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Liquid Biofuels as Alternative Transport Fuels in Nigeria

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Abstract

This paper examines the potentials of liquid biofuels as alternative transport fuel in Nigeria. The transport sector of Nigeria's economy is probably the most vulnerable sector, as it responds very sensitively to rises in prices of conventional fuels, most of which are today imported into the country, though ironically, Nigeria is the sixth largest exporter of crude oil. This has necessitated the search for renewable, sustainable and environmentally friendly energy resources. This paper compares fossil fuels and liquid biofuels in terms of availability of raw materials, methods of production, fuel properties and associated environmental impacts in the Nigerian context. It concludes that liquid biofuels should, baring the problems of availability, be preferred to fossil fuels for powering the transport sector in the country.

Keywords: Liquid Biofuels, Alternative Transport fuels

Introduction

Biofuels can be defined as fuels produced from agricultural resources. They can be produced from agricultural and forest products and the biodegradable portion of industrial and municipal waste. Research and development efforts in the area of renewable liquid fuels to supplement/substitute petroleum fuels focus on two major fuels: bioethanol which could be made from crop grains or sugarcane and biodiesel produced from vegetable oils and animal fats[1,2,3]. Our focus in this work is on bioethanol and biodiesel which could be used as sources of power for cars, trucks and aircraft. These two presently account for more than 95 percent of global biofuels usage[4]. The use of liquid biofuels as alternative transportation fuels constitutes one of the few options for reducing Nigeria's reliance on fossil fuel.

Biofuels, as alternative renewable energy resources, have received considerable attention in the recent past. German Engineer Rudolf Diesel's first eponymous engine in 1896 was run using peanut oil and was demonstrated at the 1901 Paris Exposition. Henry Ford, one of the pioneer automobile manufacturers, designed his first car model to run on ethanol. These visionary inventors expected that their new inventions would run on fuels derived from plants, but cheap petroleum proved more popular at the beginning of the 20th century[5]. The oil crises of the 1970s, however, rekindled interest in the use of renewable fuels and the following main factors have sustained this interest to date:

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[1] Bugaje, I.M. (2006). Renewable Energy for Sustainable Development in Africa: a Review. Renewable and Sustainable Energy Review, vol. 10(6), p. 603 – 612.

[2] Bobboi, U., Usman A.M. and Kwanyo, U.A. (2006). Advances in biodiesel production, use and quality assessment. University of Maiduguri Faculty of Engineering Seminar Series, vol. 4(1), p. 1 – 10.

[3] Ngala, G.M., Abdulrahim A.T. and Usman M.L. (2006). Developments in bioethanol production, uses and its potential as an alternative fuel in developing countries. University of Maiduguri Faculty of Engineering Seminar Series ,Vol.4(1): p. 11 – 19**.**

[4] Bugaje, I.M. and Mohammed I.A. (2008). Biofuels Production for Transport Sector in Nigeria. International Journal of Development Studies ,Vol.3,No 2 p.36-39

[5] Goering, C. E., Schwab A. W., Daugherty M. J., Pryde E. H., Heakin A. J. (1982) Fuel properties of eleven vegetable oils, Transactions of the SAE, 25(6), p. 1472 – 1477, 1483.

i. Prices of petroleum products have been on the increase since the oil crises[6].
ii. Uncertainties in oil supplies due to political instability and conflicts in some oil producing areas of the world[7,8].
iii. Growing anxiety over the future security of the world's supply of crude oil[9].

The purpose of this study is to examine the technical potentials of biofuels in reducing reliance on petroleum products for transportation, principally in automobiles as alternative transport fuel in Nigeria.

Biomass resources are abundant in Nigeria, but as feedstock for transportation fuels they have constraints and implications for environmental protection. Biomass is a renewable resource that can also offer net CO_2 benefits because living plants take up CO_2 through the process of photosynthesis. Although biomass can be produced continuously over a long term, the amount that can be `produced at a given time is limited by the availability of the natural resources that support biomass production[10,11,12]. Most arable land in Nigeria is already being used for food, feed, and fiber production. Although the technologies for producing fuels from plant sugar and starch are known and used commercially, the technologies for producing fuels from lignocelluloses feedstock have yet to be demonstrated on a commercial scale[13,14]. There has been growing worldwide interest in biofuels as renewable sources of energy to substitute for petroleum-derived products. Unlike crude oil, feed stocks for biofuels – plants for ethanol and animal fats for biodiesel – are more uniformly dispersed, being available in every country, albeit in varying quantities and at different costs. Concerns over having to rely on a limited number of countries for crude oil supply and these countries' enormous market power also make biofuels attractive as a means of enhancing security of energy supply[15].

The bulk of current and future uses of biofuels target the transport sector whereby biofuels substitute for gasoline and diesel, either wholly or partially by blending with the petroleum products. Because the contribution of the transport sector to greenhouse gas (GHG) emissions will grow in the coming decades, substitution of gasoline and diesel with biofuels has the

[6] EIA, (Energy Information Administration). 2009. Annual Energy Outlook 2008 with Projections to 2030. U.S. Department of Energy.
[7] Bobboi, U., Usman A.M. and Kwanyo, U.A. (2006). Advances in biodiesel production, use and quality assessment. University of Maiduguri Faculty of Engineering Seminar Series, vol. 4(1), p. 1 – 10.
[8] Peterson, C. L., Wagner G. L., Auld D. L., (1983).Vegetable oil substitutes for diesel fuel, Transactions of the ASAE, 26(2), p. 322 - 327, p. 332.
[9]USDA (2005). Synthetic diesel may play a significant role as renewable fuel in Germany. Production Estimates and Crop Assessment Division.
[10] Dayo, F.B. (2008). Clean Energy Investment in Nigeria. The Domestic Context.
[11] Ololade, B.G. (2007). Biofuel-cassava-ethanol in Nigeria the investors Haven current issues and success factors. Being papers presented at the 2007 international fuel ethanol workshop and Expo ,USA.
[12] EBB, (2005). Biodiesel production statistics for 2004, European Biodiesel Board, Available at: http://www.ebb-eu.org/stats.php., 2005.
[13] Kallivroussis, L., Natsis A., Papadakis G. (2002). *The energy balance of sunflower production for biodiesel in Greece*, Biosystems Engineering, 81(3), p. 347 – 354
[14] Ricards, I. R., (2005). Energy balances in the growth of oilseed rape for biodiesel and of wheat for bioethanol, Levington Agriculture Report, 2000, Available at: www.org/net/com.
[15] Bugaje, I.M. and Mohammed I.A. (2007). Biofuels as Petroleum Extender: Prospects and Challenges in Nigeria. Petroleum Training Journal, vol. 4, p. 11 – 21.

added advantage of addressing global climate change[16]. In industrialised countries, the amount of feedstock available at reasonable prices that can be used for biofuel production using technologies that are commercially available today is relatively small compared to petroleum imports. The situation will change if biofuels from agricultural residues, energy crops, wastes (forestry, mill, municipal), and other feed stocks become commercially viable[17,18]. Ethanol is the most commonly used biofuel to substitute for gasoline, and biodiesel to substitute for diesel. Both Ethanol and biodiesel contain oxygen and their combustion results in lower exhaust emissions as well as reduced quantities of harmful pollutants. The production and use of ethanol is much more common than for biodiesel at the present time, largely due to the lower cost of production of ethanol from biomass[19].

Uses of Biofuels

The most prevalent use of biofuels is as fuel for automobiles. Ethanol is used primarily in spark-ignition engine vehicles. The amount of ethanol generally ranges from 5% blended with gasoline to 100%. The ethanol added to gasoline needs to be free of water, or else a phase separation can occur between gasoline and water-ethanol. This is the reason why anhydrous ethanol is used in a gasoline-ethanol blend. Anhydrous ethanol is transported separately to terminals to minimize contact with water and typically blended into gasoline just before loading into trucks by splash blending, a process that requires no special equipment or temperature control. Gasoline containing 5 to 10 percent ethanol is the most common blend. Gasoline containing 85 percent ethanol is also used but to a much lesser extent.

Hydrous ethanol is used neat, that is, without addition of gasoline, in vehicles designed specifically for it. Because hydrous ethanol does not require complete dehydration, it is cheaper to manufacture than anhydrous ethanol. Brazil has the largest market for vehicles running on hydrous ethanol. Aside from vehicles manufactured to run on hydrous ethanol, flex-fuel vehicles in Brazil run on any mixture of a gasoline-ethanol blend and hydrous ethanol[20].

Another application of ethanol is as a feedstock in the manufacture of ethers, most commonly ethyl tertiary-butyl ether (ETBE), an oxygenate with high blending octane used in gasoline. ETBE contains 44% ethanol. Ethanol from sugar beet in France is used primarily in the form

[16] Bugaje, I.M. and Mohammed I.A. (2008). Biofuels Production for Transport Sector in Nigeria. International Journal of Development Studies ,Vol.3,No 2 p.36-39

[17] Shumaker, G. A., McKiossick J., Ferland C., Doherty B., (2005). *A study on the* feasibility of biodiesel production in Georgia, 2003, accessed 15 June 2005.

[18] USDA, (2005). Synthetic diesel may play a significant role as renewable fuel in Germany. Production Estimates and Crop Assessment Division.

[19] Kaufman, K. R., German T. J., Patt, Derry J. (1986) Field evaluation of sunflower oil/diesel fuel blends in diesel engines. Transactions of the ASAE, 29(1), p. 2 – 9.

[20] Bugaje, I.M. and Mohammed I.A. (2008). Biofuels Production for Transport Sector in Nigeria. International Journal of Development Studies ,Vol.3,No 2 p.36-39

of ETBE in gasoline[21]. Ethanol can also be blended into diesel. The blends are referred to as "e-diesel." E-diesel contains up to 15 percent ethanol by volume and an emulsifier, and is a micro-emulsion. As with gasoline-ethanol blends, e-diesel is prepared by splash blending. Biodiesel is used either neat (100%) or blended with diesel, typically ranging in proportion from 2 to 20%. Diesel containing up to 5% biodiesel is gaining popularity, and is accepted by automobile manufacturers[22].

Feedstocks for Liquid Biofuels Production

The biomass resources are generated from agriculture, and construction and municipal waste. There are great potentials in rural areas to support the production of biofuels in Nigeria. About 70% of the country's labour force resides in rural areas. This labour force can be trained and retrained to implement innovations arising from the biofuel industry[23].

The land resources of Nigeria are presently is use as shown in Figure 1. Out of the total land area of 92.4 million hectares 79.4 million and 13.0 million hectares are occupied by land and water respectively. Agricultural land occupies 71.9 million hectares. This indicates a high potential for agricultural production, a considerable proportion of which can be applied as feedstock in biofuels manufacture.

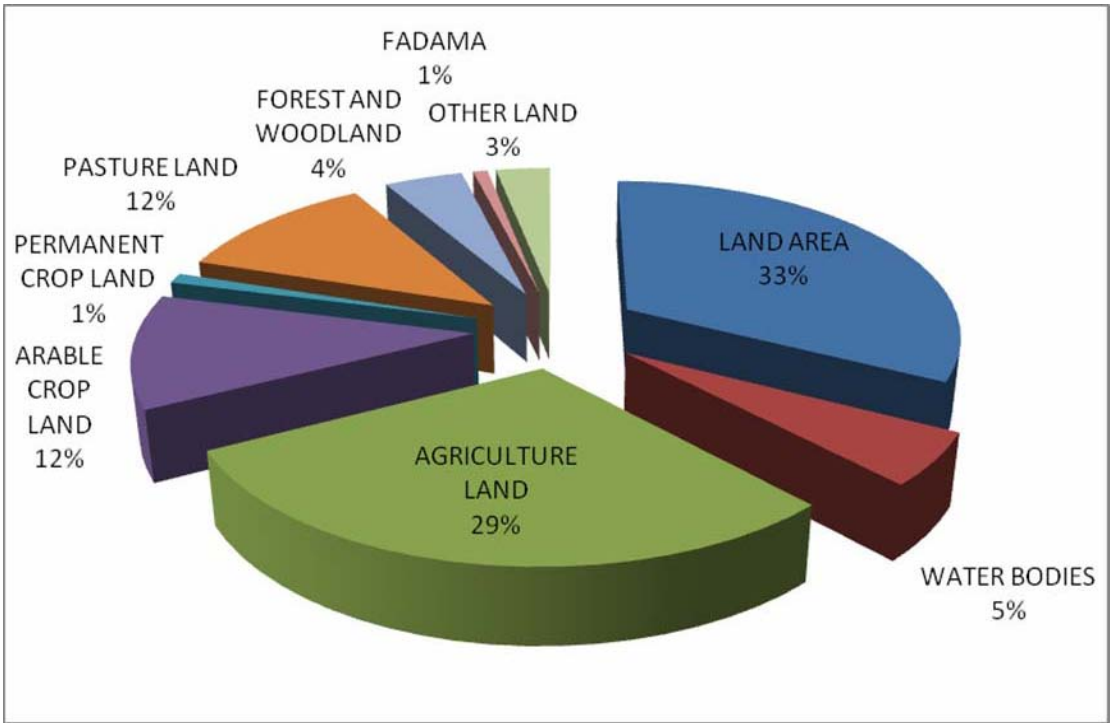

Figure1. Nigeria land area usage.

[21] Ortiz-Canavate, J. (1994). Characteristics of different types of gaseous and liquid biofuels and their energy balance. J. Agric. Engng Res., vol. 59, p. 231 – 238.

[22] McDonnel, K. P., Ward S. M., Timoney D. J., (1995). Hot water degummed rapeseed oil as a fuel for diesel engines, J. Agric. Engng Res., 60, p. 7 – 14.

[23] Bugaje, I.M. and Mohammed I.A. (2008). Biofuels Production for Transport Sector in Nigeria. International Journal of Development Studies ,Vol.3,No 2 p.36-39

Agricultural production, which is solely in rural areas, results in cassava, sugar cane, rice, maize, Jatropha seeds, and crop residue. In 2005, bio energy reserves/potentials of Nigeria stood at: fuel wood 13,071,464 hectares, animal waste 61 million tonnes per year, crop residue 8.3 million tonnes[24]. Nigeria can conveniently engage in the production of biofuels given its cassava, sugar cane, rice, maize and sorghum output. More so, cassava production, has witnessed a phenomenal increase from 35.98 million metric tonnes in 1999 to about 44.693 million tonnes in 2004, a 24% increase in five years.

Table 1 shows the capacities of Nigeria's sugarcane plantations and mills. Per capita sugar consumption in Nigeria is estimated at 8kg. In the year 2000 the total import of sugar was put at 750,000 tonnes per annum and growing at the rate of 7% [25]. Presently, Nigeria's sugar needs are met 100% by imports. The already established, now idle, sugarcane plantations, totalling 64,000 hectares could be put to immediate use to produce cane for bioethanol production.

Table 1: Capacities of Nigeria's sugar cane plantations and mills[26]

COMPANY	AREA PLANTED (hectares)	LAND AVAILABLE(hectares)	SUGAR Metric Tonnes
NISUCO, Bachita	5,600	12,500	60,000
SAVANAH SUGAR Co. Numan	4,500	29,000	100,000
LAFIAI SUGAR Co.	560	7,500	3,000
SUNTI SUGAR Co.	420	15,000	3,000
Total	11,080	64,000	166,000

Oil Seeds Production

Production of biodiesel from oil seeds is potentially going to create a new window of opportunity for agriculture and at the same time mitigate GHG emissions and generate environmental benefits for agriculture herself. Biodiesel from edible oil seeds, such as palm oil and soya bean oil grown for traditional markets may prove too expensive for use as fuel and may bring about rising cost of food.

[24] Dayo, F.B. (2008). Clean Energy Investment in Nigeria. The Domestic Context.

[25] Bugaje, I.M. and Mohammed I.A. (2008). Biofuels Production for Transport Sector in Nigeria. International Journal of Development Studies ,Vol.3,No 2 p.36-39

[26] Bugaje, I.M. and Mohammed I.A. (2008). Biofuels Production for Transport Sector in Nigeria. International Journal of Development Studies ,Vol.3,No 2 p.36-39

Nigeria needs to develop the use of non-edible oils such as Castor and Jatropha as major non -edible raw materials for biodiesel production. Globally, Jatropha caucus is taking centre stage as the oil seed of choice in biodiesel production. In India, over 30% of the over 35 million litres per day of diesel consumption comes from biodiesel produced from Jatropha seeds[27]. Jatropha grows very well in Nigeria and is already planted by farmers but mainly for border demarcation of small farm land holdings. Castor also grows very well as a weed across the entire northern states of the Federation.

The Technologies of Biofuel Production

In Nigeria, the biofuel industry is still at its infancy. Though policy guidelines are available at the NNPC for the development of the industry, few most ground breaking achievements have been made. The Kaduna State Government in 2007 set up a pilot plant for bioethanol production to demonstrate the technology and its viability using local design and materials. In Ahmadu Bello University, a pilot plant for biodiesel production has also been set up[28]. Efforts elsewhere in the country have been limited to bench scale production of bioethanol and biodiesel from a number of feed stocks. There is need to move further from this and scale up for commercial production. Ethanol is produced from fermentation of sugars and biodiesel from the reaction of plant or animal oils with methanol. These processes are described below.

Ethanol

All processes for ethanol production involve fermentation of sugars to ethanol using yeast. These microorganisms, the most commonly used of which is Baker's yeast, work best with six-carbon sugars such as glucose. Therefore, biomass materials containing high levels of glucose are the easiest to convert to sugar. This makes conversion of sugarcane to ethanol the simplest process of all. In the process, which is used extensively in Brazil, sugarcane is crushed and soluble sugars are extracted by washing with water. The sugarcane residue (called bagasse) can be burned to generate electricity, heat, or both. Yeast is added to effect fermentation at 32 – 35°C and a pH of 5.2 after the raw cane juice is filtered and heated. Fermentation of sugars produces ethanol and carbon dioxide in a series of complicated chemical reactions summarised as follows:

$$\underset{Sucrose}{C_{12}H_{22}O_{11}} + H_2O \xrightarrow{Invertase} \underset{Sugar}{2C_6\,H_{12}0_6} -------1$$

$$C_6H_{12}O_6 \xrightarrow{zymase} \underset{Ethanol}{2C_2\,H_5OH} + 2CO_2 -------2$$

Advanced biofuels derived from low-cost woody biomass could offer higher yields at lower cost and with lower environmental impacts than traditional biofuels.

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[27] (Chetri *et al.*, 2008).

[28] Bugaje, I.M. and Mohammed I.A. (2008). Biofuels Production for Transport Sector in Nigeria. International Journal of Development Studies ,Vol.3,No 2 p.36-39

Table 2: Physical properties of ethanol[29]

Density and phase	0.789g/cm^{3}, liquid
Solubility in water	Fully miscible
Melting point	-114.3^{o}C(158.8K)
Boiling point	78.4^{o}C (351.6K)
Acidity	15.9 (H^+ from OH group)
Viscosity	1.20cP at 20^{o}C

Table 3: Parameters of bioethanol compared with petrol[30]

Fuel	Density (kg/l)	Viscosity (mm^2/s)	Flash point (^{o}C)	Caloric value (MJ/kg)	Caloric value (MJ/l)	Octane Number (RON)	Fuel-Equivalent
PMS	0.76	0.6	≤ 21	42.7	32.45	92	1
BIOETHANOL	0.79	1.5	≤ 21	26.8	21.17	≥100	0.65

Biodiesel

Biodiesel is produced by transesterification of large, branched triglycerides into smaller, straight chain molecules of methyl esters using an alkali or acid or enzyme as catalyst. Many studies have been done on the transesterification of Jatropha oil to produce biodiesel[31]. In these studies, transesterification of vegetable oils was noted to be is an important reaction that produces fatty and alkyl esters, and methyl and ethyl esters which are excellent substitutes for diesel fuel.

Two approaches for transesterification of vegetable oils for production of biodiesel are suggested. The first is a chemical one in which alcoholylsis of oils by methyl or ethyl alcohol in the presence of a strong acid or base produces biodiesel and glycol. The base-catalysed transesterification is much faster and less corrosive than the acid-catalyzed reaction. Thus alkali hydroxides are the most commonly used catalyst. However, if the feedstock has a high free fatty acid (FFA) content (as is common with rendered fats and spent restaurant oils), excess of alkali causes loss of the free fatty acids as their insoluble soaps. This decreases the final yield of ester and consumes alkali. As an alternative in these cases one can conduct an

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[29] Misau, I.M., Bugaje, I.M. and Mohammed, I.A. (2007). Pilot Plant for Fuel-grade Bioethanol Production from Sugarcane. International Workshop on Renewable Energy for Sustainable Development in Africa, organised by the National Centre for Renewable Energy Research and Development University of Nsukka and the Italian Agency for new and Renewable Energy Technologies, Nsukka, Nigeria.

[30] Atadashi, I.M., Bugaje, I.M. and Mohammed, I.A. (2007). Design and Construction of Biodiesel Pilot Plant. First biofuels Conference in Nigeria organised by Executive Reach and Raw Materials Research and Development Council, (RMRDC), held at Yar'adua Centre, Abuja, Nigeria.

[31] Peterson, C. L., Wagner G. L., Auld D. L., (1983).Vegetable oil substitutes for diesel fuel, Transactions of the ASAE, 26(2), p. 322 - 327, p. 332

acid-catalysed reaction that requires higher reaction temperature (100^0C) and longer reaction times than alkali catalysed reaction[32].

The second approach is the enzymatic one in which lipase catalysed transesterification is carried out in no aqueous environments. Chemical transesterification is efficient in terms of reaction time. However, the chemical approach to synthesize biodiesel from triglyceride has its drawbacks, such as difficulty in the recovery of glycerol and the energy intensive nature of the process. In contrast, biocatalysts allow synthesis of specific alkalyl esters and usually recovery of glycerol and transesterification of glycerides with high free fatty acid content[33].

A common drawback in the use of enzymes-based process is the high cost of the enzymes. Immobilization of enzymes has generally been used to obtain reliable enzyme derivatives[34]. There are three stepwise reactions with intermediate formation of diglycerides and monoglycerides resulting in the production of three moles of methyl esters and one mole of glycerol from triglycerides. The overall reaction is shown as Figure 2.

Transesterification process is a set of three consecutive chemical reactions between ester and an alcohol in the presence of a catalyst. Alkylesters in the carbon range C_{12} – C_{20} are the result and are known as biodiesel with glycerol as a by-product[35].

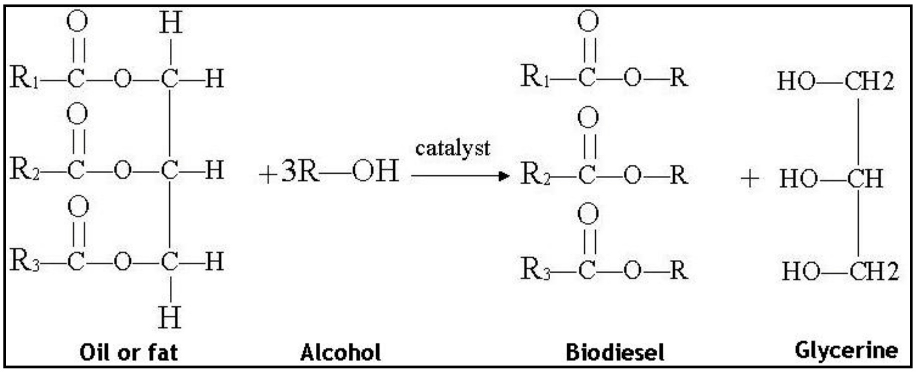

Figure 2: Transesterification reaction

[32] Shweta, S. Sharma, S. and Gupta, M.M. (2004). Biodiesel preparation by Lipase catalysed transesterification of Jatropha oil. Energy and Fuels 18 (11), 154.

[33] Kaufman, K. R., German T. J., Patt, Derry J. (1986) Field evaluation of sunflower oil/diesel fuel blends in diesel engines. Transactions of the ASAE, 29(1), p. 2 – 9.

[34] Dorado, M. P., Arnal J. M., Gomez, Gil A., Lopez F. J. (2002) The effect of a waste vegetable oil blend with diesel fuel on engine performance, Transactions of the ASAE, 45(3), p. 519 – 523.

[35] Atadashi, I.M., Bugaje, I.M. and Mohammed, I.A. (2007). Design and Construction of Biodiesel Pilot Plant. First biofuels Conference in Nigeria organised by Executive Reach and Raw Materials Research and Development Council, (RMRDC), held at Yar'adua Centre, Abuja, Nigeria.

Table 4: Parameters of biodiesel and pure oil in comparison with fossil diesel[36]

Fuel	Density (Kg/l)	Viscosity mm^2/s	Flashpoint (^oC)	Caloric value (MJ/Kg)	Caloric value (MJ/l)	Cetane Number	Fuel Equivalence
Diesel	0.84	5	80	42.7	35.87	50	1
Rapeseed oil	0.92	74	317	37.6	34.59	40	0.96
Biodiesel	0.88	7.5	120	37.1	32.65	56	0.91

Biofuels and The Transport Sector

Biofuels are a serious option to compete with petroleum products in the transport sector compared to other technologies such as hydrogen, because biofuel technologies are already well developed and available in many countries[37]. Besides, the use of biofuel blends of 10 – 20 percent requires no engine modification. Furthermore, there is now what is called Flexi-Fuel Vehicle (FFV) technology which is sufficiently well developed to allow the gradual introduction of biofuel in any country. FFV cars run with any type of fuel blend from pure gasoline to up 85% biofuel blend[,38,39].

Biofuels and The Environment

Biofuels are not only renewable and sustainable energy sources but are toxic-free and so more environmentally friendly than conventional petroleum-based fuels[40]. Biofuels are also biodegradable and therefore their accidental spillage is of no significant environmental hazard. The use of biofuels helps in reducing the accumulation of CO_2 in the atmosphere because the process by which plants make their food for growth is photosynthesis, which consumes atmospheric carbon dioxide in the presence of solar energy.

Another major advantage of biofuels is that their combustion does not lead to the emission of sulphur compounds into the atmosphere, unlike petroleum products. Sulphur compounds are hazardous to humans and also cause "acid rain" which is harmful to animal life[41]. Thus biofuels are cleaner than petroleum-based fuels. Figure 3 shows the favourable impact of biodiesel blends on vehicle exhaust.

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[36] Peterson, C. L., Wagner G. L., Auld D. L., (1983).Vegetable oil substitutes for diesel fuel, Transactions of the ASAE, 26(2), p. 322 - 327, p. 332.

[37] Bugaje, I.M. and Mohammed I.A. (2008). Biofuels Production for Transport Sector in Nigeria. International Journal of Development Studies ,Vol.3,No 2 p.36-39

[38] Lew, F. (2005). Biofuels for Transport: A Viable ? International Energy Agency (IEA), published September 2005.Available at: http//www.oecdobserver.org/

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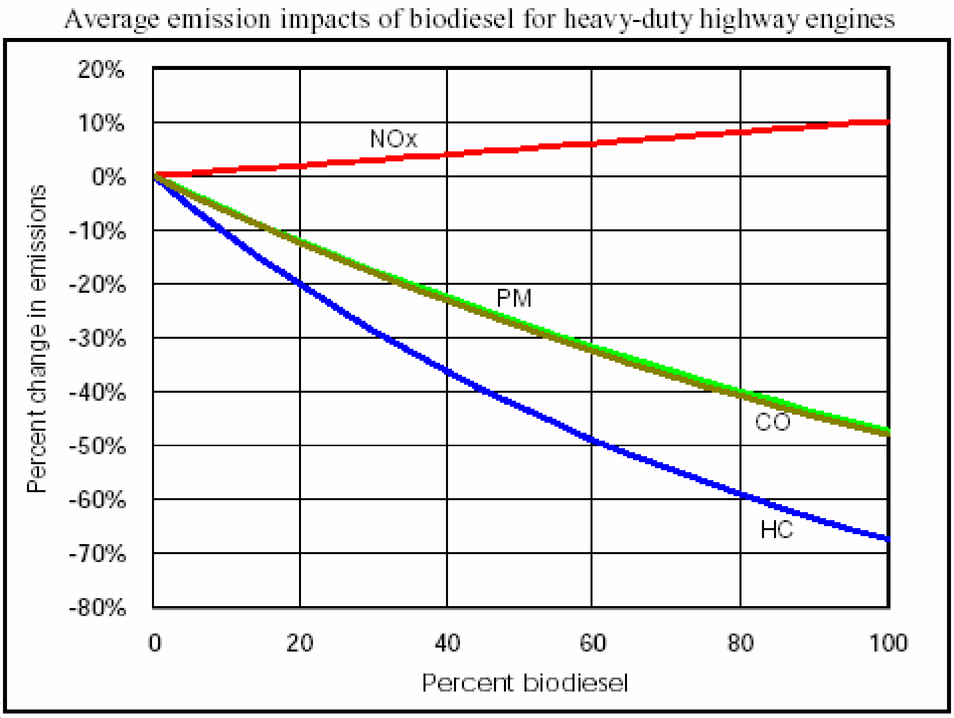
[40] Munoz, M., Moreno F., Morea J. (2004). Emissions of an automobile diesel engine fuelled with sunflower methyl ester, Transactions of the ASAE, 47(1), p. 5 – 11.

[41] Monyem, A., Van Gerpen J. H., Canakci M. (2001). The effect of timing and oxidation on emissions from biodiesel-fuelled engines. Transactions of the ASAE, 44(1), p. 35 – 42.

Figure 3 : Biodiesel impact on exhaust emission[42]



(Source; Bugaje and Mohammed,2008.)

Performance of Biofuels as Transport Fuels

Bioiesel as transport fuel has several virtues[43,44,45]. Its calorific value is up to 95% that of petroleum diesel and offers comparable engine power. It has slightly higher viscosity, and offers better lubricity than petroleum diesel; hence there is reduced wear of engine and injector pump. Biodiesels are non-toxic with no aromatics and are almost no sulphur. Biodiesels are biodegradable and increase the degradability of petroleum fuel when blended with them, thus any spillage of fuel does not contaminate the environment. They reduce greenhouse emissions since the CO_2 emitted when they are combusted is equal to the amount consumed by the plant during its growth period. They dissipate engine heat better than petroleum fuel. They do not necessitate serious engine and fuel system modification before use. The feedstock for their production is renewable. Bioethanol, for instance, has high octane rating and this prevents engine detonation (knocking) under load. Bioethanol withstands high compression ratio in an engine which leads to more power per stoke, greater efficiency and better economy.

[42]Bugaje, I.M. and Mohammed I.A. (2008). Biofuels Production Technology. Science and Technology Forum (STF), Zaria, Nigeria.

[43] Zhang, X. Peterson C., Reece D., Haws R., and Moeller, G. (1998) .Biodegradability of biodiesel in an aquatic environment. Transactions of the ASAE, 41(5), p. 1423 – 1430.

[44]NBB, (2005). Production and testing of ethyl and methyl esters, National Biodiesel Board, Available at: http://www.nbb.org/resources/reportsdatabase /reports/gen/19941201 gen-005.pdf.

[45]EBB, (2005). Biodiesel production statistics for 2004, European Biodiesel Board, Available at: Http://www.ebb-eu.org/stats.php., 2005.

Research has shown that using biodiesel could dispense with the negative engine conditions encountered by the use of straight vegetable oils (SVOs). Kaufman[46] successfully completed a 200-hour durability test using sunflower methyl ester (ME) to run a diesel engine. In another test, Kaufman[47] ran four tractors on two blends of sunflower ME and petroleum diesel for a period of 7,616 hours (spanning more than three years) and found that bearing wear was normal and there were no power losses or injector and ring coking problems. In another work, two trucks fuelled with biodiesel and operated for a combined distance of 80,467 km showed normal rate of engine wear. Goodrum[48] reported better results with peanut ME compared to the qualitative low-sulphur petroleum diesel (D2). Prankl *et al*[49] ran 9 vehicles and 1 stationary engine over an interval of 1 – 3 engine oil drains using biodiesel made from rapeseed, sunflower and camelina oils with high iodine numbers and concluded that no unusual deposits were found in the engines.

While the suitability of biodiesel as a fuel is being researched, concurrent studies are also being conducted to determine the quality of the renewable fuel with respect to its emission products.

Economics of Biofuel Production

In the commercial development of liquid bio-fuels, high production cost still remains a critical issue. Today bio-fuel competitiveness depends on the national legislative frameworks and subsidies in the countries involved. Subsidies can be both agricultural aids and market incentives for the biofuels. In Nigeria, such legislative frameworks are yet to be enacted[50]. However some NNPC policy guidelines have been issued and include 100% uptake agreement and tax-reliefs.

Biofuel production competes with the food industry because the feedstock used consists of edible food materials. Thus, the effect of producing oils for biofuel must be weighed against producing them for food needs. Alternatively, non-edible oils can be produced to serve as more convenient feedstock. Cheaper feedstock such as animal fats and spent or waste frying oils are increasingly being considered as feedstock, since they are claimed to be unhealthy for human and animal consumption due to their trans-fatty acids contents. However, these oils must be purified before esterification[51].

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[46]Kaufman, K. R., German T. J., Patt, Derry J. (1986) Field evaluation of sunflower oil/diesel fuel blends in diesel engines. Transactions of the ASAE, 29(1), p. 2 – 9.

[47]Kaufman, K. R., German T. J., Patt, Derry J. (1986) Field evaluation of sunflower oil/diesel fuel blends in diesel engines. Transactions of the ASAE, 29(1), p. 2 – 9.

[48]Goodrum, J. W., Patel, W.J. and McClendon R. W. (1996) Diesel injector carbonisation by three alternative fuels, Transactions of the ASAE, 39(3), p. 817 – 821.

[49]Prankl, H., Woergetter M., Rathbauer J., (1999). Technical performance of vegetable oil methyl esters with a high iodine number, The 4th Biomass Conference of the Americas, 29 August - 2 September, Oakland, California.

[50]Bugaje, I.M. and Mohammed I.A. (2008). Biofuels Production Technology. Science and Technology Forum (STF), Zaria, Nigeria.

[51]Schlautman, N. J., Schinstock, J. L., Hanna, M. A., (1986). Unrefined expelled soybean oil performance in a diesel engine, Transactions of the ASAE, 29(1), 70 – 73, 80.

It has been established that the dominant factor in biofuel production is the cost of feedstock, with capital equipment constituting only 7% of the final product cost. Shlautman[52] observed that due to low oil yield and production costs, biofuel production on commercial basis is possible where government incentives exist. Such incentives are given to feedstock farmers, biofuel producers, marketers and/or users. For instance, the pump price for biodiesel in the US ranges between 2 – 3 times higher than that of petroleum fuel, but in Europe where subsides for biofuel exist, the two fuels have about the same price. For instance, Germany fully exempted biofuels and biofuel blends from motor-fuel tax until 2009[53].

In terms of production energy efficiency, cultivation of rapeseed for biodiesel would be more efficient than that of wheat for bioethanol. Kallivroussis [54] found an energy output/input ratio of 4.5:1 arising from growing sunflower for biodiesel production and that production of biodiesel returns 3.2 units of energy for each unit used in production. Another advantage of biodiesel is that the by-products from its manufacture (e.g. glycerine and fertiliser) have economic value.

The cost of production of 10t/day (12,500liters/day) bioethanol plant is given in Table 5.

Table 5: Production cost in a bioethanol plant[55]

Materials	Unit	Costs US$
Sugar juice	Tonnes	2,500
Steam	Tonnes	7,700
Electricity	kW	80
Cooling water	m^3	50
Process water	m^3	70
Sulphuric acid	kg	100
Salts	litre	600
Ant-foam	litre	160
Yeast	kg	1300
	Total	12,560

[52] Schlautman, N. J., Schinstock, J. L., Hanna, M. A., (1986). Unrefined expelled soybean oil performance in a diesel engine, Transactions of the ASAE, 29(1), 70 – 73, 80.
[53] USDA, (2005). Synthetic diesel may play a significant role as renewable fuel in Germany. Production Estimates and Crop Assessment Division.
[54] Kallivroussis, L., Natsis A., Papadakis G. (2002). *The energy balance of sunflower production for biodiesel in Greece*, Biosystems Engineering, 81(3), p. 347 – 354
[55] Rodrigues, 2006

Biofuels Quality Assessment

Biofuels are currently produced in many countries and are required to some recognized legislation/standard specifications such as ASTM D6751, EN14214, DIN 51606 and ON C1191 in the US, EU, Germany and Austria respectively. This was done to ensure that some minimum standards as regards regulated emissions are complied with. Several analytical methods are employed in assessing biofuel quality, but the common ones are chromatographic and spectroscopic methods[56].

Some studies have been conducted on exhaust emissions of biofuel to determine their effects on health and the environment. It has been found that the black fumes from diesel engines were reduced by 86% when B100 was used compared to that of petroleum fuel. Researchers reported that exhaust emissions from MEs of rapeseed, soybean and animal fat have lower soot, hydrocarbons, carbon monoxide, gum deposit and particulate matter (up to 39% less) concentrations than those of petroleum fuel[57,58,59]. This is mainly because biofuels do not contain sulphur. There is therefore a lower chance of acid rain than for petroleum fuel. Even the odour of emissions of biofuel was found to be less offensive than that of nitrogen oxides (NO_x). However, there are several reports indicating slightly higher concentrations of the particulate matter for biofuel than for petroleum[60,61,62].

Problems Associated With Biofuels

Apart from the higher NO_x in biodiesel emissions, there are a few other reported drawbacks of biofuels which include the following: Fuel ethanol is produced from biologically renewable feedstock. With the development of sustainable and environmentally sensitive agricultural production methods, the impact of farming practices is very minimal[63].

a. Biofuels sometimes degrade natural rubber and plastics.
b. Using biofuels entails more frequent changes of fuel filters because they clog fuel lines and filters.
c. There is fire hazard if rags soaked with biofuel are piled due to oxidation which can cause spontaneous combustion.
d. Biofuels have a shelf life of 6 months; hence ~~its~~ production should be tailored to meet

[56] Knothe, (2001). Analytical methods used in the production and fuel quality assessment of biodiesel, Transactions of the ASAE, 44(2), p. 193 – 200.

[57] Peterson, C. and Reece D. (1996) . Emission characteristics of ethyl and methyl ester of rapeseed oil compared to low sulphur diesel control fuel in a chassis dynamometer test of a picking truck, Transactions of the ASAE, 39(3), p. 805 – 816.

[58] Clarke, N. N. and Lyons D. W. (1999). Class 8 truck emissions testing: the effects of test cycles and data on biodiesel operation, Transactions of the ASAE, 42(5): p. 1211-1219.

[59] Munack, A., Schroeder O., Krahl J., Buenger J. (2001). Comparison of relevant exhaust gas emissions from biodiesel and fossil fuel, Agricultural Engineering International, 2001, Available at: http://cigr-ejournal.tamu.edu/Volume3.html.

[60] Clarke, N. N. and Lyons D. W. (1999). Class 8 truck emissions testing: the effects of test cycles and data on biodiesel operation, Transactions of the ASAE, 42(5): p. 1211-1219.

[61] Munack, A., Schroeder O., Krahl J., Buenger J. (2001). Comparison of relevant exhaust gas emissions from biodiesel and fossil fuel, Agricultural Engineering International, 2001, Available at: http://cigr-ejournal.tamu.edu/Volume3.html.

[62] Munoz, M., Moreno F., Morea J. (2004). Emissions of an automobile diesel engine fuelled with sunflower methyl ester, Transactions of the ASAE, 47(1), p. 5 – 11.

[63] NBB, (2002). Biodiesel production and quality. National Biodiesel Board, http://www.biodiesewl.org/pdffiles/fuelfactsheets/prod quality.pdf. Accessed 13 June 2005.

demand.

Efforts are on to tackle the problems posed by biofuel use. For instance, the need to standardise biofuels before widespread use has been addressed because, as noted earlier, some recognized standards already exist. The first two problems listed above are also being addressed by original equipment manufacturers *(OEMs).* There are reports that some *OEMs* have extended the warranties of their products to include biofuel use. The short shelf life of biofuels is being tackled through attempts to incorporate some additives.

Conclusions

From the comparison between petroleum fuels and liquid biofuels, liquid biofuels are more economically, environmentally and socially sustainable. They are therefore the most sustainable alternative fuels for the transport sector. They could be used alone or blended with petroleum fuels, without any major changes in vehicle engines. The need to develop Nigerian indigenous technology to exploit our vast biofuel potentials is emphasized in view of the failure of past policies of technology importation in the petroleum refining industries.