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Abstract--**In Nigeria today, fossil fuels constitute the major source of energy for the economy with consumption costs in excess of ₦ 654 billion for petrol, ₦ 303.2 billion for diesel and ₦ 194 billion for Kerosene. The global debate on Climate Change/CO_2 emissions and domestic concerns on economic, environmental and energy security implications have necessitated alterative energy options and created opportunities for sustainable biofuel enterprise in Nigeria. Jatropha curcas (known as Lapalapa in Yoruba-speaking parts of Nigeria) is an uncultivated non-food wild-species plant with great potential for bioenergy development in the country. The seeds are resistant to a high degree of aridity and contain 27-40% oil that can be processed to produce a high-quality biodiesel fuel, usable in a standard diesel engine. With estimated diesel demands in Nigeria being 3600-4200 thousand metric tonnes by 2020, there is an expansive opportunity for jatropha biofuel enterprise in the country. This study examines the strategic issues (technological, economic, environmental, and socio-cultural) governing its development and proposes policy recommendations for its successful exploitation.**

I. INTRODUCTION

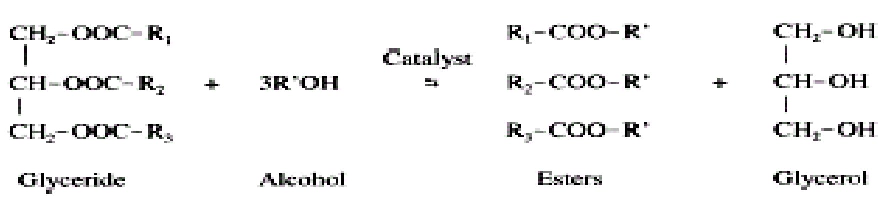
Nigeria, a country situated in West Africa, is well endowed with energy resources such as crude oil, natural gas, coal, tar sand, and biomass. The country is a member of the Organization of Petroleum Exporting Countries (OPEC), is the largest producer of crude oil in Africa and the eleventh largest in the world (2.45 million bpd). Nigeria also has the 10th largest proven reserves of crude oil in the world (36.22 billion barrels). The energy sector clearly dominates economic activities constituting almost 40% of GDP. Inspite of these considerable resources, Nigeria is bedevilled by energy problems and the country's refining capacity is insufficient to meet domestic demand – Nigeria's 4 state-held refineries have a combined nameplate capacity of 438,750 bbl/d, but problems including sabotage, fire, poor management and a lack of regular maintenance contribute to the current operating capacity of less than 30% of installed capacity. This shortfall necessitates the massive importation of petroleum products [3].

Fossil fuels constitute the major source of energy for the Nigerian economy with consumption quantities and costs in excess of 8644 thousand tonnes of petrol (₦ 654 billion), 2368 thousand tonnes of diesel (₦ 303.2 billion) and 1389 thousand tonnes of kerosene (₦ 194 billion) [6]. The country's huge population (150 million people), very poor public transport system, and extremely deplorable electricity production system (less than 4,000 MW of electricity produced) play huge contributory roles in this situation [6]. The global debate on Climate Change/CO_2 emissions and domestic concerns on economic, environmental and energy security implications of fossil fuel consumption have also necessitated developing alterative energy options and created opportunities for sustainable biofuel enterprise in the country. The Federal Government of Nigeria (FGN) in recognising the need for bio-energy alternatives set up a national biofuels initiative under the Renewable Energy Division (RED) of the Nigeria National Petroleum Company (NNPC). This Division is coordinating the Domestic Industry programme and the national biofuels policy. Viable feedstock plants are being reviewed for cultivation with Jatropha curcas being a strong choice for biodiesel production. Nigeria recognises that estimated national diesel demands will be between 3600-4200 thousand metric tonnes by 2020, hence there could be an expansive opportunity for jatropha biofuel enterprise in the country [3],[9].

Jatropha curcas is an uncultivated non-food wild-species plant with great potential for bioenergy development in the country. The Jatropha plant can reach a height up to 5 m and its seed yield ranges from 7.5 to 12 tonnes per hectare per year, after five years of growth. The seeds are resistant to a high degree of aridity and contain 27-40% oil by weight basis. This oil can be processed to produce a high-quality biodiesel fuel, usable in a standard diesel engine [1],[5].

A. Chemistry of Jatropha Biodiesel Production

Biodiesel is produced by transesterification of large, branched triglycerides in to smaller, straight chain molecules of methyl esters, using an alkali or acid or enzyme as catalyst. 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:



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Alcohols such as methanol, ethanol, propanol, butanol and amyl alcohol are used in the transesterification process. Methanol and ethanol are used most frequently, especially methanol because of its low cost, and physical and chemical advantages. They can quickly react with triglycerides and sodium hydroxide is easily dissolved in these alcohols. Stoichiometric molar ratio of alcohol to triglycerides required for transesterification reaction is 3:1. In practice, the ratio needs to be higher to drive the equilibrium to a maximum ester yield [12].

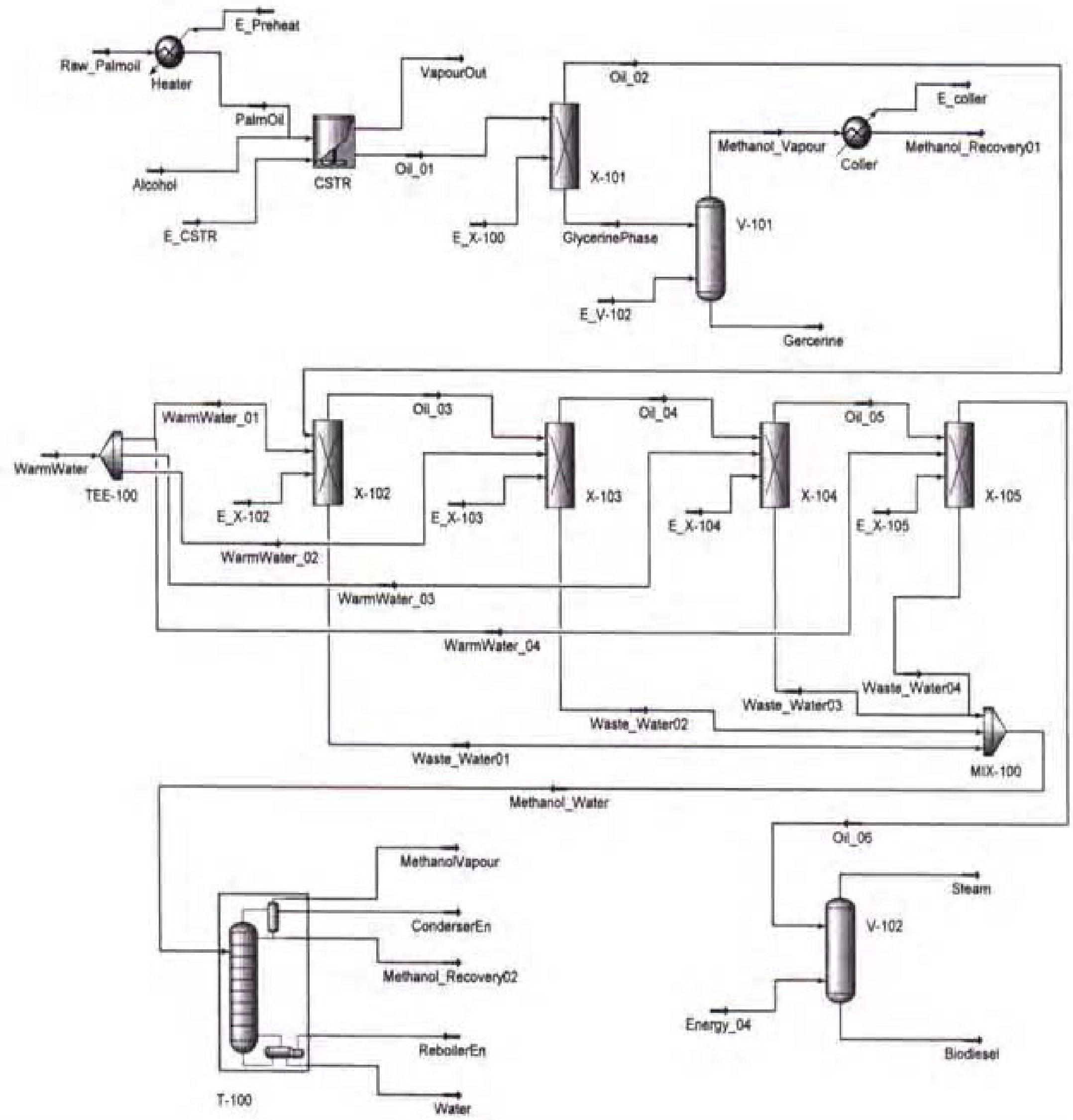

Fig. 1. Flow diagram of the preliminary biodiesel process, PFD_1.

From Fig. 1, the PFD_1 consists of a continuous stirred tank reactor (CSTR), glycerin-oil separation tanks (X-101), an evaporator V-101 to evaporate methanol from glycerin and a distillation column to separate methanol from waste water. The unreacted methanol from this unit is then recycled to the reactor. Oil from X-101 contains soap from saponification of free fatty acid and NaOH catalyst, so tanks X-102 to X-105 are washing tanks used to remove soap from methyl ester by warm water. Waste water from this washing still contains a large amount of methanol and then is sent to distillation column (T-101) [7],[2].

B. Benefits of Jatropha Bio-Diesel Production in Nigeria [11].

- Wasteland Reclamation and Reforestation
- Income generation from previously unusable areas
- Increased demand for employment in infrastructure, logistics and Transportation
- Improved Agricultural Development and Rural Society Enhancement. This will involve the development of irrigation systems, soil preparation, Plantation maintenance, seed collection, and oil extraction.

II. TECHNOLOGICAL AND ECONOMIC ASSESSMENT

A. Project Planning Theory

Every project must start with a clearly defined statement of the objective it is intended to achieve and against which its success can be measured. This is usually called the 'project definition'. Since ultimate success lies in the market place, the objectives must be clearly defined in terms of market need, albeit modified by an assessment of these needs in terms of what is likely to be technically achievable in practice. The project definition needs to be concise and specific, determining the planning objectives for all the tasks forming part of the project and, in particular, must lay down clear guidance on technical performance required, cost limitations, and the project duration [4],[13].

Developing jatropha biodiesel enterprise in Nigeria therefore requires providing planning objectives or guidelines for successful operation. These objectives are to:

(a) determine the diesel fuel demand projections in the country;
(b) assess the technology and engineering economy of possible substitution levels, and
(c) analyse biofuel technology capability in Nigeria's universities and research institutes.

III. METHODOLOGY

Diesel fuel consumption data in Nigeria from 1989 to 2005 were obtained from the Central Bank of Nigeria (CBN) and projections till 2019 estimated. Technological and economic data for jatropha biofuel production in the country were obtained from both primary and secondary sources. The secondary sources consisted of selected national and international agencies. The primary sources consisted of three national research institutions under the Federal Ministry of Science & Technology, five universities, a civil engineering firm, a bank and an insurance firm. Technological information analysed include input feedstock requirements, environmental considerations, and land requirement for feedstock crop production, while economic information analysed include feedstock costs, processing costs, and biofuel market potential. The biotechnology capability analysis utilised primary (raw) data obtained from a previous study carried out in our Agency. That study covered 10 universities and 5 research institutes spread across Nigeria. Faculties sampled were the Natural Sciences, Engineering/Technology, and Agriculture. The data were analyzed using Coate's model of technology assessment, engineering economy methods and statistical methods where appropriate.

IV. RESULTS

A. Diesel Fuel Demand Projections in Nigeria (Up to 2019)

Diesel demand in Nigeria has been rising steadily in Nigeria since 1996, and this is expected to continue till it reaches between 3600-4200 Thousand Tonnes by 2020. This steady growth is precipitated by rising transportation requirements and the industrial/domestic need for diesel fuel to power generators in view of deteriorating services from the national electricity authority. It is pertinent to note that the high and low lines in the projection zone constitute the upper and lower limits of expected diesel fuel demand in the country.

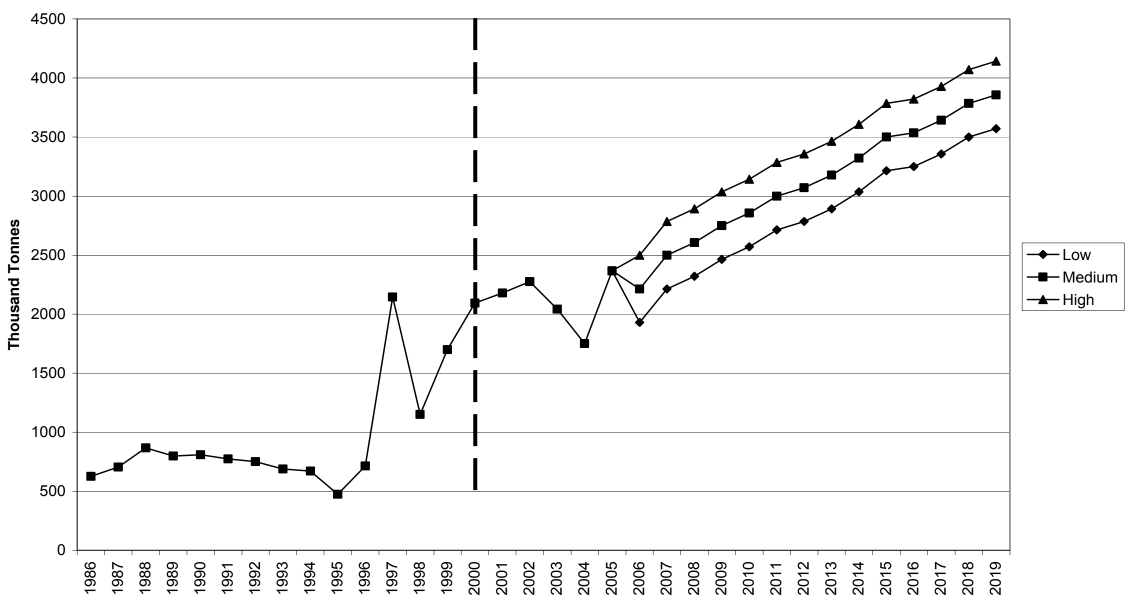

Fig 1. Diesel Consumption in NIgeria - Actual and Projected

B. Technology Assessment and Engineering Economy of Possible Substitution Levels

1) Bio-Diesel Substitution Requirements

Fig 2 below provides information on bio-diesel substitution levels at different percentage requirements of 10% substitution (B10), 25% substitution (B25) and 50% substitution (B50). The national bio-diesel substitution target is between 20-25% (B20-25); however policy provisions for developing increased substitution capacity and export market competences, and the possibility of not meeting set the set target necessitated developing planning premises of B10-B50 substitution.

2) Jatropha Oil Requirements

Fig 3 is a graph representing the jatropha oil requirements needed to meet the biodiesel substitution levels determined in Fig 2.

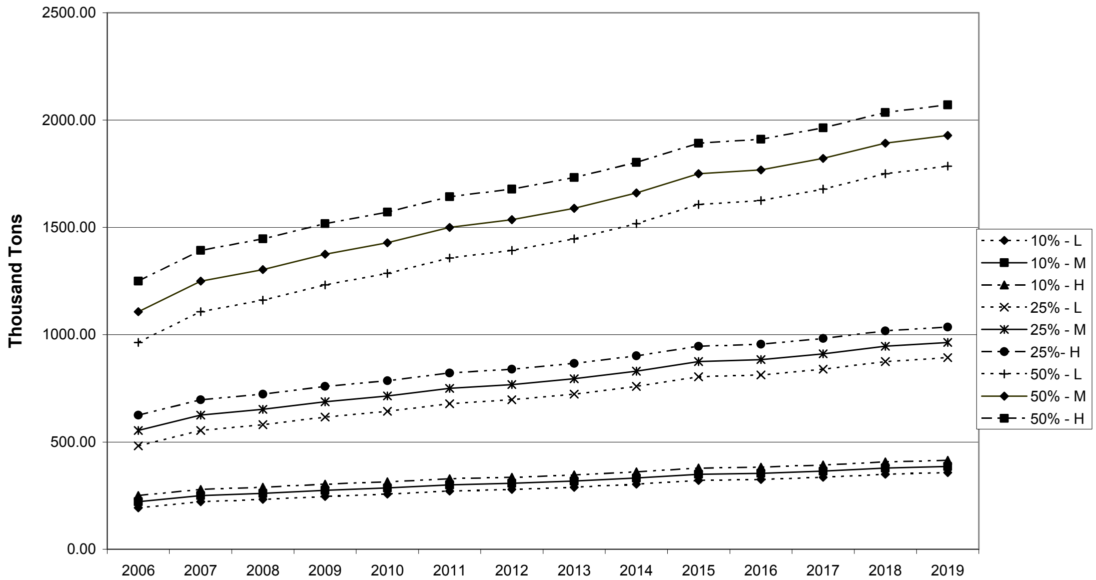

Fig 2. Bio-Diesel Substitution in AGO

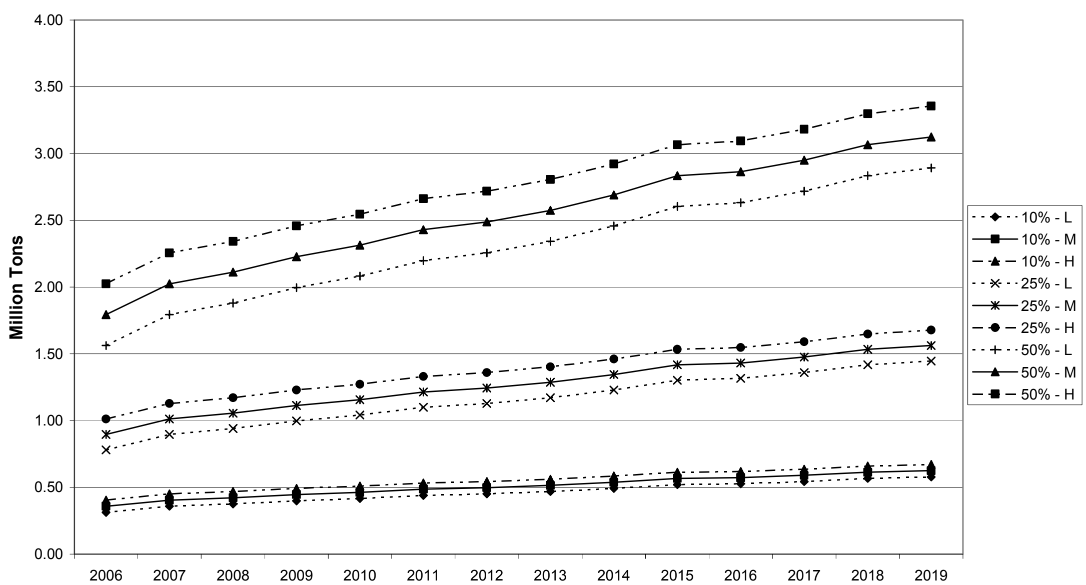

Fig 3. Jatropha Oil Requirements for Bio-diesel Substitution

3) Landmass Requirements

Fig 4 presents the total landmass requirements for the cultivation of the jatropha curcas plant.

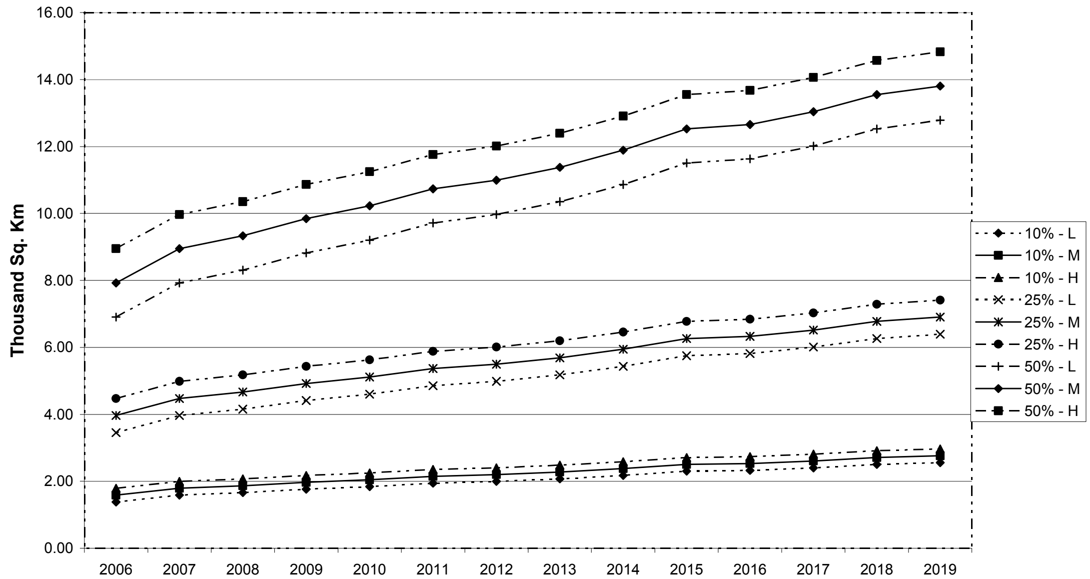

Fig 4. Landmass Requirements for Cultivating Jatropha Curcas

4) Environmental Considerations

Fossil fuels use over the last two centuries has had a major influence on improving human economic activities and contributed significantly to altering the environment. These environmental alterations have not always been good – it is on record that acid rain and global warming are two of the most serious environmental issues related to large-scale fossil fuel combustion. Other environmental problems include land reclamation and oil spills (associated with its mining and transportation) and public health considerations (respiratory diseases and cardiovascular-related deaths). The major by-product of fossil fuel combustion is carbon dioxide (CO_2), and it is what scientists call a greenhouse gas. Greenhouse gases absorb solar heat radiated from the earth's surface and retain this heat, keeping the earth warm and habitable for living organisms. Rapid industrialization through the 19th and 20th centuries, however, has resulted in increasing fossil fuel emissions, raising the percentage of carbon dioxide in the atmosphere by about 28 percent. This dramatic increase in carbon dioxide has led some scientists to predict a global warming scenario that could cause numerous environmental problems, including disrupted weather patterns and polar ice cap melting. CO2 induced global warming is also harmful to human health. High-temperature events are blamed for increasing the number of cardiovascular-related deaths, enhancing respiratory problems, and fuelling a more rapid and widespread distribution of deadly infectious diseases, such as malaria, dengue and yellow fever [8].

Jatropha bio-diesel substitution in domestic diesel consumption will reduce CO_2 emissions and decrease these environmental concerns. Carbon dioxide (CO_2) will be produced in the substitution option, however it is estimated that all the CO_2 will be absorbed by the jatropha plants cultivated. Table 1 below therefore provides information on the amount of carbon dioxide reduction associated with the various substitution levels.

TABLE 1. $C0_2$ REDUCTION VIA JATROPHA BIO-DIESEL SUBSTITUTION (THOUSAND TONS)

	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
10% - L	0.59	0.68	0.71	0.75	0.79	0.83	0.85	0.89	0.93	0.98	0.99	1.03	1.07	1.09
10% - M	0.68	0.77	0.80	0.84	0.87	0.92	0.94	0.97	1.02	1.07	1.08	1.12	1.16	1.18
10% - H	0.77	0.85	0.89	0.93	0.96	1.01	1.03	1.06	1.10	1.16	1.17	1.20	1.25	1.27
25% - L	1.48	1.69	1.78	1.89	1.97	2.08	2.13	2.21	2.32	2.46	2.49	2.57	2.68	2.73
25% - M	1.69	1.91	2.00	2.10	2.19	2.30	2.35	2.43	2.54	2.68	2.71	2.79	2.90	2.95
25%- H	1.91	2.13	2.21	2.32	2.41	2.51	2.57	2.65	2.76	2.90	2.92	3.01	3.12	3.17
50% - L	2.95	3.39	3.55	3.77	3.94	4.15	4.26	4.43	4.65	4.92	4.97	5.14	5.36	5.47
50% - M	3.39	3.83	3.99	4.21	4.37	4.59	4.70	4.87	5.08	5.36	5.41	5.58	5.79	5.90
50% - H	3.83	4.26	4.43	4.65	4.81	5.03	5.14	5.30	5.52	5.79	5.85	6.01	6.23	6.34

5) Engineering Economic Evaluation

Table 2 presents the net cost of jatropha biodiesel production in Nigeria. It is important to note that the costs assumed here are estimates derived by the careful extrapolation of information obtained from literature. The current pump price of diesel in Nigeria is ₦ 110 (US$ 0.73) per litre, hence the bio-substitution option would provide for a profit margin of ₦ 26 (US$ 0.17) per litre. This profit margin could lead to the direct creation of 35,000 jobs from the bio-diesel industry by 2019. This figure has also been calculated from literature.

TABLE 2. ECONOMICS OF JATROPHA BIODIESEL PRODUCTION (ESTIMATES)

Item	US$/Litre	₦/Litre
Cost of raw jatropha oil	0.44	66
Biodiesel processing cost	0.18	27
Cost of production	0.62	93
Less return from crude glycerol	0.06	9
Net Cost of Production	**0.56**	**84**

Exchange Rate: US$ 1 = ₦ 150 (2009 rates)

Using this net cost of production for analysis, it is possible to determine production costs for the jatropha bio-substitution option at its different substitution rates. This information is presented in Table 3 below.

TABLE 3. PRODUCTION COSTS FOR JATROPHA BIO-DIESEL SUBSTITUTION (US$ MILLION)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
10% - L	126	144	151	161	168	177	182	189	198	210	138	219	228	233
10% - M	144	163	170	179	186	196	200	207	217	228	230	237	247	251
10% - H	163	182	189	198	205	214	219	226	235	247	249	256	265	270
25% - L	314	361	378	402	419	442	454	471	495	524	530	547	570	582
25% - M	361	407	425	448	466	489	501	518	541	570	576	594	617	629
25% - H	407	454	471	495	512	535	547	565	588	617	623	640	663	675
50% - L	629	722	757	803	838	885	908	943	989	1048	1059	1094	1141	1164
50% - M	722	815	850	896	931	978	1001	1036	1083	1141	1152	1187	1234	1257
50% - H	815	908	943	989	1024	1071	1094	1129	1176	1234	1245	1280	1327	2411

C. Survey of National Technological Capability in Jatropha Bio-Diesel Production in Nigerian Universities and Research Institutes

This section presents a strategic consideration on the technical competences of Nigerian researchers for biofuel development. The Education and Research sector play a key role on any country's national system of innovation. Other key players are Government, Finance, and Industry. Bearing in mind Nigeria's global aspiration to be one of the leading economies by 2020, and the national development agenda tagged '7-Point Agenda', it is necessary to analyse the technical competence level of the Education and Research sector relative to biofuel development. 301 respondents returned their questionnaires.

Table 4 shows the distribution of respondents according to academic affiliations, gender, and qualification.

Slightly more than 50% of the respondents in Table 4 above have their specialisations closely related to bio-energy development as shown in Table 5. Men working in Universities top this assessment.

TABLE 4 ACADEMIC AFFILIATIONS, GENDER AND QUALIFICATION OF RESPONDENTS

	Universities				**Research Institutes**					
	PhD		**MSc**		**PhD**		**MSc**		**BSc**	
Gender	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Male	169	88.5	69	87.3	6	66.7	13	68.4	3	100
Female	22	11.5	10	12.7	3	33.3	6	31.6	0	0

TABLE 5. SPECIALISATIONS CLOSELY RELATED TO BIO-ENERGY DEVELOPMENT

	Universities				**Research Institutes**					
	PhD		**MSc**		**PhD**		**MSc**		**BSc**	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Male	83	87.3	43	91.5	2	66.7	5	71.4	0	0
Female	12	13.7	4	8.5	1	33.3	2	28.6	0	0
Total	152 (50.4% of 301 Respondents)									

On paper, it would look like Nigeria has the technical competences for bio-energy development. However, further analysis (as shown in Table 6) reveals that less than 12% of Nigerian researchers have continuous research output in bio-energy development from 2005 to 2009. Only 36 respondents (11.99% of all respondents sampled in the study) are in this category. One can conveniently argue therefore that although Nigeria has some bio-energy development related knowledge and skills, the country lacks the critical mass of expertise required to push this skill into a buoyant indusrial sector as theorised by Ogbimi [10].

TABLE 6. CONTINUOUS RESEARCH OUTPUT IN BIO-ENERGY DEVELOPMENT (2005-2009)

	Universities				Research Institutes					
	PhD		MSc		PhD		MSc		BSc	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Male	15	75	13	92.9	1	50	1	100	0	0
Female	5	25	1	7.1	1	50	0	0	0	0
Total	36 (11.99% of 301 Respondents)									

V. CONCLUSION

Jatropha bio-diesel development is a viable option to reducing fossil diesel consumptions in Nigeria. It has been shown to reduce costs and stimulate a national biofuel industry in the country. Bio-diesel substitution levels at different substitution rates of 10% (B10), 25% (B25), and 50% (B50) have been calculated and presented in graphs for quick accessibility. Technological and economic analyses of the various substitution options have provided planning objectives and guidelines for sustainable bio-diesel production. These guidelines show bio-diesel substitution in AGO, Landmass requirements for cultivation, Jatropha oil utilization requirments, CO_2 reduction calculations, and production costs estimates up till 2019. With estimated national net production costs of bio-diesel (per litre) at ₦ 84 (US$ 0.56) and current fossil-diesel pump prices at ₦ 110 (US$ 0.73), the bio-substitution option could provide profits up to ₦ 26 (US$ 0.17) per litre for investors, and create as many as 35,00 direct jobs in the bio-diesel industry by 2019. The option offers business possibility to agricultural enterprises and rural employment.

Analysis of national technical competences in Nigeria's universities and research institutes show that while slightly more than 50% of researchers have specialisations closely related to bio-energy development, less than 12% of these researchers actively researched in this critical area between 2005 and 2009. A critical challenge therefore would be to increase the number of researchers with competences in this all-important economic sub-sector.

VI. POLICY RECOMMENDATIONS

1. The Government should, as a matter of urgency, develop and implement a comprehensive *explicit* biofuel policy.
2. The planning premises for bio-diesel development will be more detailed as more and deeper research occurs. It is therefore recommended that more intrusive techno-economic assessments be carried out for better planning guidelines.
3. Adequate financial cover for biofuel enterprise development should be made. The Government of Nigeria is trying to remove the subsidies given on petroleum product importation. It is a reasonable suggestion to utilize this multi-million dollar fund to provide financial cover for the bio-energy industry.
4. There is a need to strengthen the National Innovation System as it relates to bio-energy development. The Government would need to harmonise national Science & Technology, Education, Industrial, and Economic policies towards achieving a sustainable bio-energy industry.

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