

Review

The Potential of Sustainable Biomass Producer Gas as a Waste-to-Energy Alternative in Malaysia

Jun Sheng Teh ¹, Yew Heng Teoh ^{1,*} , Heoy Geok How ², Thanh Danh Le ^{3,*}, Yeoh Jun Jie Jason ²,
Huu Tho Nguyen ⁴ and Dong Lin Loo ¹

- ¹ Engineering Campus, School of Mechanical Engineering, Universiti Sains Malaysia, Nibong Tebal 14300, Penang, Malaysia; sheng97@student.usm.my (J.S.T.); donglin12@gmail.com (D.L.L.)
 - ² Department of Engineering, School of Engineering, Computing and Built Environment, UOW Malaysia KDU Penang University College, 32 Jalan Anson, Georgetown 10400, Penang, Malaysia; heoygeok.how@kdupg.edu.my (H.G.H.); jjason5831@gmail.com (Y.J.J.)
 - ³ Faculty of Mechanical Engineering, Industrial University of Ho Chi Minh City, 12 Nguyen Van Bao Street, Ward 4, Go Vap District, Ho Chi Minh City 71408, Vietnam
 - ⁴ Department of Mechatronics Engineering Technology, Ho Chi Minh City University of Food Industry, 140 Le Trong Tan Street, Tan Phu District, Ho Chi Minh City 760310, Vietnam; tho.nh@hufi.edu.vn
- * Correspondence: yewhengteoh@usm.my or yewhengteoh@gmail.com (Y.H.T.); lethanhhdanh@iuh.edu.vn (T.D.L.)



Citation: Teh, J.S.; Teoh, Y.H.; How, H.G.; Le, T.D.; Jason, Y.J.J.; Nguyen, H.T.; Loo, D.L. The Potential of Sustainable Biomass Producer Gas as a Waste-to-Energy Alternative in Malaysia. *Sustainability* **2021**, *13*, 3877. <https://doi.org/10.3390/su13073877>

Academic Editor: Mohammad Jafari

Received: 12 January 2021

Accepted: 17 March 2021

Published: 1 April 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Abstract: It has been widely accepted worldwide, that the greenhouse effect is by far the most challenging threat in the new century. Renewable energy has been adopted to prevent excessive greenhouse effects, and to enhance sustainable development. Malaysia has a large amount of biomass residue, which provides the country with the much needed support the foreseeable future. This investigation aims to analyze potentials biomass gases from major biomass residues in Malaysia. The potential biomass gasses can be obtained using biomass conversion technologies, including biological and thermo-chemical technologies. The thermo-chemical conversion technology includes four major biomass conversion technologies such as gasification, combustion, pyrolysis, and liquefaction. Biomass wastes can be attained through solid biomass technologies to obtain syngas which includes carbon monoxide, carbon dioxide, oxygen, hydrogen, and nitrogen. The formation of tar occurs during the main of biomass conversion reaction such as gasification and pyrolysis. The formation of tar hinders equipment or infrastructure from catalytic aspects, which will be applied to prevent the formation of tar. The emission, combustion, and produced gas reactions were investigated. It will help to contribute the potential challenges and strategies, due to sustainable biomass, to harness resources management systems in Malaysia to reduce the problem of biomass residues and waste.

Keywords: biomass; producer gas; tar; energy consumption; thermo-chemical technology; sustainable energy; Malaysia

1. Introduction

Principally, the worldwide energy consumption is still dependent on fossil fuels. This will create a critical energy crisis, with environmental consequence. The increase in energy demands will cause a rise in the use of finite fossil fuels. Furthermore, combustion fossil fuels produce substantial greenhouse gases (GHG), such as CH₄, SO₂, NO_x, and other toxic gases or pollutants, which will cause global warming and acid rains [1].

Worldwide fossil energy reserves can classified into oil, natural gas, and coal. Reserves and resources are terms which are used interchangeably [2]. Every reserve is a resource, but not every resource is a reserve. The present oil reserves stand at around 6951.8 trillion cubic feet, natural gases at around 244.1 thousand million tonnes, and coal reserves at about 1,054,782 tonnes [3]. Figure 1 shows the worldwide fossil fuel consumption from 1990 to 2018. The fossil fuel energy reserves have been decreasing due to the year-over-year demand, due to the growth in the population and economy [4]. The governments need to

support related research and development, on the new energy alternatives, or substitutes, in order to replace it, before all of it runs out.

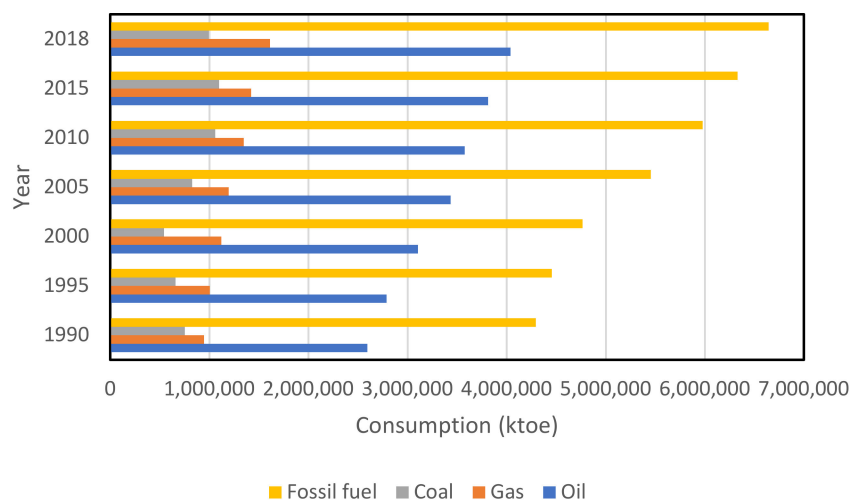


Figure 1. The fossil fuel consumption worldwide from 1990 to 2018.

Worldwide, the energy consumption has increased linearly with the growth in the population [5]. The highest energy consumption has been in China for the year 2019 [6].

People like to spend about 90 percent of their time indoors, using air conditioning systems, which may cause the energy consumption to be much higher. A few simple changes can help unravel an uncomplicated and less difficult lifestyle. These steps will reduce emissions due to energy consumption, which is related to the produced gas emissions from energy consumption, which is also connected to the global warming.

Global warming drives climate change, which is a by-product of the ever increasing global use of energy. Scientific data has shown that the average global temperatures have increased by more than 2 °C, and this will affect human beings. Nearly one million flora and fauna will face the threat of extinction [7]. The target of the United Nations Framework Convention on Climate Change (UNFCCC) is meant to realize the “stabilization of GHG concentrations in the atmosphere”. From the national submissions received by the UNFCCC on the emissions of GHG in 2020 from across 75 parties, it was calculated that the total amount was about 80 percent, of which, most of the worldwide emissions were from energy consumption [8]. Fossil fuels are categorized as “non-renewable energy” as they cannot form an energy reserve for future generations. Renewable energy is key toward replacing oil, natural gas, and coal, which will run out. Biomass energy, can be generated from the production of gases, instead of the use of fossil fuels. It is important to grow renewable fuels which can substitute declining fossil fuels, in order to reduce global emissions [9].

The main objective of this paper is to review potential biomass produced gases from a Malaysian context. It presents a comprehensive review of the solid biomass technology, to obtain biomass produced gases (CO, O₂, CO₂, H₂, and N₂) for sustainable renewable energy.

2. Energy Consumption in Malaysia

Over the past year, the energy consumption in Malaysia increased with the growth in the population and the economic expansion. Malaysia’s total energy consumption in 2018 was 720 terawatt-hour (TWh) which was a 3.3 percent increase in comparison to 2017. Figure 2 shows the fossil fuel consumption, which include oil products, natural gas, coal, biofuel, and wastes. The Association of Southeast Asian Nation (ASEAN) countries accounted for about four percent of the total global GHG emissions [10]. The energy consumption will be directly related to the total CO₂ emissions, which will cause a negative impact to the environment. The Nationally Determined Contribution (NDC) intends to

minimize the severity of the GHG emissions against the gross domestic product (GDP), by about 45 percent by 2030, against the backdrop values seen in 2005 [11]. The burning of fossil fuels to generate energy for electricity and power is important in Malaysia. Malaysia has been investing in renewable energy, which have been focused on hydroelectricity power and solar photovoltaics technology. Figure 3 shows the CO₂ emission increased linearly over the number of years.

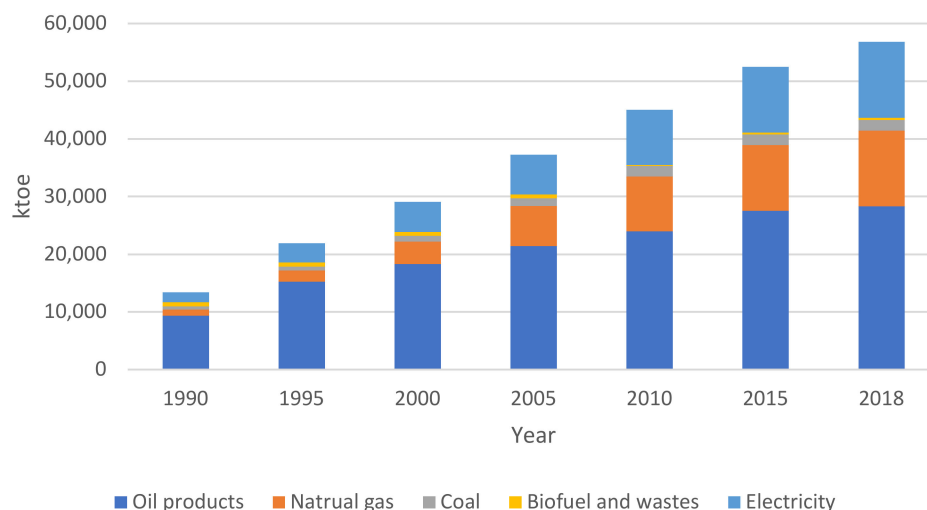


Figure 2. Total final consumption by source by Malaysia in years 1990–2018.

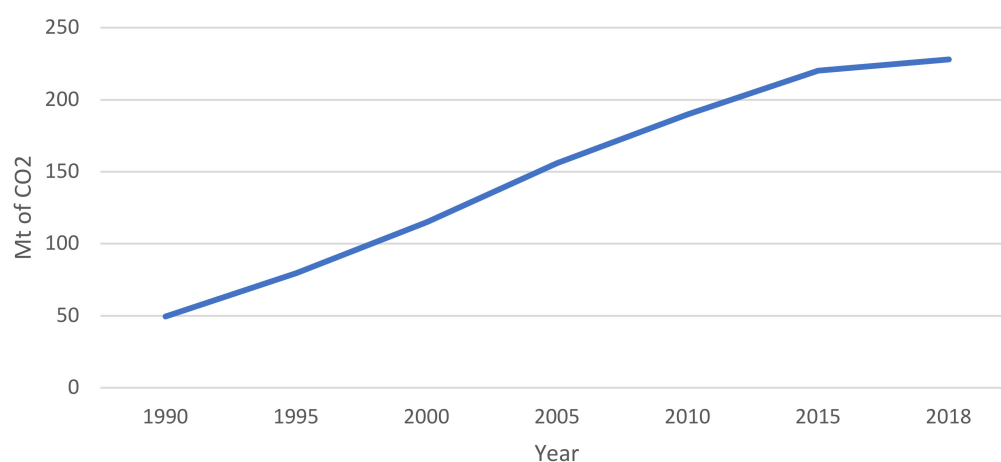


Figure 3. Total of CO₂ emissions by Malaysia in years 1990–2018 [12].

3. Main Biomass Resources Malaysia

Malaysia is a tropical country which is located between the equator on a 7° N latitude line and is affected by the maritime air streams. It experiences a warm and wet weather year long. Therefore, palm oil and rubber is a long-term investment, Malaysia is a major global producer of palm oil in the world [13].

In the 2001 Eighth Malaysia plan, of the renewable energy policy was launched as a “Five-Fuel Diversification Policy” [14]. The “fifth fuel” influences the momentous energy source, after the four primary resources: oil, gas, hydropower, and coal [15]. The “fifth fuel” is a substitute for fossil fuels, in order to gain the potential as an alternative to fossil fuels [16].

In the biomass category, it is mostly derived from animals, plants, and the microbial organism. However, some of the energy sources are related directly or indirectly to renewable origins. Biofuels can be considered a source of renewable energy for the biomass sector, as it contains a high density energy performance factor. Due to the energy performance factor,

it can be seen as a replacement for the petroleum-based fuels. This kind of the biofuels are derived from the living organisms, such as plants, through digestate fertilization, fats of the animals, and even plants residues. The replacement of the biofuel is meaningful for the environment as it comes from plants, compared to fossil minerals or diesel, and is absent of the sulfur and other harmful pollutants.

3.1. From Palm Oil Mill

The availability of palm sourced from the biomass residues [17]. The palm oil mill process carries out the extraction of base palm oil and the fresh fruit bunches [18]. Every tonne of fresh fruit bunch produces various types of mesocarp fiber, kernel shell, empty fruit bunches (EFB), and liquid palm oil mill effluent. Table 1 shows the characteristics showed that the moistures content was higher than coal, which is used in Malaysia. The fiber and the kernel shells usually go through combustion processes to co-generate steam and power. The excess shell produces solid fuels for economic growth [19].

Torrefaction is a thermal method in biomass conversion for biomass materials to bio-coal, which is known as biochar. It helps in the biomass conversion energy process, such as direct combustion for the industry. The thermal degradation of the biomass in an inert atmosphere, take places at about 1 atmosphere (atm) pressure, between 200 °C and 300 °C. This process can improve the yield of the energy with suitable parameters having an optimum higher heating value and the holding time [20]. As shown in Figure 4, about 70 percent of the initial biomass weight and about 90 percent of the original biomass energy are obtained while the remaining (30 percent biomass weight and 10 percent biomass energy) are released as liquid and gases [21]. Thus, it is seen as a potential for investigating the wastes as a feedstock for torrefaction.

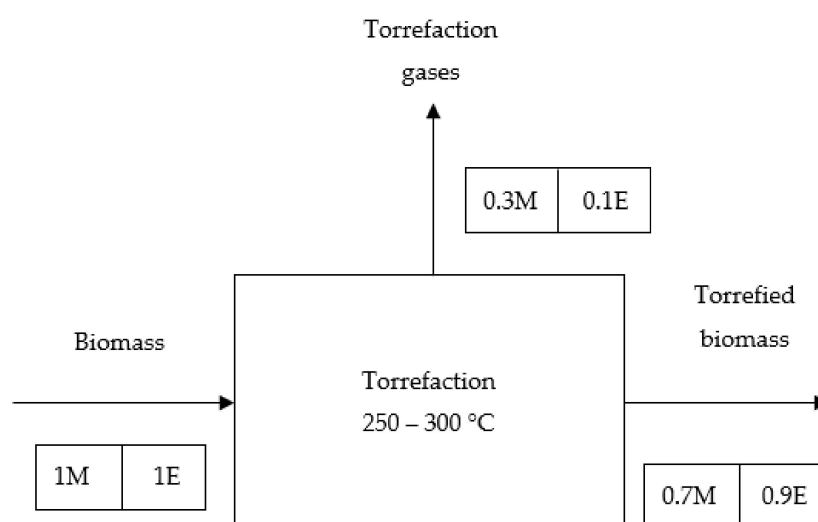


Figure 4. Typical mass and energy balance of the torrefaction process [21].

Table 1 shows the availability of the palm oil by the percentage of production across different categories of palm oil. The study of the production and the moisture were carried out by the C.Mee Chin and M.A. Sukiran. The solid wastes of the palm oil are considered as biomass residues for use as biomass energy for replacing fossil fuel [19–23]. Table 2 shows the proximate analysis of composition of palm oil with the fixed carbon, volatile matter, and ash. The characterization of the palm oil for biomass energy can be analyzed for further value, according to the potential usage from the proximate analysis [22–24]. The percentage of the composition of the palm oil can be determine by the burning or combustion of the material to investigate the optimum yield of the energy. In addition, the safety issues of the combustion are more importance due to ensure the requirements of the process. Table 3 shows the ultimate analysis of the composition of the palm oil and the percentage of the produced gas. There have been a few surveys which have been

recorded in Table 3 according to the produced gas [19,22,23]. Three products are produced during torrefaction such as solid products (brown to black uniform solid, lipid product (condensable volatile organic compounds) and gases (CO_2 , CO , and CH_4), as shown in Figure 5 [22]. The ultimate analysis method displays the combustion of the product source, to measure the weight of produced gas. The torrefaction and combustion of the palm oil can release the produced gas and generate biofuels, which is useful as a future potential energy source. The hemicellulose fraction of the biomass is initially converted, and higher fractions of hemicellulose lead to greater mass changes. The mass yield of the biomass after torrefaction ranged from 24 to 95%, with the energy density ranging between 1 and 58% higher after torrefaction (the energy yield ranged between 30 and 90%). Figure 6 shows the scheme of torrefaction and palletizing processes for the biomass process [25].

Table 1. Availability of types of palm oil.

Sources	Types	Moisture (%)	Production (%)	References
Mill	Mesocarp fiber	42.0	13.0	[19]
		35.0–48.0	-	[22]
Mill	Kernel shell	17.0	5.5	[19]
		11.0–13.0	-	[22]
Mill	Empty fruit bunches	65.0	22.0	[19]
		66.0–69.0	-	[22]
Mill	Liquid palm oil effluent	95.0	70.0	[19]
Field	Fronds	71.0	-	[19]
		62.0–77.0	-	[22]
Field	Trunk	76.0	-	[19]
		67.0–81.0	-	[22]

Table 2. Proximate analysis of palm oil.

Composition of Palm Oil	Proximate Analysis (% dwb)			References
	Fixed Carbon	Volatile Matter	Ash	
Empty fruit bunches	75.7	17	7.3	[23]
	10.8–14.5	86.5–87.7	-	[22]
	15.08–16.04	72.83–72.97	3.95–4.62	[24]
Mesocarp fiber	72.8	18.8	8.4	[23]
	7.6–17.4	84.0–85.6	-	[22]
	14.05–14.88	75.11–75.48	4.80–5.11	[24]
Kernel shell	76.3	20.5	3.2	[23]
	13.2–20.4	82.7–84.4	-	[22]
	15.31–15.70	73.20–73.81	2.16–2.57	[24]

Table 3. Ultimate analysis of biomass.

Composition of Palm Oil	Ultimate Analysis (% dwb)						References
	Carbon	Hydrogen	Nitrogen	Oxygen	Sulfur	Ash	
Empty fruit bunches	43.80–54.76	4.37–7.42	0.25–1.21	38.29–47.76	0.035–1.10	-	[26]
	48.80	6.30	0.70	37.30	0.20	2.30	[23]
	45.90	5.70	0.80	47.60	45.90	5.70	[19]
	48.72	7.86	0.25	48.18	-	-	[22]
Mesocarp fiber	45.20	5.50	1.10	48.20	45.20	5.50	[19]
	47.20	6.00	1.40	36.70	0.30	8.40	[23]
	46.40	9.28	0.39	50.21	-	-	[22]

Table 3. Cont.

Composition of Palm Oil	Ultimate Analysis (% dwb)						References
	Carbon	Hydrogen	Nitrogen	Oxygen	Sulfur	Ash	
Kernel shell	49.70	5.70	0.40	44.00	49.70	5.70	[19]
	52.40	6.30	0.60	36.70	0.20	3.20	[23]
	53.35	6.43	0.37	38.01	Trace	-	[27]
	57.91	12.60	0.04	49.99	-	-	[22]
Palm kernel cake	45.30	10.20	2.50	42.00	45.30	10.20	[19]
Trunk	41.90	6.00	3.80	48.40	41.90	6.00	[19]
	51.41	11.82	0.17	51.16	-	-	[22]
Frond	42.40	5.80	3.60	48.20	42.40	5.80	[19]
	48.43	10.48	12.40	46.50	-	-	[22]
Coal	52.50–65.40	3.80–4.30	0.60–1.40	8.00–13.40	52.50–65.40	3.80–4.30	[19]
	64.34	4.06	-	14.93	0.42	15.41	[28]
	79.40	5.29	12.20	-	0.30	-	[29]

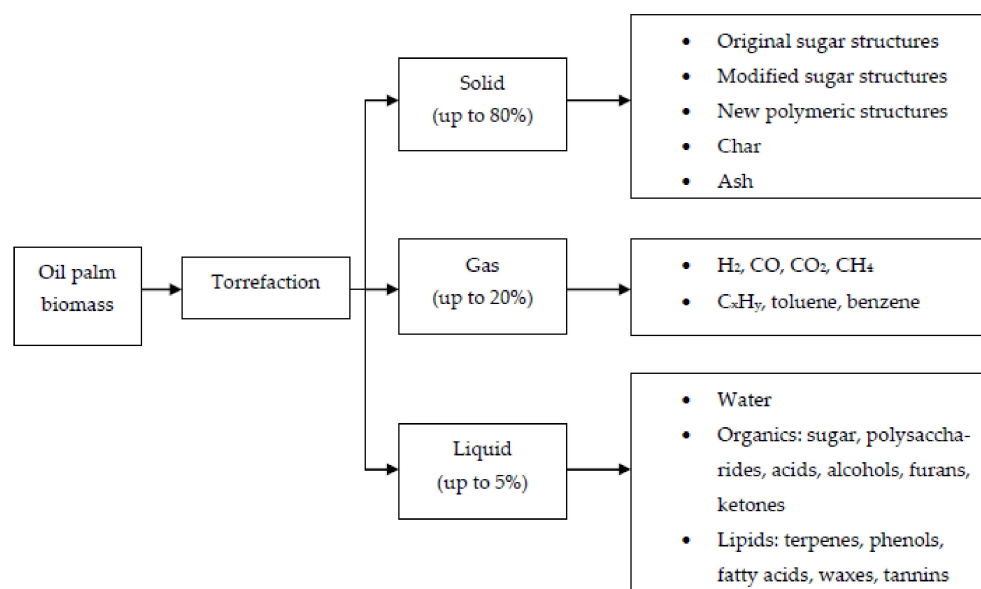


Figure 5. The products from torrefaction process.

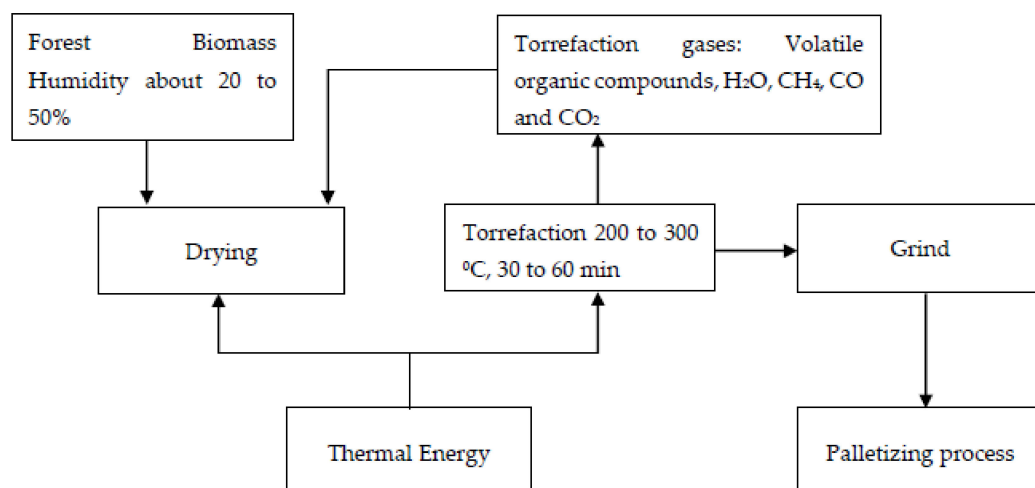


Figure 6. The scheme of torrefaction and palletizing process for biomass.

3.2. From Field

The total palm oil in Malaysia mounted to around 5.9 million hectares of cultivated land in 2019 which was around a 0.9 percent increase in comparison to 2018. Therefore, the crude palm oil (CPO) production was linearly correlated to the plantation area. Approximately 19.86 million tonnes of CPO production accounted to for about around 1.8 percent, of which was only 19.52 million tons in 2018. This was due to the increase in the yield of the fresh fruit bunches (FFB) and oil extraction rate (OER) [30]. Table 4 shows the palm oil industry performance in Malaysia between 2018 and 2019.

Table 4. Malaysian palm oil industry performance [30].

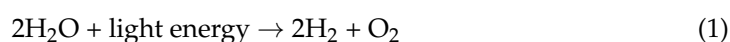
Sources	2019	2018	Difference	
			Volume/Value	%
Planted area (mil hectares)	5.90	5.85	0.05	0.9
CPO production (mil tonnes)	19.86	19.52	0.34	1.8
FFB yield (tha ^{−1})	17.19	17.16	0.03	0.2
Oil extraction rate (%)	20.21	19.95	0.26	1.3
Palm oil exports (mil tonnes)	16.88	15.36	1.52	9.9
Palm oil imports (mil tonnes)	0.98	0.84	0.14	16.1
Closing stocks (mil tonnes)	2.01	3.22	(1.21)	(37.6)
CPO price (RMt ^{−1})	2.08	2.23	(0.15)	(6.9)
Export revenue (RM billion)	64.84	67.52	(2.68)	(4.0)

4. Technology

The main ways for biomass energy conversion are through biological processes, and thermochemical processes [31]. The hydrogen production in biomass energy conversions are commonly carried out in biological processes. Thermochemical processes encompass four different types of processes, as shown in Figure 7 below [1]. Biological processes drive the conversion of the biomass into the fuels which includes the reaction or fermentation of the bacteria. In biomass technology conversion, mostly sugarcane and palm oil industries carry out such kinds of reactions to produce the fuels, which contain ethanol, and methane, etc. These reactions produce gases which contain hydrogen, oxygen, and carbon dioxide. The most important factor is hydrogen production. Hydrogen is also the most important chemical element in the evolution of fuel and provides the maximum fuel per unit weight (142 kJ/g) energy content. In addition, hydrogen gas can work safer than domestic natural gases [32]. Large reductions in unit costs, notably in bulk transportation and storage, and in fuel cells, are needed for hydrogen to be competitive. Finding a practical solution to the problem of storing hydrogen on board vehicles is a critical challenge [33]. Storage of hydrogen can be categorized into three paths; compressed gas in high-pressure tanks, as a liquid in dewars or tanks (temperature at −253 °C), or as a solid through either absorbing or reacting with metals or chemical compounds, or by storing in an alternative chemical form [34].

4.1. Direct Bio Photolysis

Direct bio photolysis is optimizing the process through members of the division in the paraphyletic group convert from water to hydrogen with the reaction follow by below:



Hydrogen generates members of the division in the paraphyletic group under anaerobic conditions which will produces hydrogen or apply hydrogen through donation of electrons during the process. The H₂ ions which are generated will convert into hydrogen gas via the hydrogenase enzyme which is present in cells. The Photosystem II (PSII) generates electrons for transfer of the ferredoxin by absorbing light energy, and by applying light energy absorbed by the photosystem I (PSI) [35,36]. Table 5 shows the direct bio-photolysis

hydrogen production by green microalgae. A rechargeable hydrogenase process can be present by reaction below:

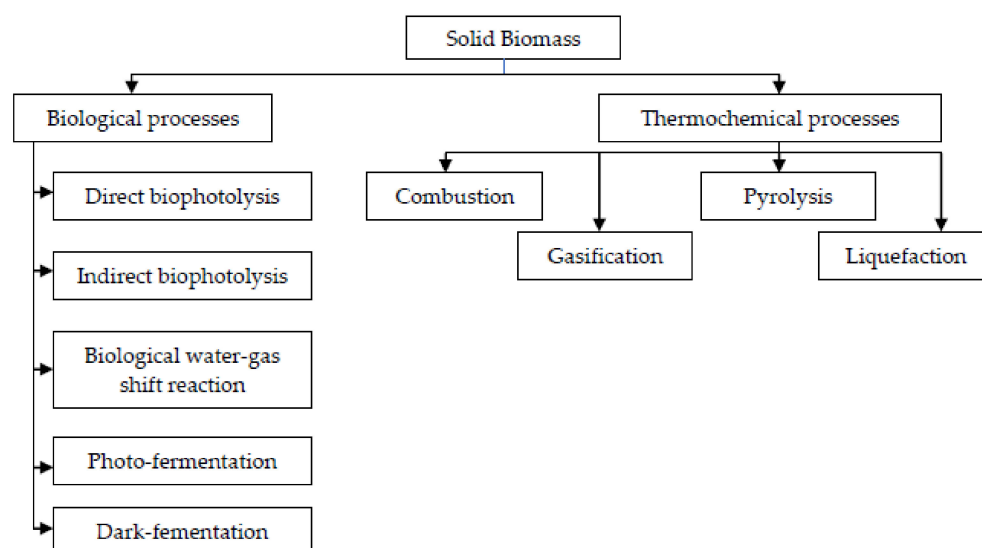
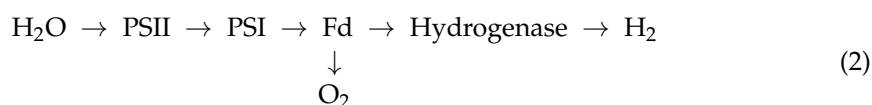


Figure 7. Energy process on biomass.

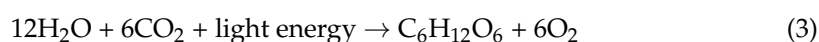
Table 5. Direct bio-photolysis hydrogen production by green microalgae.

Organism	Maximum Hydrogen Evolution (mmol/hChl/h) ^a	Maximum Hydrogen Productivity (mmol/L/h) ^b (kJ/L/h) ^b	Gas for Growth; Carbon Source; Light Intensity (w/m ²) ^c	H ₂ evolution Medium; Light Intensity (w/m ²) ^c	Reference
<i>Chlamydomonas reinhardtii</i> cc124	5.94	0.094 (0.022)	97% air 3% CO ₂ ; Acetate (17 mM); 43	Argon; S-free acetate (17 mM); 65	[37]
<i>Platymonas subcordiformis</i>	(0.01) ^a	0.002 (0.0005)	Air; Seawater nutrients; 22(L/D) ^d	N ₂ . S-free seawater; 35	[38]
<i>Chlamydomonas reinhardtii</i> cc1036	5.91	0.48 (0.12)	Air; Acetate (17 mM); 22	Argon. S-free acetate (17 mM); 26	[39]

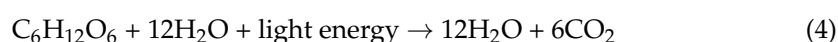
Note: ^a The specific hydrogen evolution rate due to per gram of dry cell. ^b Hydrogen production per photobioreactor liquid volume during hydrogen evolution. The heat of combustion of hydrogen at around 0.24 kJ/mmol at 25 °C. ^c 1 W/m² = 4.6 μmol E/m²/s (APR). APR: photosynthetically active radiation which includes the light energy with the wavelength at around 400 to 700 nm. ^d 14-h light and 10-h dark.

4.2. Indirect Bio Photolysis

Indirect bio photolysis chemical process different with direct bio photolysis is process to form hydrogen from water by cyanobacteria by the reaction below:



and



Cyanobacteria is normally found at nutrient-rich water surfaces [40]. Cyanobacteria can be present with the organisms in blue-green algae. Cyanobacteria contains phyco-biliproteins which can perform oxygen photosynthesis. The H₂ producing cyanobacteria process consists of either fixing nitrogen or non-nitrogen fixing. Some examples of nitrogen fixing bacteria are *Anabaena*, cyanobacteria, *Beijerinckia* [41].

4.3. Biological Water–Gas Shift Reaction

The water–gas shift reaction is used to convert carbon monoxide through the water molecule reaction to carbon dioxide and hydrogen. The reaction is exothermic, which means that the equilibrium of the reaction shifts to the right and favors the lower temperature of formation of hydrogen and carbon dioxide products [42]. If the equilibrium moves to the left at higher temperatures, it limits the complete carbon monoxide to hydrogen conversion. Commercialized water gas reactions are carried out by inserting two inserts, which are arranged using adiabatic reactors, which act as high-temperature water–gas shift (300 to 450 °C), and the low temperature water–gas shift (200 to 250 °C) to optimize the carbon monoxide conversion, followed by energy-intensive processes, such as solvent absorption or pressure swing absorption, for the separation of hydrogen and carbon dioxide. The full conversion of the water–gas shift reaction with dioxide separation. This is possible by extracting hydrogen from the retentate stream of the reactor is possible in a single membrane reactor at high temperatures (500 °C) [43].

In a heterogeneous gas-phase reaction with carbon monoxide and steam, a traditional water–gas shift reactor uses a metallic catalyst. While the balance favors the formation of products at lower temperature, the reaction kinetics are much quicker at higher temperatures [44]. The reaction of water–gas shift reaction has shown below:



A range of catalysts need to be produced to activate the water–gas shift reaction. Table 6 shows the different catalytic performances in the water–gas shift reaction. In some conditions, such as supercritical water and plasma systems, non-catalytic water gas change reactions may be chosen [45].

Table 6. The catalytic performance of microporous silica membrane reactors used for water–gas shift reaction.

Membranes	Temperature (°C)	Feed Pressure (MPa)	Catalysts	Conversion (%)	References
Silica	280	0.6	CuO/CeO ₂	97	[46]
Silica	350	0.15	Fe-Cr/Al ₂ O ₃	85	[43]
Silica	450	0.2	Fe-Cr/Al ₂ O ₃	97	[47]
Co-SiO ₂	250	0.2	Cu/ZnO/Al ₂ O ₃	95	[48]
Co-SiO ₂	300	0.4	Cu/ZnO/Al ₂ O ₃	92	[49]

4.4. Photo-Fermentation

The development of photo fermentative hydrogen requires the conversion of organic compounds into carbon dioxide and hydrogen, without the evolution of oxygen, in the presence of light as an energy source [44]. Even with a relatively high partial hydrogen pressure, the production of photo fermentative hydrogen can fully transform organic compounds into hydrogen. In the photo fermentation process, photosynthetic bacteria play a key role, and it is efficiency dictates the range of utilization and conversion efficiency of the substrate to hydrogen [50].

Solid waste typically contains high concentrations of carbon, in particular organic acids. Most industrial waste is used as substrates in the development of photofermentative hydrogen [51]. Table 7 shows the photo fermentative hydrogen production of photo-non sulfur bacteria by waste. Most of the production of photofermentative hydrogen by purple non-sulfur bacteria from agricultural biomass requires the use of simple sugars obtained

from the pretreatment of complex biomass [44]. Table 8 shows the photo fermentative hydrogen production, which includes palm oil mill effluent (POME), molasses, and glycerol.

Table 7. Photo fermentative hydrogen production by photo-non sulfur bacteria.

Wastes	Organism	Light Intensity	Operation	Hydrogen Production	References
POME and pulp and paper mill	<i>R. sphaeroides</i> NCIMB8253	7 klux	Batch	8.72 mL H ₂ /mL medium	[52]
POME and pulp and paper mill	<i>R. sphaeroides</i> NCIMB8253	7 klux	Batch	14.438 mL H ₂ /mL medium	[53]
Beet molasses	<i>Rhodobacter capsulatus</i> JP91	200 W/m ²	Batch	10.5 mol H ₂ /mol sucrose	[54]
Beet molasses	<i>Rhodobacter sphaeroides</i> O.U.001	200 W/m ²	Batch	0.5 mol H ₂ /mol sucrose, 1.01 L H ₂ /L culture	[55]
Crude glycerol	<i>Rhodopseudomonas palustris</i> CGA009	200 W/m ²	Batch	6.1 mol H ₂ /mol glycerol	[56]
Crude glycerol	<i>Rhodopseudomonas palustris</i>	175 W/m ²	Batch	6.69 mol H ₂ /mol glycerol	[57]

Table 8. Photo fermentative hydrogen production from various agricultural biomass.

Biomass	Pre-Treatment Methods	Microorganism	Fermentation Condition	Hydrogen Production	References
Oil palm empty fruit bunch	6% H ₂ SO ₄ , autoclaved at 120 °C for 15 min	<i>Rhodobacter sphaeroides</i> S10	pH 7, 35 °C, 14.6 W/m ² illuminance and batch mode	22.4 mL H ₂ /L h	[58]
Corn cob	30 U/mg cellulase	Photosynthetic bacteria isolated from silt sewage, pig and cow manures (<i>Rhodospirillum rubrum</i> , <i>Rhodopseudomonas capsulata</i> , <i>Rhodopseudomonas palustris</i>)	10.5 g/L reducing sugar, low-energy LED lamps, 20% (v/v) inoculum, baffled photo fermentative bioreactor and 24 h HRT	589.21 mmol/L 6.98 mmol/L h	[59]
Rice straw	Milling followed by immobilized cellulase	Photosynthetic bacteria isolated from silt sewage, pig and cow manures	20% (v/v) mixed bacteria, 30 °C, pH 7 (initial), 3 klux illuminance	140.26 mmol/L 3.76 mmol/L h	[60]
Wheat straw	H ₂ SO ₄ (pH 3) and autoclaved at 90 °C for 15 min	<i>Rhodobacter sphaeroides</i> NRLL	5 g/L initial sugar, pH 7, 30 °C, 3 klux, shaking at 100 rpm and −200 mV ORP	115.3 mL H ₂ 0.9 mL H ₂ /h	[61]
		<i>Rhodobacter sphaeroides</i> DSZM		135.1 mL H ₂ 1.5 mL H ₂ /h	
		<i>Rhodobacter sphaeroides</i> RV		178 mL H ₂ 3.69 mL H ₂ /h 1.23 mol H ₂ /mol glucose	

4.5. Dark Fermentation

The dark fermentation process requires the application of strict or optional anaerobic species to turn substrates such as simple sugars, glycerol, fatty acids, and carbohydrates into volatile fatty acids, alcohols, solvents, carbon dioxide, hydrogen, and methane [62]. Compared to other biological processes which produce hydrogen, the primary benefits of dark fermentation lies in its light independence. Independent light processes are anerobic processes known as dark fermentation processes. POME management is one of the most challenging issues. The most used POME treatment method is the anaerobic ponding system, which is not environmentally friendly. Fostering the sustainable practice of closed anaerobic digestion is important. POME is used to generate renewable biogas in the palm

oil industry. POME undergoes anaerobic digestion of wastewater, where biogas is freely released or captured as energy [63].

The possibility of using renewable biomass as feedstock and higher production rates of hydrogen, is also accompanied by low energy input requirements. The palm oil mill effluent (POME) uses biomass residues from the palm oil. Since POME is a complex material and depends on the processing of palm oil, its composition varies. In general, organic molecules such as fatty acids, proteins, carbohydrates, nitrogenous compounds, lipids, and minerals are highly concentrated in POME [64]. During dark fermentation processes, this organic matter could be metabolized either by pure culture or bacterial consortia, which are primarily used as feedstock when complex materials are added, due to the presence of assorted species that could function synergistically, raising the degradation and consumption of these materials. Figure 8 shows the degradation of complex materials which occurs in four phases in the dark fermentation of POME. Complex substrates, such as long-chain fatty acids and triacylglycerol, are hydrolyzed by hydrolytic bacteria into simpler molecules, such as oleic acid, palmitic acid, and glycerol. Acidogenic bacteria facilitates the conversion of these molecules into volatile fatty acids, usually acetic and butyric acids, and ultimately into alcohols and ethanol in the second process. The synthesis of organic acids in the series produces acetate and butyrate and cogenerates hydrogen during acetogenesis as well. Methanogenic microflora can reduce the produced hydrogen to methane. However, because POME is a complicated material, the substrates could not be readily accessible for bacterial cells, resulting in a long adaptive phase, and low conversion rates. It is mandatory to exclude hydrogen-consuming bacteria from the medium, preventing methanogenesis, in order to generate hydrogen. The advantages of dark fermentation can produce hydrogen all day long, without light while photo fermentation needs bacteria under a wide spectral light condition.

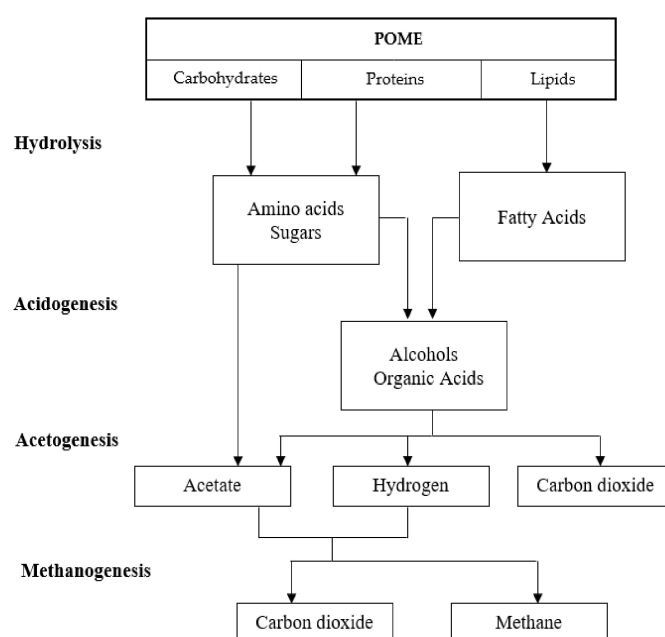


Figure 8. Scheme model for dark fermentation of POME [65].

4.6. Combustion

Combustion is an intricate phenomenon which contains coupled heat and chemical reaction in mass transfer [66] and fluid discharge [67]. In terms of air, the volume ratio in binary mixtures of oxygen and nitrogen which are 21 percent and 79 percent, respectively. Air mixture can represent more constituents, but it is not important for this chemical reaction for the combustion and gross analysis [68]. The hot gas is emitted by the combustion process at temperatures between 700 °C and 1000 °C. The biomass must be pre-dried for biomass combustion at about 50 percent humidity [69]. Therefore, combustion is an

efficient technology that converts to bio-fuel and generates heat. The bio-fuel processing is not entirely a new technology, since no bio-fuels will be produced after the complete combustion of the raw feedstock [70]. The residual gas in the complete or incomplete combustion of hydrocarbons, happen in the presence of the oxygen, which contains a few combustion products and gaseous mixes. The residual gases, such as carbon monoxide and carbon dioxide, are primarily caused by combustion emissions that damage the air quality and pollute it. During the combustion process, it will generate carbon dioxide but there is no net increase of carbon dioxide in the atmosphere. Under the 1997 Kyoto Protocol's CDM, the palm oil industry has an opportunity to reap the financial benefits from GHG emissions, through reductions by using palm biomass as fuel, to replace fossil fuels. Unlike fossil fuels that emit large quantities of carbon dioxide when burnt, the carbon dioxide emitted by burning palm biomass is totally recycled or sequestered by the oil palm. There is therefore no net increase of carbon dioxide in the atmosphere. These biomass products are renewable and can be replenished by the oil palm. The ultimate source of energy content of this biomass is the sun [71].

The combustion reaction can provide a relatively fuel content source for human use in the combustion engine, diesel vehicles, etc. Such a kind of reaction generally will save costs in the biomass implementation for burning organic material. However, the emissions of the produced gas is harmful to the environment and individuals.

4.7. Gasification

Gasification is a chemical reaction that converts carbonate elements into raw chemical substrates or gaseous fuels. The resulting gas mixture can be called as synthesis gas, or syngas. For the production of syngas, the gasification of fossil fuels is common in the biomass process [72]. The syngas is mostly composed of CO, H₂, N₂, CO₂, and some hydrocarbon elements or compound (CH₄, C₂H₄, C₂H₆, etc.) [73]. The gasification process operates in an oxygen-deficient environment and contains heat. Furthermore, it demands a medium reaction, such as air, oxygen, subcritical steam, and some gaseous mixtures [74].

The condition of the gasification reaction takes place under the gasifier. Thus, the gasifier is a very important variable that affects the reaction process during the gasification. In general, the gasifiers can be categorized into three broad groups which are known as the fixed bed, fluidized bed gasifier, and the entrained flow gasifiers [73].

The characteristics of the three different gasifiers shows as Table 9 [75,76]:

Table 9. Characteristics of three different gasifiers [73].

Gasifier	Characteristics
Fixed bed	<ul style="list-style-type: none"> - Slight capacity - Can operate substantial particles - Producer gas has a low heating value - Producer gas has a high quality content - High gasification agent consumption - Ash is removed as slag or dry
Fluidized bed	<ul style="list-style-type: none"> - Medium capacity - Constant thermal distribution - High temperature operation - Producer gas has a low quality content - Suitable for raw material with low level of fusion temperature - Ash is removed as slag or dry
Entrained flow	<ul style="list-style-type: none"> - Huge capacity - High temperature operation - Unfit for high-ash-content feedstocks - Requires huge consumption of oxygen - Residence times is slightly lower - Ash is removed as slag

As it results in a substantial reduction in carbon dioxide emissions compared to fossil fuels and generates high calorific gas from a renewable energy resource, biomass gasification is receiving increased attention. Major efforts have been made to apply and prepare gasification technology for the market and to evolve it into a mature and practical, but also competitive, technology. The flexibility of the gases produced is the primary driver for the interest in biomass gasification [77].

Biomass gasification can be classified into various gasification due to the application of the gasification agents, such as air gasification, oxygen gasification, steam gasification, hydrogen gasification, and carbon dioxide gasification. In modern technology, this mixture can be either steam-O₂ gasification, or air-CO₂ gasification [78,79].

Biomass air gasification works at temperatures between 800 °C and 1800 °C and the reactions are categorized into four categories; drying, devolatilization, combustion, and reduction [80–82].

In air gasification, the mixture of air is not fully oxidized by the biomass. Thus, the gasification emanates heat such that the gasification creates some hydrogen gas flow, carbon monoxide, carbon dioxide, methane, other hydrocarbons, and nitrogen [83]. Because of the much simpler way to produce the gasification process, air gasification can be considered uncomplicated, and inexpensive, because air is easy to acquire and air gasification can provide its own temperatures without the use of a heat generator. In comparison, the volume of nitrogen at about 79 percent is not part of the reaction and the nitrogen dilutes the synthesized gas content. However, the calorific value is considered to be less than 3–5 MJ/Nm³ because of the produced gas [84].

Gasification is a dynamic process that can easily be affected by the biomass composition, grain size, temperature, and the equivalence ratio (ER). Due to biomass gasification, the ER is a significant component. ER is the ratio between the overall combustion and the reaction equation of the real amount of air supply to the reaction and the potential amount of air as follows [85]:

$$ER = \frac{Air_i}{Air_j} \quad (6)$$

where the Air_i is the actual amount of air supplied, and the Air_j is the stoichiometric air actual amount of air supplied.

4.8. Pyrolysis

Pyrolysis is the thermochemical conversion of biomass into volatiles, gas, and a mixture of liquid compounds through the thermal movement in an inert atmosphere [86]. In the absence of oxygen at temperatures between 350 °C and 550 °C [87], the thermochemical pyrolysis method can work well. Using three principles, the pyrolysis process can be namely three categories, such as slow pyrolysis, fast pyrolysis, and flash pyrolysis.

The three pyrolysis process conversion technologies have different operating conditions and outcomes for the pyrolysis techniques. Firstly, the slow pyrolysis heating rate is lower than 1 °C/s, the pyrolysis temperature is between 300 °C and 700 °C, and the pyrolysis residence time is higher than 450 s. The heating rate of the slow pyrolysis is lower than 1 °C/s, the pyrolysis temperature is between 300 °C and 700 °C, and the residence time of the pyrolysis is higher than 450 s. The heating rate of the fast pyrolysis is between 10 °C/s to 300 °C/s, and the temperature of the pyrolysis is between 550 °C and 1250 °C. The residence time of the pyrolysis is between 0.5 s and 200 s. Lastly, the heating rate of the flash pyrolysis is higher than 1000 °C/s, and the temperature of the pyrolysis is between 800 °C and 1300 °C. The residence time of the pyrolysis is lower than 0.5 s [88].

The fast pyrolysis can be consider origin development stage compare to the combustion process in the biodiesel production [89]. The bio-oil is produced by liquid in the pyrolysis process. The process of pyrolysis is an endothermic reaction can be representing by below [1]:

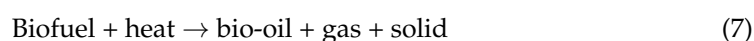


Table 10 shows the three different pyrolysis technologies on the operating condition and the results [90].

Table 10. Summary of the three different pyrolysis technologies [88].

Conversion Technology	Operating Conditions	Product Yields
Slow pyrolysis	Temperature: 300 °C to 700 °C Vapor residence time: 10 to 100 min Heating rate: 0.1–1 °C/s Feedstock size: 5–50 mm	Bio-oil: ~30 wt.% Biochar: ~35 wt.% Gases: ~35 wt.%
Fast pyrolysis	Temperature: 400 °C to 800 °C Vapor residence time: 0.5 to 5 s Heating rate: 10–200 °C/s Feedstock size: <3 mm	Bio-oil: ~50 wt.% Biochar: ~20 wt.% Gases: ~30 wt.%
Flash pyrolysis	Temperature: 800 °C to 1000 °C Vapor residence time: <0.5 s Heating rate: >1000 C/s Feedstock size: <0.2 mm	Bio-oil: ~75 wt.% Biochar: ~12 wt.% Gases: ~13 wt.%

The advantages of pyrolysis processes compared to other thermo-chemical technologies are broad. Firstly, the yield of the main product, which is bio-oil can be as high as 75 percent. Secondly, the product of the bio-oil has a high content of the carbon. Thirdly, the product of the bio-oil has contains low concentration nitrogen and sulfur. Furthermore, the higher heating value of the product which is bio-oil, is much higher compared to fossil fuels. The products such as bio-oil, bio-syngas, or biochar, can be manufactured by adjusting the input operational of parameters [91].

4.9. Liquefaction

The medium temperature and high-pressure thermochemical method is called hydrothermal liquefaction. The hydrothermal liquefaction is a thermochemical reaction, which converts from the wet biomass into fluid fuel [92]. The main product in this reaction is the liquid biocrude oil, along with the solid, liquid, and gaseous by products. The liquefaction process occurs under the thermally compressed water, in the range of temperature between 250 °C and 550 °C, with a compressed pressure around 5 MPa to 25 MPa [93]. This reaction does not need any drying process, digestate technology. The main product is biocrude, which is part of petroleum oil. It has high potential after strengthening. Thus, with the use of alkaline catalysts, this will suppress the formation of the char and improve the yield and quality of the oil.

By comparison, the liquefaction of the feedstock feeding method is much more complicated and expensive than the pyrolysis process and has little interest in the liquefaction process. The energy regeneration from the biomass into fossil fuel is high, typically round 80 percent, which is considered outstanding to other biomass technologies [94–96].

4.10. Summary of Thermochemical Conversation Process

Table 11 shows the comparison across several thermochemical conversion processes. To conclude, the different thermochemical processes will experience various temperatures and pressure, to release the energy conversion to obtain the necessary outcomes [97].

Table 11. Comparison of thermochemical conversion process.

Process	Temperature (°C)	Pressure (MPa)	Drying	Hydrogen Production	References
Liquefaction	250–550	5–25	Not required	Not favourable	[92,93]
Pyrolysis					
Slow pyrolysis	300–700	0.1–0.5	Necessary	High purity of hydrogen	[98]
Fast pyrolysis	400–800	0.1–0.5	Necessary	Recommended production	[88]
Flash pyrolysis	800–1000	0.1–0.5	Necessary	Most suitable for application	[88]
Combustion	700–1000	≥ 0.1	Executable in about 50 percent moisture content, if not the biomass needs to pre-dried	Not a suitable for sustainable development	[68–70]
Gasification	500–1300	≥ 0.1	Necessary	Recommended production	[78,79]

Three thermochemical processes are prevalent here: pyrolysis, liquefaction, and gasification. The comparison between pyrolysis and gasification, showed that the pyrolysis process has a lower temperature than the gasification process. The thermal decomposition of the volatile components of the material is converted into additional syngas, and non-volatile carbon char, which will remain from the pyrolysis process. The liquefaction process has gained good attention to utilize this waste, because of its versatility and potential to be used as a construct medium in a product that incorporates all the helpful functional groups present in the liquefying solvents and biomass. Compared to other thermochemical processes, this process requires relatively low temperature conditions that can conserve more fuel, emit less pollutants and is much cheaper. However, there are risks to getting so much variety depending on the feedstock, which includes the processes considered as higher critical points, and severe reaction conditions [99]. This process is not favorable in the hydrogen production for biomass thermochemical process. The gasification method was chosen as a much more sustainable option, due to the fact that it adds value to low, or negative-value feedstocks by converting them in marketable fuels and products.

5. Potential Biomass Producer Gas

Malaysia is a country which is considered as the second largest worldwide producer of palm oil [100]. This study will incorporate the ability to supply biomass, and investigate the potential to generate and enhance biomass energy [101]. The technology applies across different reactions, which will produce various outcomes for produced gas or residues. The potential biomass product which is converted from waste to energy, can produce biofuel, biogas, and methane conversions.

The producer gases are obtained from the analysis, which can be considered friendly to environment [102]. The analysis of experiments carried out by bio-renewable researchers on palm oil biomass established its the chemical compositions. The final study of the biomass of palm oil revealed the presence of elements such as carbon (C), hydrogen (H₂), nitrogen (N), sulfur (S), and oxygen (O). In the biomass, the ratios of H:C and O:C are determined by the energy released during the combustion process, which is regarded as the strength of the bonds between the elements in the fuel [103].

The results from the research on the proximate analysis of the palm oil briquette, refers to the percentage quantity of the macromolecules in the food, to obtain the properties of the palm oil briquette. The ultimate analysis was carried out for experimenting on the raw materials, to study the potential and availability of palm oil and the tung tree waste. The palm oil wastes include different residues, for example, palm oil fronds, EFB, and palm

kernel cake. The properties of the elements in the Table 3 are shown with the percentages obtained from the ultimate analysis [23].

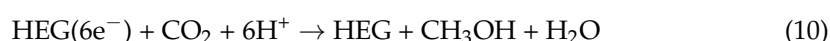
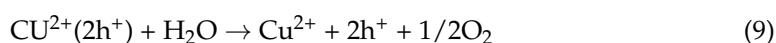
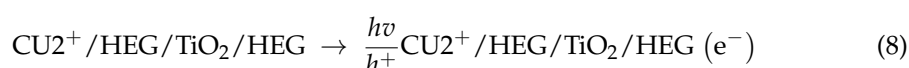
5.1. Carbon Monoxide

During the combustion of fossil fuels, it produces gaseous pollutants which cause variation in the atmospheric composition. Carbon monoxide (CO) is produced from sulfur-based fossil fuel combustion [104] and the burning of gasoline, biomass, and fuel. CO needs to be regulated to maintain the air quality, because of the hydroxyl radical (OH) which manages the oxidizing quantum of the troposphere [105]. CO goes through several processes or mechanisms to reduce diseases which bind with hemoglobin to create carboxyhemoglobin for reducing oxygen which is essential to human organs and prenatal development [106]. Modern steam reforming plants typically use pressure swing adsorption through gas separation/methanation, to remove carbon dioxide from the hydrogen products. This process also removes any main carbon monoxide and methane to produce 99.99 percent pure hydrogen. Alternative solvent-based separation technologies, such as amines, help in the absorption of carbon dioxide, through the removal of carbon monoxide from the gas products using a separate methanation step. The reversal of the reforming reaction creates undesired carbon monoxide, which is converted to methane is methanation [107].

5.2. Carbon Dioxide

The combustion of biomass residues increase the volume of carbon dioxide (CO₂) in the atmosphere [108]. CO₂ is considered to have an important role in GHG since fossil fuel utilization, in particular for the combustion of the biomass residues especially, from coal combustion, which causes serious global warming [109]. CO₂ is used to strengthen the sustainability for the advancement of the posterity, which can be obtained through the photosynthesis of plants, which naturally depletes CO₂ and sunlight to emancipate the oxygen. It can create biomass as a carbon-neutral energy source. The utilization of CO₂ for biofuels does not reduce global warming, but it can grant an abundance of accessible carbon source for future years [110].

The photocatalytic compound of methanol decreases CO₂ through the form of graphene [111]. In truth, due to the elemental adsorption properties of graphene, the initial reactants of CO₂ could be ingesting on the exterior of graphene, which has been simulated along with copper (II) sulfate (CuSO₄) nanoparticles. The strengthen in the visible light illuminated reduction of productivity of CO₂ to methanol is show as below equation:



5.3. Oxygen

For humans, flora, and fauna, oxygen is a gas that encourages cellular development and longevity. Photosynthesis is the process by which plants produce oxygen, which accounts for half of the oxygen on the planet. The pyrolysis condition are approximately 46 to 79 percent oxygen in the primitive biomass, which would be converted to water, and approximately 17 to 34 percent of CO₂ [112]. The higher oxygen content of biodiesel in a power supply is about 10% to 11%, which can result in complete self-combustion in the vehicle [113].

5.4. Nitrogen

During the thermal conversion of biomass, nitrogen in the biomass is released as nitrogen-containing volatiles (volatile-N), including NO_x precursor gases such as ammonia (NH₃), hydrogen cyanide (HCN), isocyanic acid (HNCO) and nitrogen oxides (NO_x and

N_2O), and toxic contaminants like organic nitrogenated compounds and N_2 . The nitrogen compound is a fertilizer that can induce algal boom, lowering oxygen levels in the water, while ammonia-nitrogen is harmful to marine organisms [114]. Ammoniacal nitrogen has been listed as one of the major contaminants polluting several rivers, that is contribute to the eutrophication mechanism is used to assess the water quality [115]. Temperature rises will degrade lake water quality by lowering hypolimnetic dissolved oxygen concentrations and increasing mineralization and nitrogen release from lake bottom sediments. The higher temperatures cause pollutants to volatilize and pesticide compounds to degrade in the soil and surface waters, and as precipitation occurs, the toxins are flushed through rivers and drinking reservoirs, causing major water quality issues and public health concerns [116].

The management of nitrogen is a significant improvement for sustainable, energy efficient and eco-friendly farming systems in mass manufacturing [117]. In biomass production, nitrogen fertilization can raise the bioenergy crop construction. Nitrogen fertilization will not alter soil CO_2 flux, which is hardly duplicated between the fertilized and unfertilized treatments. It also increases the production biomass yield according to the increase in the nitrogen fertilization, such as switchgrass. Nitrogen amendments can improve the net GHG profits by $2.6 \text{ Mg ha}^{-1}\text{y}^{-1}$ and $9.4 \text{ Mg ha}^{-1}\text{y}^{-1}$ as CO_2eq , compared to the control [118]. Some sugarcane varieties were found to have new biological nitrogen fixation behavior with endophytic diazotrophic bacteria such as *Azopirillum* and *Azotobacterial* [119]. Thereby, this nitrogenous fertilizers can act as the input in the main energy. The main types of N fertilizers used in the oil palm are urea, containing 46 % of N, and ammonium sulfate, with 21 % of N. Figure 9 shows the revenue of the nitrogen by industry in Malaysia. The development of nitrogen in Malaysia showed an increase from 2017, but it was fluctuated in about 2015.

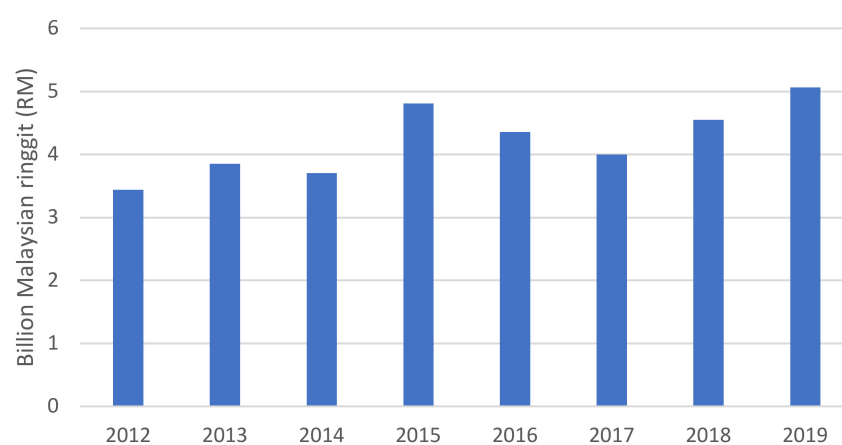


Figure 9. The sales values of manufactured fertilizers and associated nitrogen in Malaysia.

5.5. Hydrogen

Hydrogen production can produce various technologies and reactions. Hydrogen can produce the required energy through electrochemical processes. Electrochemical processes produce compounds of the hydrogen fuel, through the reaction with the oxygen and fuel cells, to generate electricity. Hydrogen can be recognized as an important energy source of the future. Biomass energy is a latent and dependable energy source for manufacturing hydrogen [120].

5.5.1. Hydrogen from Biomass Pyrolysis

Pyrolysis processes produce quick or flash pyrolysis for bio-fuel processing [121]. The production of hydrogen from rapid or flash pyrolysis is recommended because the rise in temperature with the experiment for biomass use will increase the hydrogen content. Pyrolysis gas composition of torrefied wood will shows in Table 12 [122].

Table 12. Pyrolysis gas composition of Torrefied wood [122].

Producer Gas	Torrefied Wood Content
Oxygen/Argon	2.9
Carbon dioxide	22.5
Carbon monoxide	30.1
Methane	22.0
Hydrogen	20.1

5.5.2. Hydrogen from Biomass Gasification

Biomass gasification is described in Section 4.3. Gasification processes are mostly suitable for biomass, and have a moisture content of around 5 percent to 35 percent [123]. The key problem is the creation of the tar structure when the length of the reaction is due to the gasification process itself. The formation of the tar may cause the structure of tar formation to affect the form of polymerization into a complex compound that will change the thermochemical reaction, which is favorable for hydrogen production [124].

The input parameters due to the biomass gasification will affect the formation and decomposition of tar. Thus, the input parameters of biomass gasification have a fixed temperature, gasifying agent, and residence time. The significance of these interactions are suppressed at the highest temperature of 900 °C, as the thermal cracking of tar become dominant [125]. The application of additives will help reduce the formation tar in the gasifier, which are dolomite, olivine, and char [126]. The improved of gas yields of the products are seen when dolomite is applied. Thus, higher steam to biomass ratios, which are due to steam, are also found to minimize tar. The restructuring of the tar occurs with an increased partial steam pressure. With an increase from 1.6 to 2.2 in the H/C ratio, the hydrogen content is also increased. An increased low heating value of 4 to 6 MJ/Nm³ and a decreased tar content from 18 to 2 g/Nm³ [127].

5.5.3. Hydrogen Production from Gasification in Supercritical Water (SCW)

Hydrogen Production through the Reaction Integrated Novel Gasification (HyPr-RING) method for the integration of water-hydrocarbons are done in accordance to sub-critical and supercritical water conditions, the change water–gas process and intake of CO₂ and other pollutants in a particular reactor. With its distinct capacity and characteristics, water plays a profuse role in stimulating the gasification reaction. Water properties represent a hyper-critical point and play an important role in chemical reactions [128].

5.6. Tar in Biomass

In the thermo-chemical technology conversion processes such as gasification and the pyrolysis processes, the generation of the produced gases includes various byproducts, such as NO_x, SO₂, and tar [129]. The conversion process to syngas is an important technique for the manufacturing industry, in product fuels, and in chemical element by using the C1 chemistry [130]. The gasification process has been already investigated as a non-catalytic system [131]. The expectations are that the catalysis decreases the tar concentration during the catalysis conversion and reduction in the temperature during in the produced gas [132]. If the fuel gas is used directly for combustion, there is no restriction on the amount of tar, given the fact that the gasifier outlet and burner inlet do not allow the gas to cool down below the tar dew point [133]. Tar can act as a volatile, at which lower than room temperature. Increase of the temperature will reduce the total yield of the tar and formation of CO, benzene, naphthalene, and polycyclic aromatic hydrocarbons (PAHs) [134]. The incomplete combustion of organic matter, such as wood, coal, or oil will creates PAHs. As a rule, the lower the fire temperature and available oxygen, the more incomplete the burning of these materials, and the more PAHs are produced [135]. Gasification residues in PAHs are classified for their high content [136]. PAH is carcinogenic, permanent, accumulates in living species, and its reproduction is partially inhibited. In addition, short-term symptoms such as eye pain, nausea, vomiting and confusion can be caused by PAHs, while long-term

health effects include cataracts, damage to the kidney and liver and jaundice [137]. It must be operated at a high temperature above 900 °C in the gasifier in order to achieve an effective carbon conversion of the biomass and low tar content in the result, which is the produced gas [138].

5.7. Summary of Producer Gas and Residues

Table 13 shows the summary of the producer gas and residue that produced by the source of the biomass. The benefit and the consequence of the environmental for the future is show as below:

Table 13. Summary of producer gas and residues.

Producer Gas/Residues	Benefit	Consequence in Biomass
Carbon monoxide	Carbon monoxide can reduce diseases which bind with hemoglobin to emerge carboxyhemoglobin.	Modern steam reforming plants typically use pressure swing adsorption through gas separation/methanation to remove carbon dioxide from the hydrogen product. This process also removes any main carbon monoxide and methane to produce 99.99 percent pure hydrogen.
Carbon dioxide	It can utilize the carbon dioxide to strengthen sustainability for the advance of posterity which through the photosynthesis of plants naturally deplete carbon dioxide and sunlight to emancipate the oxygen.	It will cause a serious contribution to global warming.
Oxygen	Oxygen or air gasification coupled with a water–gas shift is the most widely practiced process route for biomass to hydrogen.	The higher oxygen content around 10 percent to 11 percent of biodiesel can cause its complete combustion in self engine.
Nitrogen	Nitrogen can provide the improvement sustainable, energy efficient and eco-friendly farming system on energy manufacturing.	Nitrogen can increase the production biomass yield according to the increase nitrogen fertilization.
Hydrogen	Hydrogen fuel reacts with the oxygen and through the fuel cell to generate the electricity	Hydrogen is an inexhaustible, abundant, and liable to use for instead for the fossil fuel.
Tar	Tar is producer residues but does not have any benefit to the reaction on the thermochemical.	Tar will hinder and corrosive the process mechanism. Incomplete combustion of organic matter, such as wood, coal, or oil will creates PAHs. short-term symptoms such as eye pain, nausea, vomiting and confusion can be caused by PAHs, while long-term health effects include cataracts, damage to the kidney and liver and jaundice

5.8. Catalytic

The tar catalytic reform most commonly occurs during the biomass gasification or pyrolysis. The development of the catalytic mostly takes place to eliminate the tar formation during the biomass process, and it is still is a significant challenge under current conditions [139]. Catalysts are commonly applied in the chemical and petroleum industry to improve the rates of the reaction, which are currently unachievable.

Catalytic gasification of biomass can be classified into two types such as low-temperature catalytic gasification of biomass and high-temperature catalytic gasification of biomass. The range of temperature of low-temperature catalytic gasification is between 350 and 600 °C while the high-temperature catalytic gasification of biomass is between 500 and 750 °C. Both of the catalytic gasification have a similar function to improve the efficiency of the reaction [140].

The catalysts can be applied across several formations of components in the gaseous product. The production of the syngas and methane can be produced in very little amount. Catalytic gasification can be applied to promote or to suppress the formation of methane.

A possible technique to increase the distinctive function of the bio-oil is through catalytic pyrolysis. The feedstock composition process can be upgraded because of the pyrolysis process, but it needs to be fixed with the necessary catalysts to control the pyrolysis process. However, some parameters in its biomass supplies include the optimum catalyst/biomass ratio, and the homogeneous fractions of chemical pyrolysis products, which will be needed for the necessary catalysts. A possible renewable fuel in the IC engine can be considered as a catalytic esterified biomass–pyrolysis–oil. Catalysis pyrolysis is a technique for increasing the distinctive characteristics of bio-oils, by extracting oxygenated compounds, raising the calorific value level, reducing viscosity, and increasing the stability level [141].

The most common and famous method for improving its use is hydrodeoxygenation and catalytic cracking. Catalytic cracking may take into account the use of the producer gas in a new technology. Catalytic cracking is used to upgrade bio-oil via the catalytic medium by removing oxygen in the form of water and carbon dioxide from the bio-oil compound. This chemical reaction will disrupt the C–C bonds via several reaction such as dehydration, decarboxylation, and decarboxylation. The advantages of the catalytic cracking include much better performances at the atmospheric pressure and in condition without the addition of hydrogen.

6. Challenges for Sustainable of Biomass Energy in Malaysia

Firstly, environmental challenges confront the energy change, such as climatic change, the atmosphere, and water pollution which is a by product of increased use of fossil fuels. Secondly, sustainability in the power sector is a challenge for the use of biomass in Malaysia. Thus, it is needed to ensure the sufficient and continuous supply of biomass which is crucial in Malaysia. The development of technology in Malaysia will transform biomass resources into utilizable elements, which at present have not been established [142].

The biomass challenges in Malaysia can be broken down into three groups: technological barriers, financial barriers, and barriers to social knowledge.

6.1. Technical Barriers

The research and development (R&D) in biomass utilization in Malaysia is evolving tremendously. The government needs to drive cooperation with the support of universities for researching on the potential of biomass producer gases by using different technological methods. The Fundamental Research Grant Scheme (FRGS) encourages the student to expand the boundaries of knowledge. On the other hand, the government also needs to further expand the pathways for the biofuel and biochemical transformation techniques.

The technical barrier may face certain technology barriers related to unsuitability, because of the insecure power supply in some developing countries. There is very limited handling of the equipment in practice on the equipment, and in this area. The limitation of handling such equipment will depend on the environmental policies and certainly due to the lack of knowledge [143].

Biomass supplies or residues are still a main issue for biomass utilization in Malaysia [144]. In Malaysia, palm oil is the main requirement to attain the sustainable demand for the biomass industry. The mesocarp fiber, kernel shell, EFB, and liquid palm oil mill effluents are all biomass residues for converting waste to energy for the palm oil industry. In order to improve the sustainability of the supply of biomass, the use of pyrolysis serves as a latent fertilizer in planning, which determines the application of biomass from the base of the supply chain, which can be regarded as an intermediate derived from biomass [145].

6.2. Financial Barrier

Malaysia has a diversified and balanced economy, with a mature, broad-based manufacturing sector, a modern and mature agricultural sector, and an effective, profitable, and equally mature service sector with a fast-paced economy, which is capable of adapting rapidly to evolving supply, demand, and competition patterns. An economy which is technologically competent, completely capable of adapting, innovating, and inventing, increasingly technology-intensive, heading towards higher and higher levels of technology, and an economy that has solid and coherent industrial ties across the system, will prosper [146].

Malaysia has a long-term availability, at reasonable cost and economic merit, of suitable biomass feedstock. Biomass fuel can be sourced locally in Malaysia and across ASEAN. The size of the installed capacity would have a greater effect on the overall costs. The relatively broad discrepancies between the net effect of the GDP and revenues arising from the use of biomass from palm oil are attributed to the cost of opportunity. Resources from other operations are taken from the transport and refining of palm biomass, for ethanol production, and other sectors. This is particularly important to labor, as Malaysia already enjoys full employment at present. The development of a biobased economy thus directly and indirectly affects many other areas of the economy, as well as the education, finance, and innovation systems [147].

One of the difficulties that hinder the growth of the biomass industry in Malaysia is the financial barrier. Malaysia's current situation faces an issue with regards to funding for the implementation of clean energy technologies. Thus, renewable energy innovations also deal with the question of viable investment in the economy. Furthermore, the lack of the experience and knowledge with regards to renewable energy in the infrastructure may increase the cost of the capital of renewable energy projects, and may increase the risks of investment for the certain renewable energy sectors [148].

The biomass industry is a labor-intensive industry [144]. A labor-intensive industry is a difficult barrier of entry, which minimizes the emulation across other industries [149]. The failure to certify perennial and sustainable raw material supply, besides the availability of a trusted supply, can be considered as a feedstock risk and supply chain issues, which can cause financial and business risks [150].

6.3. Social Awareness Barrier

For decades, the Malaysian palm oil industry has supported the local economy and the livelihoods of many people, particularly in the rural areas. Due to the abundance of new employment opportunities for local citizens, the establishment of large-scale biomass power plants can produce a higher demand for biomass energy. Local communities in rural areas will also engage in economic activities, in particular in centers for the collection and processing of biomass, to further alleviate poverty and minimize rural migration to urban and suburban areas [151].

Social awareness barriers are listed as one of the challenges for the biomass sector in Malaysia. The lack of coordination between stakeholders for dealing between the supply chain and the customer is important to decide in planning of environmental costs during purchasing. Original equipment manufacturers (OEMs) manage the competitive market, which has the advantage of having a highly dependent internal focused environment. The supply chain will compare the scale and coordination of costs for their supply sources. The acts of deforestation to supply these resources, the loss of ecosystem, and the loss of the homes of the indigenous people due to lack of various areas for industries, are all issues which need to be dealt with. Thus, this will impact soil erosion and destruction of the ecosystem and the environment [152].

7. Strategies to Improve Sustainable Biomass in Malaysia

The emission of the carbon dioxide causes a severe effect, as it acts as a greenhouse gas on the atmosphere. The Malaysian government must focus on the effect, it has on the

environment to accelerate a sustainable biomass sector for the country. Agensi Inovasi Malaysia (AIM) is an agency formed by the government to create wealth through development, skill, and innovation. AIM, through the National Biomass Strategy Delivery Unit, have planned to create a BioHub Concept for sustainable biomass development which includes in biorefineries and biochemical plants.

The BioHub concept will drive the development in Malaysia for certain states which are seen as a potential for the availability of around 80 percent of the resources, such as in Johor, Sabah, and Sarawak. This BioHub project is considered as a long-term investment, between the range of 18 to 24 months. Malaysia's industrial energy includes palm oil, forestry, and city-based solid wastes, which will stand to deliver about RM30 billion of the Gross National Income (GNI). The most important consequence is reducing carbon dioxide emissions by 12 percent for the future [153].

Biomass is a carbon dioxide neutral energy source. The significant release of carbon dioxide by burning forests is almost the same as that seen during the crop of timber. This will cause a drastic reduction in carbon dioxide emissions, which will mitigate global warming [154].

7.1. Palm Oil Renewable Energy Industry

Malaysia has one of the largest agricultural palm oil companies. For the purpose of reducing waste and transforming waste into useful goods, the government of Malaysia has carried out research for introducing sustainable energy sources.

The production of palm oil has put the nation into the world market. Because of the sustainable growth of palm oil, this global demand will boost Malaysia's financial position and the average annual production of palm oil will continue to rise every year. From 2016 to 2020, the annual production of palm oil in Malaysia hit 15.4 million tonnes.

The development of palm oil biomass will be a downstream barrier on the electric tariffs. The growth of palm oil biomass for the generation of electricity in Malaysia will be affected by this due to the huge number of the palm oil companies, who are developing business models in the palm oil industry. On the other hand, it also can lead to the purposes of utilizing solid wastes for electricity energy generation for the feedstock supply in the market. The improvement of the waste-to-energy conversion with current equipment and development mechanisms for the future in the country, need to be examined to provide a much more cost-effective solution for waste disposal [155].

7.2. Policy Implications, Policy Framework and Industry Roadmap Models

Government action are required to help court major investors who have interests in projects or businesses for the palm oil energy, which are focused on the renewable energy industry.

Malaysia's biomass will mainly focus on the intensification of palm oil projects. The government have been carried out the Economic Transformation Program (ETP) in 2010, which focused on palm oil. The aim of the project was to lead the industry and to achieve the yield target of about 26.2 t per hectare in 2020, for national fruit bunches. The replantation project is a long-term effort to produce fresh fruit bunches and it will cause a low harvest of small energy producers. This will a low outcome of products and thus will cause a low national average yield. To overcome this situation, the Malaysian government introduced a financial grants to smaller producer energy holders with the monthly allowance to overcome their financial burden, which amounted to about US \$157 to improve the yield of fresh fruit bunches, while they could also can enjoy discounts agricultural products for their produce [156].

The government is committed to ensuring the sustainable spread of biomass production by establishing a good climate for the growth of industry. This can provide more business options, which includes not having to pay tax, better management of the finances, and other new and interesting success plans, and ways of reaching goals. The policy framework seeks to introduce the responsibilities of the stakeholders to the industry for

their businesses. These have six enforced policy drivers which have been determined by the government [155]:

1. Renewable Energy Policy and Act
2. Feed-in Tariff (FiT) system
3. Biomass Financing Policy
4. Electricity Supply Act
5. Physical Infrastructure System
6. Awareness Campaign

The FiT system is a structural reform for providing a long-term policy for renewable energy source in the industry. This policy system was introduced in 2011, which was meant to drive the renewable energy industry in Malaysia. Therefore, the FiT system produces the electricity from the renewable sources, and ensures that renewable energy provides a long-term growth for the industry, companies, and individuals [157].

This policy is mainly focused on municipal solid wastes rather than biomass residues. Therefore, the policies are meant to regulate the sustainable management of the biomass wastes for the purpose of power generation. Government can through the policy, control and provide the biomass financing mechanism to regulate the abundance of resources, and to deter milling and burning of fossil fuels. Thus, the government is central to bring about more financial reasons for connecting businesses-centered surrounding on building low-cost energy production avenues.

By contrast, the industrial road map has superior plans of reaching goals which are aligned to the policy framework. It can provide the needed scenario to predict the next action in the framework strategy. This is at the review stage, for providing the drive during the implantation process. The stakeholders need to voice their opinions about the necessary improvement and actions for achieving their final targets [155].

7.3. Strategies for Sustainable Conversion Technology

The solid biomass conversion technology is primarily divided into biological and thermo-chemical technologies. The biomass conversion technology widely applies to the biomass energy sector, which includes combustion, gasification, pyrolysis, and modular systems. Malaysia's biomass industry primarily uses combustion or combined heat and power (CHP) systems or combinations of both, to mill the palm oil to about 77 percent, based on studies and surveys. On the other side, with a gasification method, only 5 percent of plants use it. Therefore a traditional boiler system is used to achieve over 70 percent efficiency using the proper technology and equipment. Most of the installations in the current plants still operate with low-pressure boilers, which can only achieve 40 percent of the overall cogeneration efficiencies [157].

The government has a range of policy instruments for R&D utilization of biomass to increase the rate of return for new technologies, and to promote its growth. A solution's complexity should be measured very early on in the process. The costs and time required for training should be included in the budget and deployment plan, considering the need to adapt training to different forms of learning to achieve the best possible benefit from it.

The strategies on financial barrier, Malaysia's biomass industry primarily uses combustion or combined heat and power (CHP) systems or combinations of both to mill the palm oil about to 77 percent. With a gasification method, only 5 percent of plants use it. A traditional boiler system can achieve over 70 percent efficiency, but most of the installations in the current plants still operate with low-pressure boilers, which can only achieve 40 percent of the overall cogeneration efficiency [157]. This would ensure that the spending on biomass conversion technologies is cost-effective to resolve this situation. This can however be easily calculated based on the estimate that the plant must generate a high level of energy to overcome the duration of the performance, and maintenance of the energy application. The mechanism needs to generate an amount of energy over a certain period of time, which will correlate with the efficiency, and will overcome the outdated equipment with low conversion efficiencies and unsustainability [158]. The maintenance

of the equipment can also have some energy production efficiency, but a high cost may also be considered in the long-term. The industry is therefore wary of changing its current machinery inefficiencies, and poor machine efficiencies, because of the additional potentials from the burning of solid biomass waste is meant to ingratiate its daily output, rather than exporting it to the grid. However, biomass technology investment requires high upfront costs and offers a longer payback period, which hampers the industry from being replaced by low-carbon technologies.

The advantage of sharing a cost strategy will reduce the financial risk and it will improve the economic scale in the biomass business. The government plays an important role for introducing the policies in the business and initiating a role to create the partnership model required for this kind of business. This will lead the economy of the country and provide more opportunity for developers to combine small capacity plants and turn them into large-scale facilities.

The government can also increase the FiT system payment to provide high offers or technology bonuses to the energy producers. Thus, the policy can be reformed by replacing or upgrading the low-pressure boilers, which produce low carbon emissions, which can be seen as an offer or reward.

The strategies on social awareness barrier, the higher role of the industry or the government toned to be able to achieve supply chain alignments, by aligning priorities and incentives through various supply chain roles and stages. Other steps which can be taken to achieve cooperation include the exchange of sales data and joint forecasting and planning, the introduction of a single replenishment control point, and enhancing operations along with lead times to minimize lot sizes. The way to stop the deforestation is to provide services that consume less to urge people to shop for sustainably certified items, spread awareness, and raise consciousness of the effort.

7.4. Strategies for Planning on Short-Term, Medium-Term, and Long-Term Efforts

For the development in biomass or any businesses, there are many factors which need to be considered before carrying out the strategies on these models. These are important sectors associated with business development, financial matters, business investment and other matters related to the market. These can be classified into three recommend ways, including short-term, medium-term, and long-term strategies. For different periods, the terms of the strategies will depend on the capital-intensive aspect.

Firstly, the short-term strategies plan can be carried out on certain actions. The short-term strategies can be considered the range of between six months and one year. The implementation of this short-term period can include innovations for the biomass conversion energy, or design of low-carbon producing recipes for the mechanisms [159]. The low carbon production will gain the required efficiencies for the process, and it also can reduce the feedstock inputs and lower energy consumption. Therefore, the investigation into the types of palm oil include empty fruit bunches, mesocarp fiber, and trunk, to implement the function of diversification of fuels in the combustion technology [160]. To strengthen the capacity of the research and development on the biomass conversion technology. There needs to be an elimination of independent suppliers who sell the additional electricity to the third party for their own benefit [161]. There is a need for an investigation into the solid biomass wastes, which can be a potential energy sources. Although it is considered as a medium-term period for the study, it can obtain the composition of the chemicals for the conversion of the biomass solid wastes conversion, which is an important sector for renewable energy sources.

The medium-term strategy period can consider the range between one year and three, or four years. It deals with the creation of the collection on the fuel to figure out the composition or potential to replace the conversion system during the combustion or other technology [162]. This implementation method is very significant in the energy source to sustainable renewable energy. For example, the improvement of the physical mechanism and the equipment in the industry. Others include the maintenance of the equipment in

industry, the improvement and innovation projects in the industry, and also maintaining the yield and efficiency of the production [163]. Furthermore, enhancement of the composition investigation of the producer gas is necessary to drive the biological and thermo-chemical conversion technologies. The government can also develop a cost-sharing model plan to provide more stakeholders to join, for providing more building infrastructure [164]. This can improve the capacity of the equipment, to obtain new technology or equipment to study more fundamental knowledge and skills for the biomass conversion technology. Due to the composition of the producer gas, the composition of the syngas includes carbon monoxide, carbon dioxide, hydrogen, and other mixtures of air. Thus, future studies are needed to obtain the optimal of the parameters of the composition to replace the depleted fossil fuel.

The improvement of the research and development activities in the palm oil industry need to be considered as part of the strategic plan. In Malaysia, the huge plantation of palm oil is a major benefit of the country, and the types of the palm oil such as mesocarp fiber, fresh fruit bunches, and the field of the palm oil trunk and ponds, are very practical and useful for the sector. The palm oil residues go through thermo-chemical conversion processes and it can obtain syngas, which includes carbon monoxide, carbon dioxide, hydrogen, and other mixtures of air. The syngas which is obtained can be investigated for replacement of fossil fuels in the future, or next generation.

The long-term strategies need to consider a range above five years. The extension of the grid size or lines, and improvement of the level of facilities is the main driver to upgrade the technology in the country [165]. The improvement of technology not only improves the knowledge, and it can provide the economy, businesses, and infrastructure.

8. Conclusions

In this review, Malaysia has been identified as a major palm oil producer. Malaysia is the largest producer and exporter of palm oil, globally. There are various solid biomass technologies, such as biological processes and thermo-chemical processes, which need to be developed further. In the biological process, the dark fermentation is an anaerobic digestion process, which can produce hydrogen using palm oil mill effluents, and there is no oxygen limitation problem. In the thermo-chemical process, gasification processes are seen as a more sustainable process, due to the fact that it adds value to low, or negative-value feedstocks by converting them into marketable fuels and products.

Thus, hydrogen production is seen as an energy carrier of the future since it is inexhaustible, plentiful, and liable to use. Moreover, hydrogen is the most suitable, succession chemical element in fuel evolution, and it contains the highest energy content of fuel per unit weight.

Author Contributions: Conceptualization, J.S.T.; Software, J.S.T., H.T.N. and Y.H.T.; Validation, J.S.T. and Y.H.T.; Formal analysis, J.S.T.; Resources, J.S.T. and Y.H.T.; Writing—original draft preparation, J.S.T. and Y.H.T.; Writing—review and editing, Y.H.T., H.G.H., Y.J.J. and D.L.L.; Visualization, Y.H.T., T.D.L. and H.T.N.; supervision, Y.H.T., H.G.H. and Y.J.J.; Project administration, J.S.T., T.D.L.; Funding acquisition, Y.H.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: This study was supported by the Ministry of Higher Education of Malaysia and Universiti Sains Malaysia (USM) through the Fundamental Research Grant Scheme (FRGS)-203.PMEKANIK.6071444 (Title: Mechanism Study of Combustion and Formulation of Surrogate Biomass Producer Gas Using a CVCC System) and Universiti Sains Malaysia Research University (RUI) Grant Scheme 1001.PMEKANIK.8014136 (Title: Effect of Fuel Injection Strategies and Intake

Air Supply Control on Performance, Emissions, and Combustion Characteristics of Diesel Engine Fueled with Biodiesel Blended Fuels).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Mohammed, M.; Salmiaton, A.; Azlina, W.W.; Amran, M.M.; Fakhru'L-Razi, A.; Taufiq-Yap, Y. Hydrogen rich gas from oil palm biomass as a potential source of renewable energy in Malaysia. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1258–1270. [CrossRef]
2. Roser, H.R.M. Fossil-Fuels@Ourworldindata.Org. Available online: <https://ourworldindata.org/fossil-fuels> (accessed on 9 November 2020).
3. Ruhe, C.H.W. Statistical Review. *JAMA J. Am. Med. Assoc.* **1973**, *225*, 299–306. [CrossRef]
4. Wei, J.; Cen, K. Empirical assessing cement CO₂ emissions based on China's economic and social development during 2001–2030. *Sci. Total Environ.* **2019**, *653*, 200–211. [CrossRef] [PubMed]
5. Cao, X.; Dai, X.; Liu, J. Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade. *Energy Build.* **2016**, *128*, 198–213. [CrossRef]
6. Ma, X.; Wang, C.; Dong, B.; Gu, G.; Chen, R.; Li, Y.; Zou, H.; Zhang, W.; Li, Q. Carbon emissions from energy consumption in China: Its measurement and driving factors. *Sci. Total Environ.* **2019**, *648*, 1411–1420. [CrossRef]
7. Shuit, S.H.; Tan, K.T.; Lee, K.T.; Kamaruddin, A.H. Oil palm biomass as a sustainable energy source: A Malaysian case study. *Energy* **2009**, *34*, 1225–1235. [CrossRef]
8. Gao, Y.; Gao, X.; Zhang, X. The 2 °C Global Temperature Target and the Evolution of the Long-Term Goal of Addressing Climate Change—From the United Nations Framework Convention on Climate Change to the Paris Agreement. *Engineering* **2017**, *3*, 272–278. [CrossRef]
9. Ibeto, C.; Ofoefule, A.; Agbo, K. A Global Overview of Biomass Potentials for Bioethanol Production: A Renewable Alternative Fuel. *Trends Appl. Sci. Res.* **2011**, *6*, 410–425. [CrossRef]
10. Data-and-Statistics@Www.Iea.Org. Available online: <https://www.iea.org/data-and-statistics> (accessed on 16 October 2020).
11. Fulton, L.; Mejia, A.; Arioli, M.; Dematera, K.; Lah, O. Climate Change Mitigation Pathways for Southeast Asia: CO₂ Emissions Reduction Policies for the Energy and Transport Sectors. *Sustain. J. Rec.* **2017**, *9*, 1160. [CrossRef]
12. Shafie, S.; Mahlia, T.; Masjuki, H.; Ahmad-Yazid, A. A review on electricity generation based on biomass residue in Malaysia. *Renew. Sustain. Energy Rev.* **2012**, *16*, 5879–5889. [CrossRef]
13. Ng, W.P.Q.; Lam, H.L.; Ng, F.Y.; Kamal, M.; Lim, J.H.E. Waste-to-wealth: Green potential from palm biomass in Malaysia. *J. Clean. Prod.* **2012**, *34*, 57–65. [CrossRef]
14. Dharfizi, A.D.H.; Ghani, A.B.A.; Islam, R. Evaluating Malaysia's fuel diversification strategies 1981–2016. *Energy Policy* **2020**, *137*, 111083. [CrossRef]
15. Samsudin, M.S.N.; Rahman, M.M.; Wahid, M.A. Power Generation Sources in Malaysia: Status and Prospects for Sustainable Development. *J. Adv. Rev. Sci. Res.* **2016**, *25*, 11–28.
16. Kumaran, P.; Hephzibah, D.; Sivasankari, R.; Saifuddin, N.; Shamsuddin, A.H. A review on industrial scale anaerobic digestion systems deployment in Malaysia: Opportunities and challenges. *Renew. Sustain. Energy Rev.* **2016**, *56*, 929–940. [CrossRef]
17. Khatun, R.; Reza, M.I.H.; Moniruzzaman, M.; Yaakob, Z. Sustainable oil palm industry: The possibilities. *Renew. Sustain. Energy Rev.* **2017**, *76*, 608–619. [CrossRef]
18. Montoya, J.; Valdés, C.; Chaquea, H.; Pecha, M.B.; Chejne, F. Surplus electricity production and LCOE estimation in Colombian palm oil mills using empty fresh bunches (EFB) as fuel. *Energy* **2020**, *202*. [CrossRef]
19. Chin, C.M.; Wahid, M.B.; Weng, C.K. Availability and Potential of Biomass Resources from the Malaysian Palm Oil Industry for Generating Renewable Energy. *Oil Palm Bull.* **2008**, *56*, 23–28. Available online: <http://palmoilis.mpob.gov.my/publications/OPB/opb56-meechin.pdf> (accessed on 9 October 2020).
20. Sankaran, R.; Show, P.L.; Nagarajan, D.; Chang, J.S. *Exploitation and Biorefinery of Microalgae*; Elsevier B.V.: Amsterdam, The Netherlands, 2018.
21. Akogun, O.; Waheed, M.A. Property Upgrades of Some Raw Nigerian Biomass through Torrefaction Pre-Treatment- A Review. *J. Physics: Conf. Ser.* **2019**, *1378*, 032026. [CrossRef]
22. Uemura, Y.; Omar, W.N.; Tsutsui, T.; Yusup, S.B. Torrefaction of oil palm wastes. *Fuel* **2011**, *90*, 2585–2591. [CrossRef]
23. Sukiran, M.A.; Abnisa, F.; Daud, W.M.A.W.; Abu Bakar, N.; Loh, S.K. A review of torrefaction of oil palm solid wastes for biofuel production. *Energy Convers. Manag.* **2017**, *149*, 101–120. [CrossRef]
24. Husain, Z.; Zainac, Z.; Abdullah, Z. Briquetting of palm fibre and shell from the processing of palm nuts to palm oil 2002. *Biomass Bioenergy* **2002**, *22*, 505–509. [CrossRef]
25. Aziz, M.A.; Uemura, Y.; Sabil, K.M. Characterization of oil palm biomass as feed for torrefaction process. In Proceedings of the 2011 National Postgraduate Conference—Energy and Sustainability: Exploring the Innovative Minds, NPC 2011, Perak, Malaysia, 19–20 September 2011. [CrossRef]
26. Garcia, D.P.; Caraschi, J.C.; Ventorim, G.; Vieira, F.H.A.; Protásio, T.D.P. Comparative Energy Properties of Torrefied Pellets in Relation to Pine and Elephant Grass Pellets. *Bioresour.* **2018**, *13*, 2898–2906. [CrossRef]
27. Chang, S.H. An overview of empty fruit bunch from oil palm as feedstock for bio-oil production. *Biomass- Bioenergy* **2014**, *62*, 174–181. [CrossRef]

28. Salema, A.A.; Ani, F.N.; Mouris, J.; Hutcheon, R. Microwave dielectric properties of Malaysian palm oil and agricultural industrial biomass and biochar during pyrolysis process. *Fuel Process. Technol.* **2017**, *166*, 164–173. [\[CrossRef\]](#)
29. Zhang, Y. *Trace Elements Characteristics of Ultra-Low Emission Coal-Fired Power Plants*; Elsevier Ltd.: Amsterdam, The Netherlands, 2019.
30. Caillat, S.; Vakkilainen, E. *Large-Scale Biomass Combustion Plants: An Overview*; Woodhead Publishing Limited: Cambridge, UK, 2013.
31. Ghulam Kadir, A.P. Oil Palm Economic Performance in Malaysia and R&D Progress in 2019. *J. Oil Palm Res.* **2020**. [\[CrossRef\]](#)
32. Kumar, G.; Dharmaraja, J.; Arvindnarayan, S.; Shoban, S.; Bakonyi, P.; Saratale, G.D.; Nemestóthy, N.; Bélafi-Bakó, K.; Yoon, J.; Kim, S. A comprehensive review on thermochemical, biological, biochemical and hybrid conversion methods of bio-derived lignocellulosic molecules into renewable fuels. *Fuel* **2019**, *251*, 352–367. [\[CrossRef\]](#)
33. Momirlan, M.; Veziroglu, T. Current status of hydrogen energy. *Renew. Sustain. Energy Rev.* **2002**, *6*, 141–179. [\[CrossRef\]](#)
34. Storage@www.fsec.ucf.edu. Available online: <http://www.fsec.ucf.edu/en/consumer/hydrogen/basics/storage.htm> (accessed on 10 February 2021).
35. Miao, Y.-X.; Wang, X.-Z.; Gao, L.-H.; Chen, Q.-Y.; Qu, M. Blue light is more essential than red light for maintaining the activities of photosystem II and I and photosynthetic electron transport capacity in cucumber leaves. *J. Integr. Agric.* **2016**, *15*, 87–100. [\[CrossRef\]](#)
36. Winkler, M. 6Fe9-hydrogenases in green algae: Photo-fermentation and hydrogen evolution under sulfur deprivation. *Int. J. Hydrogen Energy* **2002**, *27*, 1431–1439. [\[CrossRef\]](#)
37. Kosourov, S.; Tsygankov, A.; Seibert, M.; Ghirardi, M.L. Sustained hydrogen photoproduction by *Chlamydomonas reinhardtii*: Effects of culture parameters. *Biotechnol. Bioeng.* **2002**, *78*, 731–740. [\[CrossRef\]](#)
38. Guo, Z.; Liu, Y.; Guo, H.; Yan, S.; Mu, J. Microalgae cultivation using an aquaculture wastewater as growth medium for biomass and biofuel production. *J. Environ. Sci.* **2013**, *25*, S85–S88. [\[CrossRef\]](#)
39. Laurinavichene, T.; Fedorov, A.; Ghirardi, M.; Seibert, M.; Tsygankov, A. Demonstration of sustained hydrogen photoproduction by immobilized, sulfur-deprived *Chlamydomonas reinhardtii* cells. *Int. J. Hydrogen Energy* **2006**, *31*, 659–667. [\[CrossRef\]](#)
40. Yokoi, H.; Maki, R.; Hirose, J.; Hayashi, S. Microbial production of hydrogen from starch-manufacturing wastes. *Biomass Bioenergy* **2002**, *22*, 389–395. [\[CrossRef\]](#)
41. Flores, E.; Arévalo, S.; Burnat, M. Cyanophycin and arginine metabolism in cyanobacteria. *Algal Res.* **2019**, *42*, 101577. [\[CrossRef\]](#)
42. Amos, W.A. *Biological Water-Gas Shift Conversion of Carbon Monoxide to Hydrogen*; National Renewable Energy Lab.: Golden, CO, USA, 2004; pp. 1–21.
43. Meng, L.; Tsuru, T. *Microporous Silica Membrane Reactors*; Elsevier Inc.: Amsterdam, The Netherlands, 2019.
44. Reungsang, A.; Zhong, N.; Yang, Y. *Chapter 7 Hydrogen from Photo Fermentation*; Springer: Singapore, 2018.
45. Chen, W.-H.; Chen, C.-Y. Water gas shift reaction for hydrogen production and carbon dioxide capture: A review. *Appl. Energy* **2020**, *258*, 114078. [\[CrossRef\]](#)
46. Brunetti, A.; Barbieri, G.; Drioli, E.; Granato, T.; Lee, K.-H. A porous stainless steel supported silica membrane for WGS reaction in a catalytic membrane reactor. *Chem. Eng. Sci.* **2007**, *62*, 5621–5626. [\[CrossRef\]](#)
47. Galuszka, J.; Giddings, T.; Iaquaniello, G. Membrane assisted WGS—Experimental study and reactor modeling. *Chem. Eng. J.* **2012**, *213*, 363–370. [\[CrossRef\]](#)
48. Battersby, S.; Duke, M.C.; Liu, S.; Rudolph, V.; Da Costa, J.C.D.; Da Costa, J.C.D. Metal doped silica membrane reactor: Operational effects of reaction and permeation for the water gas shift reaction. *J. Membr. Sci.* **2008**, *316*, 46–52. [\[CrossRef\]](#)
49. Battersby, S.; Smart, S.; Ladewig, B.; Liu, S.; Duke, M.C.; Rudolph, V.; Da Costa, J.C.D.; Da Costa, J.C.D. Hydrothermal stability of cobalt silica membranes in a water gas shift membrane reactor. *Sep. Purif. Technol.* **2009**, *66*, 299–305. [\[CrossRef\]](#)
50. Rai, P.K.; Singh, S. Integrated dark- and photo-fermentation: Recent advances and provisions for improvement. *Int. J. Hydrogen Energy* **2016**, *41*, 19957–19971. [\[CrossRef\]](#)
51. Banu, J.R.; Kannah, R.Y.; Kavitha, S.; Usman, T.M.M.; Gunasekaran, M.; Kumar, G.; Kim, S.-H. *Biohydrogen: Resource Recovery from Industrial Wastewater*; Elsevier: Amsterdam, The Netherlands, 2020.
52. Budiman, P.M.; Wu, T.Y. Ultrasonication pre-treatment of combined effluents from palm oil, pulp and paper mills for improving photofermentative biohydrogen production. *Energy Convers. Manag.* **2016**, *119*, 142–150. [\[CrossRef\]](#)
53. Budiman, P.M.; Wu, T.Y.; Ramanan, R.N.; Jahim, J.M. Improving photofermentative biohydrogen production by using intermittent ultrasonication and combined industrial effluents from palm oil, pulp and paper mills. *Energy Convers. Manag.* **2017**, *132*, 110–118. [\[CrossRef\]](#)
54. Keskin, T.; Hallenbeck, P.C. Hydrogen production from sugar industry wastes using single-stage photofermentation. *Bioresour. Technol.* **2012**, *112*, 131–136. [\[CrossRef\]](#) [\[PubMed\]](#)
55. Kars, G.; Alparslan, Ü. Valorization of sugar beet molasses for the production of biohydrogen and 5-aminolevulinic acid by *Rhodobacter sphaeroides* O.U.001 in a biorefinery concept. *Int. J. Hydrogen Energy* **2013**, *38*, 14488–14494. [\[CrossRef\]](#)
56. Ghosh, D.; Tourigny, A.; Hallenbeck, P.C. Near stoichiometric reforming of biodiesel derived crude glycerol to hydrogen by photofermentation. *Int. J. Hydrogen Energy* **2012**, *37*, 2273–2277. [\[CrossRef\]](#)
57. Ghosh, D.; Sobro, I.F.; Hallenbeck, P.C. Stoichiometric conversion of biodiesel derived crude glycerol to hydrogen: Response surface methodology study of the effects of light intensity and crude glycerol and glutamate concentration. *Bioresour. Technol.* **2012**, *106*, 154–160. [\[CrossRef\]](#) [\[PubMed\]](#)

58. Pattanamane, W.; Choorit, W.; Deesan, C.; Sirisansaneeyakul, S.; Chisti, Y. Photofermentive production of biohydrogen from oil palm waste hydrolysate. *Int. J. Hydrogen Energy* **2012**, *37*, 4077–4087. [\[CrossRef\]](#)
59. Zhang, Z.; Wang, Y.; Hu, J.; Wu, Q.; Zhang, Q. Influence of mixing method and hydraulic retention time on hydrogen production through photo-fermentation with mixed strains. *Int. J. Hydrogen Energy* **2015**, *40*, 6521–6529. [\[CrossRef\]](#)
60. Zhang, Z.; Yue, J.; Zhou, X.; Jing, Y.; Jiang, D.; Zhang, Q. Photo-fermentative Bio-hydrogen Production from Agricultural Residue Enzymatic Hydrolyzate and the Enzyme Reuse. *Bioresour.* **2014**, *9*, 2299–2310. [\[CrossRef\]](#)
61. Kapdan, I.K.; Kargi, F.; Oztekin, R.; Argun, H. Bio-hydrogen production from acid hydrolyzed wheat starch by photo-fermentation using different *Rhodobacter* sp. *Int. J. Hydrogen Energy* **2009**, *34*, 2201–2207. [\[CrossRef\]](#)
62. Bastidas-Oyanedel, J.-R.; Bonk, F.; Thomsen, M.H.; Schmidt, J.E. Dark fermentation biorefinery in the present and future (bio)chemical industry. *Rev. Environ. Sci. Biotechnol.* **2015**, *14*, 473–498. [\[CrossRef\]](#)
63. Zainal, B.S.; Ahmad, M.A.; Danaee, M.; Jamadon, N.; Mohd, N.S.; Ibrahim, S. Integrated System Technology of POME Treatment for Biohydrogen and Biomethane Production in Malaysia. *Appl. Sci.* **2020**, *10*, 951. [\[CrossRef\]](#)
64. Kelly-Yong, T.L.; Lee, K.T.; Mohamed, A.R.; Bhatia, S. Potential of hydrogen from oil palm biomass as a source of renewable energy worldwide. *Energy Policy* **2007**, *35*, 5692–5701. [\[CrossRef\]](#)
65. Garritano, A.N.; Faber, M.D.O.; De Sá, L.R.; Ferreira-Leitão, V.S. Palm oil mill effluent (POME) as raw material for biohydrogen and methane production via dark fermentation. *Renew. Sustain. Energy Rev.* **2018**, *92*, 676–684. [\[CrossRef\]](#)
66. Ramesh, K. Influence of heat and mass transfer on peristaltic flow of a couple stress fluid through porous medium in the presence of inclined magnetic field in an inclined asymmetric channel. *J. Mol. Liq.* **2016**, *219*, 256–271. [\[CrossRef\]](#)
67. Shafie, N.A.M.; Said, M.F.M.; Latiff, Z.A.; Rajoo, S. Discharge and flow coefficient analysis in internal combustion engine using computational fluid dynamics simulation. *ARPN J. Eng. Appl. Sci.* **2017**, *12*, 2598–2603.
68. Jenkins, M.B.; Bexter, L.L.; Miles, R.T., Jr.; Miles, R.T. Combustion Properties of Biomass Flash. *Fuel Process. Technol.* **1998**, *54*, 17–46. [\[CrossRef\]](#)
69. Salimbeni, A. Techno-economic assessment of lignocellulosic biomass energy conversion by slow oxidative pyrolysis. *Renew. Sustain. Energy Rev.* **2015**, *53*, 1486–1489. [\[CrossRef\]](#)
70. Zhang, Y.; Cui, Y.; Chen, P.; Liu, S.; Zhou, N.; Ding, K.; Fan, L.; Peng, P.; Min, M.; Cheng, Y.; et al. *Gasification Technologies and Their Energy Potentials*; Elsevier B.V.: Amsterdam, The Netherlands, 2019.
71. Ngan, M.A. Carbon Credit from Palm: Biomass, Biogas and Biodiesel. *Palm Oil Eng. Bull.* **2002**, *65*, 24–26.
72. Rauch, R.; Hrbek, J.; Hofbauer, H. Biomass gasification for synthesis gas production and applications of the syngas. *Wiley Interdiscip. Rev. Energy Environ.* **2014**, *3*, 343–362. [\[CrossRef\]](#)
73. Zhang, Y.; Zhao, Y.; Gao, X.; Li, B.; Huang, J. Energy and exergy analyses of syngas produced from rice husk gasification in an entrained flow reactor. *J. Clean. Prod.* **2015**, *95*, 273–280. [\[CrossRef\]](#)
74. Okolie, J.A.; Nanda, S.; Dalai, A.K.; Berruti, F.; Kozinski, J.A. A review on subcritical and supercritical water gasification of biogenic, polymeric and petroleum wastes to hydrogen-rich synthesis gas. *Renew. Sustain. Energy Rev.* **2020**, *119*, 109546. [\[CrossRef\]](#)
75. Damartzis, T.; Zabaniotou, A. Thermochemical conversion of biomass to second generation biofuels through integrated process design—A review. *Renew. Sustain. Energy Rev.* **2011**, *15*, 366–378. [\[CrossRef\]](#)
76. Manara, P.; Zabaniotou, A. Towards sewage sludge based biofuels via thermochemical conversion—A review. *Renew. Sustain. Energy Rev.* **2012**, *16*, 2566–2582. [\[CrossRef\]](#)
77. Neubauer, Y. Biomass gasification. *Biomass Combust. Sci. Technol. Eng.* **2013**, *8*, 106–129. [\[CrossRef\]](#)
78. Parvez, A.; Mujtaba, I.; Wu, T. Energy, exergy and environmental analyses of conventional, steam and CO₂-enhanced rice straw gasification. *Energy* **2016**, *94*, 579–588. [\[CrossRef\]](#)
79. Adnan, M.A.; Susanto, H.; Binous, H.; Muraza, O.; Hossain, M.M. Feed compositions and gasification potential of several biomasses including a microalgae: A thermodynamic modeling approach. *Int. J. Hydrogen Energy* **2017**, *42*, 17009–17019. [\[CrossRef\]](#)
80. De Oliveira, J.L.; Da Silva, J.N.; Martins, M.A.; Pereira, E.G.; Oliveira, M.D.C.T.B.E. Gasification of waste from coffee and eucalyptus production as an alternative source of bioenergy in Brazil. *Sustain. Energy Technol. Assess.* **2018**, *27*, 159–166. [\[CrossRef\]](#)
81. Yao, Z.; You, S.; Ge, T.; Wang, C.-H. Biomass gasification for syngas and biochar co-production: Energy application and economic evaluation. *Appl. Energy* **2018**, *209*, 43–55. [\[CrossRef\]](#)
82. Gao, X.; Zhang, Y.; Li, B.; Yu, X. Model development for biomass gasification in an entrained flow gasifier using intrinsic reaction rate submodel. *Energy Convers. Manag.* **2016**, *108*, 120–131. [\[CrossRef\]](#)
83. Lozano, F.J.; Lozano, R. Assessing the potential sustainability benefits of agricultural residues: Biomass conversion to syngas for energy generation or to chemicals production. *J. Clean. Prod.* **2018**, *172*, 4162–4169. [\[CrossRef\]](#)
84. Aydin, E.S.; Yucel, O.; Sadikoglu, H. Numerical and experimental investigation of hydrogen-rich syngas production via biomass gasification. *Int. J. Hydrogen Energy* **2018**, *43*, 1105–1115. [\[CrossRef\]](#)
85. Kihedu, J.H.; Yoshiie, R.; Naruse, I. Performance indicators for air and air–steam auto-thermal updraft gasification of biomass in packed bed reactor. *Fuel Process. Technol.* **2016**, *141*, 93–98. [\[CrossRef\]](#)
86. Collard, F.-X.; Blin, J. A review on pyrolysis of biomass constituents: Mechanisms and composition of the products obtained from the conversion of cellulose, hemicelluloses and lignin. *Renew. Sustain. Energy Rev.* **2014**, *38*, 594–608. [\[CrossRef\]](#)

87. Zhang, R.; Cummer, K.; Suby, A.; Brown, R.C. Biomass-derived hydrogen from an air-blown gasifier. *Fuel Process. Technol.* **2005**, *86*, 861–874. [CrossRef]
88. Zhang, Y.; Chen, P.; Liu, S.; Peng, P.; Min, M.; Cheng, Y.; Anderson, E.; Zhou, N.; Fan, L.; Liu, C.; et al. Effects of feedstock characteristics on microwave-assisted pyrolysis—A review. *Bioresour. Technol.* **2017**, *230*, 143–151. [CrossRef] [PubMed]
89. Meier, D.; Faix, O. State of the art of applied fast pyrolysis of lignocellulosic materials—A review. *Bioresour. Technol.* **1999**, *68*, 71–77. [CrossRef]
90. Jenkins, R.W.; Sutton, A.D.; Robichaud, D.J. *Pyrolysis of Biomass for Aviation Fuel*; Elsevier Inc.: Amsterdam, The Netherlands, 2016.
91. Azizi, K.; Moraveji, M.K.; Najafabadi, H.A. A review on bio-fuel production from microalgal biomass by using pyrolysis method. *Renew. Sustain. Energy Rev.* **2018**, *82*, 3046–3059. [CrossRef]
92. Minowa, T.; Kondo, T.; Sudirjo, S.T. Thermochemical liquefaction of indonesian biomass residues. *Biomass Bioenergy* **1998**, *14*, 517–524. [CrossRef]
93. Akhtar, J.; Amin, N.A.S. A review on process conditions for optimum bio-oil yield in hydrothermal liquefaction of biomass. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1615–1624. [CrossRef]
94. Toor, S.S.; Rosendahl, L.; Rudolf, A. Hydrothermal liquefaction of biomass: A review of subcritical water technologies. *Energy* **2011**, *36*, 2328–2342. [CrossRef]
95. Goyal, H.; Seal, D.; Saxena, R. Bio-fuels from thermochemical conversion of renewable resources: A review. *Renew. Sustain. Energy Rev.* **2008**, *12*, 504–517. [CrossRef]
96. Lewandowski, W.M.; Ryms, M.; Kosakowski, W. Thermal Biomass Conversion: A Review. *Process.* **2020**, *8*, 516. [CrossRef]
97. Basu, S. Introduction. *Int. Fem. J. Polit.* **2018**, *21*, 4–8. [CrossRef]
98. Huang, H.-J.; Yuan, X.-Z. Recent progress in the direct liquefaction of typical biomass. *Prog. Energy Combust. Sci.* **2015**, *49*, 59–80. [CrossRef]
99. Guerrero, M.R.B.; Salinas Gutiérrez, J.M.; Meléndez Zaragoza, M.J.; López Ortiz, A.; Collins-Martínez, V. Optimal slow pyrolysis of apple pomace reaction conditions for the generation of a feedstock gas for hydrogen production. *Int. J. Hydrogen Energy* **2016**, *41*, 23232–23237. [CrossRef]
100. Mekhilef, S.; Siga, S.; Saidur, R. A review on palm oil biodiesel as a source of renewable fuel. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1937–1949. [CrossRef]
101. Gan, P.Y.; Li, Z.D. Econometric study on Malaysia's palm oil position in the world market to 2035. *Renew. Sustain. Energy Rev.* **2014**, *39*, 740–747. [CrossRef]
102. Werner, A.K.; Vink, S.; Watt, K.; Jagals, P. Environmental health impacts of unconventional natural gas development: A review of the current strength of evidence. *Sci. Total Environ.* **2015**, *505*, 1127–1141. [CrossRef]
103. Onoja, E.; Chandren, S.; Razak, F.I.A.; Mahat, N.A.; Wahab, R.A. Oil Palm (*Elaeis guineensis*) Biomass in Malaysia: The Present and Future Prospects. *Waste Biomass Valorization* **2019**, *10*, 2099–2117. [CrossRef]
104. El Morabet, R. *Effects of Outdoor Air Pollution on Human Health*, 2nd ed.; Elsevier Inc.: Amsterdam, The Netherlands, 2018.
105. Thompson, A.M. The Oxidizing Capacity of the Earth's Atmosphere: Probable Past and Future Changes. *Science* **1992**, *256*, 1157–1165. [CrossRef]
106. Kim, K.-H.; Jahan, S.A.; Kabir, E. A review of diseases associated with household air pollution due to the use of biomass fuels. *J. Hazard. Mater.* **2011**, *192*, 425–431. [CrossRef]
107. Stein, W.; Edwards, J.; Hinkley, J.; Sattler, C. Natural Gas: Solar-Thermal Steam Reforming. *Encycl. Electrochem. Power Sources* **2009**, 300–312. Available online: <http://www.sciencedirect.com/science/article/pii/B978044452745500294X> (accessed on 9 October 2020).
108. Keeling, C.D. Industrial production of carbon dioxide from fossil fuels and limestone. *Tellus* **1973**, *25*, 174–198. [CrossRef]
109. Zhao, B.; Su, Y. Process effect of microalgal-carbon dioxide fixation and biomass production: A review. *Renew. Sustain. Energy Rev.* **2014**, *31*, 121–132. [CrossRef]
110. Rahman, F.A.; Aziz, M.A.; Saidur, R.; Abu Bakar, W.A.W.; Hainin, M.; Putrajaya, R.; Hassan, N.A. Pollution to solution: Capture and sequestration of carbon dioxide (CO₂) and its utilization as a renewable energy source for a sustainable future. *Renew. Sustain. Energy Rev.* **2017**, *71*, 112–126. [CrossRef]
111. Krishnamurthy, S.; Lightcap, I.V.; Kamat, P.V. Electron transfer between methyl viologen radicals and graphene oxide: Reduction, electron storage and discharge. *J. Photochem. Photobiol. A Chem.* **2011**, *221*, 214–219. [CrossRef]
112. Luik, H.; Johannes, I.; Palu, V.; Luik, L.; Kruusement, K. Transformations of biomass internal oxygen at varied pyrolysis conditions. *J. Anal. Appl. Pyrolysis* **2007**, *79*, 121–127. [CrossRef]
113. Nematian, T.; Barati, M. *Nanobiocatalytic Processes for Producing Biodiesel from Algae*; Elsevier Inc.: Amsterdam, The Netherlands, 2019.
114. Purwono; Rezagama, A.; Hibbaan, M.; Budihardjo, M.A. Ammonia-Nitrogen (NH₃⁺N) and Ammonium-Nitrogen (NH₄⁺N) Equilibrium on the Process of Removing Nitrogen by Using Tubular Plastic Media. *J. Mater. Environ. Sci.* **2017**, *8*, 4915–4922.
115. Ngadiman, N.; Bahari, N.I.; Kaamin, M.; Hamid, N.B.; Mokhtar, M.; Sahat, S. Water Quality of Hills Water, Supply Water and RO Water Machine at Ulu Yam Selangor. *IOP Conf. Ser. Mater. Sci. Eng.* **2016**, *136*, 012081. [CrossRef]
116. Kibria, G. World Rivers in Crisis: Water Quality and Water Dependent Biodiversity Are at Risk- Threats of Pollution, Climate Change & Dams Development. *Res. Gate* **2015**, 1–11. [CrossRef]

117. Pedroso, G.M.; Hutmacher, R.B.; Putnam, D.; Six, J.; Van Kessel, C.; Linquist, B.A. Biomass yield and nitrogen use of potential C4 and C3 dedicated energy crops in a Mediterranean climate. *Field Crop. Res.* **2014**, *161*, 149–157. [CrossRef]
118. Nikiema, P.; Rothstein, D.E.; Min, D.-H.; Kapp, C.J. Nitrogen fertilization of switchgrass increases biomass yield and improves net greenhouse gas balance in northern Michigan, U.S.A. *Biomass Bioenergy* **2011**, *35*, 4356–4367. [CrossRef]
119. Biswas, B.; Gresshoff, P.M. The Role of Symbiotic Nitrogen Fixation in Sustainable Production of Biofuels. *Int. J. Mol. Sci.* **2014**, *15*, 7380–7397. [CrossRef]
120. Ni, M.; Leung, D.Y.; Leung, M.K.; Sumathy, K. An overview of hydrogen production from biomass. *Fuel Process. Technol.* **2006**, *87*, 461–472. [CrossRef]
121. Ruano, P.; Aiguo, G.W.; Danielle, A.; Hua, S. *We Are IntechOpen, the World's Leading Publisher of Open Access Books Built by Scientists, for Scientists TOP 1%*; Intech: Vienna, Austria, 2016; p. 13. Available online: <https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection-in-biometrics> (accessed on 16 November 2020).
122. Nunes, L.J.R.; Matias, J.C.D.O.; Catalão, J.P.D.S. Applications for Torrefied Biomass. *Torrefaction Biomass Energy Appl.* **2018**, 203–214. [CrossRef]
123. Couto, N.; Rouboa, A.; Silva, V.; Monteiro, E.; Bouziane, K. Influence of the Biomass Gasification Processes on the Final Composition of Syngas. *Energy Procedia* **2013**, *36*, 596–606. [CrossRef]
124. Aouad, S.; Labaki, M.; Ojala, S.; Seelam, P.; Turpeinen, E.; Gennequin, C.; Estephane, J.; Aad, E.A. A Review on the Dry Reforming Processes for Hydrogen Production: Catalytic Materials and Technologies. In *Frontiers in Ceramic Science*; BenthamScience: Oak Park, IL, USA, 2018.
125. Šuhaj, P.; Husár, J.; Haydary, J. Gasification of RDF and Its Components with Tire Pyrolysis Char as Tar-Cracking Catalyst. *Sustain. J. Rec.* **2020**, *12*, 6647. [CrossRef]
126. Rapagnà, S.; Spinelli, G. Biomass gasification with dolomite and olivine particles as a bed inventory in presence of ceramic filters. *Chem. Eng. Trans.* **2016**, *52*, 289–294. [CrossRef]
127. Ponzio, A. *Thermally Homogeneous Gasification of Biomass/Coal/Waste for Medium or High Calorific Value Syngas Production*; KTH Industrial Engineering and Management: Stockholm, Sweden, 2008.
128. Matsumura, Y.; Minowa, T.; Potic, B.; Kersten, S.R.; Prins, W.; Van Swaaij, W.P.M.; Van De Beld, B.; Elliott, D.C.; Neuenschwander, G.G.; Kruse, A. Biomass gasification in near- and super-critical water: Status and prospects. *Biomass Bioenergy* **2005**, *29*, 269–292. [CrossRef]
129. Han, J.; Kim, H. The reduction and control technology of tar during biomass gasification/pyrolysis: An overview. *Renew. Sustain. Energy Rev.* **2008**, *12*, 397–416. [CrossRef]
130. Wang, L.; Li, D.; Koike, M.; Koso, S.; Nakagawa, Y.; Xu, Y.; Tomishige, K. Catalytic performance and characterization of Ni-Fe catalysts for the steam reforming of tar from biomass pyrolysis to synthesis gas. *Appl. Catal. A Gen.* **2011**, *392*, 248–255. [CrossRef]
131. Bridgwater, A. Catalysis in thermal biomass conversion. *Appl. Catal. A Gen.* **1994**, *116*, 5–47. [CrossRef]
132. Buentello-Montoya, D.; Zhang, X.; Marques, S.; Geron, M. Investigation of competitive tar reforming using activated char as catalyst. *Energy Procedia* **2019**, *158*, 828–835. [CrossRef]
133. Kundu, K.; Chatterjee, A.; Bhattacharyya, T.; Roy, M.; Kaur, A. Thermochemical Conversion of Biomass to Bioenergy: A Review. In *Prospects of Alternative Transportation*; Springer: Berlin/Heidelberg, Germany, 2018.
134. Yu, Q.; Brage, C.; Chen, G.; Sjöström, K. Temperature impact on the formation of tar from biomass pyrolysis in a free-fall reactor. *J. Anal. Appl. Pyrolysis* **1997**, *40–41*, 481–489. [CrossRef]
135. German Environment Agency. *Polycyclic Aromatic Hydrocarbons—Harmful to the Environment! Toxic! Inevitable?* German Environment Agency Press, Umweltbundesamt: Dessau, Germany, 2016; p. 24.
136. Meyer, S.; Glaser, B.; Fischer, D.; Quicker, P.; Noel, Y.; Kuffer, Y.N.A.G. Thermal Removal of Polycyclic Aromatic Hydrocarbons from Gasification Biochars. *Environ. Risk Assess. Soil Contam.* **2014**. [CrossRef]
137. Polycyclicaromatchydrocarbons@www.idph.state.il.us. Available online: <http://www.idph.state.il.us/envhealth/factsheets/polycyclicaromatchydrocarbons.htm> (accessed on 10 February 2021).
138. Devi, L.; Ptasiński, K.J.; Janssen, F.J. A review of the primary measures for tar elimination in biomass gasification processes. *Biomass Bioenergy* **2003**, *24*, 125–140. [CrossRef]
139. Shen, Y.; Yoshikawa, K. Recent progresses in catalytic tar elimination during biomass gasification or pyrolysis—A review. *Renew. Sustain. Energy Rev.* **2013**, *21*, 371–392. [CrossRef]
140. Kaur, R.; Gera, P.; Jha, M.K.; Bhaskar, T. *Thermochemical Route for Biohydrogen Production*; Elsevier: Amsterdam, The Netherlands, 2019.
141. Mohamed, A.R.; Lee, K.T. Energy for sustainable development in Malaysia: Energy policy and alternative energy. *Energy Policy* **2006**, *34*, 2388–2397. [CrossRef]
142. Chan, Y.H.; Cheah, K.W.; How, B.S.; Loy, A.C.M.; Shahbaz, M.; Singh, H.K.G.; Yusuf, N.R.; Shuhaili, A.F.A.; Yusup, S.; Ghani, W.A.W.A.K.; et al. An overview of biomass thermochemical conversion technologies in Malaysia. *Sci. Total Environ.* **2019**, *680*, 105–123. [CrossRef]
143. Mustapa, S.I.; Peng, L.Y.; Hashim, A.H. Issues and challenges of renewable energy development: A Malaysian experience. In *Proceedings of the International Conference on Energy and Sustainable Development: Issues and Strategies (ESD 2010)*, Chiang Mai, Thailand, 2–4 June 2010; pp. 1–6. [CrossRef]

144. Eker, M.; Spinelli, R. Labor-intensive techniques for recovering energy biomass from forest tending operations. *Biomass Bioenergy* **2018**, *115*, 223–230. [CrossRef]
145. Wu, L.; Moteiki, T.; Gokhale, A.A.; Flaherty, D.W.; Toste, F.D. Production of Fuels and Chemicals from Biomass: Condensation Reactions and Beyond. *Chem* **2016**, *1*, 32–58. [CrossRef]
146. a27d509d27f9d478bc3ac944c6c87c54634c128d@www.pmo.gov.my. Available online: <https://www.pmo.gov.my/vision-2020/malaysia-as-a-fully-developed-country/> (accessed on 10 February 2021).
147. Van Meijl, H.; Smeets, E.; van Dijk, M.; Powell, J.; Tabeau, A. *Macro-Economic Impact Study for Bio-Based Malaysia*; Wageningen UR: Wageningen, The Netherlands, 2012.
148. Yusoff, S.; Kardooni, R. Barriers and challenges for developing RE policy in Malaysia. In Proceedings of the 2012 International Conference on Future Environment Energy IPCBEE, Singapore, 26–28 February 2012; Volume 28, pp. 6–10.
149. How, B.S.; Ngan, S.L.; Hong, B.H.; Lam, H.L.; Ng, W.P.Q.; Yusup, S.; Ghani, W.A.W.A.K.; Kansha, Y.; Chan, Y.H.; Cheah, K.W.; et al. An outlook of Malaysian biomass industry commercialisation: Perspectives and challenges. *Renew. Sustain. Energy Rev.* **2019**, *113*, 109277. [CrossRef]
150. Dale, V.H.; Kline, K.L.; Richard, T.L.; Karlen, D.L.; Belden, W.W. Bridging biofuel sustainability indicators and ecosystem services through stakeholder engagement. *Biomass Bioenergy* **2018**, *114*, 143–156. [CrossRef]
151. Salleh, S.F.; Roslan, M.E.M.; Rahman, A.A.; Shamsuddin, A.H.; Abdullah, T.A.R.T.; Sovacool, B.K. Transitioning to a sustainable development framework for bioenergy in Malaysia: Policy suggestions to catalyse the utilisation of palm oil mill residues. *Energy Sustain. Soc.* **2020**, *10*, 38. [CrossRef]
152. Tan, Z.; Chen, K.; Liu, P. Possibilities and challenges of China's forestry biomass resource utilization. *Renew. Sustain. Energy Rev.* **2015**, *41*, 368–378. [CrossRef]
153. Index@www.nbs2020.gov.my. Available online: <https://www.nbs2020.gov.my/> (accessed on 16 November 2020).
154. Koh, M.; Hoi, W. Sustainable biomass production for energy in Malaysia. *Biomass Bioenergy* **2003**, *25*, 517–529. [CrossRef]
155. Umar, M.S.; Urmee, T.; Jennings, P. A policy framework and industry roadmap model for sustainable oil palm biomass electricity generation in Malaysia. *Renew. Energy* **2018**, *128*, 275–284. [CrossRef]
156. Varkkey, H.; Tyson, A.; Choiruzzad, S.A.B. Palm oil intensification and expansion in Indonesia and Malaysia: Environmental and socio-political factors influencing policy. *For. Policy Econ.* **2018**, *92*, 148–159. [CrossRef]
157. Umar, M.S.; Jennings, P.; Urmee, T. Strengthening the palm oil biomass Renewable Energy industry in Malaysia. *Renew. Energy* **2013**, *60*, 107–115. [CrossRef]
158. Solangi, K.; Islam, M.; Saidur, R.; Rahim, N.; Fayaz, H. A review on global solar energy policy. *Renew. Sustain. Energy Rev.* **2011**, *15*, 2149–2163. [CrossRef]
159. Emission Reduction Panacea or Recipe Trade War Eus Carbon Border Tax Debate@www.cleanenergywire.org. Available online: <https://www.cleanenergywire.org/factsheets/emission-reduction-panacea-or-recipe-trade-war-eus-carbon-border-tax-debate> (accessed on 10 February 2021).
160. Ryabov, G.A.; Antonenko, E.V.; Krutitskii, I.V.; Folomeev, O.M.; Belyaev, A.V. Application of the Technology of Combustion of Solid Fuels in a Circulating Fluidized Bed. *Power Technol. Eng.* **2018**, *52*, 308–313. [CrossRef]
161. Abbasi, M.H.; Taki, M.; Rajabi, A.; Li, L.; Zhang, J. Coordinated operation of electric vehicle charging and wind power generation as a virtual power plant: A multi-stage risk constrained approach. *Appl. Energy* **2019**, *239*, 1294–1307. [CrossRef]
162. Dong, J.; Tang, Y.; Nzihou, A.; Chi, Y.; Weiss-Hortala, E.; Ni, M. Life cycle assessment of pyrolysis, gasification and incineration waste-to-energy technologies: Theoretical analysis and case study of commercial plants. *Sci. Total Environ.* **2018**, *626*, 744–753. [CrossRef] [PubMed]
163. Lee, M.; Yun, J.J.; Pyka, A.; Won, D.; Kodama, F.; Schiuma, G.; Park, H.; Jeon, J.; Park, K.; Jung, K.; et al. How to Respond to the Fourth Industrial Revolution, or the Second Information Technology Revolution? Dynamic New Combinations between Technology, Market, and Society through Open Innovation. *J. Open Innov. Technol. Mark. Complex.* **2018**, *4*, 21. [CrossRef]
164. Dreyer, B.; Lüdeke-Freund, F.; Hamann, R.; Faccar, K. Upsides and downsides of the sharing economy: Collaborative consumption business models' stakeholder value impacts and their relationship to context. *Technol. Forecast. Soc. Chang.* **2017**, *125*, 87–104. [CrossRef]
165. Sergi, B.; Babcock, M.; Williams, N.J.; Thornburg, J.; Loew, A.; Ciez, R.E. Institutional influence on power sector investments: A case study of on- and off-grid energy in Kenya and Tanzania. *Energy Res. Soc. Sci.* **2018**, *41*, 59–70. [CrossRef]