BIOFUELS: 2020 AND BEYOND, INNOVATIONS AND ADVANCES

Introduction

The increasing environmental concerns that have come to light have encouraged shifts to use eco-friendly biofuels instead of fossil fuels. The positive effects of biofuels compared to fossil fuels are well known, such as the fact that greenhouse gas (GHG) emissions of biofuel combustion are very low, and that they are produced from environmental sources. However, there are significant concerns about biofuels, such as the "Food vs. Fuel" debate. This debate first took root in the early 2000s, where biofuels began to become more popular. Using feedstocks such as maize and other edible oil-rich plants for technological advancements was interpreted as efforts towards favoring the middle-class over the lower-class population by taking away essential resources [1].

There are currently four types of biofuels: first, second, third, and fourth generation, with each type having its advantages and disadvantages. The second, third, and fourth generation biofuels address the main issue of the Food vs. Fuel debate due to their non-edible feedstock sources. Globally, there have been significant advancements in biofuel production, concerning processing and initial materials used. In 2006, 115 million metric tons of vegetable oils were produced with the USA, Brazil, China, Nigeria, Pakistan, and Thailand, among other countries contributing to 80% of this production value [2]. Over the years this has changed with many other countries stepping up their biofuel production and some of these countries are no longer market leaders. In the last decade, a lot of changes have occurred. Countries using lignocellulosic feedstocks and algae are important to note because of the novel achievements that have been made with the future of biofuels for second and third generation fuels. In this article we will try to focus on those market leaders from the last decade like Brazil, Nigeria, Malaysia, and Pakistan just to see where they are now and what recent progress they have made with their available resources in biofuel production processes. It gives us an interesting opportunity to study new developments and advancements that are ongoing around the world.

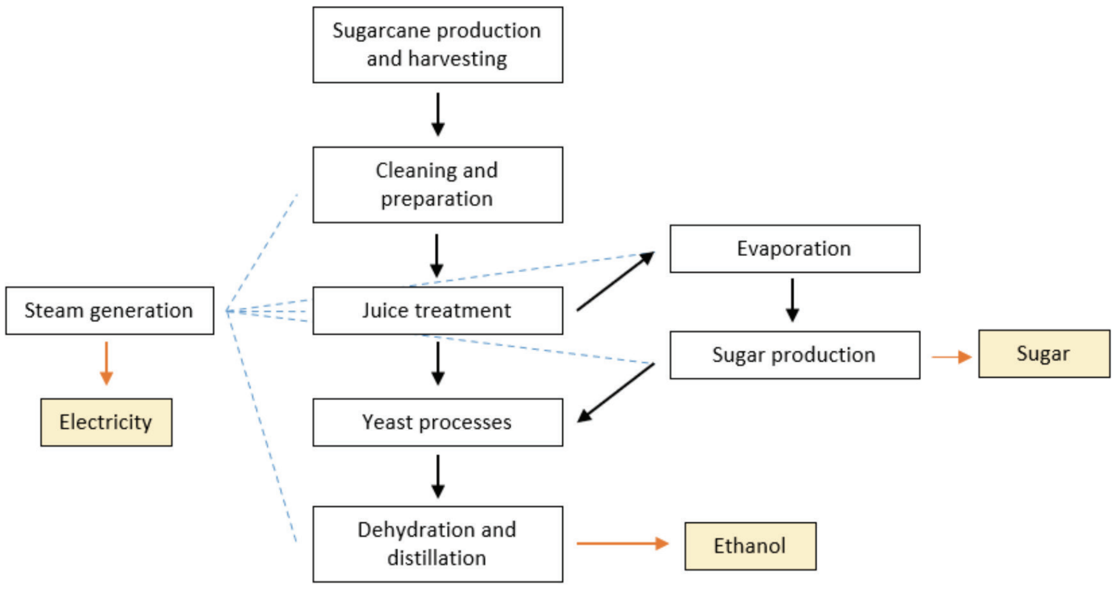


Figure 1. Brazilian sugarcane plant process to produce ethanol [10].

Overview

First generation (1G) biofuels are produced from harvested food-based biomass, such as corn and soybean plants. There is a prominent potential for large-scale production of 1G biofuels, but they do not have a high delivered energy gain compared to fossil energy input regarding second, third, or fourth generation biofuels [3]. Furthermore, there is a land area concern with this type of biofuel because the initial process of growing these crops followed by cultivating them requires a significant amount of arable farmland [4].

Second generation (2G) biofuels differ from 1G biofuels because they are produced from corn stalks and other non-food biomass, like switchgrass or wood. 2G biofuels can also be referred to as lignocellulosic and can be used as biodiesel, ethanol, and other biochemicals [3]. Although the initial sourcing of 2G biofuels can be from edible crops, the actual parts of the crops that are used during production are non-edible.

Recently, it has been found that algal biomass is becoming the more popular source for biofuel production instead of plant biomass [5]. Third generation (3G) biofuels are produced from algae and produce no land area concern because algae can be cultivated in water environments or unused drylands. Microalgae is a grouping of eukaryotes and cyanobacteria that can survive in extreme environmental conditions. Increasing lipid and carbohydrate composition through metabolic engineering can increase microalgae biomass yield [4]. A major advancement with the use of microalgae is that it is possible to genetically modify through photosynthesis and light penetration improvements [6]. Genetically modified algae are used in fourth generation (4G) biofuels.

Specifically, Brazil has produced a noteworthy amount of biofuel over the past years using sugarcane in first generation biofuels as well as banana waste to produce second generation biofuels. Nigeria has used sweet sorghum to make bioethanol and is investigating opportunities to use cassava to make bio-oil. Malaysia has shown similar advancements in biofuel production through the use of palm oil for first- and second-generation biofuels. Furthermore, microalgae have been studied recently to produce third generation biofuels in both Malaysia and Pakistan.

-Brazil

The presence of sugarcane in Brazil in the 14th century caused Portugal and other colonies to heavily invest in Brazil's sugar industry, demonstrating the importance of this product to Brazil. The growth of the sugar industry during the following decades can be due to these initial colonial investments. Furthermore, Brazil signed the Paris Climate Conference of 2015 to reduce GHG emissions, causing a push to use more biofuels [7]. After 2005, there was an increase in sugarcane production because of flex technology in the automotive industry. This is shown with Brazil being the largest sugarcane producer in the world, with approximately 650 million tons being produced in 2017 [8].

With the importance of sugarcane and initiatives this country has taken to reduce environmental damage, a logical development would be using this crop to make environmentally friendly fuel sources. The National Alcohol Program, or Proalcool program of 1975, encouraged the country to produce ethanol from its sugarcane supply to limit the country's oil imports [9]. Through sucrose fermentation, 1G ethanol can be produced directly from sugarcane. A major shortcoming of other starting biomass, such as starch, is that the starch must first be hydrolyzed to fermentable sugar and can then be turned into ethanol [8].

The rich history of Brazil with sugarcane and biofuels has resulted in many improvements and advancements in 1G ethanol production. Figure 1 demonstrates the nine processes that are done on sugarcane to produce electricity, ethanol, and sugar. After harvesting sugarcane, the sugarcane must be cleaned to rid impurities in a cleaning process with a 90% dirt removal. Crushing mills are then used to produce sugarcane juice, with a 96% efficiency. Impurities are then removed from the juice through heating and flash evaporation. After the impurities are removed, there is a 15 wt.% of solids present in the clarified juice. The juice must undergo a further evaporation process at 98°C to result in the juice having 65 wt.% solids present. Crystallizers then separate sugar crystals from the clarified juice into two groupings; final product sugar and intermediate sugar. Molasses is the byproduct of the sugars and is recycled into the fermentation reactor. Through yeast fermentation of predominantly sucrose, as well as the other simple sugars of glucose and fructose, ethanol is produced. Yeast acid washing can then be done with the remaining yeast available from the fermentation processes, demonstrating a recycling mechanism where the yeast undergoes another fermentation cycle. Finally, to achieve alcohol content between 92.6-93.8 wt.%, dehydration and distillation processes must occur.

Besides sugarcane, bananas also show a promising resource for biofuels. For every ton of bananas harvested in Brazil, there are approximately 3 tons of pseudostem, coming out to approximately 85% of harvested fruit being pseudostems [11]. Oftentimes, the pseudostems are left on the harvesting fields to act as a type of fertilizer but leaving this waste material on the fields creates much excess CO_2 [12, 13]. Biogas can be produced from these pseudostems; however, there is a low yield due to its chemical structure. Biogas is an important biofuel because it can produce fertilizer and collect organic waste. It is made from anaerobic digestion of organic matter with a composition of 48-65% methane and 36-41% CO_2. To solve the issue of the chemical structure of the waste material, alkali pretreatment can be used, such as NaOH. An alkaline pretreatment breaks down chemical bonds and allows microorganisms to perform anaerobic digestion more easily.

Table 1. Properties of banana pseudostems before and after alkaline pretreatment [13].

Properties	Values
pH	5.85
pH with NaOH	13.14
pH with NaOH after 48 hours	10.12
Moisture content	92%
Carbon	43.72%
Nitrogen	0.70%

The pH values seen in Table 1 were measured with an Elico-L1617 pH meter, the moisture content was measured with an oven dry method, and the carbon and nitrogen content were measured with a muffle furnace and titration procedure. Biogas digesters were used in this experiment to simulate methane formation at temperature ranges of 27-39°C for 50 days. These temperature ranges are where methane production is optimized. In one trial, 7kg of fresh banana pseudostems and 5kg of water were used and in a second trial, 7kg of banana pseudostems with alkali pretreatment and 5kg of water were used.

After soaking the banana pseudostems in wet state NaOH for two days, it was found that there was greater methane production compared to when the pseudostems were not soaked with any pretreatment. A higher methane production determined by ignition test with blue flame demonstrates a greater biogas production, meaning that with proper pretreatment procedures biogas production can be improved on using this banana byproduct.

Table 2. Sugars produced from white and red sorghum bran after dilute acid hydrolysis [16].

Sample	Time (min)	Treatment	Concentration (g/L)			
			Glucose	Xylose	Maltose	Arabinose
White sorghum bran	15	1% H_2SO_4	27.37 ± 4.09	1.2 ± 0.21	2.58 ± 0.08	2.04 ± 0.19
		3% H_2SO_4	32.24 ±7.27	1.1 ± 0.02	1.60 ± 0.04	1.96 ± 0.00
	30	1% H_2SO_4	28.07 ± 0.96	1.06 ± 0.10	1.45 ± 0.07	2.01 ± 0.10
		3% H_2SO_4	34.53 ± 8.04	1.15 ± 0.02	1.38 ± 0.02	1.92 ± 0.10
	15	1% HNO_3	25.77 ± 1.15	3.11 ± 0.41	1.12 ± 0.04	2.17 ± 0.40
	30	1% HNO_3	26.34 ± 1.05	2.15 ± 1.57	1.00 ± 0.02	2.13 ± 0.40
Red sorghum bran	15	1% H_2SO_4	26.48 ± 1.06	0.75 ± 0.05	2.22 ±0 .76	1.66 ± 0.10
		3% H_2SO_4	32.17 ± 6.05	0.79 ± 0.01	4.18 ± 0.16	2.13 ± 0.60
	30	1% H_2SO_4	27.11 ± 4.84	0.75 ± 0.00	1.30 ± 0.15	1.95 ± 0.00
		3% H_2SO_4	31.68 ± 5.71	4.53 ± 0.32	1.56 ± 0.08	3.63 ± 2.70
	15	1% HNO_3	28.25 ± 0.33	2.51 ± 0.04	1.04 ± 0.04	1.76 ± 0.00
	30	1% HNO_3	26.13 ± 1.52	2.46 ± 0.00	0.81 ± 0.00	1.98 ± 0.00

Values are means (n = 3) ± SD.

-Nigeria

Approximately 85% of Nigeria's energy consumption came from traditional biomass of charcoal and wood fuel. However, Nigeria has low rates of energy consumption, with an average of only 40% of Nigerians having access to electricity and 18% of rural areas having access to electricity. These small percentages result in the country having limited economic growth and low industrialization.

Nigeria is in West Africa, with 41.2% of its land area being arable. Coupled with this, approximately 70% of its population is involved in agriculture [14]. The Everything but Arms Initiative, Economic Partnership Agreements, and African Growth and Opportunity Act allow Africa to export biofuel to the US and EU easily through these trading policies [3]. There are a great variety of feedstocks available that could be used for biofuel production, with the major two being sugarcane and cassava. Nigeria produces 30 million tons of cassava annually, making it one of the world's leaders in cassava production [15].

Nigeria is the second-largest sweet sorghum producing country, with this cereal plant having similar amounts of soluble (sucrose and glucose) and insoluble (cellulose and hemicellulose) carbohydrates [16, 17]. The presence of these soluble and insoluble carbohydrates means that sorghum would be a very suitable crop for bioethanol production. Sweet sorghum is very efficient in photosynthesis and withstands dry and flooded conditions, demonstrating high stability. The bioethanol production process of this cereal is very similar to Brazil's bioethanol process using sugarcane [17]. The three methods of producing biofuel from sorghum are sugar-to-ethanol, starch-to-ethanol, and cellulosic ethanol processes.

The potential of sorghum bran for bioethanol production has been investigated, as lignocellulosic biomass has a lower water footprint than 1G and 3G feedstocks. A shortcoming of using the waste of sorghum is that a pretreatment process must be done because the insoluble sugars have lignin present and do not undergo hydrolysis easily to produce simple sugars, such as glucose, sucrose, and fructose. Such pretreatment processes include steam explosion or alkaline pretreatments, which increase production costs.

Enzymatic hydrolysis was observed using dimethyl sulfoxide to produce hydrolysate. It was found that the glucose concentrations observed after this hydrolysis process was 55g/L in white sorghum bran (WB) and 61g/L in red sorghum bran (RB). These concentrations correspond to a 49.9% and 57.6% hydrolysis yield. It was concluded that the process of gelatinization of the hydrolysate with hot water increases hydrolysis yields. Furthermore, dilute acid hydrolysis was done on WB and RB using sulfuric acid.

Table 2 shows how dilute acid hydrolysis resulted in high glucose yields for both WB and RB. The highest glucose yield observed in WB was after 30 minutes with 3% sulfuric acid, while the highest glucose yield observed in RB was after 15 minutes with 3% sulfuric acid as well. After solid loading ratio tests were done during the dilute acid hydrolysis process, it was found that there were similar hydrolysis yield results in both enzymatic and dilute hydrolysis processes. This is promising given that sulfuric acid is cheaper than the enzymes needed for the enzymatic hydrolysis, providing a more cost-efficient and accessible method to produce hydrolysate for fermentation.

With Nigeria's substantial cassava production, experiments have been conducted using this feedstock as a biofuel resource. The non-edible parts of cassava consist of the stem, leaves, peel, and bagasse. It has been determined that through pyrolysis, bio-oil can be produced from the peel of this crop. Pyrolysis is the process of heating materials without air being present. At a specific temperature of 525°C, there was an observed 51.2% bio-oil yield. Using the non-toxic stem with high lignocellulosic content, biogas could be produced using pyrolysis as well. It was found that for each mg of sugar-free cassava stem, 153.3Nm3 of biogas was produced. Approximately 35% of the cassava plant is the stem and using this part of the crop as well as the peel demonstrates that cassava residues can be efficient in biofuel production [18].

Cassava bioethanol can be made from the cassava roots, like the process of creating bioethanol from sugarcane in Brazil. Cassava bioethanol is carbon neutral and can undergo carbon capture, removing carbon dioxide from the air. Table 3 shows values of

Table 3. Estimated CO_2 capture (in million tons) from low, medium, and high consumption rates of various cassava bioethanol substitution percentages [19].

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
5% - L	0.91	0.98	1.05	1.13	1.19	1.27	1.35	1.42	1.49	1.60	1.65	1.69	1.80	1.87
5% - M	0.95	1.03	1.10	1.17	1.23	1.32	1.39	1.46	1.54	1.64	1.70	1.77	1.85	1.92
5% - H	0.99	1.07	1.14	1.23	1.27	1.36	1.44	1.51	1.58	1.68	1.74	1.82	1.89	1.96
10% - L	1.82	1.96	2.11	2.26	2.37	2.55	2.69	2.84	2.99	3.19	3.31	3.46	3.60	3.75
10% - M	1.90	2.05	2.20	2.34	2.46	2.64	2.78	2.93	3.08	3.28	3.40	3.54	3.69	3.84
10% - H	1.99	2.14	2.28	2.43	2.55	2.72	2.87	3.02	3.16	3.37	3.49	3.63	3.78	3.92
15% - L	2.72	2.94	3.16	3.38	3.58	3.82	4.04	4.26	4.48	4.79	4.96	5.18	5.40	5.62
15% - M	2.86	3.08	3.29	3.51	3.69	3.95	4.17	4.39	4.61	4.92	5.11	5.32	5.53	5.75
15% - H	2.99	3.21	3.43	3.65	3.82	4.09	4.31	4.52	4.74	5.05	5.23	5.48	5.67	5.89

Table 4. Potential ethanol yield from EFBs in Malaysia based on cellulose and hemicellulose amounts.

Year	Fresh fruit bunches (FFBs) yield (tonnes/hectare)	Empty fruit bunches, EFBs yield at 23% of FFBs (tonnes/hectare)	Potential of ethanol from EFBs (37.21% cellulose)	Potential of ethanol from EFBs (24.7% hemicellulose)	Total potential of ethanol production from EFBs (tonnes)
2007	19.93	4.58	0.496	0.263	0.759
2008	20.18	4.64	0.503	0.267	0.770
2009	19.20	4.42	0.479	0.254	0.733
2010	18.03	4.15	0.450	0.239	0.689
2011	19.69	4.53	0.491	0.261	0.752
2012	18.89	4.34	0.470	0.250	0.720
2013	19.02	4.37	0.474	0.251	0.725
2014	18.63	4.28	0.464	0.246	0.710
2015	18.48	4.25	0.461	0.244	0.705
2016	15.91	3.66	0.397	0.211	0.608

CO_2 removal at 5, 10, and 15% substitution of national petrol consumption.

As expected, with a higher biofuel substitution percentage, carbon capture values will be greater. Because GHG emissions and the amount that are currently in the atmosphere are a major concern, the carbon neutrality of biofuels made from cassava is an appealing feature. The cassava plant has high versatility, being able to be made into bio-oil, biogas, and bioethanol. Using the lignocellulosic materials of the plant does not interfere with food consumption and produces useful fuels.

-Malaysia

The Association of Southeast Asian Nations (ASEAN) has suitable land that can be used to grow biomass. Malaysia, specifically, has a great amount of fertile land suitable for agriculture, producing 168 million tons of biomass per year. Malaysia was considered the second-largest palm oil producer in the world in 2019, with palm oil being a good source of biofuels.

Malaysia produces a large amount of biodiesel, with 490 million liters produced in 2017 and expected growth to 815 million liters to be produced in 2027. Transesterification is a one-step process that is more cost-efficient due to higher biodiesel yield and is more sustainable compared to ester-transesterification, a two-step biodiesel production process [20]. There are currently 16 palm biodiesel refineries in Malaysia, and because palm oil is cheap and has a high oil yield of 4-5 million tons of oil per hectare, this specific type of feedstock is one of Malaysia's most promising for creating different biofuels [21]. The transesterification process involves triglyceride hydroprocessing using catalysts and lignocellulose conversion. The triglyceride and alcohol reaction produce esters and glycerol, resulting in biodiesel and glycerol being separable due to their density differences [20].

Similar to first, second, third, and fourth generation biofuels, there is first, second, and third generation bioethanol. First generation bioethanol is produced from food-based biomass, with a considerable disadvantage being production requirements, such as land area use and destruction. Second generation bioethanol is produced from lignocellulosic biomass and outperforms fossil fuels in terms of environmental friendliness and energy output [22]. These advantages that second generation bioethanol possess make it a more reliable alternative to fossil fuels. An advancement in Malaysia is using empty fruit bunches (EFBs) that are very cheap and have a high sugar content for second generation bioethanol. Cellulose is a major component of EFBs and can undergo fermentation easily to produce bioethanol.

Table 4 demonstrates calculated yields of the approximate 4 million metric tons/hectare of EFBs produced based on a 23% yield from FFBs. Cellulose calculations were done as follows: "Potential bioethanol from cellulose (metric tons) = cellulose amount (metric tons) × theoretical yield (0.5111) × glucose recovery efficiency (0.76) × glucose fermentation efficiency (0.75)". Additionally, hemicellulose calculations were done as follows: "Potential bioethanol from hemicelluloses (metric tons) = hemicellulose amount (metric tons) × theoretical yield (0.5175) × xylose recovery efficiency (0.90) × xylose fermentation efficiency (0.50)".

Oil palm empty fruit bunches demonstrate a potential feedstock for bioethanol production in Malaysia. Through proper pretreatment processes, such as enzymatic hydrolysis, sugar production can be optimized, and the following steps of hydrolysis and fermentation can be conducted. However, more research must be done exploring ethanol yields [22]. Palm press fiber can also be used for ethanol production, with a 24 wt.% cellulose composition and 14.40 wt.% hemicellulose composition. It is important to note that the empty fruit bunches of oil palms must be in the form of fiber before being used to generate biofuels [23]. Oil palm residues are a promising feedstock for second generation ethanol production in terms of their high cellulose and hemicellulose content, as well as their ethanol yield potentials.

With the amount of palm oil being used for biodiesel and biofuel production, there is high food pricing for edible palm oil. Finding alternative resources to make 3G biofuels would be beneficial to the country to reduce the dependence on palm oil for eco-friendly energy sources and allow the population to pay lower prices for palm oil consumption. Microalgae are found to be a good alternative because of the ability to double their biomass in one day and through their natural process of photosynthesis, CO_2 would be absorbed with oxygen and water being released. Chlorophyceae and Chrysophyceae microalgae species are commonly used in 3G biofuels [4]. Microalgae diatoms of the Bacillariophyceae species are also commonly used [24]. An additional advantage of using microalgae as a feedstock source is they have a greater biodiesel yield compared to cotton or palm plants [5].

According to Table 5, microalgae can produce the greatest amount of biodiesel in the smallest amount of land required for cultivation purposes compared to well-known feedstocks, such as palm oil and rapeseed. The geographical location of Malaysia has the greatest amount of sun irradiance, which is good for microalgae growth. Cosmetic products and medicine made from microalgae have already been an important development in Malaysia, demonstrating a promising possibility of this feedstock being used in the future for biofuels.

-Pakistan

Pakistan is an energy deficient country, like Nigeria, that has a national electricity shortage of approximately 4760MW. Studies have been done focusing on microalgae indigenous to Pakistan to help improve the energy sector. Microalgae is a promising source for biodiesel production because of their oxidative stability and fatty acid composition. Furthermore, biodiesel releases less carbon monoxide and hydrocarbons into the environment than traditional diesel fuel does, causing less damage to the environment.

The 11% oxygen content of biodiesel results in less harmful emissions from exhaustion. Table 6 demonstrates that microalgal biodiesel releases significantly fewer hydrocarbons and NOx in ppm than petroleum diesel. The large difference in NOx release can be because microalgal oil does not have many short-chain fatty acids.

Microalgae also have high photosynthetic efficiency compared to terrestrial crops. The use of indigenous microalgae means that there would be no importation costs and the microalgae would be adaptable to local environmental areas [26]. 32 different strains from the hot Cholistan desert, cold northern areas, and salt ponds of Pakistan were studied at temperatures of 12, 20, and 35°C with biomass production, neutral lipid content, and fatty acid content observed. The classes of all the strains were either Chlorophyceae or Trebouxiophyceae. The biomass production was determined by the dry weight of the microalgae after 15 days of incubation, and the neutral lipid content was determined by the percent lipid produced/dry weight multiplied by the biomass produced. Finally, using a gas chromatograph with flame ionization detector, the fatty acid composition was found.

It was found that 11 strains demonstrated good growth rates at each temperature and that all the strains had similar production rates over the different temperatures. Many microalgae species have already been recognized to produce lipid contents of 20-50% of their biomass [27], with 19 of the studied strains showing promising neutral lipid content suitable for biofuels. Oleic acid, C18:1 was found in 31 of the 32 strains, with values of >75% in 9 strains and <50% in 6 strains. Palmitic acid, C16:0 was the second most abundant fatty acid in these same 15 strains. The high oleic acid content contributes to the good oxidative stability that microalgae possess [26].

28 million hectares of land are unused in Pakistan because of unfavorable growing conditions, but this land could be used to cultivate microalgae, producing new jobs [25]. Since microalgae are grown in water environments, using wastewater for microalgae production to reduce nutrient requirements has been suggested. Agricultural wastewater or artificial wastewater are both known to demonstrate high biomass and lipid content of microalgae for biofuel production [27]. However, due to the contaminants in wastewater, a pretreatment process must be done, which can be timely and may require more costs. Seawater could be an alternative for microalgae cultivation because it has many nutrients that microalgae need and would not have to undergo a pretreatment process [2].

Conclusion

Brazil, Nigeria, Malaysia, and Pakistan have all shown advancements in biofuel production. Biofuels are better energy sources because they are more environmentally friendly and do not favor wealthy countries in terms of resourcing and production. In terms of GHG emissions, microalgal biodiesel has shown significantly less emissions compared to petroleum diesel. Additionally, problems of energy deficiency can be solved with available resources. A major appeal of biofuels is that waste products that would be disposed of have the potential to become something that can help economies in terms of job production and industrialization.

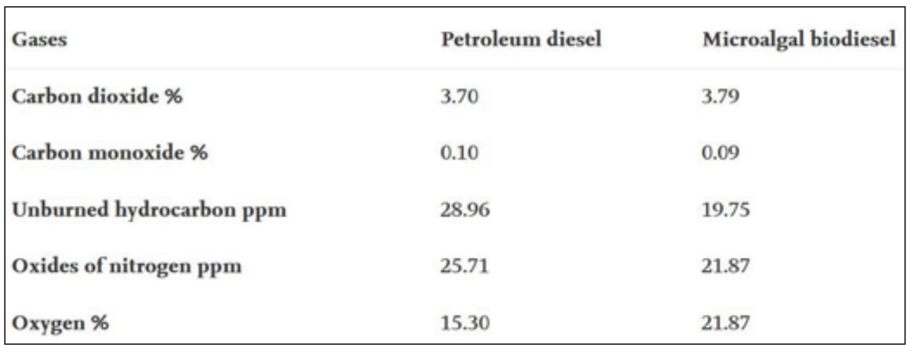
Brazil has demonstrated very efficient 1G bioethanol production, as well as a high potential for banana waste material to be used for 2G biogas. Nigeria, with its abundance of sweet sorghum and cassava, has encouraged the possibility of 2G biofuel to be produced. Malaysia has a high oil palm biodiesel production with a significant number of biodiesel refineries already present. It has been determined that oil palm empty fruit bunches have a high ethanol production potential from their high cellulose and

Table 5. Efficiency of different feedstocks for biodiesel production and land area required in Malaysia [24].

Feedstock	Oil Yield (kg/ha /year)	Conversion efficiency (%)	Biodiesel Yield (kg/ha/yr)	Amount of land required (thousand ha)	Percentage of arable land in Malaysia (%)
Soybean	375	95	356	1235	68.3
Rapeseed	1000	95	950	463	25.6
Jatropha	2000	98	1960	224	12.4
Palm oil	5000	94	4700	93	5.1
Microalgae*	75,000	80	60,000	7	0.4

*50% oil by weight in biomass.

Table 6. Exhaust emissions of petroleum and microalgal biodiesel [25].



Gases	Petroleum diesel	Microalgal biodiesel
Carbon dioxide %	3.70	3.79
Carbon monoxide %	0.10	0.09
Unburned hydrocarbon ppm	28.96	19.75
Oxides of nitrogen ppm	25.71	21.87
Oxygen %	15.30	21.87

hemicellulose content. Lastly, Pakistan has had a specific focus on microalgae for 3G biofuel generation because of the various types of environmental regions. There are promising outlooks for native strains of microalgae to be used from the impressive growth rates and neutral lipid content.

Although economically feasible processing methods have been determined for various kinds of biofuels, it is important for these methods to be implemented. Biofuel production of all different types of feedstocks are possible for the future, but it is currently up to individual countries and nations to determine how they would like to carry out these methods and when. The fact that many new ideas and methods have been thought of is promising for the future as environmental concerns continue to grow.

References

[1] Thompson, P. B. (2012). The agricultural ethics of biofuels: the food vs. fuel debate. Agriculture, vol. 2, no. 4, p. 339-358, doi:10.3390/agriculture2040339

[2] Shah, S. H., Raja, I. A., Rizwan, M., Rashid, N., Mahmood, Q., Shah, F. A., & Pervez, A. (2018). Potential of microalgal biodiesel production and its sustainability perspectives in Pakistan. Renewable and sustainable energy reviews, vol. 81, p. 76-92, https://doi.org/10.1016/j.rser.2017.07.044

[3] Nguyen, Q., Bowyer, J., Howe, J., Bratkovich, S., Groot, H., Pepke, E., & Fernholz, K. (2017). Global production of second-generation biofuels: Trends and influences. Dovetail Partners Inc.

[4] Abdullah, Bawadi, et al. (2019). Fourth generation biofuel: A review on risks and mitigation strategies. Renewable and sustainable energy reviews, vol. 107, p. 37-50, https://doi.org/10.1016/j.rser.2019.02.0188

[5] Rodionova, Margarita V., et al. (2017). Biofuel production: challenges and opportunities. International Journal of Hydrogen Energy, vol. 42, no. 12, p. 8450-8461, https://doi.org/10.1016/j.ijhydene.2016.11.125

[6] Tandon, P., Jin, Q. (2017). Microalgae culture enhancement through key microbial approaches. Renewable and sustainable energy reviews, vol. 80, p. 1089-1099, https://doi.org/10.1016/j.rser.2017.05.260

[7] Costa, J. A. M. (2020). From Sugarcane To Ethanol: The Historical Process That Transformed Brazil Into A Biofuel Superpower. Mapping Politics, vol. 10.

[8] Antunes, Felipe AF, et al. (2019). Biofuel Production from Sugarcane in Brazil. In Sugarcane Biofuels (p. 99-121). Springer, Cham.

[9] Bordonal, R.d.O., Carvalho, J. L. N. Lal, R., de Figueiredo, E. B., de Oliveira, B. G., & La Scala, N. (2018). Sustainability of sugarcane production in Brazil. A review. Agronomy for Sustainable Development, vol. 38, no. 13, https://doi.org/10.1007/s13593-018-0490-x

[10] Maga, D., Thonemann, N., Hiebel, M., Sebastião, D., Lopes, T. F., Fonseca, C., & Gírio, F. (2019). Comparative life cycle assessment of first-and second-generation ethanol from sugarcane in Brazil. The International Journal of Life Cycle Assessment, vol. 24, no. 2, p. 266-280

[11] de Souza, P. K., Souza, O., Sellin, N., & Marangoni, C. (2019). Evaluation of Second-Generation Ethanol Production from Mixtures of Banana Pseudostem, Peel and Rejected Fruit Using Aspen Hysys Simulation. Industrial Biotechnology, vol. 15, no. 4, p. 268-278, doi:10.1089/ind.2018.0040

[12] Guerrero, A. B., Ballesteros, I., & Ballesteros, M. (2018). The potential of agricultural banana waste for bioethanol production. Fuel, vol. 213, p. 176-185, https://doi.org/10.1016/j.fuel.2017.10.105

[13] Karthika, P. K., & Narayanan, D. K. (2016). Performance analysis of biogas production potential from banana pseudo-stem. International Journal of Research in Electrical & Electronics Engineering, vol. 4, no. 2, p. 01-07

[14] Adamu, I. (2020). Achieving Sustainable Energy Growth Through the Development and Adoption of Biofuels Technology in Nigeria for Enhanced Productivity. International Journal Of Science for Global Sustainability, vol. 6, no. 2

[15] Aliyu, A. S., Deba, A. A., Saidu, H., Mohammed, I. L., & Usman, M. M. (2017). Biofuel development in Nigeria: Prospect and challenges. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, vol. 39, p. 1-9

[16] El-Imam, A. M. A., Greetham, D., Du, C., & Dyer, P. S. (2019). The development of a biorefining strategy for the production of biofuel from sorghum milling waste. Biochemical Engineering Journal, vol. 150, 107288, https://doi.org/10.1016/j.bej.2019.107288

[17] Dar, R. A., Dar, E. A., Kaur, A., & Phutela, U. G. (2018). Sweet sorghum-a promising alternative feedstock for biofuel production. Renewable and Sustainable Energy Reviews, vol. 82, p. 4070-4090, https://doii.org/10.1016/j.rser.2017.10.066

[18] Sivamani, S., Chandrasekaran, A. P., Balajii, M., Shanmugaprakash, M., Hosseini-Bandegharaei, A., & Baskar, R. (2018). Evaluation of the potential of cassava-based residues for biofuels production. Reviews in Environmental Science and Bio/Technology, vol. 17, no. 3, p. 553-570

[19] Ogundari, I. O., Momodu, A. S., Famurewa, A. J., Akarakiri, J. B., & Siyanbola, W. O. (2012). Analysis of Sustainable Cassava Biofuel Production in Nigeria. Energy & environment, vol. 23, no. 4, p. 599-618

[20] Rezania, Shahabaldin, et al. (2020). Technical Aspects of Biofuel Production from Different Sources in Malaysia – A Review. Processes, vol. 8, no. 8, 993

[21] Yusoff, Mohd Nur Ashraf Mohd, et al. (2020). Sustainability of palm biodiesel in transportation: a review on biofuel standard, policy, and international collaboration between Malaysia and Colombia. BioEnergy Research, p. 1-18

[22] Derman, E., Abdulla, R., Marbawi, H., & Sabullah, M. K. (2018). Oil palm empty fruit bunches as a promising feedstock for bioethanol production in Malaysia. Renewable Energy, vol. 129, p. 285-298, https://doi.org/10.1016/j.renene.2018.06.003

[23] Piarpuzan, D., Quintero, J. A., & Cardona, C. A. (2011). Empty fruit bunches from oil palm as a potential raw material for fuel ethanol production. Biomass and bioenergy, vol. 35, no. 3, p. 1130-1137, doi:10.1016/j.biombioe.2010.11.038

[24] Hossain, N., Hasan, M. H., Mahlia, T. M. I., Shamsuddin, A. H., & Silitonga, A. S. (2020). Feasibility of microalgae as feedstock for alternative fuel in Malaysia: A review. Energy Strategy Reviews, vol. 32, 100536, https://doi.org/10.1016/j.esr.2020.100536

[25] Ali, M., Sultana, R., Tahir, S., Watson, I. A., & Saleem, M. (2017). Prospects of microalgal biodiesel production in Pakistan–A review. Renewable and Sustainable Energy Reviews, vol. 80, p. 1588-1596, https://doi.org/10.1016/j.rser.2017.08.062

[26] Alam, M. M., Mumtaz, A. S., Russell, M., Grogger, M., Veverka, D., & Hallenbeck, P. C. (2019). Isolation and characterization of microalgae from diverse Pakistani habitats: Exploring third-generation biofuel potential. Energies, vol. 12, no. 14, 2660, doi:10.3390/en12142660

[27] Manzoor, M., Tabssum, F., Javaid, H., & Qazi, J. I. (2015). Lucrative future of microalgal biofuels in Pakistan: a review. International Journal of Energy and Environmental Engineering, vol. 6, no. 4, p. 393-403

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