to 2022. Additionally, the goals of this study are to reveal the technology available to produce hydrogen from this biomass and its related economic and environmental benefits.

2.0 INTRODUCTION TO PALM BIOMASS-BASED HYDROGEN ECONOMY

A hydrogen economy is an economy that relies on hydrogen as the commercial fuel and would deliver a substantial fraction of the required energy. The hydrogen economy contributes to reducing fossil fuel consumption for decreasing carbon emissions [13, 14]. Based on that concept, this review focuses on identifying the opportunities and challenges toward developing a palm biomass-based hydrogen economy. Fuel from hydrogen is today's global target for achieving sustainability in the energy and environment for combating global warming and climate change. Figure 1.0 presents a general conceptual model of the green hydrogen economy.

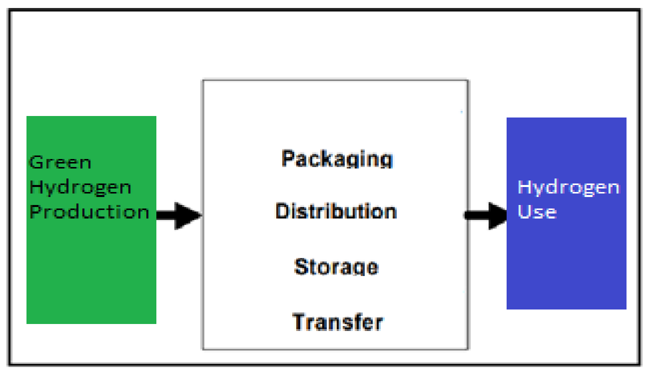

Figure 1.0: General Model of Hydrogen Economy [15].

The required primary resources for producing green hydrogen are biomass and advanced technology [11, 16]. Pyza et al. (2022) and Shahidul et al., (2021) stated that the global energy and emission problems will not solve until a significant percentage of hydrogen increases in the energy mix. To achieve this goal, relevant stakeholders need to pay attention to developing the required infrastructure relating to hydrogen production [17, 18]. However, hydrogen gas is the lightest of all gaseous energy, and the ratio of heating value to volume is also lower. These properties of hydrogen cause higher packing and transportation costs than that of fossil fuel energy [15, 19].

3.0 HYDROGEN POTENTIAL IN PALM BIOMASS

The earth receives around 1000W(m)$^{-2}$ of energy from the Sun and a fraction of this solar energy converts into biomass through photosynthesis. Indeed, a part of this energy absorbs by palm oil trees. Water, solar energy, and CO_2 transform into palm biomass. The process of biomass growth in a palm oil plant is presented by equation 1.0.

$$Es + CO_2 + 6H_2O \longrightarrow C_6H_{12}O + 6O_2 \qquad \text{Eq (1)}$$

Here, Es is the solar energy, and $C_6H_{12}O_6$ is biomass that holds solar energy [20, 21].

The source of hydrogen in palm biomass is $C_6H_{12}O_6$. This biomass contains Cellulose (58% wt.), Hemicellulose (21.5% wt.), and lignin (20% wt.) [22, 23]. On a dry weight basis, the calorific value of palm biomass is between 17 to 21 MJ.(kg-EFB $)^{-1}$ [24, 25]. The low heating value (LHV) of this biomass is about 15.0 MJ(kg-EFB$)^{-1}$ with 0.24 $kgCO_2eq$ emission [12, 24, 26, 27]. Palm biomass is a highly volatile feedstock for energy production [28, 29]**;** and can be converted into heat, syngas, and hydrogen [30, 31]**.**

4.0TECHNOLOGICAL ADVANCEMENT IN HYDROGEN PRODUCTION FROM PALM BIOMASS

Organic Rankine Cycle (ORC) has been used for energy production from palm biomass [32, 33]. In the first step of ORC, moisture has been removed from this biomass by heat treatment. In the second step, pallets are produced as an energy feedstock. Finally, gasification and pyrolysis with combined heat and power (CHP) cycle have been used for hydrogen production [34]. Figure 2.0 is presented a general conceptual model of the hydrogen production process from palm biomass.

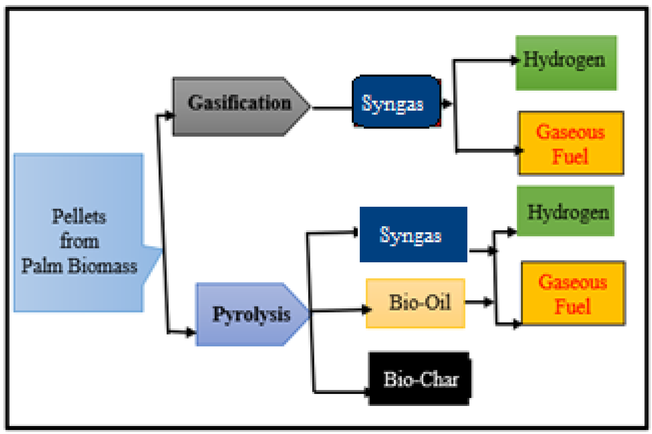

Figure 2: Hydrogen Production Model from Palm Biomass

Figure 2.0 demonstrates that bio-oil and biochar are produced in the first stage, and hydrogen production in the second stage.

4.1 Feedstock Preparation from Palm Biomass

Energy production performance from palm biomass by pyrolysis and gasification depends on the quality of the feedstock. Three steps are involved in feedstock preparation. In the first step, alkaline solutions (NaOH) have been used in cleaning palm biomass for pre-treatment. In the second stage, the moisture content of palm biomass has been reduced by heat treatment. In the third stage, the shredding process has been applied to decrease the size of this biomass (≤500 μm) [34], [35]. Finally, pellets are produced to be used as feedstock for the pyrolysis and gasification process.

5.0 TECHNOLOGIES FOR HYDROGEN PRODUCTION FROM PALM BIOMASS

Gasification and pyrolysis have been used in hydrogen production from palm biomass. The combined heat and power (CHP) cycle has been adopted with these processes for increasing thermal efficiency. The membrane separation technology also has been installed for separating hydrogen from the syngas stream [11].

5.1 Palm Biomass Pyrolysis for Hydrogen Production

Pyrolysis is an effective thermal process that is used for producing energy from biomass. Pyrolysis is an endothermic process that requires thermal energy from an external heat source [36–39]. Traditionally, palm biomass pellets have been fed into a reactor [40, 41]; and hot air (≥700°C) and steams (≥900 °C) are also supplied to the reactor for decomposing biomass. This process occurs at a higher heat transfer rate and a process temperature of around 300°C to 900 C. Figure 3.0 is presented a schematic diagram of the palm biomass pyrolysis process.

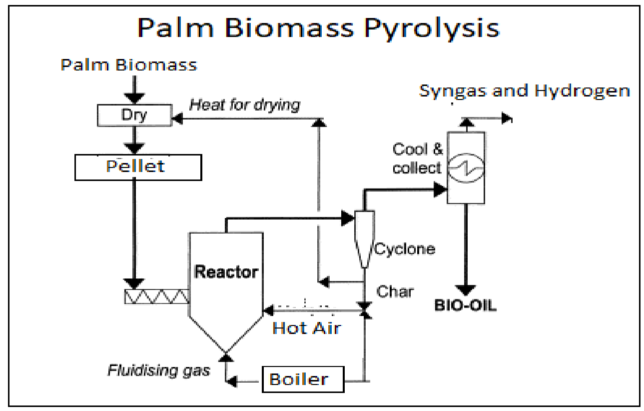

Figure 3.0: Typical diagram of Palm Biomass Pyrolysis [11]

This process is performed in the absence of oxygen. Through the degrading process, palm biomass is converted into vapor. A rapid cooling system has been used for condensing the biomass vapor into bio-oil [40, 42]. The energy products of pyrolysis are bio-oil, biogas, biochar, and hydrogen, [43–45]. The pyrolysis with catalysis offers a higher hydrogen yield at a lower process time and energy [46, 47]. In the final stage, hydrogen has been pushed through the scrubber and membrane to remove impurities from the gas stream [48]. The energy products of palm biomass pyrolysis are listed in Table 1.0.

Table 1.0: Yields of EFB's Pyrolysis

Pyrolysis Temperature (^{0}C)	Energy Product of Palm Biomass Pyrolysis (wt %) [5, 49 34, 50]			
	Bio-oil	Syngas	Biochar	Hydrogen
300-400	48.5	15.2	36.5	-
500	56.2[34], [50]	18.5	25.3	< 5%
600	40.[51]	29.5	20.10	5%-10%
600-950	<40 [52]	>30	<20	>10%

Table 1.0 demonstrates that at pyrolysis temperatures from 300^{0}C to 500^{0}C, the dominant energy products are bio-oil (≈48.5% wt.) and bio-char (≈36.5.5% wt.) [5, 49, 53]. Dolah et al. (2017) and Yahaya et al., (2016) disclosed that the bio-oil has started to convert into syngas at 500^{0}C process temperature, and at the same time volume of biochar is beginning to reduce. Dolah et al.(2016) reviled that the yield of syngas attain the highest level (≥30% wt.) at the temperature of 900^{0}C [54].

5.1.1 Hydrogen Production Performance from Palm Biomass by Pyrolysis

Hornung (2014) found that the syngas and hydrogen production performance appeared to be optimum at the temperature of 950℃. The author also stated that at optimum operating conditions, the carbon emission rate per unit of energy is also lower [$(kgCO_2eq(kW)^{-1})$] [40]. When hydrogen produces from palm biomass without CHP, the emission rate is found to be 0.15 kg CO_2eq $(kWh)^{-1}$ at a thermal efficiency of 40%. Emission is found to be 0.06 kg CO_2eq $(kWh)^{-1}$ when the plant operates with CHP at a thermal efficiency of 90% [40, 55, 56].

Rocchetti *at el*.(2013) and Mohammad et al.(2012) demonstrated that at optimum operating conditions, the H_2 yield was 127 gH_2 (kg- EFB)$^{-1}$ [21, 57, 58]. It was also reported that the LHV of hydrogen-produced palm biomass was about 150 MJ$(Kg\text{-}H_2)^{-1}$ [51, 56, 59]. Ekman Nilsson et al.(2017) conclude that pyrolysis with CHP is an effective thermal process technology for producing hydrogen from palm biomass [60].

5.2 Palm Biomass Gasification for Hydrogen Production

Palm biomass gasification is an endothermic process and an effective means of hydrogen production. In this process, heat energy requires to supply from external sources [61, 62]. Thermal energy has been used in the gasifier to decompose biomass for producing hydrogen [57, 58, 63]. Additionally, CHP has been also installed with the gasifier for increasing thermal efficiency [64, 65].

The first step of the gasification process is to feed pellets into the gasification reactor [66]. The updraft and downdraft reactors with CHP have been used for the palm biomass gasification process [61, 67, 68]. Vineet Sing (2017) stated that with a feedstock of high moisture (≈50%), the upwards draft reactor has appeared to be efficient. It was reported that the fixed bed (FXB) upward draft gasifier is efficient for dried palm biomass [69]. Higher hydrogen yield can achieve from a catalytic steam gasifier than from a traditional gasifier [61, 70]. Heryadi et al.(2019) and Salomon *et al*.(2013) reported that hot air (≥700°C) and steam (≥950°C) have been supplied into the reactor as the means of thermal energy [71 72]. The waste heat of the gasifier has been recycled by CHP equipment, which contributes to increasing thermal efficiency by up to 95%. Additionally, CHP has also been used to decrease the carbon emission rate [CO_2eq $(kW)^{-1}$[65, 73]–[75].

The hydrogen production is started in the reactor at the temperature of 700°C, and the highest yield was recorded at 950°C [16], [76]. Equation (2) and Equation (3) present exothermic reactions of palm biomass gasification [77, 78].

$C + H_2O \rightarrow CO + H_2,\ \Delta H = -1, 21, 400$ J/mol Eq. (2).

$C + CO_2 \rightarrow 2CO,\ \Delta H = -1, 72, 600$ J/mol Eq. (3).

The energy products of the gasification process are syngas, hydrogen, and biochar [77, 79]. It was disclosed that hydrogen mole fraction yield depends on the temperature of the palm biomass gasification process, and typically hydrogen yield increases with the reactor's temperature [16, 70, 80].

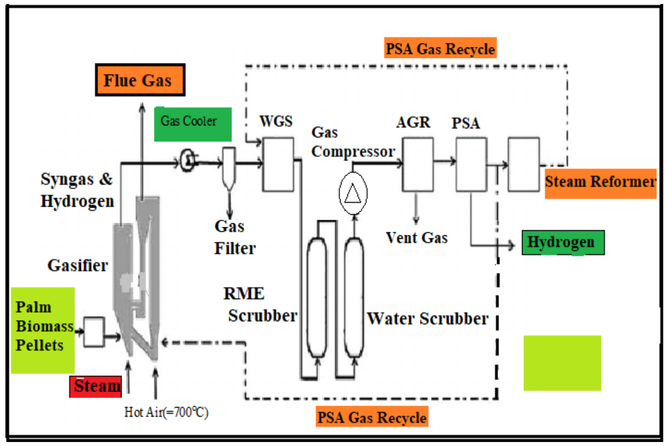

Figure 4.0: Gasification Process for Palm Biomass

5.2.1 Hydrogen Production Performance in Palm Biomass Gasification

The highest hydrogen production performance from a gasifier can be obtained by optimizing the hot air and steam supply to the reactor. At 700°C temperature, the volumetric gas output from palm biomass gasifier is CO(39.71%), CO_2(16.48 %), H_2 (36.26%), and CH_4 (7.55 %) [77, 81]. Mohmmad et al.(2012) disclosed that at optimum operating conditions, the H_2 yield appeared to be 127 $gH_{2(}$kg-EFB)$^{-1}$ [57, 58].

The gaseous energy outputs from the palm biomass gasifier are higher than that of palm biomass pyrolysis. The ratio of carbon emission to energy outputs in the gasifier process is also less than pyrolysis. In that aspect, the gasifier process is a better choice for producing hydrogen from palm biomass [82, 83].

Various case studies have reported that hydrogen production from palm biomass by pyrolysis and gasification with CHP provides a few benefits. For example, these technologies have been used to enhance thermal efficiency from 60 to 95 % by capturing and recycling waste heat [73–75]; and also used to decrease the carbon emission rate per unit of hydrogen [CO_2eq$(kWh)^{-1}$ [65, 84–86].

6.0TECHNOLOGY FOR HYDROGEN PURIFICATION

Syngas and hydrogen are the gaseous energy products of palm biomass pyrolysis and gasification. The gas stream produced from the gasifier contains some impurities, and a series of cleaning processes have been used to remove those impurities. Typically, the syngas cools down to remove condensable hydrocarbons. In the final stage, a membrane is used to separate hydrogen from the syngas stream [87]. Figure 5.0 is presented the hydrogen purification steps.

The water gas shift (WGS) method has appeared to be an effective process in hydrogen purification. The WGS reaction is shown by equation 4.1 [87, 88]:

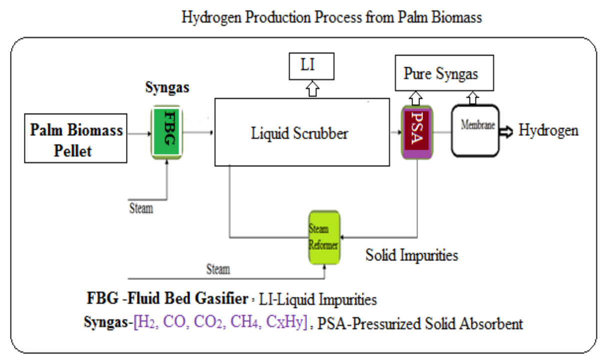

Figure 5: Hydrogen Cleaning with Scrubber and Membrane

6.1 Liquid Scrubber for Removing Hydrocarbon from Gas Stream

$CO + H_20 \rightarrow H_2 + CO_2$, $\Delta H = -41.2$ kJ. mol^{-1} Eq (4.1)

In this process, CO_2 emits from the gas stream, and hydrogen density increases. The impurity removal efficiency of this scrubber is to be over 50%.

6.2 Pressure Swing Absorption for Increasing Hydrogen Density

The pressure swing absorption (PSA) is a scrubber,. has been used for removing impurities from the gas stream [88, [89]. In Increasing hydrogen purification performance, activated carbon has been used as an adsorbent in the PSA system.

6.3 Membrane in increasing Hydrogen Production Performance

The proton exchange membrane system with Pt-Co/C anode electrocatalyst is a proven hydrogen purification process. Vermaak *et al*. (2021) reported that high-purity hydrogen (>99.9%) can be obtained from a low purity feed (20% H_2). The proton membrane is simple, modular type, easy to install, and does not require chemicals in the operating process [87].

7.0 HYDROGEN USE IN ECONOMIC

Hydrogen is an energy carrier, and its performance in economic activities depends on physical and chemical properties. The atom of hydrogen gas is the smallest of all gaseous atoms and has a lower atomic weight among all gases. The weight of this gas is about 8.0 times lighter than methane gas. The LHV of hydrogen gas is about 150 MJ (kg)$^{-1}$, which is about 3.0 times higher than methane gas [LHV-for methane is 50 MJ (kg)$^{-1}$]. At standard temperate and pressure, the density of hydrogen is 0.09 kg (m^3)$^{-1}$. At 200 bar, the energy density is about 2.5 GJ(m^3)$^{-1}$ and at 800 bar, 10 GJ(m^3)$^{-1}$ [90, 91].

According to the International Renewable Energy Agency (IRENA), the wave of hydrogen would replace fossil fuel for producing electricity [92]. The liquid hydrogen produced from palm biomass can be used through Fuel Cells for transportation systems and the manufacturing industry [93].

8.0 CHALLENGES IN HYDROGEN PRODUCTION FROM PALM BIOMASS

Palm biomass is a potential source of green hydrogen production despite a few challenges. The challenges from a technological perspective are converting gaseous hydrogen into liquid form and packing it for transportation. In the aspect of the economy, the challenges are costs involved in production and transportation and mode of use in economic activities.

8.1 Challenges in Gaseous Hydrogen Converting to Liquid for Packing and Transportation

Hydrogen liquefaction for packing is a challenging issue due to the requirement of higher energy consumption in this process. The USA department of energy disclosed that liquefaction is an energy-intensive process as its boiling temperature is low (−253 ◦C at 1 atm) and even cannot be cooled down by the throttling processes. It also requires pre-cooling during the liquefaction process, which increases the energy consumption [94]. Theoretically, the required energy for hydrogen liquefaction is 2.7 kWh(kg-H_2)$^{-1}$ at a feed pressure of 2.5 MPa [95]. The hydrogen liquefaction process demonstrates that the specific energy requirement for this work is about 10kWh(kg-H_2)$^{-1}$ [96]. Estimates also show that for hydrogen liquefaction process requires about 13% of the total energy content in a hydrogen carrier vessel [90, 91, 97, 98].

8.2 Challenges in Hydrogen Packing and Transportation

Hydrogen gas atoms are the smallest of all gaseous atoms and the ratio of volume to weight is also higher. Due to these reasons, hydrogen requires a large vessel for transportation. An insulated double wall tank is also needed for hydrogen transportation. These factors cause extra investment and operating costs [99–102].

8.3 Challenges in Safety Measure for Hydrogen Handling

Safety issue in hydrogen production and handling is a challenging issues for stakeholders. Hydrogen safety is defined as the mitigation of danger when used as energy and fuel. The challenges of hydrogen safety are vulnerability to leakage and a wide range of fuel-to-oxygen ratios for combustion [103, 104]. Liquid hydrogen requires careful attention and treatment due to its extremely low boiling temperature and high hydrogen density [103, 105]. Direct contact with liquid hydrogen and cold oil-off gas from liquid hydrogen lead to severe burning, similar to a thermal burn [106].

A few standards for safety measures have been established to adopt liquid and gaseous hydrogen in the economy. The available safety standards are International Standardization Organization (ISO), European Industrial Gases Association (EIGA), in the United Kingdom, National Renewable Energy Laboratory (NREL) in the USA, National Fire Protection Association (NFPA) in the USA, and the People's Republic of China [107–111].

8.4 Challenges in Hydrogen Production at Affordable Cost

The current challenge in the hydrogen economy is to offer an affordable cost for the end users. The hydrogen production costs depend on a few dynamic factors. The cost of technology required to produce hydrogen from biomass is higher than that used for fossil fuel energy. Capital expenses per unit of energy (kW) in infrastructure development are also higher than required for fossil fuels. Operating expenses for handling hydrogen per unit (kW) are higher compared to the other gaseous energy [112, 113]. For example, as of 2021 the production cost for green hydrogen range from US\$2.7(kg)$^{-1}$ to 8.8(kg)$^{-1}$. A significant price would decrease in 2030 between US$2.0 to US$ 6.0(kg)$^{-1}$ due to reducing the cost of hydrogen technologies and shifting production from pilot to commercial scale. By 2050, the estimated price of green hydrogen is between 1.5 to US$5.0 (kg)$^{-1}$. Predicted the green hydrogen cost would be about US$1.0(kg)$^{-1}$ or less in the countries where cheaper renewable biomass is available [112–114].

9.0 BENEFITS OF HYDROGEN PRODUCTION FROM PALM BIOMASS

A significant percentage of emissions can reduce by producing hydrogen from carbon emission potential palm biomass [115, 116]. It is reported that the hydrogen production yield from palm biomass at higher thermal efficiency (CHPŋ≥95%) is $127gH_2$(kg-EFB)$^{-1}$ [21, 57, 58]. These findings demonstrate that hydrogen production from palm biomass would bring economic and environmental sustainability [117, 118].

Groethe *et al.* (2010); and Mazloomi and Gomes (2012) disclosed that the emission balance between hydrogen production from palm biomass and electricity production from coal is about -1368gCO_2eq(kWh)$^{-1}$ [108, 109]. Yang *et al*. (2017) revealed that when hydrogen production from palm biomass without CHP, the emission rate is 0.15 kg CO_2eq.(kWh)$^{-1}$ at a thermal efficiency of 40% [119]. Loh (2017); Abdullah and Sulaim (2013) and Shahidul et al. (2018) found that emission is 0.06 kg CO_2eq (kWh)$^{-1}$ when the plant operates with CHP at a thermal efficiency of 90%. When hydrogen produces from palm biomass with CHP, the emission reduction rate appears to be 60 kgCO_2eq(t-EFB)$^{-1}$ [120–122]. These findings demonstrate that hydrogen production from palm biomass in Southeast Asian countries would be a sustainable way to replace hydrocarbon fuel and would contribute to achieving economic and environmental sustainability.

10.0 CONCLUSION AND RECOMMENDATION

A key measure to combat climate change is renewable energy production and use for economic activities. If renewable energy produces from a carbon emission potential biomass, it could bring a synergic effect on the environment. Palm biomass is a renewable potential source of hydrogen. Hydrogen production from palm biomass liquefaction, and packing for use in economic activities would contribute to achieving economic and environmental sustainability in Southeast Asia countries. Optimizing the production process at higher thermal efficiency would also contribute to reducing the carbon emission rate per unit of energy. Indeed, safety issues must get priority during production and use.

The palm biomass is a potential source of green hydrogen production despite a few challenges. Information published in journals demonstrates that the technology required to produce hydrogen is not in the mature stage. Even the required infrastructure is not ready for hydrogen production, liquefaction, packing, transportation, and machinery for using hydrogen. Utilizing palm biomass potentials in hydrogen production for achieving economic and environmental sustainability requires a comprehensive plan. The plan shall address the palm biomass supply chain, R&D for technology development, and safety issues. Additionally, attention requires to develop human resources for handling hydrogen technology efficiently. In the first phase, small-scale projects would undertake to produce liquid hydrogen. At the initial stage of hydrogen production and use, the targeted end users would be micro industries involved in agriculture activities of water treatment plants and farm machinery.

In the end, this review concludes that the hydrogen production from palm biomass would contribute to mitigating carbon emissions and climate change effect. Indeed, the palm biomass economy may empower Southeast Asian countries to achieve economic (SDG 8) and environmental sustainability (SDG 13).

10.1 Implication of Findings

The information listed in this paper on hydrogen production from palm biomass would be a reference for researchers in developing research methodology for producing green hydrogen. This information would also attract government agencies and industries to implement a palm biomass-based hydrogen economy.

11.0 ACKNOWLEDGMENT

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12.0 REFERENCES

[1] L.Kwee; H.Hashim; H.Ying; U.Shin; N. Yunus; L/ Shiun, "Biogas Generated from Palm Oil Mill Effluent for Rural Electrification and Environmental Sustainability," *Chem. Eng. Trans.*, vol. 61, pp. 1537–1542, 2017.

[2] L. Loh S.K., Nasrin A.B., Mohamad Azri S., Nurul Adela B., Muzammil N., Daryl Jay T., Stassha Elanor R.A. and 2017 W.S., Choo Y.M., Kaltschmitt M., "First Report on Malaysia's Experiences and Development in Biogas Capture and Utilization from Palm Oil Mill Effluent Under the Economic Transformation Programme: Current and Future Perspectives," *Renew. Sustain. Energy Rev.*, vol. 74, pp. 1257–1274, 2017.

[3] A. H. Zamri, M. F. M. A., Akhiar, A., Shamsuddin, "Talking points of green and sustainable palm oil mill system in Malaysia," *Int. J. Recent Technol. Eng.*, vol. 8, no. 8, pp. 6474–6479, 2019.

[4] MPOB statistics, "MPOB -Economic and Industry Development Divisions," 2021. [Online]. Available: https://bepi.mpob.gov.my/index.php/en/production/production-2021/production-of-crude-oil-palm-2021

[5] M. I. Shahidul, M. L. Malcolm, and J. J. Eugene, "Methane Production Potential of POME: A Review on Waste-to-Energy [WtE] Model," *Sci Int*, vol. 30, no. 5, pp. 717–728, 2018.

[6] S. B. Uemura, Y.; Omar, W.N.; Tsutsui, T.; Yusup, "Torrefaction of oil palm wastes," *Fuel*, vol. 90, pp. 2585–2591, 2011.

[7] F. Abdullah, N., Gerhauser, H. & Sulaiman, "Fast pyrolysis of empty fruit bunches," *Fuel*, vol. 89, pp. 2166–2169, 2010.

[8] Y.-S. Wong, T. T. Teng, S.-A. Ong, M.

Norhashimah, M. Rafatullah, and H.-C. Lee, “Anaerobic Acidogenesis Biodegradation of Palm Oil Mill Effluent Using Suspended Closed Anaerobic Bioreactor (SCABR) at Mesophilic Temperature,” *Procedia Environ. Sci.*, vol. 18, pp. 433–441, 2013, doi: 10.1016/j.proenv.2013.04.058.

[9] M. I. Shahidul, B. Shahnur, M. M. Lamoh, M. S. Hashmi, and M. S. Islam, “The Role of Engineering in Mitigating Global Climate Change Effects: Review of the Aspects of Carbon Emissions from Fossil Fuel-Based Power Plants and Manufacturing Industries,” in *Reference Module in Materials Science and Materials Engineering*, Elsevier, 2018.

[10] A. A. M. Ali, M. R. Othman, Y. Shirai, and M. A. Hassan, “Sustainable and integrated palm oil biorefinery concept with value-addition of biomass and zero emission system,” *J. Clean. Prod.*, vol. 91, 2015, doi: 10.1016/j.jclepro.2014.12.030.

[11] M. I. Shahidul, “Renewable Energy Production from Palm Biomass by Pyrolysis: A Path to Achieve Economic and Environmental Sustainability the Hydrogen Economy: The Past-Present-Future,” *Sci.Int.(Lahore*, vol. 34, no. 3, pp. 199–204, 2022.

[12] T. and S. B. Y. Yoshimitsu Uemura, Wissam N.Omar, “Torrefaction of oil palm wastes,” *Fuel*, vol. 90, no. 8, pp. 2585–2591, 2011.

[13] Jingzheng Ren; Suzhao Gao; and Lichun Dong, “The Role of Hydrogen Energy: Strengths, Weaknesses, Opportunities, and Threats,” in *Hydrogen Economy*, 2017, pp. 1–33. [Online]. Available: https://www.sciencedirect.com/book/9780128111321/hydrogen-economy

[14] Beatriz Zornoza; ClaraCasado and AlbertoNavajas, "Chapter 11 - Advances in Hydrogen Separation and Purification with Membrane Technology," *Renew. Hydrog. Technol.*, pp. 245–268, 2013.

[15] Bernard Chukwud ashie-Lewis; and Somtochukwu GodfreyNnabuifeb, “Hydrogen Production, Distribution, Storage and Power Conversion in a Hydrogen Economy- A Technology Review,” *Chem. Eng. J. Adv.*, vol. 8, no. 15, 2021.

[16] O. V. Carvalho-Netto *et al.*, “The potential of the energy cane as the main biomass crop for the cellulosic industry,” *Chemical and Biological Technologies in Agriculture*, vol. 1, no. 1. Springer International Publishing, 2014. DOI: 10.1186/s40538-014-0020-2.

[17] D Pyza;P Gołda; E Sendek-Matysiak, “Use of hydrogen in public transport systems,” *J. Clean. Prod.*, vol. 335, 2022.

[18] M. I. Shahidul, Shahnur. B; and, and Baini. R, "Renewable Energy Potential of Sugarcane Waste Biomass: A Review," *Sci Int*, vol. 33, no. 3, pp. 23–236, 2021.

[19] E.Schmidt, *Technische Thermodynamik*, 11th ed. 1975.

[20] P.Malik; M.Awasthi'S.Sinha, "Biomass-based gaseous fuel for hybrid renewable energy systems: An overview and future research opportunities," *Energy Res.*, vol. 45, no. 3, pp. 3464–3494, 2021, DOI: doi.org/10.1002/er.6061.

[21] M I Shahidul, “Renewable Energy Production from Palm Biomass by Pyrolysis: A Path to Achieve Economic and Environmental Sustainability,” *Sci Int*, vol. 34, no. 3, pp. 199–204, 2022.

[22] N.S. Bentsen and C. Filby, "Biomass for energy in the European Union-A review of bioenergy resource assessments," *Biotechnol. Biofuels*, vol. 5, no. 1, p. 25, 2012.

[23] H. Abdullah, N. & Gerhauser, “Bio-oil derived from empty fruit bunches,” *Fuel*, vol. 87, no. 12, pp. 2606–2613, 2008.

[24] Hadi A; Dato P; Abd I; Mohammad W; Ir P; Sobri. M, "Spreadsheet Modelling for Temperature Profile Inside Palm Oil Fresh Fruit Bunch," *J. Ind. Eng. Res.*, vol. 1, no. 6, pp. 25–32, 2015.

[25] B.Nyakuma; A.Johari; A.Ahmad; T. Abdullah, "Comparative Analysis of the Calorific Fuel Properties of Empty Fruit Bunch Fiber and Briquette," *Int. Conf. Altern. Energy Dev. Ctries. Emerg. Econ.*, vol. 52, pp. 466–473, 2013.

[26] R.Fono-Tamo;O.Koya, “Characterisation of Pulverised Palm Kernel Shell for Sustainable Waste Diversification,” *Int. J. Sci. Eng. Res.*, vol. 4, no. 4, pp. 6–10, 2013.

[27] R. F. and P. J. Arias B, Pevida C, Fermoso J, Plaza MG, "Influence of torrefaction the grindability and reactivity of woody biomass.," *Fuel Process Technol.*, vol. 89, pp. 169–175, 2008.

[28] S. J. Abnisa F, Arami-Niya A, Daud WMAW, “Characterization of Bio-oil and Bio-char from Pyrolysis of Palm Oil Wastes,” *BioEnergy Res*, vol. 6, pp. 830–840, 2013, DOI: doi:10.1007/s12155-013-9313-8.

[29] Alias N; Ibrahim N; Hamid M, "Pyrolysis of empty fruit bunch by thermogravimetric analysis," *Energy Procedia*, vol. 61, pp. 2532–2536, 2014, doi: : 10.1016/j.egypro.2014.12.039.

[30] Y. Jianga, Edwin van der Web, E. C. van Ierlandb, and K. J. Keesmana, "The potential role of waste biomass in the future urban electricity system," *Biomass and Bioenergy*, vol. 107, pp. 182–190, 2017, doi: https://doi.org/10.1016/j.biombioe.2017.10.001.

[31] H. RJ, : “Evaluation of plant biomass resources available for replacement of fossil oil,” *Plant Biotechnol J*, vol. 8, pp. 288–293, 2010.

[32] United Nations, “No Biofuel production technologies: status, prospects and implications for trade and development Title,” New York, 2008. [Online]. Available: https://unctad.org/system/files/official-document/ditcted200710_en.pdf

[33] M. N. A. Nur, Bin Taufiq, Zulkarnaen Pane, “Application of Biomass from Palm Oil Mill for Organic Rankine Cycle to Generate Power in North Sumatera Indonesia,” in *IOP Conference Series Materials Science and Engineering*, 2017, pp. 1–7.

[34] R. K. and H. H. Rozzeta Dolah, “A Comprehensive Review on Biofuels from Oil Palm Empty Bunch (EFB): Current Status, Potential, Barriers and Way

Forward," *Sustainability*, vol. 13, pp. 1–29, 2021, doi: 10210. https://doi.org/10.3390/su131810210.

[35] S. H. Chang, "An Overview of empty fruit bunch from oil palm as feedstock for bio-oil production," *Biomass Bio Energy*, vol. 62, pp. 174–181, 2014.

[36] R. Kumar, R.S.; Sivakumar, S.; Joshuva, A.; Deenadayalan, G.; Vishnuvardhan, "Bio-fuel Production from Martynia annua L. Seeds using Slow Pyrolysis Reactor and its Effects on Diesel Engine Performance, Combustion and Emission Characteristics," *Energy*, vol. 217, 2021.

[37] K.Sembiring;N.Rinaldi; S.Simanungkalit, "Bio-oil from Fast Pyrolysis of Empty Fruit Bunch at Various Temperature," *Energy Procedia*, vol. 65, pp. 162–169, 2015.

[38] Mohsin Raza; Abrar Inayat; Ashfaq Ahmed; Farrukh Jamil; Chaouki Ghenai; Salman R. Naqvi; Abdallah Shanableh; Muhammad Ayoub; Ammara Waris; and Young-Kwon, "Progress of the Pyrolyzer Reactors and Advanced Technologies for Biomass Pyrolysis Processing," *Sustainability*, vol. 13, no. 9, pp. 1–42, 2021.

[39] W.Isahak; M. Hisham M; M.Yarmo; T.Y.Hin, "A review on bio-oil production from biomass by using pyrolysis method," *Renew. Sustain. Energy Rev.*, vol. 16, no. 8, 2012.

[40] A. Hornung, *Transformation of Biomass: Theory to Practice*. Wiley-VCH Verlag GmbH & Co. KGaA, 2014.

[41] Y. Zhang, L.; Liu, R.; Yin, R.; Mei, "Upgrading of bio-oil from biomass fast pyrolysis in China: A review," *Renew. Sustain. Energy Rev*, vol. 14, pp. 66–72, 2013.

[42] S. Kim, S.W.; Koo, B.S.; Ryu, J.W.; Lee, J.S.; Kim, C.J.; Lee, D.H.; Kim, G.R.; Choi, "Bio-oil from the pyrolysis of palm and Jatropha wastes in a fluidized bed," *Fuel Process. Technol.*, vol. 108, pp. 118–124, 2013.

[43] S. . Yahaya, H.; Hamdan, H.; Dolah, R.; Muhid, N.; Rashidi, K.A.; Rashidi, "Catalytic fast-pyrolysis process design and equipment setup for converting palm oil empty fruit bunch biomass to bio-oil," *Adv. Res. Fluid Mech. Therm. Sci*, vol. 32, pp. 1–8, 2017.

[44] S.Bridgwater; A. Banks, *Catalytic fast pyrolysis for improved liquid quality*, 2nd ed. 2016.

[45] H. . Pogaku, R.; Hardinge, B.S.; Vuthaluru, H.; Amir, "Production of bio-oil from oil palm empty fruit bunch by catalytic fast pyrolysis: A review," *Biofuels*, vol. 7, pp. 647–660, 2016.

[46] M. Z. . Mohamed, A.R.; Hamzah, Z.; Daud, "Optimization of the pyrolysis process of empty fruit bunch (EFB) in a fixed-bed reactor through a central composite design," in *AIP Conf.*, 2016, pp. 1172–1177. doi: https://doi.org/10.1063/1.488775.

[47] M. Perkins, G.; Bhaskar, T.; Konarova, "Process development status of fast pyrolysis technologies for the manufacture of renewable transport fuels from biomass," *Energy Rev.*, vol. 90, pp. 292–315, 2018.

[48] M Auta; L Ern and B Hameed, "Fixed-bed Catalytic and Non-Catalytic Empty Fruit Bunch Biomass Pyrolysis," *J. Anal. Appl. Pyrolysis Pyrolysis*, vol. 107, pp. 67–72, 2014.

[49] Z. Mohamed, A.R.; Hamzah, Z.; Daud, M.Z.M.; Zakaria, "The effects of holding time and the sweeping nitrogen gas flowrates on the pyrolysis of EFB using a fixed bed reactor," *Procedia Eng.*, vol. 53, pp. 185–191, 2013.

[50] Y. Dai, X., Wu, C., Li, H., and Chen, "The fast pyrolysis of biomass in CFB reactor," *Energy Fuels*, vol. 14, pp. 552–557, 2000, doi: 10.1021/ef9901645.

[51] Y. Chan, Y.; Dang, V.I.; Yusup, S.; Lim, M.T.; Zain, A.M.; Uemura, "Studies on Catalytic Pyrolysis of Empty Fruit Bunch (EFB) using Taguchi's L9 Orthogonal Array," *J. Energy Inst.*, vol. 87, pp. 227–234, 2014.

[52] A. Aktawan, Maryudi, and S. Salamah, "Biomass conversion of tamarind waste to syngas through gasification process on downdraft gasifier," in *IOP Conference Series: Materials Science and Engineering*, Nov. 2019, vol. 674, no. 1.

[53] Shahidul et al., "Methane Production Potential Of POME: A Review On Waste-To-Energy [WTE] Model," *Sci Int*, vol. 30, no. 5, pp. 717–728, 2018.

[54] Dolah R; Hamdan H; Muhid N; Yahaya H; Rashidi K A ; and Rashidi.S, "Second Generation Catalytic Pyrolysis of Oil Palm Empty Fruit Bunches into Bio Oil," 2016.

[55] S. Y. Xu Y, Hu X, Li W, "Preparation and Characterization of Bio-oil from Biomass," in *Progress in Biomass and Bioenergy Production*, 2011. doi: DOI: 10.5772/16466.

[56] L. W. C. and C. Y. Y. Chin Kit Ling, H`ng Paik San, Eng Hooi Kyin, Lee Seng Hua, "Yield and Calorific Value of Bio Oil Pyrolysed from Oil Palm Biomass and its Relation with Solid Residence Time and Process Temperature," *Asian J. Sci. Res.*, vol. 8, no. 352–358, 2015, doi: 10.3923/ajsr.2015.351.358.

[57] M. Khan, Z., Yusup, S., Melati, "Integrated catalytic adsorption (ICA) Steam Gasification System for Enhanced Hydrogen Production Using Palm Kernel Shel," *Int J Hydrog. Energy*, vol. 39, pp. 3286–3293, 2013.

[58] S. Nipattummakul, N.; Ahmed, II; Gupta, A. K.; and Kerdsuwan, "Hydrogen and Syngas Yield from Residual Branches of Oil Palm Tree Using Steam Gasification," *Int J Hydrog. Energy*, vol. 36, no. 6, pp. 3835–3843, 2011.

[59] A. Talero, G.F.; Rincon, S.L.; Gonzalez, "Use of Colombian Oil Palm Wastes for Pellets Production: Reduction of the Process Energy Consumption by Modifying Moisture Content," in *In Proceedings of the 6th International Conference on Engineering for Waste and Biomass Valorisation*, 2016, pp. 23–26.

[60] A. Ekman Nilsson *et al.*, "A Review of the Carbon Footprint of Cu and Zn Production from Primary and Secondary Sources," *Minerals*, vol. 7, p. 168, Sep. 2017, doi: 10.3390/min7090168.

[61] Abrar Inayata; Zakir Khan; Muhammad Aslam; Muhammad Shahbaz; Murni M. Ahmade; M.I. Abdul Mutalibe and, "Integrated adsorption steam

gasification for enhanced hydrogen production from palm waste at bench scale plant," *Int. J. Hydrogen Energy*, vol. 46, no. 59, pp. 30581–30591, 2021.

[62] S. Nor Afzanizam, Nazri;, ChengTung Chonga; and N. Jo-Han, "A Review of Palm Oil Biomass as a Feedstock for Syngas Fuel Technology," *J. Teknol. (Sciences Eng.*, vol. 72, no. 5, pp. 13–18, 2015.

[63] K. Shahlan, S.S., Kidam, K., Amran, T.A., Mohamad, W.A., Ljil, M.P., Hamidah, “Hydrogen Gas Production from Gasification of Oil Palm Empty Fruit Bunch (EFB) in a Fluidized Bed Reactor,” *J. Energy Saf.*, vol. 2, no. 1, pp. 27–38, 2018.

[64] S. S. Goran Jankes, Marta Trniinic, Mirjana Stamenic, Tomislav, "Biomass gasification with CHP production: A review of the state of the art technology and near future perspectives," *Therm. Sci.*, vol. 16, no. 1, pp. S115–S130, 2012.

[65] E. O. A. M.Börjesson, “Biomass CHP Energy Systems: A Critical Assessment,” *Compr. Renew. Energy*, vol. 5, pp. 87–97, 2012.

[66] S. K. and K. Laohalidanond, “Renewable Energy from Palm Oil Empty Fruit Bunch,” in *Renewable Energy-Trends and Applications*, 2011, p. 150. doi: DOI: 10.5772/25888.

[67] dan R. M. A. N. Belgiorno, G. De Feo, C. Della Rocca, “Energy from gasification of solid wastes,” *” Waste Mana*, vol. 23, no. 1, pp. 1–15, 2003.

[68] S. Aktawan, A., Maryudi, Salamah, "Biomass conversion of tamarind waste to syngas through gasification process on downdraft gasifier," 2018.

[69] M. Z. Vineet Singh Sikarwar, *Encyclopedia of Sustainable Technologies*. 2017. [Online]. Available: https://www.sciencedirect.com/referencework/9780128047927/encyclopedia-of-sustainable-technologies#book-info

[70] K. Rahima, R. M. I. Hasan, M. M., and Z. Yaakob., “Sustainable oil palm industry: The possibilities,” *Renew. Sustain. Energy Rev.*, vol. 76(C), pp. 608–619, 2017.

[71] R. Heryadi1, A. S. Uyun, and K. A. and O. A. , E Yandri, S M Nur, “Biomass to methanol plant based on gasification of palm empty fruit bunch,” 2019. doi: doi:10.1088/1755-1315/293/1/012036.

[72] E. C. and M. A. Salomon M, Gómez M F, “Pelletization: An alternative for polygeneration in the palm oil industry Biomass Convers,” *Biorefinery*, vol. 3, no. 3, pp. 213–229, 2013.

[73] M. M. Damirchi, H.; Najafi, G.; Alizadehnia, S.; Mamat, R.; Nor Azwadi, C.S.; Azmi, W.H.; Noor, “Micro Combined Heat and Power to Provide Heat and Electrical Power Using Biomass and Gamma-Type Stirling Engine,” *Appl. Therm. Eng.*, vol. 103, pp. 1460–1469, 2016.

[74] Po-ChihKuo and Wei Wu, “Design of Co-gasification from Coal and Biomass Combined heat and Power Generation System,” *Energy Procedia*, vol. 75, pp. 1120–1125, 2015.

[75] M. A. Bagherian, K. Mehranzamir, and S. M. A., Shahabaldin Rezania, Zulkurnain Abdul-Malek, Amin Beiranvand Pour, "Analyzing Utilization of Biomass in Combined Heat and Power and Combined Cooling, Heating, and Power Systems," *Process*, vol. 9, no. 6, pp. 1–29, 2021.

[76] A. Safari, F.; Tavasoli, A.; Ataei, “Gasification of sugarcane bagasse in supercritical water media for combined hydrogen and power production: A novel approach,” *Int. J. Environ. Sci. Technol*, vol. 13, no. 10, pp. 2393–2400, 2016.

[77] V. K. T. Samarjeet Sing Siwal, Qibo Zhang, Changbin Sun, Sourbh Thakur, Vijai Kumar Gupta, "Energy Production from stream gasification process and parameters that contemplate in biomass gasifier-A review," *Bioresour. Technol.*, vol. 297, p. 122481, 2020.

[78] Diyoke, C., Gao, N., Aneke, M., Wang, M., Wu, C., "Modelling of down draft gasification of biomass -an integrated pyrolysis, combustion and reduction process .," *Appl. Thermo Eng.*, vol. 142, pp. 444–456, 2018.

[79] R. C. Woolcock, P. J., Brown, “Review of Cleaning Technologies for Biomass-derived Syngas,” *Biomass and Bioenergy*, vol. 52, pp. 54–84, 2013, doi: doi:10.1016/j.biombioe.2013.02.036.

[80] G. V. Carvalho-Netto, O.V., Bressiani, J.A., Soriano, H.L., Fiori, C.S., Santos, J.M., Barbosa and G. . Xavier, M.A., Landell, M.G.A. and Pereira, “The potential of the energy cane as the main biomass crop for the cellulosic industr,” *Chem. Biol. Technol. Agric.*, vol. 1, no. 1, p. 20, 2014.

[81] M.I.Shahidul; M.M. Lamoh, *Advanced Eco-farming Technology to Achieve Sustainable Agriculture Growth in Sarawak*. UNIMAS, 2017.

[82] W. A. Mohammed, MAA, Salmiaton, A, “Air gasification of empty fruit bunch for hydrogen-rich gas production in a fluidized-bed reactor,” *Bioresour. Technol.*, vol. 110, pp. 628–636, 2012, doi: https://doi.org/10.1016/j.biortech.2012.01.056.

[83] M. O. Mondal, P., Dang, G. S., Garg, "Syngas Production Through Gasification and Cleanup for Downstream Applications—Recent Developments," *Fuel Process Technology*, vol. 92, no. 8, pp. 1395–1410, 2011.

[84] Paul Breeze, “Combined Heat and Power,” in *Power Generation Technology*, Second Edi., 2014, pp. 111–127. doi: https://doi.org/10.1016/B978-0-08-098330-1.00006-5.

[85] E. J. J. and M. R. Shahidul M. I., Malcolm M.L., “Optimization of Factors Affecting Biogas Production from POME,” *Sci.Int.(Lahore*, vol. 30, no. 6, pp. 851–859, 2018.

[86] M. I. Shahidul, M.I.; Malcolm, M.L. and Eugene, J.J;and Sharafatul, “Optimizing Productivity In Separating Biomass and Organic Materials from Palm Oil Mill Effluent: Experiment Towards Reducing Carbon Emission for Climate Change Effect,” *Sci.Int.(Lahore*, vol. 32, no. 5, pp. 547–556, 2020.

[87] Vermaak. Leandri;.Hein W. J. P. Neomagus; and Dmitri G. Bessarabov, “Hydrogen Separation and Purification from Various Gas Mixtures by Means of

Electrochemical Membrane Technology in the Temperature Range 100–160 ◦C," *Membrane*, vol. 11, no. 4, 2021, doi: https://doi.org/10.3390/membranes11040282.

[88] V. S. H. Idriss, M. Scott, "1 - Introduction to hydrogen and its properties," in *Compendium of Hydrogen Energy*, 2015, pp. 3–19.

[89] S. L. C. X. Y. L. Inalegwu, "Integration of algae cultivation to anaerobic digestion for biofuel and bioenergy production," *Adv. Bioenergy*, vol. 6, no. 1, pp. 199–300, 2021.

[90] B. E. T. Ulf Bossel, "THE FUTURE OF THE HYDROGEN ECONOMY: BRIGHT OR BLEAK?," *Distrib. Gener. Altern. Energy J.*, vol. 18, no. 3, pp. 30–70, 2003.

[91] A. Gupta, "Hydrogen Storage, Distribution and Cleaning," 2017. [Online]. Available: file:///D:/Journal publication/Publication 2022/July 2022/hydrogen properites.pdf

[92] International Renewable Energy, "Hydrogen could disrupt global trade and bilateral energy relations," 2022.

[93] R. K. and P. O. Justyna Cader, "The Impact of Economic, Energy, and Environmental Factors on the Development of the Hydrogen Economy," *Energies*, vol. 14, no. 16, 2021.

[94] US Department of Energy DOE Technical Targets for Hydrogen, "No Title," 2021.

[95] M. Bracha, M.; Lorenz, G.; Patzelt, A.; Wanner, "Large-scale hydrogen liquefaction in Germany," *Int. J. Hydrog. Energy*, vol. 19, pp. 53–59, 1994.

[96] H. Cardella, U.; Decker, L.; Sundberg, J.; Klein, "Process optimization for large-scale hydrogen liquefaction," *Int. J. Hydrog. Energy*, vol. 42, pp. 12339–12354, 2017.

[97] R. Zacharia; S.U. Rather., "Review of Solid State Hydrogen Storage Methods Adopting Different Kinds of Novel Materials," *J. Nanomater.*, vol. 2015, 2015, doi: https://doi.org/10.1155/2015/914845.

[98] H. Quack, "Study of Large Hydrogen Liquefaction Process," in *Conceptual design of a high-efficiency large capacity hydrogen liquefier. AIP Conf. Proc*, 2002, pp. 255–263.

[99] J. Godula-Jopek, A.; Jehle, W.; Wellnitz, *Hydrogen Storage Technologies: New Materials, Transport and Infrastructure;* Wiley-VCH Verlag GmbH & Co. KGaA, 2012.

[100] S. Andersson, J.; Grönkvist, "Large-scale storage of hydrogen," *Int. J. Hydrog. Energy*, vol. 44, no. 23, pp. 11901–11919, 2019, doi: https://doi.org/10.1016/j.ijhydene.2019.03.063.

[101] Matthias Niermann; Alexander Beckendorff; Martin Kaltschmitt; KlausBonhoff, "Liquid Organic Hydrogen Carrier (LOHC) – Assessment based on chemical and economic properties," *Int. J. Hydrogen Energy*, vol. 44, no. 13, pp. 6631–6654, 2019, doi: https://doi.org/10.1016/j.ijhydene.2019.01.199.

[102] D. Tietze, V.; Luhr, S.; Stolten, "Bulk Storage Vessels for Compressed and Liquid Hydrogen," in *In Hydrogen Science and Engineering: Materials, Processes, Systems and Technology*, NJ, USA: Wiley: Hoboken, 2016, pp. 659–690. doi: https://doi.org/10.1002/9783527674268.ch27.

[103] K.Ramamurthi; K.Bhadraiah; S. Srinivasa Murthy, "Formation of flammable hydrogen-air clouds from hydrogen leakage," *Int. J. Hydrogen Energy*, vol. 34, no. 19, pp. 8428–8437, 2009.

[104] M.Groethe; W.Houf; R.Schefer; G.Evans; E.Merilo, "Evaluation of barrier walls for mitigation of unintended releases of hydrogen," *Int J Hydrog. Energy*, vol. 35, no. 10, pp. 4758–4775, 2010, doi: https://doi.org/10.1016/j.ijhydene.2010.02.086.

[105] C. Mazloomi, K.; Gomes, "Hydrogen as an energy carrier: Prospects and challenges.," *Renew. Sustain. Energy Rev.*, vol. 16, no. 5, pp. 3024–3033, 2012, doi: https://doi.org/10.1016/j.rser.2012.02.028.

[106] D. Kova c, A.; Para nos, M.; Marcius, "Hydrogen in energy transition: A Review," *Int. J. Hydrog. Energy*, vol. 46, no. 16, pp. 10016–10036, 2021.

[107] J. Wei; Yuqi Lan; Shenyin, Yang; Tao, "Evaluation and prediction of the safe distance in liquid hydrogen spill accident," *Process Saf. Environ. Prot.*, vol. 146, pp. 1–8, 2021.

[108] W. Rivkin, C.; Burgess, R.; Büttner, "Hydrogen Technologies Safety Guide," Oak Ridge, TN, USA, 2016.

[109] National Fire Protection Association, "Compressed Gases and Cryogenic Fluids Code.," 2021. https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=55

[110] Chinese Standard GB/T 34584-2017 (GB/T34584-2017)., "Chines Standard," 2017. https://www.chinesestandard.net/PDF.aspx/GBT34584-2017

[111] C. S. Manual, "Chinese Standard GB/T 29729-2013 (GB/T29729-2013).," 2013. https://www.chinesestandard.net/PDF.aspx/GBT29729-2013

[112] World Energy Council, "Hydrogen Demand and Cost Dynamics," 2021. [Online]. Available: https://www.worldenergy.org/

[113] Australian National University, "Conditions for low-cost green hydrogen production: mapping cost competitiveness with reduced-form marginal effect relationships," 2021.

[114] Hydrogen Council, "Path to hydrogen competitiveness: a cost perspective," 2020. [Online]. Available: https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf

[115] L. C. I. Prasetyaning, "Promotion of Least Cost Renewables in Indonesia," 2014. [Online]. Available: https://tuewas-asia.org/wp-content/uploads/2017/06/overview_biomass_study_LCORE_FIN_withcover_smallsize.pdf

[116] EIA, "Annual energy outlook 2019. U.S. Energy Information Administration," 2019.

[117] W. S. Boon Siang Tan, Haslenda Hashim, Zarina Ab Muis, Nor Alafiza Yunus and Ho, "Potential of

Energy Recovery from an Integrated Palm Oil Mill with Biogas Power Plant," *Chem. Eng. Trans.*, vol. 63, pp. 253–258, 2018.

[118] A. Junqueira, T.L., Chagas, M.F., Gouveia, V.L.R., Rezende, M.C.A.F., Watanabe, M.D.B., Jesus, C.D.F., Cavalett, O., Milanez, A.Y., Bonomi, "Techno-economic analysis and climate change impacts of sugarcane biorefineries considering different time horizons," *Biotechnol. Biofuels*, vol. 10, no. 12, 2017, doi: https://doi.org/10.1186/.

[119] Y.Yang; J.G.Brammer; D.G.Wright; J.A.Scotta; A.V.Bridgwater, "Combined heat and power from the intermediate pyrolysis of biomass materials: performance, economics and environmental impact," *Appl. Energy*, vol. 191, pp. 639–652, 2017, doi: https://doi.org/10.1016/j.apenergy.2017.02.004.

[120] S. K. Loh, "The potential of the Malaysian oil palm biomass as a renewable energy source," *Energy Convers. Manag.*, vol. 141, pp. 285–298, 2017.

[121] N. Abdullah and F. Sulaim, "The Oil Palm Wastes in Malaysia," in *Biomass Now - Sustainable Growth and Use*, 2013. doi: 10.5772/55302.

[122] M. I. Shahidul, M. L. Malcolm, J. J. Eugene, and R. Mamunur, "Optimization of factors affecting biogas production from POME," *Sci. Int.*, vol. 30, no. 6, pp. 851–859, 2018.