Nigerian Journal of Technology (NIJOTECH)
Vol. 38, No. 3, July 2019, pp. **621 – 627**

Print ISSN: 0331-8443, Electronic ISSN: 2467-8821
www.nijotech.com
http://dx.doi.org/10.4314/njt.v38i3.12

BENEFITS AND CHALLENGES OF BIODIESEL PRODUCTION IN WEST AFRICA

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ABSTRACT
Global warming is a threat to the world and the use of fossil fuels is a major factor that contributes to climate change and the damage to the environment. Therefore, the world is looking for environmentally friendly fuels and West Africa is doing little in solving this global problem. After the review of relevant literatures, it is concluded that West Africa is blessed with vast lands that are available for cultivating Jatropha plant for biodiesel production. Farmers in the rural areas could use biodiesel in powering their farm machineries, while biodiesel blend could be used in diesel engines. Consequently, the economy of West African nations will be better for it. There is low level of awareness of the advantages of biodiesel. Therefore, academic Institutions should intensify research on the prospect of biodiesel and the gap between the institutions and the industries should be closed.

Keywords: *Africa; Biodiesel; Blends; Free Fatty Acid (FFA); Glycerin.*

1. INTRODUCTION

Global warming is not a myth; it is a reality that stares mankind in the face. According to National Research Council (NRC Washington), the current global warming level is ten times more than it was at the beginning of the 20^{th} century. At the press release in 2017 by National Aeronautics and Space Administration (NASA) , the year 2016 is not only the warmest year on record, but also, eight months in this same year are the warmest months in history [27]. The rise in heat concentration on earth is due to rise in the usage of fossil fuels over the years. The burning of fossil fuels for power generation, industrial processes and transportation produces Carbon (IV) oxide emission which is responsible for greenhouse effect. Fossil fuels deplete and their fluctuations in prices make unstable economy for countries that depend on them. In the light of these revelations, therefore, there is a global call to search for renewable and environmental friendly fuels. Biofuels are popular, solar energy is undergoing improvements so that it can be used for industrial purposes. The processing and production of biodiesel (methyl ester) from vegetable oil and animal fat remain a strong growing market in the United States and Canada as well as the European Union [7]. Biodiesel has been a major alternative to the fossil diesel. Biodiesel can be used in its pure form (B100) or as blends with fossil diesel. B5 (95% fossil diesel mixed with 5% of biodiesel)and B20(80% of fossil diesel mixed with 20% of biodiesel)are very common blends in the production of biodiesel [32,21] . Mostengine manufactures have approved of the use of a B5 (95% Fossil diesel mixed with 5% biodiesel) blend in their engines [21]. The American Standard for Testing and Materials (ASTM) which sets the international standards for diesel fuel has revised its statements so that a B5 blend is treated the same as conventional diesel ASTM D975-08a [23]. Biodiesel is a promising renewable energy for diesel engines, both now and in times to come.

2. SOURCES FOR PRODUCTION OF BIODIESEL

Biodiesel is produced by transesterification. Transesterification is the chemical reaction whereby

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glycerine is removed from the triglyceride (vegetable oil) by reacting it with an alcohol in the presence of a catalyst, to form an ester (biodiesel) [6, 12, 20, 22]. In a simpler term, to produce biodiesel, the heavy molecules in oil are broken down into lighter molecules by alcohol in the presence of a catalyst. Mixing speed, temperature of reaction and the free fatty acid content of the oil are very important factors in transesterification process [12, 25]. If methanol is the alcohol used, the biodiesel produced is a methyl ester while ethanol will produce an ethyl ester [24]. After transesterification is complete, the product separates into two distinct layers with glycerol at the bottom. Glycerol is tapped off leaving a crude biodiesel in the reaction vessel. The crude biodiesel can then be washed and purified to the required standard and alcohol used can be recovered and reused.

The type of oil used is a critical factor in the yield and quality of biodiesel produced. Biodiesel may be produced from wide range of sources which include edible plant oil such as soya bean, rapeseed, sunflower, palm and coconut oil (See table 2); and non-edible oil crops such as *Jatropha curcas*, *Calophylluminophyllum*, *Nicotianatabacum, CeibaPentandra, Calophylluminophyllum,* and *Heveabrasiliensis* [11, 31]. However, latter feedstocks are preferred for biodiesel production as it would not result in competition over land used for food or other agricultural practices [11]. Biodiesel is also produced from edible oils such as coconut oil, palm oil, and soya bean oil among others (See table 2). Most of the biodiesel is currently made from soya bean, rapeseed, sunflower, and palm oils with new considerations on mustard seed, peanut, sunflower, and cotton seed [11, 5]. Oil palm accounts for about 10% of global biodiesel production, and is rapidly increasing particularly in Indonesia and Malaysia [5, 31]. Soya oil is common as feedstock for biodiesel in the world and it accounts for approximately 90% of the biodiesel produced in the United States of America [5, 8]. Nigeria is the 13th largest producer of soya bean in the world with 591,000 metric tonnes [3]. It is estimated that Nigeria has the potential of producing 284.5 mega litres (ML) of biodiesel from 638,000ha of soya beans cultivated in 2007 [5]. Rapeseed oil is used in many European countries for biodiesel production, whereas, coconut oil and palm oils are used in Malaysia and Indonesia for biodiesel production [11]. Palm oil is the most efficient source for biodiesel yield per unit of land compared to other oil crops such as soya beans, rapeseed or sunflowers [5]. About 80% of the European Union's total biofuel production is comprised of biodiesel produced from rapeseed and sunflower seeds [11]. Rapeseed oil provides 59% of total global biodiesel raw material, followed by soya bean (25%), palm oil (10%), sunflower oil (5%), and others (1%) [11]. Producing biodiesel in commercial quantities can be expensive and approximately 80% of the cost of producing biodiesel is from the raw materials [11].

Producing biodiesel from edible oils is not good economically, but non- edible oil plants are easily available in developing countries and are very economical. Literatures [10, 16, 28] indicated that using edible oils for biodiesel production will result in scarcity and competition over food, but waste cooking oil can be a bailout here. In the United States of America, according to Energy Information Administration, (EIA) approximately 100 million gallons of waste cooking oil are produced per day while a person produces about 9 pounds of waste cooking oil per year[10]. The only issue with waste cooking oil is the high content of free fatty acids (FFAs) which will cause soaps to be formed during the transesterification processes and lower the yield of biodiesel production. This issue can be resolved by transesterification reaction which will neutralize the FFAs [19]

2.1 Recent Innovations in Biodiesel Production

Production of biodiesel is done in three stages. Pre-treatment stage, reaction stage and the washing stage, other stages such as alcohol recovery and glycerine purification stage are also feasible. Pre-treatment is done to remove food particles and reduce water content in the oil. Free fatty acid in the oil is removed by esterification process. If for an example, the free fatty acid content of the oil is 2.5% or less, then the esterification process may be skipped [20]. Otherwise, esterification should be done to reduce the FFA. There are several methods to treat high FFA waste vegetable oils in small-scale systems; the easiest is to mix the high FFA oil with low FFA oil. This method is not adequate for a high FFA batch.

Adding catalyst and water to high FFA oil has some disadvantages; the percentage of feedstock that will be lost is higher than the percentage of FFA. It has been concluded that 100 gallons of waste vegetable oil will lose more than 10 gallons if it contains 10% of FFA [20]. Reaction stage consists of mixing the catalyst with alcohol and then with the oil. This is done in a reactor with stirring mechanism. The washing stage is done to remove soaps, traces of glycerol and other contaminants from the biodiesel so that a quality product, which meets the ASTM D6751 or EN 14214 standards, is produced. Wet washing of biodiesel by water is very effective because the by-products are very soluble in water. After water washing, drying of the biodiesel is always carried out to ensure the removal of excess moisture [2]. The disadvantages of water washing are in the volume of water needed, availability, cost, emulsion and waste water treatment. Dry washing is generally done without water. Ion exhange resins and magnesium silicates are used in the conventional dry washing. It has been reported that glycerol and methanol are not removed completely to EN 14214 standard when dry washing is used [29].

In recent times, recovery of alcohol and glycerine purification are done to reduce the overall cost of production. The alcohol recovered is reused while the pure glycerine can be sold. Several attempts have been made to increase mixing efficiency of the oil, alcohol and the catalyst. Chemical strategies involve the use of a co-solvent in order to achieve a single phase of alcohol-oil. Cyclic ethers such as tetrahydrofuran (THF), 1,4-dioxane, diethyl ether, methyl tertiary butyl ether, and diisopropyl ether meet the requirements for an ideal co-solvent especially if methanol is adopted in the transesterification reaction[31]. Hosseini et al [17] used a helical ribbon-like mechanical agitator which operated at 900 rpm. This stirring speed produced 97.3% conversion of triglycerides to methyl esters in 20 minutes. Other mechanical mixing systems that are in use include; ultrasound-based agitation systems, high frequency magnetic impulse cavitation reactor, static mixers and spinning tube in tube (STT) reactors. These reactors were developed by Four Rivers Bioenergy Company [31].

2.2 Advantages and disadvantages of biodiesel production

Biodiesel is environmental friendly, emissions such as Carbon (IV) oxide, Sulphur (IV) oxide, carbon monoxide and hydrocarbons are greatly reduced. Figure 1 shows the percentage reduction in emissions with different biodiesel blends. Biodiesel is a renewable energy that can be used in any diesel engine with minor or no modifications to the engine [6, 18]. Biodiesel is renewable and easy to produce. The technology involved in its production is not complex and the raw materials can be obtained easily. Waste cooking oils can be recycled to produce biodiesel. As a fuel, the properties of biodiesel are better and it is more biodegradable than fossil diesel. Biodiesel production may be a source of foreign exchange earnings and its production will attract investors to the community and help to provide jobs for the unemployed. Low grade lands that lie idle may be used to cultivate Jatropha for the production of biodiesel. Production of biodiesel will help to improve the availability of energy for the increasing population of Africa and also stimulate economic growths in rural areas.

The production of biodiesel could lead to competition with food. Palm oil and soya bean oil produce more yield of biodiesel. Other non- edible oils such as Jatropha oil can be used to prevent this. Overall cost of producing biodiesel can be expensive, selection of raw materials should be done carefully to lower this cost. The alcohol used in the process can also be recovered and reused while glycerine may be sold to industries that need it. Land may become scarce for food production. Low grade lands should be used to produce oil crops that thrive in them. Using biodiesel in its pure form (B100) may affect the pump systems and pose problems in maintenance. Efforts are underway to ensure that this is corrected. B80 has been used in diesel engines with good success [23]. Problems often occur in the use of biodiesel in cold environments because of its high freezing point; using blends as low as B5 should solve this problem. It is deduced from Figure 1 that if the percentage of biodiesel in a blend is low, there will be an increase in the emissions.

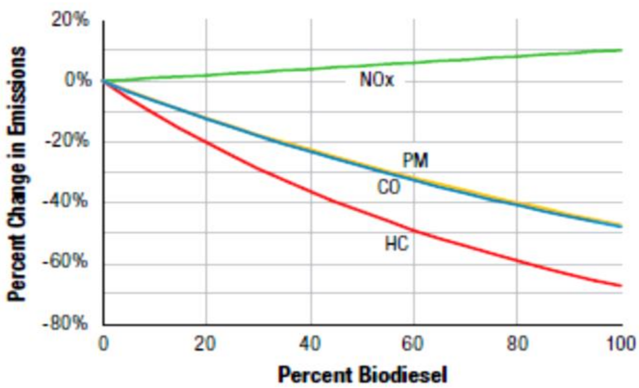

Figure 1: Biodiesel Blends and Their Emissions. Source: [32]

3. BIODIESEL AND WORLD ENERGY

In 2003, Friedrich grouped countries into three categories in order of their developmental level of biodiesel production. According to him, countries in category I think about biodiesel as being used as a fuel, even though the decision makers in these countries have not put the idea into practice. Category II countries have gone a step higher. They are characterized by research efforts, pilot projects, setting of frame conditions and financially supported technical trials. Countries in category III plan their economy on biodiesel, produce and distribute biodiesel [24]. There has been an upward trend in the usage of biodiesel over the last decades. Even though most third world countries are still struggling with the idea of using biodiesel, America and Europe are taking the lead in this regard. The assumption that 10% of the European transport consumption is to be provided by biofuels in 2020 will require a biofuel production of 22.9 billion litres of biodiesel and 29.2 billion litres of ethanol. According to the data available at British Petroleum Statistical review of world energy in 2017, North America produces more biodiesel than the rest of the world (figure 2) while United states and Brazil produced more than 52 thousand tonnes of oil equivalent in 2015 alone [7]. These countries could be said to be in phase III.

Global biofuels production rose by 2.6% in 2016, well below the 10-year average of 14.1%, but faster than in 2015 (0.4%). The US provided the largest increment (1930 thousand tonnesoil equivalent, or ktoe). Global ethanol production rate increased by 0.7%; due to fall in production in Brazil. Biodiesel production rose by 6.5% with Indonesia providing more than half of the increment(British Petroleum, 2017). Germany, France and Spain are leading in biodiesel consumption at an average of 2.5million tonnes oil equivalent as shown in table 1.Czech Republic's Preol has a crushing mill processing capacity of 400 000 tonnes a year and production capacity of the attached biodiesel factory of 100 000 tonnes a year. Slovakia republic is not left out. In Slovak, an industry produced 100000 tonnes of biodiesel in a year. A company in Hungary; Rossi Biofuels had a biodiesel factory whose capacity was 150000 tonnes of biodiesel in a year. Serbia Victoria Oil in 2007produced 100 000 tonnes of biodiesel and 35 000 tonnes of cooking oil [15]. The National Mission on Biodiesel in Thailand was launched in April 2003 and has identified Jatropha as the most suitable oil seed plant with the aim of reaching the targeted 20 % (B20) by year 2012. To achieve this, the Government has targeted 11.2 million hectares areas to be planted with Jatropha by 2012 to produce sufficient oil seeds to support the biodiesel requirements [15]. General Motors has announced that it will have twenty different diesel vehicle model options available in the U.S. market in 2017-2018; all of which are approved for use with biodiesel (B20).

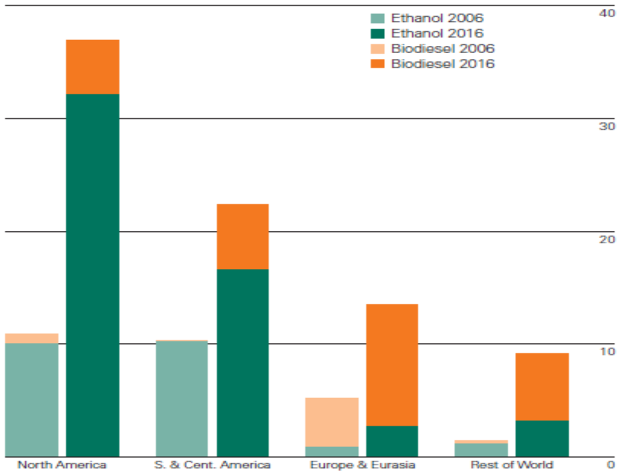

Figure 2: World Biodiesel and Ethanol Production Source: [7]

Table 1: Biodiesel Consumption in Europe. (toe) = tonnes oil equivalent. Source: [9]

Country	Bio-diesel [toe]	Country	Bio-diesel [toe]	Country	Bio-diesel [toe]
Germany	2 143 929	Portugal	310 253	Lithuania	35 372
France	2 034 500	Czech Republic	240 566	Slovenia	31 433
Spain	1 474 331	Finland	102 465	Latvia	14 644
Italy	1 286 450	Romania	138 746	Bulgaria	16 791
United Kingdom	729 077	Hungary	110 003	Cyprus	15 899
Poland	859 604	Denmark	82 502	Estonia	0
Sweden	226 953	Slovakia	97 747	Malta	0
Austria	411 822	Greece	103 396	TOTAL EU	11 018 915
Belgium	273 308	Ireland	67 704	Croatia	2 651
Netherlands	172 327	Luxemburg	39 092		

3.1 Development of Biodiesel in West Africa.

Though there are no operational commercial biodiesel plants in Africa, There are several small and medium-scale producers of biodiesel [4]. One can infer from existing literatures [4, 30] that countries like Mozambique, Zimbabwe and South Africa are in the second stage of biodiesel development while other African countries are still in stage one. South Africa's biodiesel market is dominated by several small and medium-scale producers. However, five companies have been granted licenses to generate bioethanol and biodiesel in South Africa while other potential biofuel options, such as biomethane, bioelectricity and biohydrogen production, would play a pivotal role in country's energy mix [30].

In Mali, both NGOs and European companies are producing biofuels feedstock, mostly through small scale projects based in the immediate vicinity of the company's or NGO's processing facilities. A private Dutch company in Mali aims to produce biodiesel for the country's domestic market, sourcing its feedstock from 3000 hectares (ha) of Jatropha plantation [33]. The company is investing in locally appropriate research and development, and testing new ways to improve the profitability and durability of portable engines running on biodiesel derived from Jatropha. The aim is to generate power to meet rural requirements such as grain grinding and running an electricity generator. In another view, Jatropha Mali Initiative (JMI) is a French-Malian joint venture that started in 2007 with the aim of producing biodiesel but now produces Jatropha oil for local and national markets. JMI centres on seed collection and oil expelling, they also provide training and know how on cultivation and seeds purchase [33].

Despite the fact that there is huge availability of feedstock and the potential for biodiesel production in Nigeria, production exists only at research scale [5]. There is an increase in awareness to this potential, which has led to researches by some Nigerian universities in biodiesel production from Jatropha and other edible and non-edible feedstock. Jatropha oil is currently taking the lead as feedstock in the production of biodiesel [5, 30]with over 4 000 ha of land set aside for Jatropha in Nigeria[30]. It was estimated that a hectare of Jatropha plantation is able to yield between 0.5 and 12 tonnes of nuts per annum, while one metric tonne of Jatropha nuts yields up to 139 litres of crude biodiesel [26]. The current production of biodiesel in Nigeria is still largely in the crude form except in Lagos, where three companies (Biodiesel Nigeria Limited, Avatar Energy Limited and Canrex Biofuel Limited) are engaged in the refining of biodiesel for final consumption by GSM providers, these Mobile Network Service providers use biodiesel in their base stations in Nigeria [30]. Bioethanol is another biofuel source for Nigeria if harnessed. Nigeria's importation of ethanol from Brazil was put at 11.4 and 23.8 million USD for the year 2003 and 2004 respectively [13]. In 2007, 123 million litres of ethanol was imported from brazil which translates to about 2% of the current national demand[26] .This means that bioethanol will be absorbed if produced in Nigeria; a call for private investors to engage in this venture.

Ghanaian government is interested in promoting the cultivation and use of Jatropha for biodiesel because the plant can grow almost everywhere and its cultivation will provide more jobs. Also, Ghana has a suitable climate for Jatropha. Jatropha oil is used to power multi-functional platforms (MFPs) driven by diesel engines, mostly by women for livelihoods. The oil is also used in soap making, mostly in some rural communities in the three northern regions [26]. The production cost of biodiesel from Jatropha in Ghana is estimated at US$460 per tonne of oil equivalent which is 8% higher than the price of imported petroleum diesel [26]. The government created a fund of 15 billion Cedis (7.5 billion US$) for the development of Jatropha plantations across the country. Some three billion Cedis (1.5 billion US$) have been allocated to the production of seeds and seedlings, and the remaining 12 billion Cedis (6 billion US$) are available at banks for organizations that are interested in the cultivation of Jatropha [26]. Also, in 2006, quality seeds were made available for the cultivation of about 2500 ha of land and the government ensured that by 2007, seeds were available to cultivate 5000 ha of land. As at 2005, Anuanom Industrial Bio Product Ltd. (AIBP) had installed a 500-tonne plant for processing Jatropha seed oil into biodiesel, it also installed a 2000-tonne equipment for producing organic fertilizer from by-products of biodiesel and or seed-cake [4]. Biodiesel 1, Ghana Limited, a company in Ghana, installed a Jatropha processing plant which processes 2000 tonnes of seeds per month while Biofuel Africa Ltd. established 23762 ha of Jatropha plantation for biodiesel production in the Central Gonja and Yendi Districts of Northern Ghana [4].

Table 2: Feedstock Inputs in Biodiesel Production

		Calendar Year				
Category	Input	2010	2011	2012	2013	2014
Vegetable oils	Canola oil	246	847	790	646	1,046
	Corn oil	112	304	646	1,068	970
	Cottonseed oil	W	W	-	-	-
	Palm oil	W	W	W	632	63
	Soybean oil	1,141	4,153	4,042	5,507	4,802
	Other	W	W	W	W	96
Animal fats	Poultry	100	240	176	160	173
	Tallow	170	431	385	465	355
	White grease	333	533	408	468	427
	Other	42	85	48	W	30
Recycled	Yellow grease	246	471	670	1,046	1,074
	Other	40	195	289	310	186
	Algae	-	-	-	(s)	1
Other		33	27	1	W	151

- = No data reported
W = Withheld to avoid disclosure of individual company data.
(s) = Value is less than 0.5 of the table metric, but value is included in any associated total. Source: [8]

It is right to conclude that the production and commercialization of biodiesel in Africa could provide an opportunity to diversify energy and agricultural activity and reduce dependence on fossil fuels.

4. CONCLUSION

Without gainsaying, environmental degradation exists and the results are not far-fetched. Fossil fuels deplete and their fluctuations in prices make unstable economy for countries that depend on them. Clean and renewable energy is the solution to these problems. Biodiesel has gained more acceptance as an alternative to fossil diesel in developed countries and some few African countries because it is a renewable energy that can be used in any diesel engine without modification to the engine. It is environmentally friendly in that it is more degradable than fossil diesel and major emissions from burning biodiesel are greatly reduced. West African countries have vast lands and suitable weather which may be used to produce oil crops and plants that are needed for biodiesel production. However, there is reluctance on the part of the governments and the citizens to chart this course. Factors such as lack of political will, bad business policies and low awareness level, amongst others, are responsible for this. In contrast, developed countries are already producing biodiesel in commercial quantities and truck users in North America and Asia use it for transportation, while countries in Europe are not left out (Table 1). Citizens in the Unites States operate their farm equipment on biodiesel. To overcome these challenges, therefore, favourable policies must be put in place for investors in these areas to come in. Awareness level should be raised through seminars, conferences and workshops. Farmers should be encouraged to cultivate plants for biodiesel production by making lands, farm equipment and machineries available at subsidized rates. This will encourage investors and there will be availability of energy for the increasing population of the West African countries.

5. REFERENCES

[1] Alfa Laval Ageratec,"Biodiesel Production", www.Alfalaval.com/global assets /documents /industries, energy, biofuels/ processing_ systems_ for_ biodiesel _ production _ pft00391en.pdf. Accessed on 15 April, 2018.

[2] Abdul Raqeeb, M. "Biodiesel production from waste cooking oil", *Journal of Chemical and Pharmaceutical Research*, Vol. *7*, 2015, pp. 670–681.

[3] Abila, N., 2012, "Biofuels development and adoption in Nigeria: Synthesis of drivers and incentives and enablers" *Energy Policy,* volume 43, 2012, pp. 387–395.

[4] Amigun, B., Musango, J. K., & Stafford, W., "Biofuels and sustainability in Africa", *Renewable and Sustainable Energy Reviews*, Vol. 15, 2011pp. 1360–137.

[5] Ben-iwo, J., Manovic, V., & Longhurst, P., "Biomass resources and biofuels potential for the production of transportation fuels in Nigeria", *Renewable and Sustainable Energy Reviews*, Vol. *63*, 2016, pp. 172–192.

[6] Bilgin, A., Gülüm, M., Koyuncuoglu, İ., Nac, E., & Cakmak, A., "Determination of Transesterification Reaction Parameters Giving the Lowest Viscosity Waste Cooking Oil Biodiesel", *Procedia - Social and Behavioral Sciences*, Vol. 195,2015, pp. 2492–2500.

[7] British Petroleum, www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf. Accessed on 10 May, 2018.

[8] Brorsen, W., "Projections of US production of Biodiesel Feedstock", *International council on clean transportation,* 2015, pp. 1-13.

[9] Carlini, M., Castellucci, S., & Cocchi, S., "A pilot-scale study of waste vegetableoil transesterification with alkaline and acidic catalysts", In *Energy Procedia* Vol. 45, 2014.

[10] Chhetri, A. B., Watts, K. C., & Islam, M. R.,. Waste Cooking Oil as an Alternate Feedstock for Biodiesel Production, *Energies*, Volume 1, 2008, pp. 3–18.

[11] Demirbas, A., Bafail, A., Ahmad, W., & Sheikh, M., "Biodiesel production from non-edible plant oils", *Energy Exploration an Exploitation* 2016.

[12] Ehsan, M., & Chowdhury, M. T. H. "Production of biodiesel using alkaline based catalysts from waste cooking oil: A case study", In *Procedia Engineering*, Volume 105, 2015, pp. 638–645.

[13] FAO, IUCN and UNEP. *ECOLEX, "The gateway to environmental law",* http://www.ecolex.org/start.php. Accessed on 25 April, 2018.

[14] Gumba, R. E., Saallah, S., Misson, M., Ongkudon, C. M., & Anton, A. "Green biodiesel production: A review on feedstock, catalyst, monolithic reactor, and supercritical fluid technology", *Biofuel Research Journal*, Volume *3*, 2016, pp. 431–447.

[15] Hassan, M. H., & Kalam, M. A. "An overview of

biofuel as a renewable energysource: Development and challenges". In *Procedia Engineering*, Volume 56, 2013, pp.39–53.

[16] Ho, K., Chen, C., Hsiao, P., Wu, M., Huang, C.-C., & Chang, J.-S. "Biodiesel Production from Waste Cooking Oil by Two-step Catalytic Conversion", *Energy Procedia*, Volume 61, 2014, pp. 1302–1305.

[17] Hosseini, M., Nikbakht, A. M., Tabatabaei, M., "Biodiesel production in batch tank reactor equipped to helical ribbon-like agitator", *Application of Science, Volume* 6, 2012, pp. 40-45.

[18] Jim Leidel, 2014. Biodiesel Processor System manual, Oakland University. BIODIESEL_PROCESSOR. pdf, Accessed on 22 May, 2018.

[19] Kawentar, W. A., & Budiman, A., "Synthesis of biodiesel from second-used cooking oil", In *Energy Procedia,* Volum*e*, 32, 2013, pp. 190–199.

[20] Musa, I. A.. "The effects of alcohol to oil molar ratios and the type of alcoholon biodiesel production using transesterification process", *Egyptian Journal of Petroleum*. Egyptian Petroleum Research Institute https://doi.org/10.1016/j.ejpe.2015.06.007: Accessed on 2016.

[21] Nair, J.N., & Deepthi, J. "Study of Biodiesel Blends and Emission Characteristics of Biodiesel", *International Journal of Innovative Research in Science, Engineering and Technology,* volume *2*, 2013, pp. 3710–3715.

[22] Nascimento, F. A., Antônio, L., & Cavalcanti, P., "Sustainable Biodiesel Reactor Prototype Energetically Powered By Solar Energy", https://doi.org/10.9790/16761202027277: Accessed on 2017.

[23] National Biodiesel Board. http://nbb.org/news/biodiesel-bulletin: Accessed on 15 May, 2018.

[24] Nolte, M., "Commercial Biodiesel Production in South Africa: a Preliminary Economic Feasibility Study", http://scholar.sun.ac.za/handle/10019.1/1797: accessed on 30June, 2018.

[25] Nwaigwe, K. N., Ogueke, N. V., Kamalu, C., & Anyanwu, E. E. "Design and Construction of a Biodiesel Batch Reactor With Improved Settling Capability". In *Volume 6A,*2014.

[26] Popoola, L., Larwanou, M., & Jimoh, S. O." Biofuel initiatives in West Africa and the Sahel : Potential for success", volume 17, 2015, pp. 136–148.

[27] Potter, S., Cabbage, M., & McCarthy, L.*NASA, NOAA data show 2016 warmest year on record globally*. *National Aeronautics and Space Administration (NASA)*. https://doi.org/10.1038/ngeo2934.: Accessed on 2017.

[28] Putra, R., Juliantoa, T., Hartono, P., Puspitasaria, R., & Kurniawan, A. "Pre-treatment of Used-Cooking Oil as Feed Stocks of Biodiesel Production by Using Activated Carbon and Clay Minerals", *International Journal of Renewable Energy Development*, volume 3, 2014, pp. 33–35.

[29] Rahmat, B., Setiasih, I. S., & Kastaman, R. "Biodiesel Reactor Design with Glycerol Separation to Increase Biodiesel Production Yield", *MAKARA Journal of Technology Series*, volume, 17, 2013, pp. 11–16.

[30] Sekoai, P., & Yoro, K. "Biofuel Development Initiatives in Sub-Saharan Africa: Opportunities and Challenges". *Climate*, volume 4, 2016, pp. 33.

[31] Tabatabaei, M., Karimi, K., Sárvári Horváth, I., & Kumar, R. "Recent trends in biodiesel production". *Biofuel Research Journal*, volume 2, 2015, pp.258–267.

[32] U. S. Department of Energy. "Biodiesel Blends", http://www.afdc.energy.gov/fuels/biodiesel_ blends. html: accessed on 20 May,2018.

[33] Vermeulen, S., Sulle, E., & Fauveaud, S. "Biofuels in Africa: growing small-scale opportunities" *IIED Briefing November 2009*.

[34] WBA Global Bioenergy Statistics, *World Bioenergy Association,* https://doi.org/10.1016/0165-232X (80) 90063-4: Accessed on 2014