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Review Article

Trends of Progress in Setting up Biorefineries in Developing Countries: A Review of Bioethanol Exploration in Nigeria

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ABSTRACT

In recent times, limitations and adverse effects of fossil fuels have significantly attracted researchers' attention to green fuels worldwide, especially in developed nations. As a way of assessing this actualization of biorefineries establishment in developing nations, this report surveys the works done by various researches towards this great course in terms of promoting and gaining the attention of both government and private investors about the technical and economic feasibility of embracing the use of biofuels, a case of bioethanol in Nigeria. Different classes of feedstocks were reviewed for the laboratory-scale, process scale-up, pilot plant, and techno-economic studies regarding ascertaining the technical and economic feasibility of local setup of a functional biorefinery in Nigeria, which would be beneficial environmentally and economically. The literature survey unveiled that the Bioethanol yield obtained from sugarcane-juice (72.7 %), banana-stems (84.0 %), and cassava (92.0 %) were found to be of highest potential amongst other sugar-based, lignocellulosic, and starch-based feedstock, respectively. The survey further unveils that the volume of process scale-up and economic feasibility studies does not correlate well with the laboratory-scale studies. The bulk of the research works on bioethanol has given preferential attention to laboratory studies. Only a few studies have looked into the commercialization (i.e., scale-up) of the laboratory findings and the economic implications. Presently, only sugarcane and a few cassavas are reported in the literature so far. It is, therefore, necessary for further studies to give attention to the investigation of the commercializing locally developed technologies and the exploration of their economic benefits.

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1. INTRODUCTION

Biofuel as a fuel derived from biological carbon fixation leads to the release of energy and can also be obtained from converting various lignocellulosic wastes into liquid, solid, and gaseous fuels. Today, biofuels have received much interest from the public and the scientific community [1-3]. This new-found interest buildup is attributed to certain factors such as environmental pollution caused by fossil fuels, increased oil price, and the urgent need for improved security in the world energy sector, African energy sectors, and the quest for green technology [4-6]. Some fuels obtained from solid biomass include bioethanol, bio-methanol, biodiesel, biohydrogen, and biomethane, in which some are liquid while others are gaseous fuels [7].

The world is facing global warming, which is majorly brought about by incomplete combustion and emission of harmful gases from fossil fuel consumption [8], which are non-biodegradable. Bioethanol, an alternative to fossil fuel, has high octane number, high heating value, and complete combustion in automobiles due to its rich oxygen content, leading to less poisonous gas emission [9, 10].

Over time, fossil fuels are experiencing drastic depreciation (in value) and relevance to the global scene. The demand and prices of hydrocarbon deposits are shrinking down daily, especially in developed nations. Most fossil fuel-dependent economies and oil-producing countries are gearing up policy frameworks to seek a more reliable alternative to fossil fuels. Efforts are in motion to explore bioethanol through a series of government policies to attain a paradigm shift from a nonrenewable energy source to a renewable one [11]. Nigeria is well known for being a petroleum-producing economy that is far lagging in policies and actions to gradually divorce fossil fuels for biofuels [12]. Lack of legislative-driven policies and strong political will are a few among the many rationales behind the slowdown in diverting the Nigerian state from fossil fuels to biofuels [13].

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2. BACKGROUND INFORMATION ON BIOETHANOL

Bioethanol is a substitute for fossil fuels and can be produced by fermenting sugar components from plant matter; ethanol can be produced synthetically and naturally through yeasts. About 51.3 billion liters of ethanol were produced worldwide in 2006, and ethanol production would increase in the future [14]. On a global scale, the challenges of rapid fuel exhaustion, fuel prices, and climate change have resulted in algal biomass gaining prominence in recent years. Algae are excellent resources for sustainable and renewable energy production with zero competition in the food market and do not need freshwater resources to thrive. With these recent developments in the promotion of algae used in biofuel production, there has been a growing interest in using algal biomass in an optimum manner for the production of other products like pharmaceuticals, cosmetics, wastewater treatment, and inhuman and animal fee.

Bioethanol is presently the most common biofuel, similar to about 73 % of the 135.3 billion liters of biofuel produced in 2016. The United States (USA) is the largest producer, 59 %, followed by Brazil, which produces 27 % global production [15]. Bioethanol can be used as a purely gasoline substitute or in a mixture of gasoline. The use of bioethanol in internal combustion engines has many benefits over gasoline. Presently, commercial bioethanol is of almost entirely first-generation because food crops are used as feedstock: sugarcane in Brazil, corn in the USA, and wheat and sugar beet in the European Union. The major drawback for the first-generation bioethanol is the competition over the use of arable land to cultivate food crops between biofuel feedstocks, thus increasing food prices [16].

A survey of the literature indicates that the Nigeria government has been investing largely in the importation of 300-350 million of bioethanol liters worth of 1.2 trillion Naira (i.e., 2.7 billion US dollars) on an annual basis to meet the national demand [17-19], which was primarily imported from US, Brazil, and other European countries. In recent time, the concern about the enormous amount of fund invested in importing bioethanol has strengthened the drives for different state governments in Nigeria and the federal government to give attention to the establishment of Nigeria-based biorefinery which would complement the use of petroleum fuels and would equally save the huge annual sum incurred on the importation of the bioethanol [20, 21]. Some of the concerned state governments that have taken steps towards the actualization of biorefinery in Nigeria include Kebbi, Kogi, Osun, and the Plateau States. All these states have proposed launching cassava-based bioethanol plants, including Nigerian National Petroleum Corporation (NNPC), except Kebbi State Government, which expressed an interest in setting up additional sugarcane-based bioethanol plants [22-27]. Nigeria is therefore seeking an efficient way for diversifying its energy mix [21] to reduce its overdependency upon the use of fossil fuels. The search for ways of inventing a local technology for the processing of Nigeria biomass into this fuel via the use of the local resource is also in progress. The government of Nigeria looks forward to the actualization of the dream of saving a huge cost of annual bioethanol importation and establishing functionally developed biorefineries across Nigerian communities.

3. OVERVIEW OF DIFFERENT PRODUCTION METHODS

3.1. Classification of bioethanol based on generation

This section briefly discusses various bioethanol classes based on the origin or generation of materials used either as biomass or waste. Bioethanol is classified into three categories based on generations known as the first, second, and third generations.

(a) **First-generation bioethanol:** The class of bioethanol generation consists of edible crops mainly. Examples include corn, barley, sugarcane, potato wastes, and wheat [28-30]. To a great extent, first-generation bioethanol hinges on energy crops like maize and sugarcane [30, 31]. Unlike the second-generation bioethanol, first-generation bioethanol does not demand saccharification since the sugars from these energy crops are easily accessible, making the production process simpler than second- and third-generation bioethanol [32].

(b) **Second-generation bioethanol:** This generation of bioethanol is produced using lignocellulosic materials. The lignocellulosic biomass consists of cellulose, hemicellulose, and lignin. They have advantages over first-generation bioethanol since they do not compete with food crops and are obtained from agricultural wastes such as corn stover, elephant grass, rice husk, corn cob, wheat straw, and sugarcane bagasse [30]. Since they contain a considerable amount of cellulose, they can be an excellent alternative to first-generation bioethanol. However, they require a saccharification process that increases production cost; hence, commercial-scale production is not widely feasible [29, 33-35]. Second-generation biofuel is cellulosic ethanol produced via a biochemical route, in which enzymes and other microorganisms are used to convert cellulose and hemicellulose components of the feedstocks to sugars before they are fermented to produce ethanol [36, 37].

(c) **Third-generation bioethanol:** They are primarily derived from algal biomass. Algal biomass has a very different growth yield than classical lignocellulosic biomass [38, 39]. Several algae species have been examined including fast-growing species: *Chlamydomonas reinhardtii, Dunaliella salina,* and various chlorella species [40]. Third-generation bioethanol does not compete with food, has a fast growth rate, and can be increased in wastewater and land unsuitable for agriculture than first- and second-generation bioethanol [39, 41].

Table 1. Several studies on the sugar-based bioethanol production (Note: Conventional approach=One-factor-at-a-time)

Ref.	Feedstock/Material used	Enzymes used for fermentation	Bioethanol yield, g/g %	Study approach
[42]	Raffia	*n.r.*	2.03	Conventional approach
[42]	Palm wine	*n.r.*	4.00	Conventional approach
[43]	Calabash (*Crescentia cujete*) pulp juice	*Saccharomyces cerevisiae*	6.19	RSM - CCD design approach
[44]	Sugar molasses	*Saccharomyces cerevisiae* (DIST/IPF/90)	10.50	Conventional approach
[45]	Sugarcane juice (SJ)	*Saccharomyces cerevisiae*	19.30	Factorial design approach

3.2. Classification of bioethanol based on feedstock

This section deals with the classification of bioethanol based on the raw materials used for conversion into bioethanol. Any materials that can be converted into sugar and further to bioethanol can be categorized as feedstock for bioethanol. The primary requirement of raw materials as a suitable raw material for conversion into bioethanol is its availability. However, one of the challenges encountered in bioethanol production from some raw materials like starch [46-48] and cellulosic-based [49-55] feedstock is the depolymerization of biomass into fermentable sugar before conversion into bioethanol, otherwise known as hydrolysis, which is often preceded by pretreatment. Bioethanol can be classified based on feedstock as sugar, starch, and lignocellulosic-based feedstocks (as shown in Figure 1).

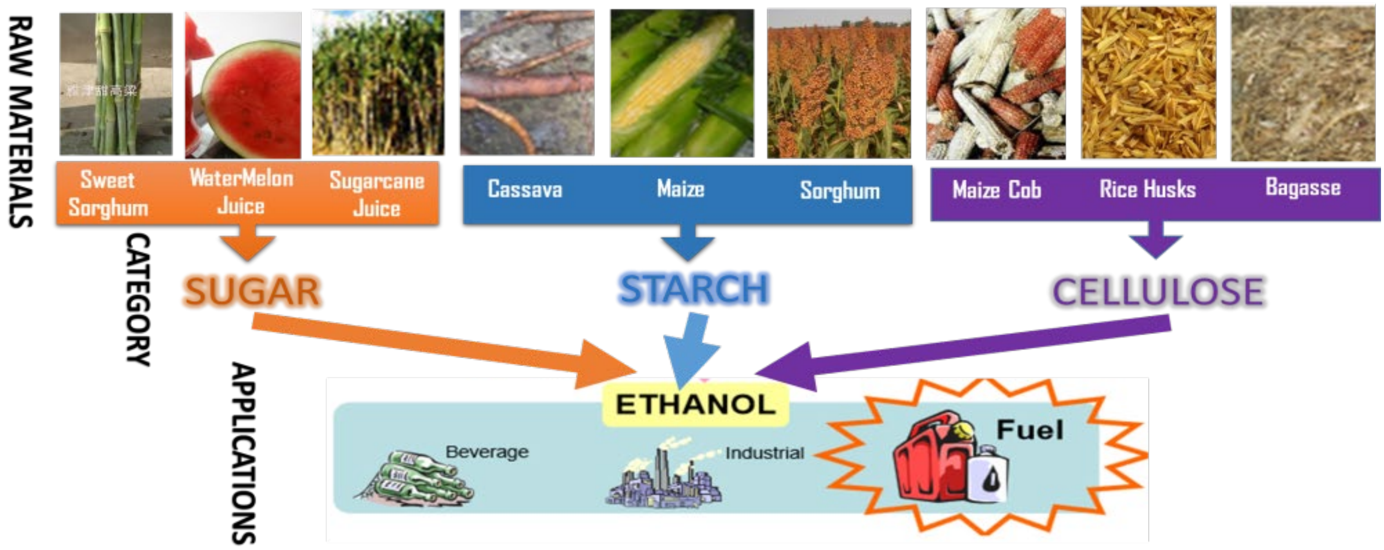


Figure 1. Raw materials, categories & applications of bioethanol [14, 56-58]

(a) **Sugar-based bioethanol:** These feedstocks for bioethanol are obtained from sugar raw materials. It requires fewer processes than starch-based bioethanol feedstock, which does not involve saccharification; hence, sugars are readily available [32]. Examples of sugar-based bioethanol feedstocks include sweet sorghum, sugarcane, molasses, and sugar beets. Essentially, they involve simple processes such as extraction (milling) to produce their high sugar components converted to bioethanol [59].

Among several studies conducted on the use of sugar-based feedstock (with details presented in Table 1), some of the feedstocks considered entail raffia [42], palm wine [42], calabash pulp juice [43], sugar molasse [44], and sugarcane juice [42, 45], among which the report on the use of sugarcane juice was found to have shown the highest yield (19.30 %), while the raffia showed the most negligible yield with 2.03 %. Moreover, a higher yield was reported by Nwufo et al. [42] which could be primarily attributed to the extended time of 12 days given for the fermentation process, unlike that of Suleiman et al. [45] which was only allowed to last the maximum of 96 hours found to be much shorter than the allowable time employed in the report of Nwufo et al. [42]. Suleiman et al. [45] reported that a lower temperature of about 30 ^oC would significantly promote the fermentation process than the higher temperature. The literature survey indicated that the bioethanol yield from sugarcane juice was the highest amongst other sugar-based biomasses, with a 72.7 % yield.

(b) **Lignocellulosic bioethanol:** These feedstocks are widely used to produce bioethanol and are primarily deposited as waste in developing countries like Nigeria. Lignocellulosic biomass as organic matter is widely available on a renewable basis, with some including energy crops, aquatic plants, agricultural waste, wood waste, and other wastes [34-36, 51, 52]. Unlike sugar and starch-based bioethanol feedstocks, accounting for 40-70 % of the total costs, lignocellulosic feedstocks only present about 30% of the total production costs [60]. Also, lignocellulosic feedstock does not compete with food. However, they have challenges in the conversion process due to the highly recalcitrant nature of lignin in the feedstocks, thus requiring complex pretreatment processes that may increase the overall cost of production [61, 62]. Examples are corn stover, algae, sugarcane bagasse, wheat straw, elephant grass, and rice husk [36, 58, 61].

Other studies on the use of cellulosic biomasses are summarized in Table 2 in which the cassava peels [49, 62-66], sweet potato peels [49, 51, 53], yam peels [62, 64], rice straw [55, 61, 67], rice husk [68-71], and much other biomasses are considered. The use of cassava peels, banana stem, rice husk, and elephant grass stem for the production of bioethanol has been proven from the reported research works to be of high yield, confirming the materials to be an excellent potential resource that facilitates the commercialization of bioethanol in developing nations, especially in Africa where these resource materials are widely and randomly disposed within the surroundings as waste for animals to feed on or allowed to decompose and pollute the environment. It also provides food security as the feedstocks are not sources of food.

A survey of the literature reveals that the rate of conversion of differentsubstrates such as yam peel [62], cassava peels [66], rice straw [61], rice husk [68], corn stover [12] and many other biomasses into bioethanol in the presence of specific enzymes like *saccharomyces cerevisiae* varies from one substrate to another. These findings indicate the significance of selecting appropriate enzymes of a specific substrate or feedstock during bioethanol fuel production from the use of biomass. Banana stem, rice husk, and elephant grass stem produced much more bioethanol than other lignocellulosic biomasses yielding 84.0 %, 80.0 %, and 78.0 %, respectively. The survey indicates that banana stem displays the highest yield among other lignocellulosic feedstock forms investigated in the literature.

(c) **Starch-based bioethanol:** These feedstocks for bioethanol are obtained from starchy materials. Starch-based raw materials require liquefaction and saccharification to hydrolyze carbohydrates into the corresponding sugar monomers [15, 72]. Production of bioethanol from starch involves three stages: hydrolysis, fermentation, and product purification [59]. Starch-based bioethanol feedstocks include wheat, barley, corn, wheat, cassava triticale potato, and rice [73].

Table 2. Several studies on the cellulosic-based bioethanol production (Note: *calculated , **glucose)

Ref.	Feedstock/Material used	Organism(s) used for fermentation	Biothanol yield, g/g % (*computed)	Study approach
[74]	Banana pseudo-stem	*Saccharomyces cerevisiae*	84.00	Conventional approach
[53]	Cassava	*C. tropicalis* (IMI 398401)	23.80	Conventional approach
[66]	Cassava peel	*Saccharomyces cerevisiae*	16.00	Conventional approach
[65]	Cassava peels	Yeast	40.00	Conventional approach
[75]	Cassava peels	*Saccharomyces cerevisiae*	17.52	Not reported
[63]	Cassava peels	*Rhizopus nigricans, Aspergillus niger, Saccharomyces cerevisiae, Spirogyra Africana*	41.00	Conventional approach
[51]	Cassava peels	*Zymomonas mobilis, Saccharomyces cerevisiae*	23.00	Conventional approach
[51]	Cassava peels	*Gloeophyllum sepiarium* and *Pleurotuso streatus*	26.00	Conventional approach
[62]	Cassava peels	*Saccharomyces cerevisiae*	11.30	Conventional approach
[54]	Cocoyam peels	*Co-culture of Aspergillus niger* and *Saccharomyces cerevisiae*	*7.00 (4.2 g-bioethanol)	Conventional approach
[54]	Cocoyam peels	*Mono Aspergillus niger* and *Saccharomyces cerevisiae*	*9.40 (5.65 g-bioethanol)	Conventional approach
[12]	Corn stover (CS)	*Saccharomyces cerevisiae*	*11.30 (143.15 mg-bioethanol/1 L-CS)	Conventional approach
[76]	Elephant grass stem	*Aspergillus niger* and *Saccharomyces cerevisiae*	78.00	Conventional approach
[77]	Groundnut shell waste (GSW)	*Saccharomyces cerevisiae* and *Aspergillus niger*	*24.14(80 mL-bioethanol/420 g-GSW)	Conventional approach
[78]	Orange peels, cassava peels, and banana peels	*Aspergillus niger* and *Bacillus cereus*	*12.44 (12.44 g-bioethanol)	Conventional approach
[50]	Orange waste	*Escherichia coli* and *saccharomyces cerevisiae*	40.00	Conventional approach
[52]	Pineapple peels	*Saccharomyces cerevisiae*	5.82	RSM designed methodology
[64]	Potato peels,	*Saccharomyces cerevisiae*	4.02	Not reported
[68]	Rice husk (RH)	Saccharomyces cerevisiae	*80.00 (48 g-bioethanol)	Not reported
[69]	Rice husk	*Trichoderma harzianum*	6.25	Not reported
[69]	Rice husk	*Aspergillus niger*	6.99	Not reported
[70]	Rice husk	*Saccharomyces cerevisiae* and *Aspergillus niger*	*25.35 (32.13 g-bioethanol/mL-RH)	Conventional approach
[71]	Rice husk pretreated with $FeCl_3$ using SHF	*Trichoderma reesei,* cellulase, *Saccharomyces cerevisiae*	3.01	Conventional approach
[71]	Rice husk pretreated with $FeCl_3$ using SSF	*Trichoderma reesei,* cellulase, *Saccharomyces cerevisiae*	3.80	Conventional approach
[79]	Rice stalks treated with hydrogen peroxide	*Co-culture of Aspergillus niger* and *Saccharomyces cerevisiae*	3.91	Conventional approach
[79]	Rice stalks treated with sulfuric acid	*Co-culture of Aspergillus niger* and *Saccharomyces cerevisiae*	5.06	Conventional approach
[55]	Rice straw	*Trichoderma viride*	*8.11 (16.21 g-bioethanol)	Conventional approach
[61]	Rice straw	*Saccharomyces cerevisiae*	49.50	Conventional approach
[80]	Spent mushroom	*Saccharomyces cerevisiae*	**23.55 (0.51 mg/L)	Conventional approach
[45]	Sugarcane bagasse	*Aspergillus niger*	14.50	2^4 factorial design method
[66]	Sugarcane bagasse	*Saccharomyces cerevisiae*	9.03	Conventional approach
[53]	Sweet potato peels	*C. tropicalis* (IMI 398401)	47.99	Conventional approach
[53]	Sweet potato peels	*C. tropicalis* (IMI 398401)	47.99	Conventional approach
[49]	Sweet potato peels	*Saccharomyces cerevisiae*	31.00	Conventional approach

[49]	Sweet potatoes peels	*Zymomonas mobilis* and *Saccharomyces cerevisiae*	12.00	Conventional approach
[49]	Sweet potatoes peels	*Gloeophyllum sepiarium* and *Pleurotuso streatus*	12.00	Conventional approach
[80]	Wastepaper	*Saccharomyces cerevisiae*	**40.03 (0.51 mg-bioethanol/L)	Conventional approach
[64]	Yam peels	*Saccharomyces cerevisiae*	1.68	Not reported
[62]	yam peels	*Saccharomyces cerevisiae*	27.08	Conventional approach

Table 3. Several studies on the starch-based bioethanol production

Ref.	Feedstock/Material used	Enzyme used for fermentation	Bioethanol yield, g/g %	Study approach
[47]	Cassava flours	Yeast	52.00	Conventional approach
[81]	Cassava starch	*Saccharomyces cerevisiae*	5.85	Not reported
[64]	Cassava effluent	*Zymomonas mobilis and Saccharomyces cerevisiae*	16.50	Not reported
[82]	Cassava starch	*Saccharomyces cerevisiae*	92.00	Not reported
[83]	A mixture of cassava, yam, and potato	*Zymomonas mobilis*	8.36	Conventional approach
[83]	A mixture of cassava, yam, and potato	*Saccharomyces cerevisiae*	6.64	Conventional approach
[83]	Yam	*Zymomonas mobilis*	6.03	Conventional approach
[83]	Potato	*Zymomonas mobilis*	5.17	Conventional approach
[83]	Cassava	*Saccharomyces cerevisiae*	6.77	Conventional approach
[83]	Yam	*Saccharomyces cerevisiae*	7.39	Conventional approach
[83]	Potato	*Saccharomyces cerevisiae*	5.51	Conventional approach
[83]	Cassava	*Zymomonas mobilis*	6.86	Conventional approach
[48]	Cassava tubers + *koji* and yeast cells	*Aspergillus awamori* IAM8928 and *Saccharomyces cerevisiae* IR2	7.05	Analytical approach
[48]	Cassava tubers + gelatinized	*Aspergillus awamori* IAM8928 and *Saccharomyces cerevisiae* IR2	6.50	Analytical approach
[84]	Cassava wastewater	Yeast	8.69	RSM - CCD Design Approach
[85]	Cassava flour	*L Novoenzym, Aspergillus niger* and *Saccharomyces cerevisiae*	20.49	Conventional approach
[85]	Cassava starch	*L Novoenzym, Aspergillus niger* and *Saccharomyces cerevisiae*	14.04	Conventional approach
[86]	Cassava pulp	Yeast	82.40	Conventional approach
[87]	Yam tuber [89]s	*Saccharomyces cerevisiae* LC 269108	5.61	Conventional approach
[48]	Cassava tubers	*Aspergillus niger*	30.00	Conventional approach
[89]	Cassava mill effluents (cme)	*Saccharomyces cerevisiae*	48.55	Conventional approach
[89]	Cassava mill effluents + Empty fruit bunch	*Saccharomyces cerevisiae*	31.34	Conventional approach
[89]	Cassava mill effluents + chaff	*Saccharomyces cerevisiae*	68.56	Conventional approach
[89]	Cassava mill effluents + cassavapeel	*Saccharomyces cerevisiae*	28.65	Conventional approach

A further survey of literature has unveiled several works that have paid attention to the exploration of starch-based materials in the search for better technology for the production of bioethanol that would result in a higher yield which would facilitate complementing the use of existing fossil fuels in meeting the energy/fuels demand in developing nations like Nigeria. Among the feedstocks studied in the literature [47, 48, 64, 81-85, 87, 89-91], Cassava, a starch-based feedstock [82, 89, 91] has been experimentally proven to have shown a higher yield (92.0 %) for the production of bioethanol among its class of feedstocks studied in the literature. However, some of this feedstock would compete with the human food source.

4. IMPORTANT FEATURES OF BIOETHANOL OVER PETROL FUEL

Some of the essential features attracting the world towards embracing the use of bioethanol include the following:

(a) **Better octane-rating:** One of the advantages of bioethanol over petrol is that the octane rating of bioethanol is higher than that of gasoline; this allows an increase in the compression ratio of an engine for increased thermal efficiency. Balat [92-94] also emphasized that bioethanol, as an alternative to fossil fuel, had high octane number, high heating value, and complete combustion in automobiles due to its high oxygen content and less toxic gas emission [12].

(b) **Less pollution:** Petrol fuel used in automobiles today, despite meeting the demand needed for automobile functioning, has certain disadvantages including releasing sulfur oxides into the atmosphere, thereby contributing to the greenhouse effect. It is, therefore, vital that the advantages of bioethanol over petrol fuel be outlined. Another advantage of bioethanol over petrol fuel is that it does not emit dark smoke, which is an oxide of Sulfur and does not contribute to air type of environmental pollution [14, 20, 95].

5. FEEDSTOCK AVAILABILITY AND QUANTITY IN NIGERIA

Although the Nigerian state stands out among agricultural-oriented African countries with many biofuel-rich crops such as sugarcane, maize is mainly grown and cultivated in Nigeria. However, it is a severe worrisome decibel for most of these crops to be effectively utilized for biofuel production and consumable foodstuff without necessarily hiking the prices and affordability of these crops. Hence, there is a need to strike out a balance between its commercial and economic benefits [96]. There is no precise effort to hint the Nigerian government, policymakers, and stakeholders on which approach would perfectly enhance Nigeria's biofuel production. Researchers have failed to suggest a viable policy to arrest the possible foreseen widening gap between crop utilization for food production and biofuel production regarding the possible price escalation [97].

Several crops are used as a biofuel source; particularly, energy crops including sugar cane, sunflower, Barbados nut, soya bean, and maize are grown with less cost and low maintenance harvest. As mentioned earlier, Nigeria, nationally recognized as highly involved in agricultural production, is rich in feedstocks, especially as waste products both from industrial and domestic uses. Although not quantified, Nwofe's report [50] emphasizes that a high volume of waste is generated in Nigeria daily. Research in Nigeria shows that the bio-energy reserve as of the year 2005 stands as follows: 1,3071,464 hectares for fuelwood, 61 million tons per year for animal waste, and 83 million tons for crop residues [98], which indicate the abundance of bio-energy resource in the country.

Fruit wastes have also been identified as a significant feedstock for bioethanol production: one of such feedstock is the orange peel. The abundance of this feedstock in Nigeria results from its enormous consumption daily [80]. Instead of covering the land with these solid wastes, it would instead benefit the country to convert the orange peels into a helpful resource by producing bioethanol and reducing land pollution. Another feedstock that is much available in Nigeria, which is also fruit, is pineapple peel. This is because Nigeria is the seventh-largest pineapple producer globally and the leading producer in Africa [99]. Therefore, it would be advantageous to use the peels disposed of as waste to produce economically viable ethanol.

Interestingly, wastepaper and spent mushrooms have been identified as potential feedstocks for bioethanol production. Spent mushroom which refers to the substrate left after the mushroom is cultivated and harvested [100]. Paper and paper products consist of about 35 % of the weight of municipal solid waste [56]. Also, an extensive collection of Irish potato peels, maize cob, plantain peels, rice husk, sweet potato peels, rotten waste tomatoes, and yam peels can essentially be found in Zamfara/Plateau, Katsina, Cross River, Kano, Kaduna, Bauchi, and Yobe states in Nigeria, according to the report of the NBS [100, 101] for agricultural items production and cost.

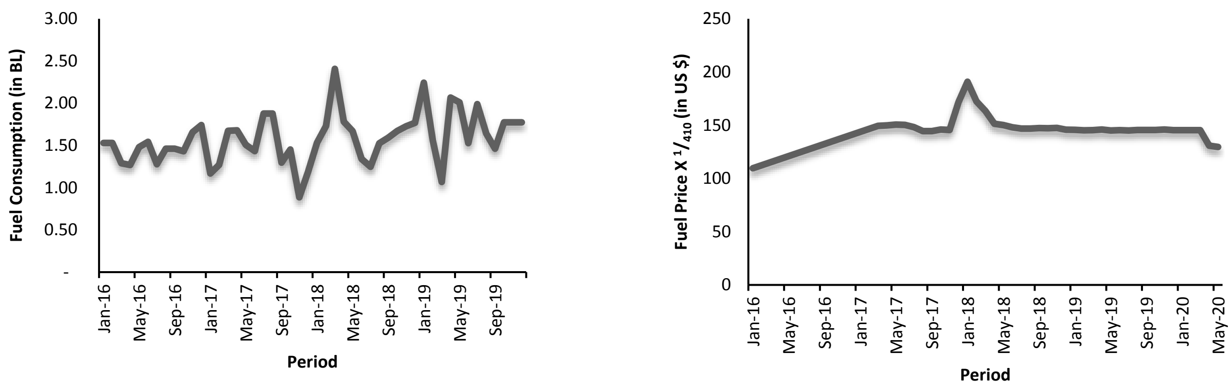
Deductions from the literature survey indicate that Nigeria is blessed with a vast land fertile to cultivate the potentially available feedstocks to produce first- and second-generation bioethanol production. Some first-generation bioethanol feedstocks available in Nigeria include potatoes, yam, sugarcane, cassava, wheat, rice, sorghum, and many others [100, 101]. Nigeria's Energy Commission of Nigeria (ECN) and NNPC recommend using cassava, sorghum, and sugarcane to produce bioethanol due to the significant yield annually reported for Nigeria's crop production. On the other hand, the second-generation bioethanol production is currently receiving significant attention for consideration due to its inedibility nature, making it uncompetitive with the food market or supply. Instead, it further facilitates better management of our agricultural, municipal, and domestic wastes daily disposed and poorly managed in most communities in Nigeria. However, investment in the production of feedstock and the establishment of processing plants for the production of third-generation bioethanol is not gaining significant expected attention in Nigeria. Only a few efforts are put into exploring its economic potentials for actualizing the establishment of a feasible biorefinery in Nigeria.

6. FUEL CONSUMPTION IN NIGERIA

Nigeria is known to be one of the world's major petroleum-producing countries globally and exports petroleum for a refining process; the country depends on developed countries for refined products by exporting the products [46]. 5.06 quadrillion kilojoules (or 4.8 quadrillion British thermal units) remains the total primary energy consumption in Nigeria as of the year 2014. Traditional biomass and waste constitute 74 %, while oil, natural gas, and hydropower comprise 13 %, 12 %, and 1 %, respectively [46]. The recent report from Knoema on the energy consumption in Nigeria indicates that it has risen to 6.25 quadrillion kilojoules (or 5.93 quadrillions British thermal unit) as of the year 2018 [102].

According to the report by Nigeria Bureau of Statistics (2016-2019), the volume of Premium Motor Spirit (PMS or petrol) consumption in Nigeria (as shown in Figure 2a) has maintained an average of 1.5 billion liters within a range of 1 billion to 2.5 billion liters of PMS. It was shown that the tremendous volume of bioethanol was needed to complement the imported PMS to fulfill the requirement of E10 provided in Nigeria's energy policy for the use or sales of PMS/petrol in Nigeria. Moreover, the price of PMS has stood at the average of 140 Naira per liter except for the usual rise report in 2018, from November 2017 to March 2018 (as shown in Figure 2b), similar to the unexpected rise experienced in the late 2020 and present times. Therefore, the promotion of bioethanol production in Nigeria would go a long way to complement PMS use, which Nigeria residents majorly use for power and transport and promote cleaner air and a safe environment with a lower release of greenhouse gases.

The adoption of bioethanol (a biofuel) worldwide is significantly rising, not leaving any class of nations developed or developing (as shown in Figure 3), including private and public sectors. Embracing and promoting the use of biofuels for their environmental friendliness is very advantageous. Unlike the risk that the present use of fossil fuels is significantly posing to the health and safety in our environment due to the gases released, the carbon monoxide is commonly released during the incomplete process of combustion which the fossil fuels do undergo as a result of their lower octane rating when compared to the biofuels with higher rating.



(a) (b)

Figure 2. (a) Fuel (PMS) consumption (expressed on Billion Liters i.e., BL) in Nigeria, (b) Fuel (PMS) price fluctuation in Nigeria expressed in Liter per Naira (1 US dollar = 410 Naira) from 2016-2020 NBS report

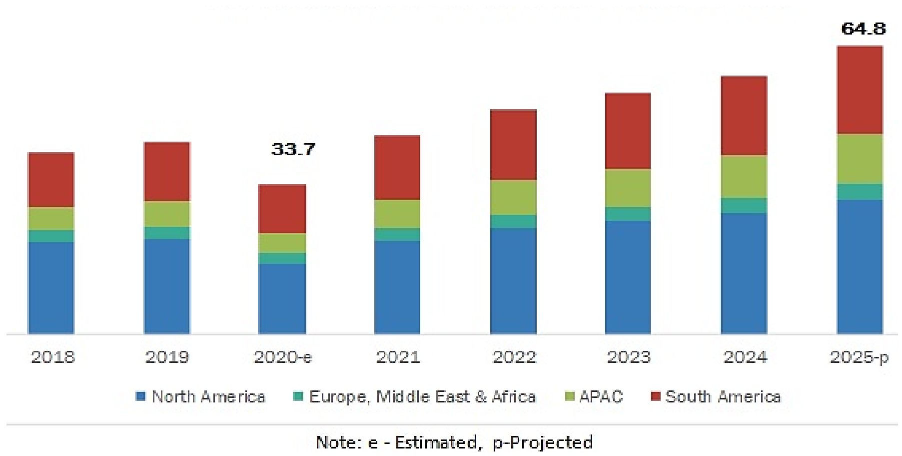


Figure 3. Global bioethanol fuel market (in USD billion) by different regions (2018-2025), where APAC is Asia-Pacific [Data Source: 2020 Bioethanol Market Global Forecast to 2025 | MarketsandMarkets.com]

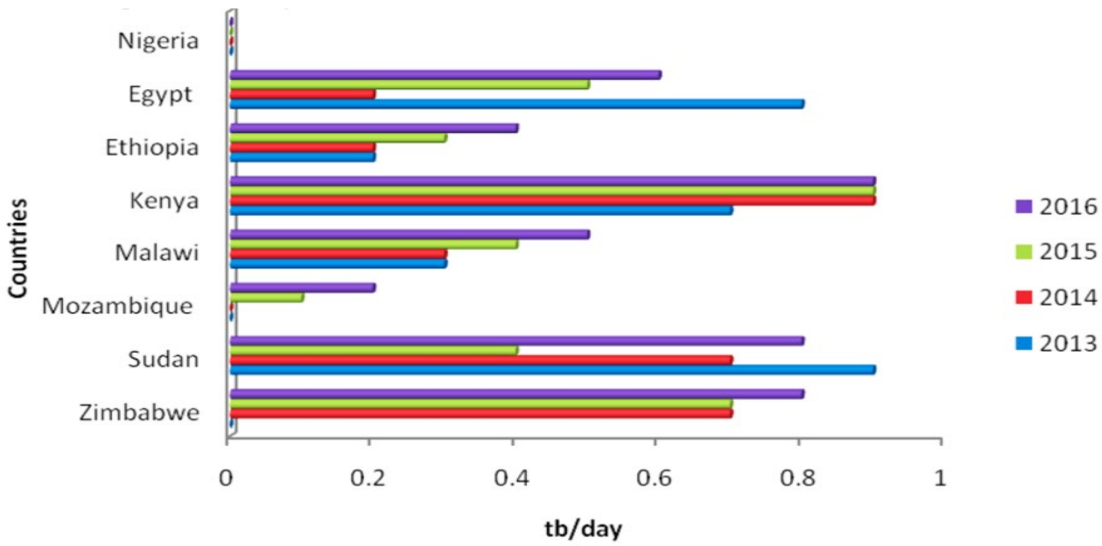


Figure 4. Fuel ethanol production in Africa from 2013 to 2016 [Data Source: 2017 Statistical Review of World Energy]

The 2017 Statistical Review of World Energy report shows that only a few African countries are presently part of this initiative, where most countries are mainly producing biofuels from the USA, Brazil, European Union, Asia, and other American continent countries. A few African countries currently into biofuels production primarily include Zimbabwe, Sudan, Malawi, Kenya, Egypt, Mozambique, and Ethiopia. Countries like Nigeria were found to have shown zero or insignificant production in line with the report (shown in Figure 4) of the 2017 Statistical Review of World Energy.

The report of Ogundari et al. [46] projected that the domestic demand for petrol (otherwise known as PMS) would have risen to two million tons and above as of the year 2019, as shown in Figure 5. As the energy demand has gradually risen in Nigeria for its residents to meet the demand for power and transport functions, the government needs to diversify its energy mix through a deliberate integration of biofuels production.

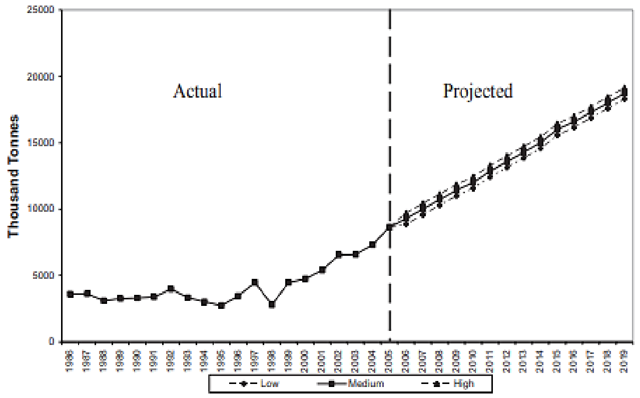


Figure 5. Domestic consumption of petrol in Nigeria (Actual & Projected values) [Source: Ogundari et al., [46]]

The report of Ogundari et al. [46] projected that the domestic demand for petrol (otherwise known as PMS) would have risen to two million tons and above as of the year 2019, as shown in Figure 5. As the energy demand has gradually risen in Nigeria for its residents to meet the demand for power and transport functions, the government needs to diversify its energy mix through a deliberate integration of biofuels production.

7. PROCESS SIMULATION, SCALE-UP, AND COMMERCIALIZATION OF BIOETHANOL FUEL IN NIGERIA

Process modeling and simulation involve developing representations of actual processes on a different platform that could facilitate the study and research of such processes [103, 104]. In recent time, the use of computer in the modeling of thermochemical, chemical, and biochemical processes is gaining significant attention among the industrialists and researchers in the study of chemical and biochemical process systems being a means that is an effective and efficient approach to studying reality via the use of process simulation, which would promote a better understanding of process plant and troubleshooting or retrofitting an existing planting process [103-105]. Deductions made from such studies would enable research works to understand better the preliminary technical and economic implications of commercializing such processes, which in most cases has already been confirmed to be feasibile from the laboratory studies findings [56, 57, 103-105].

A literature survey indicates that several research works have established the technical feasibility of setting up some functional bioethanol plants. However, some research papers have focused on using sugar-based materials while others focused on using cellulosic and starch-based materials. Some of these studies provide a report on the implication of utilizing cellulosic material like sugarcane-bagasse [56, 57] (in Figure 7), sorghum-bagasse [95] (in Figure 8), rice-husk (in Figure 9), and maize-cob [106, 107] for the production of bioethanol fuel through the process simulation approach. Other works that have employed the use of like approach are the use of sugar-based materials like molasses [14], sugarcane juice [88, 108] (in Figure 6), and many others.

Table 4. Report of the process scale-up studies

Ref.	Objectives of the work	Feedstock/Material used (Production capacity)	Study approach	Thermodynamics model used [Software used]	Key findings
[14]	Model and implement a cost-effective method of converting cane molasses, a by-product of sugar production in sugar refineries, into a liquid fuel known as bioethanol.	Sugarcane molasses (86 million liters of bioethanol per annum)	Process modeling and simulation	Non-Random Two liquid (NRTL) [Aspen HYSYS]	The parametric study found that the minimum number of trays in the distillation column for maximum purity was 40.
[95]	Model, simulate and study the financial implications of establishing or building a plant for transforming sorghum bagasse into bioethanol in Nigeria.	Sorghum bagasse (9408 kg/h of fuel-grade bioethanol)	Process modeling and simulation	NRTL [Aspen HYSYS, MATLAB, Ms-Excel 2013]	9,408 kg of fuel-grade bioethanol produced from 50,000 kg of sorghum bagasse was expensive relative to other existing bioethanol plant reports.
[88]	This study provides a pilot scale for bioethanol production from bioresources (sugarcane) through the fermentation process.	Sugarcane (100 L/day of bioethanol)	Process modeling and simulation	NRTL [SuperPro Designer]	A qualitative analysis of the fermenter and distillate using an infrared spectroscope revealed that ethanol accounted for approximately 67 % of ethanol.
[58]	Examine the cost-effectiveness of setting up a bioethanol plant in Nigeria, using waste (sugarcane bagasse) as a raw material.	Sugarcane bagasse (143 million liters/annum of fuel grade bioethanol)	Process modeling and simulation	NRTL [Aspen HYSYS, MATLAB, Ms-Excel]	The project's benefit is highly sensitive to the change(s) in sugar cane and government subsidy cost but not sensitive to the change(s) in minimum wages and taxes.
[57]	The model simulates bioethanol production from a combined cellulose and sugar feedstock and verifies the feedstock's feasibility and economic viability.	Sugarcane juice and bagasse (148 million liters/yr of bioethanol)	Process modeling and simulation	NRTL [Aspen HYSYS]	The energy efficiency of the proposed bioethanol plant was 63 %.

[56]	Examine the economic viability and sensitivity of selected variables to the bioethanol plant project's sustainability when cane juice and bagasse are used in Nigeria.	Sugarcane juice and bagasse (148 million liters/yr of bioethanol)	Process modeling and simulation	NRTL [MATLAB R2017a, Ms-Excel 2016]	According to the study's conditions, the study suggests that the proposed plant would be economically viable and profitable in Nigeria.
[106]	To comparatively investigate the material requirement, production yield, and total equipment cost involved in the rice-husk and maize-cob transformation into the bio-ethanol fuel for large-scale production using a process modeling and simulation study to promote the potential investors' interest.	Rice husk and maize -cob (9.94 kg/h and 7.32 kg/h of fuel-grade bioethanol)	Process modeling and simulation	NRTL [Aspen HYSYS, MATLAB and Microsoft Excel]	The study shows that rice husks show a high yield, while maize cob makes the production less capital-intensive.

The details of the works done so far that have advanced the scaling up and establishing the bioethanol plant in Nigeria are presented in Table 4. Studies indicate that no studies have been reported on starch-based feedstock use among the works done so far. Instead, most reports have been mainly on sugar and cellulosic-based feedstock like rice husk, maize cob, sugarcane bagasse, sorghum bagasse, molasses, and many other related feedstocks.

Most of the process scale-up studies reported in the literature have primarily been shown to have employed the thermodynamics model known as the Non-Random Two liquid (NRTL) model. Likewise, most of the studies that have majorly used Aspen HYSYS, while the report of Misau et al. [88, 108] employed SuperPro Designer simulator possessed good features and capacities similar to that of the Aspen HYSYS simulator. Some of the process flow diagrams reported for the studies of bioethanol production for the use of sugarcane juice [88, 108], sugarcane juice-bagasse [56, 57], sorghum bagasse [95, 109] and rice husk [106] to investigate the feasibility of commercial bioethanol in Nigeria. In most of the reports, the NRTL model has been reported to have the best fit to equilibrium due to the components involved in a bioethanol production process attributed to its polarity (like water and ethanol), and the vapor phase behavior can be compared to that of the ideal gas due to the low operating pressures, i.e., 1-5 atm as reported in the literature [14, 95]. Process modeling and pilot studies have reported using sugarcane juice and bagasse, indicating that it is technically feasible to set up such refineries in Nigeria.

8. ECONOMIC SIGNIFICANCE OF PROMOTING BIOETHANOL FUEL IN NIGERIA

Not only was the technical feasibility of scaling up the plant for its establishment in Nigeria carried out, but also many other studies focused on the economic feasibility of establishing this bioethanol plant in Nigeria. The report of the various research work findings is summarized in Table 5, reporting the nature of feedstocks used as well as the estimated capital and operating costs including the economic benefit of the projected deduced from studies.

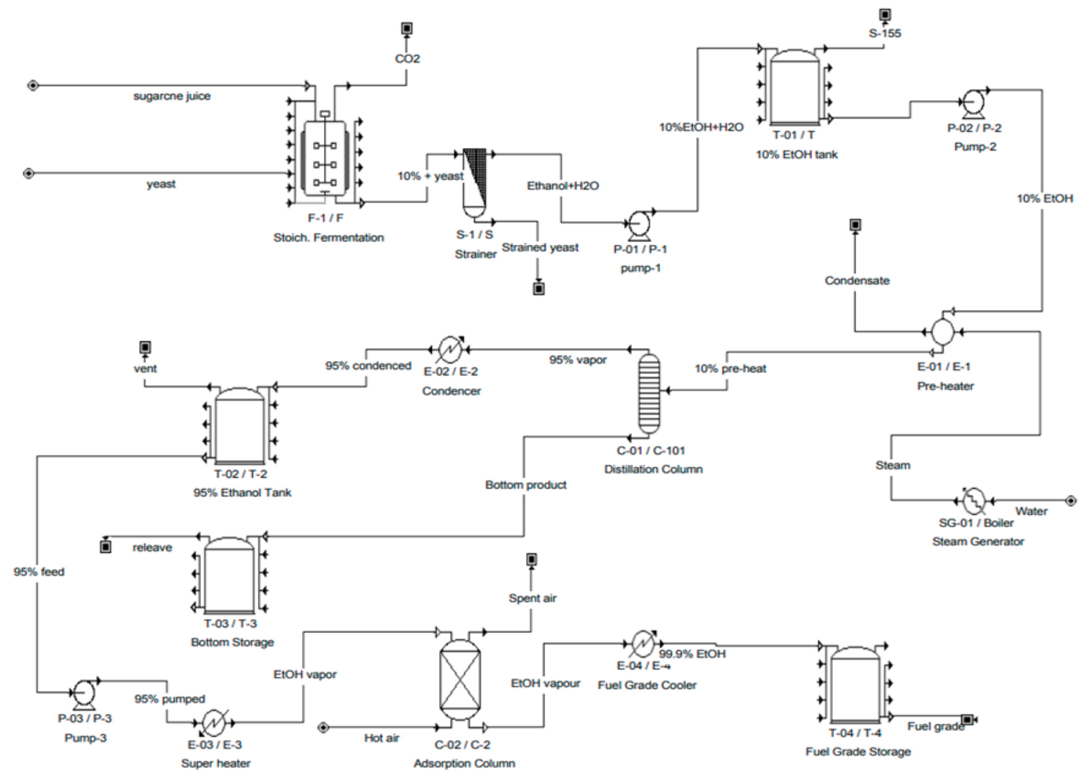


Figure 6. A Process Flow Diagram (PFD) route for sugarcane juice to bioethanol project in Nigeria [88, 108]

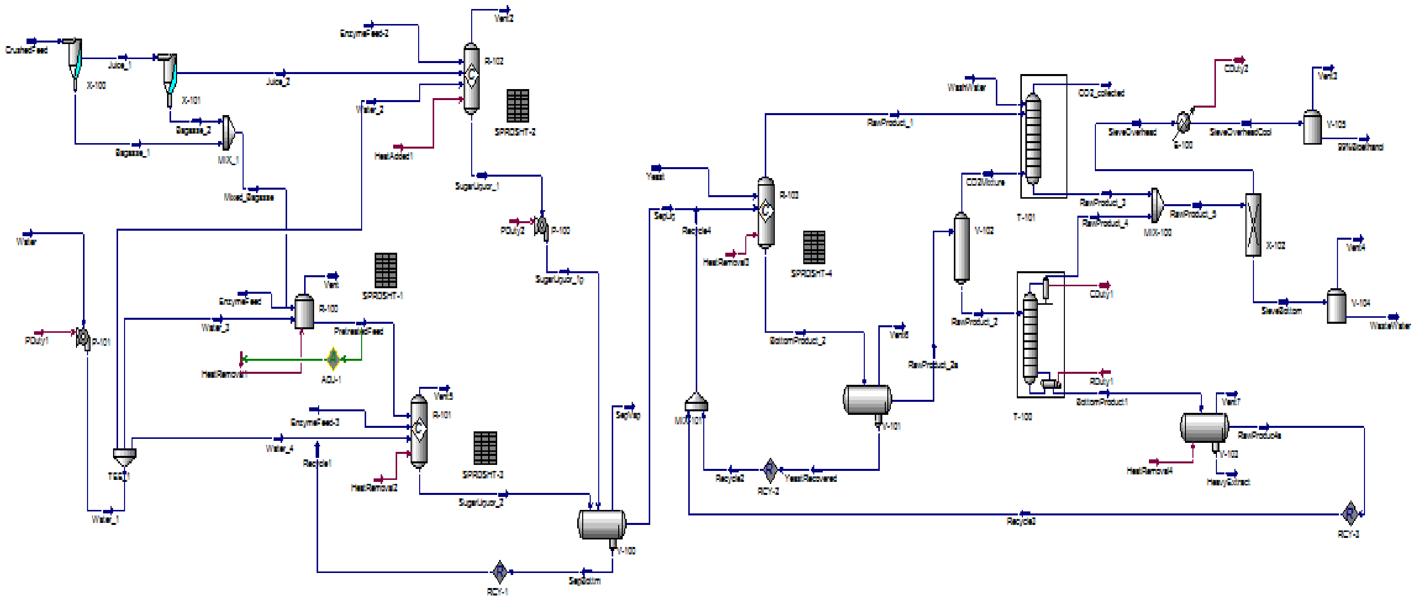


Figure 7. A PFD for the combined transformation of sugarcane juice and bagasse into bioethanol in Nigeria [57]

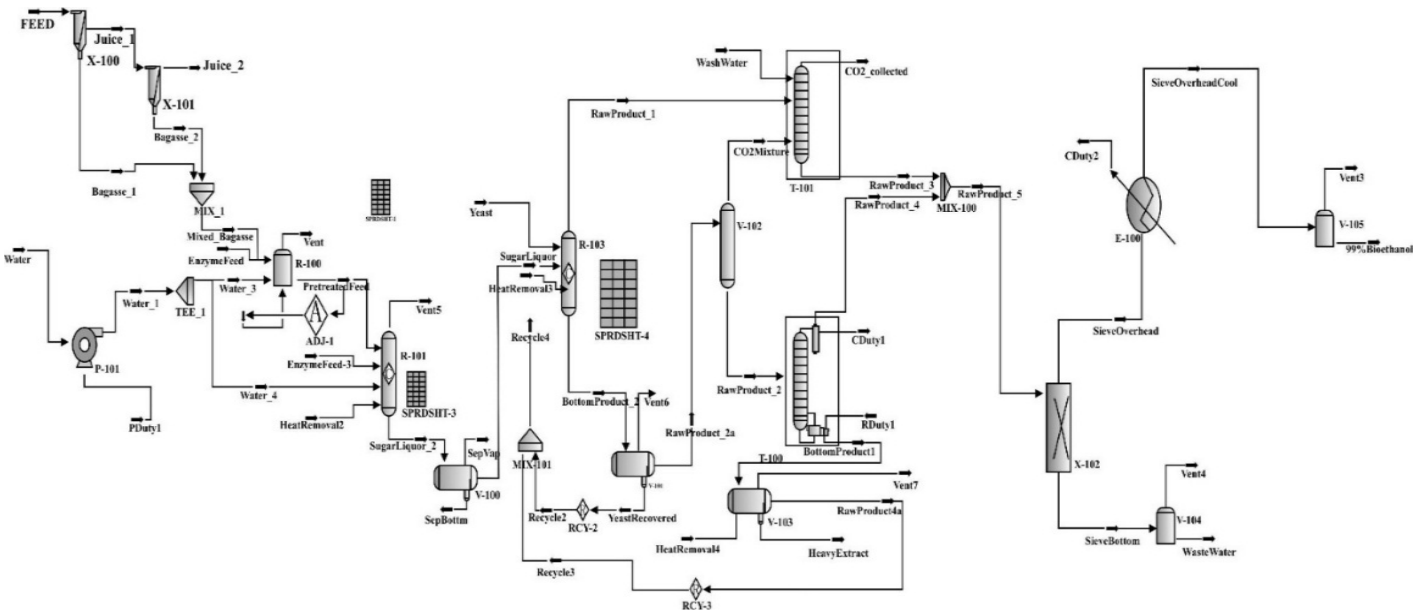


Figure 8. The PFD showing the process route for sorghum bagasse into bioethanol in Nigeria [95]

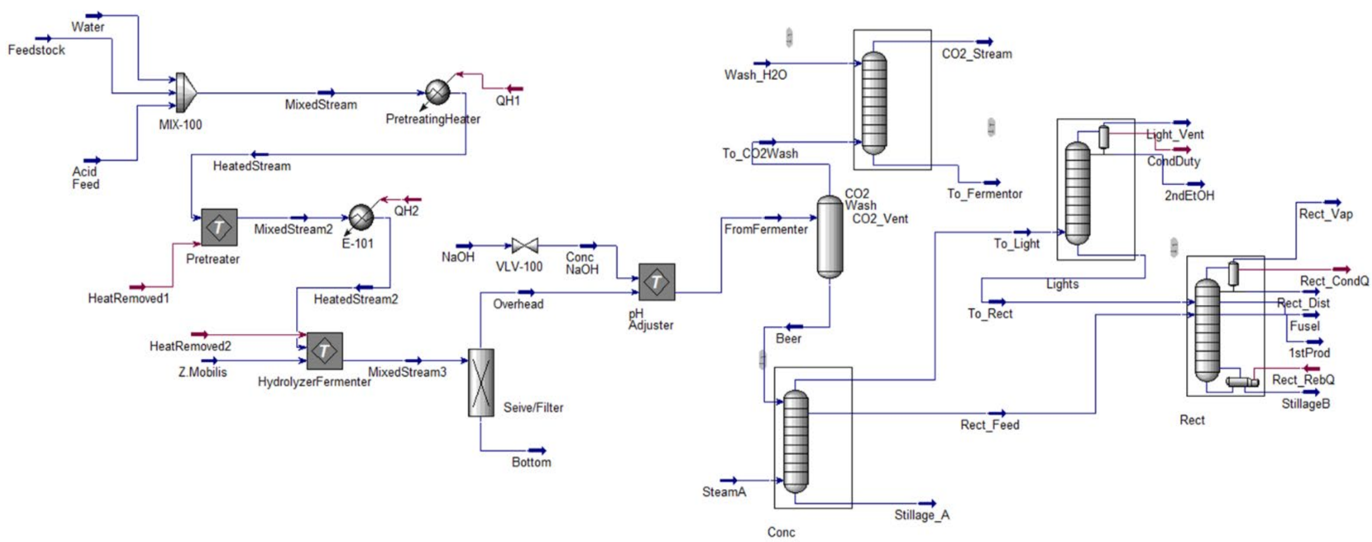


Figure 9. The PFD displaying the process route for transforming rice husk into bioethanol in Nigeria [106, 107]

Unlike the sugar and cellulose-based feedstocks whose economic feasibility studies have been reportedly conducted, literature is yet to give significant attention to the economic feasibility studies of starch-based materials, except for the study of Ogbonma et al. [48] that accounted for the economic feasibility of utilizing cassava, which was only feasible provided the plant would be situated next to the farm. However, the literature survey indicates that the stability of currency exchange rates like the Naira-Dollar exchange in Nigeria has an extended role in promoting the economic feasibility of establishing a bioethanol fuel plant across Nigeria's states and other developing nations. Also, the reports from Abemi et al. [14] and Oyegoke et al. [56] emphasize the need for developing governments to introduce a subsidy for bioethanol production to promote green fuel consumption in developing nations.

9. BIOETHANOL STUDIES TREND TOWARD THE PROMOTION OF BIOREFINERIES IN NIGERIA

The distribution of works done so far on the laboratory investigations [43, 45, 51-55, 61, 63-66, 68, 69, 71, 76, 86, 87, 110], process scale-up studies [14, 57, 58, 88, 95, 106], and the economics feasibility studies [14, 48, 56, 58, 107, 109, 111] towards the commercialization of bioethanol is graphically represented in Figure 5, where the proportion of starch [46-48, 81, 82, 84, 85, 90, 91, 112], cellulose [51, 53, 57, 58, 61, 71, 74, 77, 78, 83, 95, 109] and sugar-based [14, 44, 45, 56, 57] feedstock studied so far and the form of studies and volume of works done so far are presented.

The survey of laboratory studies carried out in the literature indicates that many laboratory research works are giving significant attention to the study of bioethanol production kinetics and optimization, even though the literature survey indicates that greater attention is given to the study of bioethanol production optimization with lesser attention given to the investigation of the reaction kinetics of the production processes, which enable the process scale-up studies to be feasibly investigated with the use of the findings obtained from the laboratory studies.

Table 5. Economic studies report for bioethanol production (CC=Capital cost, OC=Operating cost)

Ref.	Type	Feedstock/Material used (Production capacity in the study)	CC (OC)	ROI (IRR) %	NPV/NPW	Other economic parameters	Key findings made
[58]	Cellulose	Sugar cane bagasse (143 million liters)	n.r. (n.r.)	12.83 (12.10)	NGN 37.48 million	Payback period (PBP) at 10 % of 6.9 years	143 million liters of fuel-quality bioethanol require 402 metric tonnes of crushed sugar cane bagasse.
[95]	Cellulose	Sorghum bagasse (9,408 kg of bioethanol from 50,000 kg sorghum bagasse)	$1.92/L (0.83 $/L)	n.r. (n.r.)	n.r.	n.r.	The project would require capital and operating costs of $1.92 and $0.83, respectively, to produce one liter of fuel-grade bioethanol from sorghum bagasse.
[109]	Cellulose	Sorghum bagasse (59,778,931.90 L of bioethanol)	$0.64 /L (0.89 $/L)	49.99 (n.r.)	- $212 million	n.r.	It was found that it was not economically feasible to replace fuel used in Nigeria due to high exchange rates.
[107]	Cellulose	Rice husk (17.7 million liters (1789.45 kg/h) of bioethanol)	0.27 US$/L (0.51US$/L or 183.6 NGN/L)	9.89 (16.10)	$5 million	5.5 years (PBP) of 25 years	The report's findings recommend subsidizing and tax-exempt biofuel production to encourage investors and promote cleaner fuels in emerging countries.
[57]	Cellulose & sugar	Combined cellulose and sugar feedstock (148 million liters of fuel grade bioethanol)	$51 million ($ 89 million)	n.r. (n.r.)	n.r.	n.r.	375,000 liters of bioethanol can be produced from a metric tonne of crushed sugarcane at an investment and manufacturing cost of $0.34/L and $0.61/L, respectively.
[56]	Cellulose & sugar	Combined cellulose and sugar feedstock (148 million liters of fuel grade bioethanol)	$51 million or 0.34$/L) ($89million or 0.61$/L))	8.40 (11.51)	$ 20.90 million (at 10 % discount)	PBP at 10 % of 9.64 years	A plant producing 148 million liters of fuel-grade bioethanol from 402 metric tonnes per year of crushed sugarcane would be economically feasible in Nigeria.
[48]	Starch	Cassava (0.34 g-ethanol/g-cassava flour)	n.r. ($46,875)	n.r. (n.r.)	n.r.	Cost price calculated as ₦102.5/l (US$0.641/l)	It was recommended that the plant be integrated with the cassava farm is grown to make the process workable.
[14]	Sugar	Cane molasses (86 million liters of bioethanol per annum)	$ 12.86 million ($ 51.70 million)	-124. 22 (14.69)	-$85.45 million	PBP is infinity (∞)	Bioethanol production in Nigeria from molasses is economically viable if the government subsidizes it and the naira-dollar exchange rate declines.

A literature survey (presented in Figure 10) regarding the promotion of bioethanol fuels adoption in Nigeria indicates that greater attention has been given to the studies of the cellulose-based feedstock in the laboratory (46 %) and economic feasibility (8 %) studies, while sugar (4 %) and cellulose (5 %) based feedstock studies (8 %) have dedicated greater attention to the case of process scale-up studies, being vital to the commercialization of the laboratory established fact on bioethanol production in Nigeria. Moreover, the survey further indicates that the bulk of the works have mainly focused greater attention to the laboratory studies (with 81 %) while giving lesser attention to the study of process scale-up (with 8 %) and economic feasibility (with 11 %) studies with a tremendous potential of attracting the attention of government and private investor that would incur their fund on the establishment of biorefineries in Nigeria.

Moreover, it is necessary to pay more attention to the investigation into the laboratory study of the bioethanol production kinetics, the process scale-up studies of the laboratory established fact, and the exploration of the economics relevance before materializing the project and this would bring about significant pre-insights for both the government and private investors.

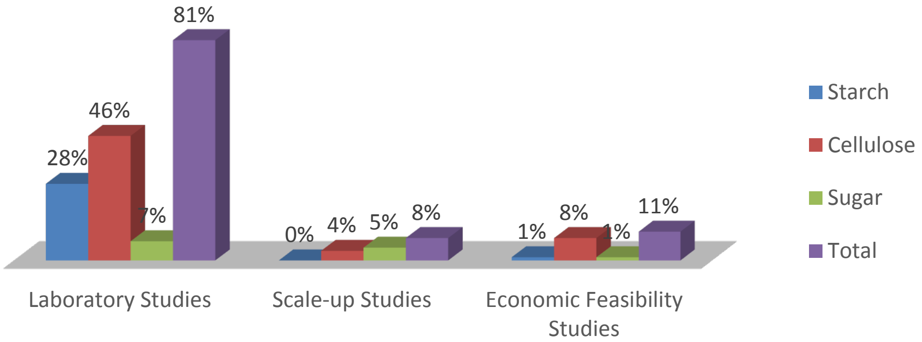


Figure10. Distribution of studies carried out at different stages in Nigeria for bioethanol production

10. CONCLUSIONS

Many research attempts to unveil the technical and economic implications of embracing bioethanol fuels in developing nations like Nigeria were successfully surveyed. The survey, which included the exploration of the laboratory-scale, process scale-up studies, and techno-economic studies carried out so far as part of the vital component of research, can be used to gain the confidence of both private investors and government to explore the financial benefits for potential investors in Nigeria.

From the literature review that has been carried out through careful research, it can be seen that bioethanol yield from sugarcane juice was the highest amongst other sugar-based feedstocks. Banana stem, rice husk, and elephant grass stem produced more bioethanol than other lignocellulosic feedstocks. The starch-based feedstock has cassava as the highest bioethanol yielding feedstock. However, the starch-based feedstock may compete with human food. The high-octane number and complete combustion of bioethanol due to oxygen presence serve as a significant advantage over fossil fuel. This makes it the center of energy research for both developed and developing countries.

However, Nigeria is far behind in the production of bioethanol despite the availability of feedstocks. Feasibility studies, process scale-up, and pilot studies have shown that venturing into bioethanol production as a country would be a good investment. Despite the work done so far, there is still room for improvement and areas to consider. Only a few studies have examined process scale-up, modeling, and economic feasibility studies for many lab-scale technologies. Politically, the snaring revelation hindering the effective sail of biofuel production may not be far from the politicking on the part of business personalities and oil rig moguls whose income and business empires might cripple down if biofuel production and utilization substitute petroleum in the Nigerian economy. It is, therefore, necessary to review bioethanol production policies in Nigeria by the appropriate authorities.

In addition, findings from literature survey have pointed to the need for further studies to focus on the investigation of process scale-up for bioethanol production through the use of starch-based and some other lignocellulosic (yet to be investigated) materials, including the exploration of its economic benefits to the national development of developing nations like Nigeria and other African countries. Moreover, the findings of this survey have also shown the need for the government to subsidize bioethanol production due to the unstable exchange rates. Therefore, adequate funds should support the transition towards green energy by supporting scale-up, feasibility, pilot study, and implementation by both government and private establishments.

11. ACKNOWLEDGEMENT

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