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REVIEW

Beneficiation of corncob and sugarcane bagasse for energy generation and materials development in Nigeria and South Africa: A short overview

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Abstract The challenges of increasing energy demand and advanced materials for infrastructural development in developing countries have necessitated the search for sustainable sources of raw materials. The high amount of agricultural residues generated in Africa owing to vast availability of arable land has been an impetus for solving some of these challenges. Therefore, this review article provides information on beneficiation and challenges of the two largely generated agricultural residues, corncobs and sugarcane bagasse, in Nigeria and South Africa. The estimated quantities of corncob and sugarcane bagasse generated by these countries are reported. The potentials of beneficiating corncob and sugarcane bagasse in energy generation, in materials development and in other purposes such as production of platform chemicals are reviewed and discussed. Various technologies deployable in the beneficiation of these wastes are enumerated, and the benefits and challenges that are associated with beneficiating these wastes are briefly discussed.

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Contents

1. Introduction

Nigeria and South Africa are two countries considered as the largest economies in Africa. In 2015, the gross domestic product (GDP) of these countries was estimated at 525 (Nigeria) and 350.63 (South Africa) billion USD [1,2]. The contribution of agriculture to the GDP of Nigeria in 2012 was 30.9% and has since been increasing to date [3]. In 2014, the growth rate of the agricultural sector was 38.53% and contributed about 26.6% to the nominal GDP of the country [4]. In Nigeria, crop production was identified as the major driver of the agricultural sector in the third quarter of 2015 [4]. Although the contribution of agriculture to South African economy is puny, South Africa remains one of the largest producers of maize in Africa followed by Nigeria and Egypt [5]. This indicates that there are huge potentials for food production regardless of the significant contribution of agriculture to the present economic growth of African nations. Recent increase in the generation of agricultural residues/wastes in Africa can be attributed to increase in demand for food due to an unprecedented population growth and rural–urban migration. These agricultural residues (biomass) consist of solid wastes as major components [6]. Okot-Okumu reported that decomposable organic matter, also known as biomass, constitutes the major form of solid waste generated in East-African countries [7]. In 2009, United Nation Environmental Programme (UNEP) reported that the continued increase in population, economic growth and improved standard of living have resulted in a sporadic increase in volume of waste biomass generated [8]. Furthermore, it was reported that about 140 billion metric tons of waste biomass are solely generated globally from agricultural activities every year [8]. In addition, ineffective disposal of the waste biomass constitutes a huge problem to the society because the decomposition of the wastes generates greenhouse gases that contribute to the global climate change [8]. International Energy Agency (IEA) estimated that the waste sector contributed to one-fifth of the global anthropogenic methane emission, a major contributor to global climate change [6]. However, substantial amount of the huge quantity of biomass generated every year can be converted to valuable products. But lack of information on the potential benefits of these wastes, lack of suitable technologies to convert them to valuable products and weak government policies are the mitigating factors towards harnessing the aforementioned potential benefits of this waste biomass in most developing countries such as Nigeria and South Africa. Furthermore, inefficient waste disposal system and lack of recycling facilities in these countries constitute an impediment as well [9]. In this article, potential benefits of waste biomass generated from agricultural residues in creating wealth are showcased and discussed. At the same time, the review seeks to explore several ways of utilizing the waste to produce valuable products, thereby provoking the thought of the stakeholders in the sector towards harnessing the benefits.

1.1. Waste biomass and classification

Several definitions of biomass have been provided in the literature (for example see [10]). Notwithstanding, biomass can be defined as a biological material derived from living, or recently living organisms or dead organic material [11]. In the context of biomass for energy, they are referred to as non-fossil fuels that are biodegradable and renewable. Biomass is considered as renewable source of energy because it releases heat energy for work when combusted in air (oxygen) or allowed to undergo natural decomposition and can be replenished unlike the fossil fuel. In addition, the CO_2 cycle is closed (i.e. amount of CO_2 released during combustion is equal to the amount of CO_2 absorbed during the plant photosynthesis) [12]. Biomass is often used to mean plant-based material, but biomass can equally apply to both animal and plant derived materials [13].

According to the Australia Institute of Energy (AIE) [14], biomass can be classified as virgin biomass and waste biomass. Virgin biomass is subdivided into two broad groups:

- Terrestrial-forest, grasses, energy crops and cultivated crops.
- Aquatic-algae and water plant.

Waste biomass is categorized into three main groups:

- Agricultural wastes, such as corn stalks, corncobs, palm kernel shell, coconut shell, sugarcane straw, sugarcane bagasse, nutshells, and manure from cattle, poultry, and hogs [11].
- Forestry residues, such as wood chips, bark, sawdust, timber slash, and mill scrap [14].
- Municipal waste, such as waste paper and yard clippings [8,14–18].

The focus of this article is on waste biomass with emphasis on corncob and sugarcane bagasse, which are produced in large quantities in Nigeria and South Africa. Virgin biomasses are consumed as food directly or used as raw materials for food processing. The increasing demand for food and the expected competition with the food chain have made virgin biomass less attractive for energy generation and materials development.

2. Generation of corncob and sugarcane bagasse in South Africa

Corn is an internationally tradable commodity. It was introduced in Africa in the 1500 and has become one of Africa's dominant food crops [19]. Corn accounts for 30–50% in the low-income household expenditure in Eastern and Southern Africa. South Africa is the continent's largest corn producer with an estimate of 14.9 and 11.3 MMT produced in 2013 and 2014, respectively [20–21]. In 2001, the Food and Agriculture Organization (FAO) statistics showed that South Africa remains the highest corn producer on the African continent with approximately 10 million metric tons in that year. In 2005, the agricultural statistics showed that the world corn production reached about 525 million metric tons, of which 1.7% was produced from South Africa. In 2009, South Africa was the 9th largest maize producing country with 12.37 million metric tons (MMT) per annum. Based on statistical analysis for 2013 on maize production, the peak period is from April to August. The month of June was the highest in 2013 with approximately 420,000 tons produced [22]. South Africa is also one of the major exporters of maize in the world [23–25]. Corn cultivation sector comprises both commercial and non-commercial farmers. The non-commercial farmers are mostly in the Eastern Cape, Limpopo, Mpumalanga and Northern KwaZulu-Natal Provinces [26]. The commercial production of maize by province is illustrated in Table 1. Primarily, corn is used for the production of maize meal which is one of the staple food items in South Africa. In addition, corn is largely used as a raw material for secondary corn products such as corn flakes, corn flour and glucose in South Africa [16]. The huge production capacity of corn in South Africa has a direct relationship with the generation of corncobs once the grains have been consumed as food or processed to other food products. Corncobs are one of the largest agricultural wastes in South Africa, amounting to about 9 million metric tons annually and making up to 20% of the corn residue [27].

Table 1 Commercial contribution by provinces to maize production during the 2012/2013 production season [26].

Province	Commercial maize production in 2012/2013 (%)
Free state	41
Mpumalanga	26
North west	14
Northern cape	6
Gauteng	5
Kwazulu natal	5
Limpopo	5
Eastern cape	2
Western cape	1
Total	100

South African agricultural sector generates the most biomass from the corn production planted on an area of 3 million hectares out of the total 14.7 million hectares of the arable land [27].

There are currently fourteen sugarcane milling companies in South Africa. Twelve of the mills are located in KwaZulu-Natal Province and the other two in Mpumalanga. Illovo sugar Limited and Tongaathulett Ltd. are the largest with each company having four sugar mills; and then followed by TSB sugar with three mills. The Gledhow sugar company, Umfolozi sugar Limited and UCL company own a mill each [28]. The South African sugar industry is a net exporter of sugar, exporting 271, 330 MTRV (253, 579MT) of sugar in 2011/2012 [28]. The sugar industry produces wastes from sugarcane as bagasse and molasses for use in electricity generation, industrial ethanol production, and paper manufacturing and as animal feed [29]. Bagasse is a fibrous biomass generated from sugarcane processing and it is the material that remains after the extraction of juice from the sugarcane stalks [30]. Like most biomass, it is composed of cellulose, hemicellulose and lignin, making it a good candidate for the production of renewable energy and bio-based chemicals [31]. Africa grows about 5% of the entire sugarcane produced in the world with sub-Sahara African countries generating 30% of the sugarcane produced in Africa. South Africa is Africa's largest producer of sugarcane followed by Sudan, Kenya and Swaziland. An average of 18MMT of sugarcane is produced annually. In 2014, Steve [32] reported that 372,000 ha of land was used for sugarcane plantation. The main production areas include northern Pondoland in the Eastern Cape, Mpumalanga and KwaZulu-Natal with the latter being the largest supply area with mostly rain-fed sugarcane [33], while about 30% of the sugarcane produced in KwaZulu-Natal is produced under irrigation [28]. The map showing the areas where sugarcane plantations and sugar mills are located in South Africa is depicted in Fig. 1.

Sugarcane in rain-fed areas is dependent on climate change. Consequently droughts or low rainfall has a negative impact on sugarcane production in the areas [28]. According to South African Sugar Association, there are approximately 24,000 registered sugarcane growers in South Africa, with over 22,500 being small-scale growers producing 8.3% of the total crop. Large-scale farmers are about approximately 1,413,323 being upcoming black farmers, producing 83.8% of the total crop and milling companies with sugarcane estates producing the remaining 7.94% [33]. South Africa is the 15th largest sugarcane producer in the world [35], producing 28.13% of the entire contribution of sub-Saharan African sugarcane production. Like in other parts of the world where sugarcane is produced in large quantities, amount of sugarcane bagasse increases with increasing sugarcane production. Therefore, South Africa generates approximately 7 million tons of bagasse annually [36].

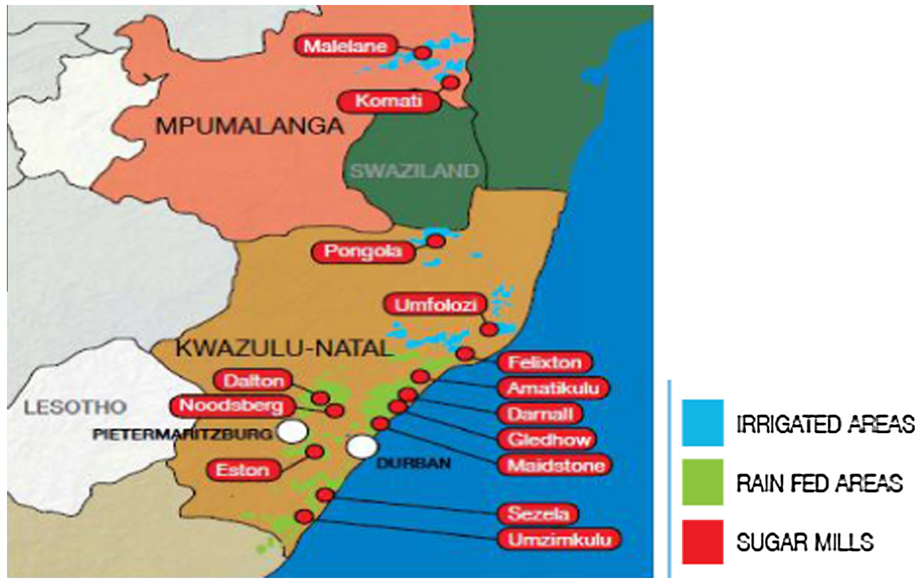

Figure 1 Location of sugarcane plantations and sugar mills in South Africa [34].

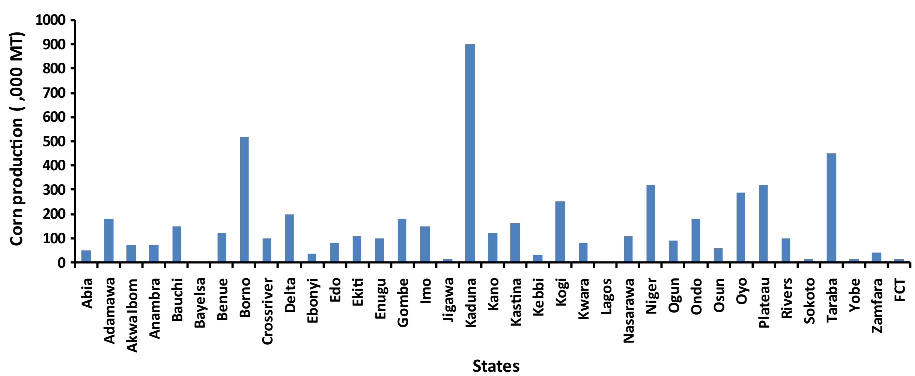

Figure 2 Corn production by states (000MT) in 2005/2006 after [37].

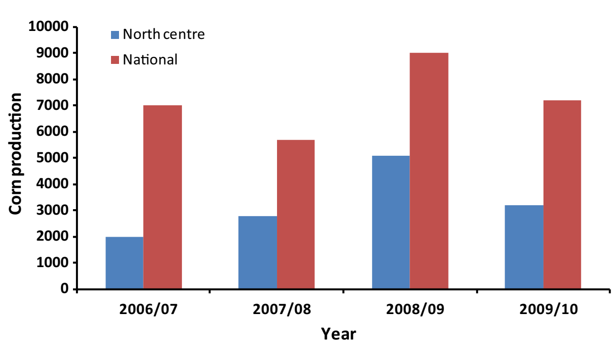

Figure 3 Yearly national and north-central maize production (000MT), 2006–2009 [37].

3. Generation of corncob and sugarcane bagasse in Nigeria

Detailed information on the production and consumption of corn in Nigeria has been reported by Cadoni and Angelucci [37]. Nigeria is the 10th largest producer of corn in the world and one of Africa's major producers of the crop. Although corn is cultivated in the entire six geopolitical zones of the country, the major area producing corn in Nigeria is the North central with Kaduna state serving as the leading production base (see Fig. 2). Between 2006 and 2010, North-central geopolitical zone output was about 31% of the national production in 2006, 58% in 2008 and dropped to 44% in 2009 (see Fig. 3).

Between 2010 and 2015, the average production of corn in Nigeria was 8.18 million metric tons. About 60% of Nigeria's corn produced is processed into flour, beer, malt drink, corn flakes, starch, syrup, dextrose and animal feeds [38]. The abundance of corn in Nigeria and South Africa has made the residues to pose serious environmental threat to these countries. In many developed countries, corn residues are used as raw materials for energy generation or new materials development. The utilization of corn residues as a potential energy resource presents new challenges and requires consideration of factors such as the following: harvesting, handling, heating value, storage methods and energy conversion methods [39].

Sugarcane was first introduced in Nigeria by the European sailors in the 15th century through the eastern and western coasts. Sugarcane was primarily cultivated for making juice and preparing of feeds for animals. Currently, Nigeria is the second largest importer of sugar in Africa. The increase in the land cultivated for sugarcane production has failed to meet the local demand for sugarcane products. For example, in 2007/08 and 2009/10, about 80,000 and 100,000 tonnes of sugarcane were produced, respectively. This is considerably low when compared to the demand of sugarcane products estimated as 1.5 billion tonnes [40]. Nigeria contributes only 1.9% to the production capacity of sugarcane in sub-Sahara Africa valued at $30,155,345 [41]. However, this is expected to increase due to the establishment of Nigeria's first sugarcane bio-refinery in Zaria in 2015 [42]. The factory was established to increase sugar and ethanol production. The recent interest shown by the government in expanding the sugar industry and establishing policies to develop biofuels from local feedstocks has necessitated the expansion of sugarcane production in Nigeria. Despite the plans to increase sugarcane production in Nigeria, strategies to manage the residues such as straw and bagasse are not in place. Ogwo et al. [43] reported that 1 ton of sugarcane generates about 270 kilos of bagasse. This indicates that if 50% of the demand for sugarcane production in Nigeria is met, sugarcane bagasse would constitute a massive waste if efforts are not in place to beneficiate it.

4. Beneficiation of corncob and sugarcane

There are basically two types of residues produced when harvesting agricultural products, namely field residues and process residues [23]. Field residues are used to cover agricultural land in order to shield the soil from rain, wind shear that leads to soil erosion, sun radiation, moisture loss and heat flux. Process residues, however, are either left to dry on the farm after which they are burnt off or found littering the streets of market places. This practice does not help in building an eco-friendly environment. Corncob and sugarcane bagasse are typical examples of process residues [23]. Research efforts seeking a sustainable economy and eco-friendly environment have necessitated the beneficiation of corncob and sugarcane bagasse among other waste biomass. This section provides a review of the potential uses of sugarcane bagasse and corncob. It is important to mention that the general criteria for the evaluation of biomass-utilizing processes are their sustainability credentials and product yield. Other equally relevant factors, especially in developing nations, are the cost of production and the socioeconomic impact on the populace. There have been several investigations on the potential uses of corncob and sugarcane bagasse in both developed and developing countries. The major areas identified from the literature can be broadly classified as energy generation and materials development.

4.1. Production of fuels and energy from corncob and sugar bagasse

Corncob is a potential thermo-chemical feedstock, with a heating value of 19.14 MJ/kg [27,44]. The large quantities generated make corncob a good potential feedstock for biofuels as well. Corncob can be used as a substitute for coal or blend with coal to reduce harmful emissions which pollute the environment. Corncob contains very low amounts of nitrogen (0.41–0.57 wt.%) and sulphur (0.03–0.05 wt.%) when compared with coal (nitrogen 0.8–1.9 wt.% and sulphur 0.7–1.2 wt.%), making them emit less sulphur oxides (SOx) than fossil fuels. The energy content of corncob is comparable to low-grade South African coal (16 MJ/kg) but this depends on the location where the corncob was obtained [27]. Corncob has been used also in the past as a fuel (in direct combustion) for cooking and heating [39]. This is still a common practice in rural areas in Nigeria and South African. Hydrogen is a clean fuel that has been reported to be obtainable from corncob. Tang et al. [45] evaluated the production of hydrogen from corncob with the use of *mesophilic bacterium clostridium hydrogeniproducens* HR-1. Corncob is considered as promising hydrogen fermentation substrate due to its low cost, abundance, high content of cellulose and hemicellulose. Tang et al. obtained H_2 yield of 65%, 90% and 86% from corncob pre-treated with acid explosion, alkali soaking or steam explosion, respectively, using enzymatic hydrolysates as the biocatalyst [45]. In the same vein, Yu et al. [46] reported that biochar obtained from pyrolysis of corncob can be used for direct carbon fuel cell yielding a maximum power of 185 mW/cm^2 at a current density of 340 mA/cm^2 and at 750 °C [46]. Similarly, Biagini et al. [47] studied the gasification of corncob in a demonstration plant using a downdraft reactor. The authors reported that a good operability of the plant was obtained with gas specific production at 2 m^3/kg, gas heating value at 5.6–5.8 MJ/m^3, cold gas efficiency in the range 66–88% and potential net power efficiency from 21.1 to 21.6%. The results were comparable to those of wood materials (chips, briquettes and pellets) used as a feedstocks in most studies in downdraft gasifiers.

The calorific value of sugarcane bagasse has made it very attractive for energy production. In Brazil about 18% of energy is generated from biomass and sugarcane bagasse constitutes larger percentage of the total biomass resources [48]. The calorific value of sugarcane bagasse depends on its residual sugar content and humidity degree. Naturally, bagasse has a low bulk density, making it difficult to handle, store and transport, and this relatively lowers its heat content as well. However, some processes have been proposed and reported to alleviate these drawbacks of sugar bagasse. Pelletization of the bagasse does not only improve its energy content, but it makes it easy to transport and to process as well. A-grade coal has energy value of 27,000 kJ/kg whereas pelletized bagasse with 20% moisture has energy value of 13,100 kJ/kg which is relatively high as compared to 7300 kJ/kg of whole bagasse with 50% moisture [49]. The aforementioned information also indicates that when it comes to energy generation, the moisture content of the bagasse is highly important. Prior to pelletizing bagasse, the moisture content should be reduced because the calorific value of the bagasse depends on the moisture and sucrose content of the material. Therefore, drying the bagasse before using as feedstock in boiler increases its steam-to-fuel ratio, thereby increasing boiler efficiency [50]. In addition, bagasse can be stored up to one year if its moisture content is less than 30% [51].

4.2. Application of corncob and sugar bagasse in materials development

Corncobs and sugarcane are suitable for use in paper, cement and concrete, particle board and composites industries. Corncob has been used to develop affordable particle boards (see Fig. 4) for potential applications in building construction.

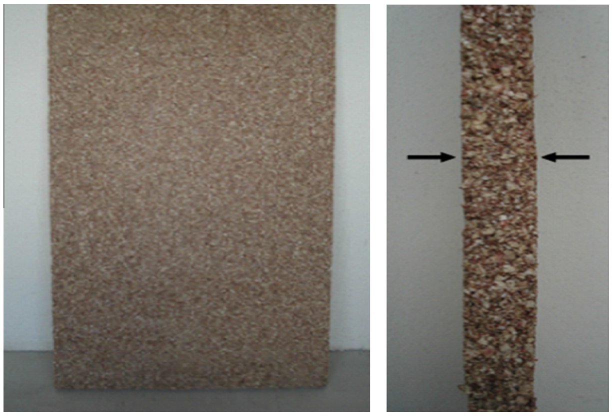

Figure 4 Corncob particle board (100 by 50 by 3 cm) [52].

Faustino et al. [52] investigated the potential of using corncob particle board as a sound-proof material and the authors reported that corncob particle board has comparable acoustic insulation properties as the other traditional materials such as glass wool and expanded polystyrene used for similar purpose. Paiva et al. [53] suggested that these particle boards can be used for thermal insulation products, light weight partition wall, ceiling among others. Furthermore, Adesanya and Raheem [54] have reported the development of concrete that contained corncob as aggregates. The authors also explored the use of corncob ash as a pozzolanic material for producing blended cement for structural applications. Similar research efforts have been made by several researchers to make agro-waste as a sustainable source of construction materials [55]. Fatile et al. [56] have also used ash obtained from burnt corncob as supplementary reinforcement in the development of low-cost and high performance aluminium hybrid composites. Aigbodion et al. [57] reported that sugarcane bagasse ash can be used as a reinforcement material for producing aluminium based composites.

4.3. Other potential uses of corncob and sugar bagasse

Other potential areas where corncob and sugarcane bagasse can be applied include industrial effluent treatment, fertilizer and animal feeds. Corncob and corn stalk have been investigated for their suitability in the removal of copper ion (Cu^{2+}) from wastewater effluents. Corncob is more potent in the removal of copper ion than the corn stalk. The functionalization of corn stalk using nitric acid could enhance the removal of copper ion when compared to non-functionalized corncob and corn stalk because of the presence of additional functional groups that bond with Cu^{2+} [58]. Mahmoud [59] reported that powdered corncob possesses the ability to remove Uranium (VI) from aqueous solution when applied in a batch and a fixed bed system. However, the rate of uptake of uranium ion in a fixed bed system depends on the feed flow rate, the bed height and the initial concentration of the solution. The use of silica extracted from corncob for water treatment was studied by Shim et al. [60]. They found that 84–88% Cu ion and 83–87% Cd ion were removed from the contaminated water within 24 h. They stressed further that corncob-alginate beads displayed are more efficient in removing Cu and Cd from wastewater stream than zeolite beads. Furthermore, the authors showcased the efficiency of using immobilized bacteria immobilized on corncob's silica/alginate in removing phenol, Cu and Cd from contaminated water with removal efficiency of 93%, 98% and 99% for phenol, Cu and Cd, respectively [60]. However, they suggested that regeneration of the beads for reuse could be a challenge and further research effort should be dedicated to investigating this. Velmurugan et al. [61] studied the extraction, characterization and catalytic potential of amorphous silica obtained from corncob using sol–gel method. Ultrafine amorphous silica of about 50 nm was obtained from the corncob and it was suggested that they are potential future materials for catalyst, controlled release application, wastewater treatment technology and dielectric materials.

Similarly, the use of sugarcane bagasse for treatment of wastewater has been reported by researchers. Ashoka and Inamador [62] reported that sulphuric acid and formaldehyde pretreated sugarcane is a cheap and effective adsorbent for the removal of dyes from effluents. Sugarcane bagasse pith has been used to prepare activated carbon for the removal of reactive dye from aqueous solution. The adsorbent capacity increased with increasing dose of activated carbon made from the bagasse pith [63]. Raymundo et al. [64] reported that sugarcane bagasse is a good bio-adsorbent for textile and wastewater treatment. Pandey et al. [65] did an extensive review which revealed that various products such as drugs, enzymes and fertilizers can be obtained from sugarcane bagasse. Shaikh et al. [66] reported that sugarcane bagasse can be used in the production of high value plastics while Santos et al. [67] showed that sugarcane bagasse can serve as cell immobilizer in the production of Xylitol.

5. Technologies deployable in the beneficiation of waste biomass

Industries such as energy, mining, wastewater treatment, textile, chemical industries, materials development industries and food processing can benefit enormously from utilization of waste biomass [68]. In addition, various energy products that can be obtained from biomass include heat and steam, electricity, producer gas, synthetic fuel oil, biogas, charcoal, methane, ethanol, biodiesel, methanol and other biofuels [68–70]. The enormous amounts of products that can be obtained from utilizing waste biomass indicate that there is a need to develop feasible technologies and apply them diligently for general benefits. Implementing proper technologies and advantageous utilization of waste biomass could be both environmental and economic efficient. There are different routes for converting biomass to bio-energy and other industrial products [71]. They are mainly classified under the three categories: biological, thermal and chemical processes. The biological processes include fermentation and anaerobic digestion while thermochemical processing of biomass revolves majorly around gasification and pyrolysis and they are currently the most applicable processes in bio-refining platforms [72]. Typical bio-refining processes for different biomass feedstock are presented in Fig. 5. Biomass refining is made functional by numerous technologies producing unique and common products depending on similarities in processing and applications. These technologies are as much as possible, assessed for alignment with the general ethos of green chemistry in order to further foster the sustainability agenda which biomass processing tends to promote.

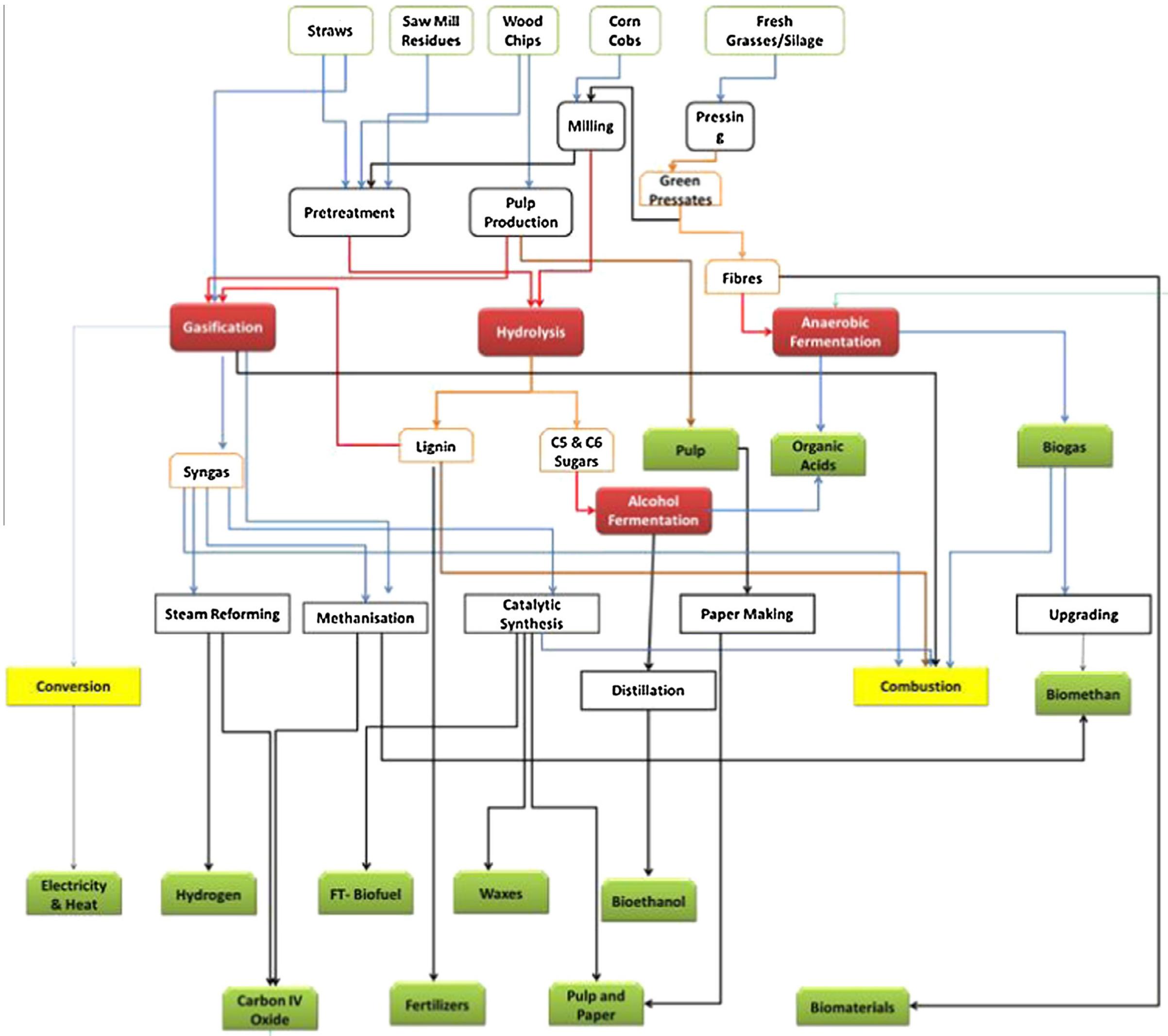

Figure 5 Comprehensive network of Lignocellulosic biomass processing scope of the integrated biorefining platform showing resulting high value products and respective bioprocess technologies. *Source:* Adapted from [73].

UNEP compiled a worldwide compendium on technologies that can be used to produce various energy products and other materials. The list below summarizes some of the effective and mostly used technologies [8]:

- Combustion: Combustion refers to burning or incineration of biomass to produce energy products such as steam and heat.
- Gasification: Produces heat, steam, synthetic gas and electricity, also practicable on a smaller scale.
- Pyrolysis: Utilization of a reactor to produce oil, gas and charcoal [68].
- Hydrolysis: Produces sugar for aerobic and anaerobic fermentation processes towards bioethanol production [69].
- Fermentation: Produces biocommodities and biofuels.
- Cogeneration: Steam production to generate mechanical power for driving alternators.
- Reduction: Production of animal feeds, ethanol, industrial absorbents and additive beverages.
- Hot-melt process: Utilization of biomass to produce paper and packaging materials.
- Thermochemical process: Production of synthetic gas, fertilizers, plastics and petroleum products.
- Composting: Organic fertilizer production.

Among the highlighted technologies for beneficiating biomass, the technologies that are very common are discussed succinctly in Sections 5.1–5.3.

5.1. Combustion

Direct Combustion of biomass is one of the most common and traditional methods of conversion of biomass to thermal energy especially in developing countries such as Nigeria and South Africa. The most significant form of corncob disposal and management in the latter has been attributed to mostly burning. The thermal efficiency of this method is usually as low as 10%, but has been shown to reach up to 60% in more

Table 2 Biomass pyrolysis techniques and characteristic process conditions [74].

Technique	Residence time (s)	Heating rate	Temperature (°C)	Product
Carbonation	Days	Very low	400	Charcoal
Conventional	300–1800	Low	600	Oil, gas, char
Fast	0.5–5	Very high	650	Bio-oil
Flash-liquid	<1	High	<650	Bio-oil
Flash-gas	<1	High	<650	Chemicals, gas
Ultra	<0.5	Very high	1000	Chemicals, gas
Vacuum	2–30	Medium	400	Bio-oil
Hydro-pyro.	<10	High	<500	Bio-oil
Methano-pyro.	<10	High	>700	Chemicals

developed and controlled combustion chambers [74]. The sulphurized-bed combustion chambers are one of the few reported chambers optimized for biomass combustion [75,76]. The most advanced form of this technique involves the chambers designed to maximize the intensity of thermo radiation and reflection in the combustion chamber under reduced oxygenation conditions while limiting the loss of complete combustion and thermal energy, which is usually lost as smoke [74]. This modified process is called gasification and is characterized with increased efficiency and more specified and valuable products [76]. A major disadvantage of this technique is their relatively high pollution levels compared with other biomass process techniques [77].

5.2. Pyrolysis

This process involves a series of thermochemical modification of biomass which releases valuable gases and chemicals from biomass. Biomass pyrolysis is generally defined as the thermal decomposition of biomass feedstock in the absence of oxygen [78,79]. It is a very cost-effective method of managing solid biomass wastes for which corncob has been optimized overtime for the production of fuels [80,81]. Bio-oil and gas fuels that are major products of this process mainly consist of CO, CO_2, H_2 and CH_4 [81,82]. As shown in Fig. 5, they can be made to undergo extra steps such as steam reforming, catalytic upgrading in order to improve their physical and chemical properties reminiscent of expected and acceptable standards of economic and environmental friendly fuels and commodities. The mechanism of pyrolysis has continued to see overall product-related improvements all of which relates to varying temperature, residence time and heating rate [74,83]. Common techniques with characteristic process conditions and products are shown in Table 2.

Efficiency of gasification is highly dependent on feedstock biocomposition. For example at 80% efficiency for multiple wastes was reported by Manya et al. with $>90\%$ of energy recovering rate from rice straws and corncob [74,84]. The yield is very promising, thus providing a strong basis for the continued application and development of this biomass processing technique.

5.3. Liquidation of biomass

Biomass liquidation is a combination of various techniques designed to extract chemical components from biomass. It generally requires relatively less harsh methods than gasification, but proceeds at relatively slower rates for feasible yields. Biomass has a very organized structure characterized by a rigid cell wall matrix which makes a preconversion treatment step very necessary in liquidation process [85]. Pretreatment could be, but not limited to, mechanical, thermochemical and biological, and bio/chemocatalytic systems that are generally explored for the hydrolysis and fermentation of resulting sugars to alcohols and organic acids as shown in Fig. 5. Fermentation has seen a lot of technical developments, with good yields, in different parts of the world. Advancements with techniques involve continuous digestion setups, multiple stage distillation and extra anaerobic digester for waste effluents [86]. Improvements in this technology have increased the potentials of a much lowered cost of production for bioenergy and biocommodities, although major challenges with the physiological limitations of biocatalysts still hinder this development. Cell-free biosystems functionalized with cheap, genetically constructed biocatalysts are being considered as the next technological phase on-scope and as such are currently seeing a lot of research effort [87].

6. Problems facing the beneficiation of corncob and sugarcane bagasse

In most developed countries, waste biomass is of high value with respect to material and energy recovery; however, developing countries such as Nigeria and South Africa are still lagging in harnessing the beneficial usage of the waste biomass [8]. Furthermore, limited research effort has been channelled to the utilization and optimization of waste biomass as a way to manage agricultural waste and convert it into a material resource [72]. Findings of Babalola et al. [88] and Agwu [89] revealed that current waste management approaches in Nigeria are inefficient [88]. Adejobi and Olurunnimbe [90] reported that the volume of waste generated in Lagos (Nigeria) does not actually constitute major environmental problems, but the inability of the government, the individuals and the waste disposal agencies to keep up with the task of proper and efficient management of waste, constitutes the burden of environmental management. There is a lack of awareness and capacity to convert most of the waste for material development and energy recovery [91]. Although there is an emerging trend in the use of biomass as renewable energy, most developing African countries that rely largely on agricultural food production are still under-utilizing biomass produced from this industry

[15]. Waste beneficiation is an effective way of addressing waste disposal problems in Nigeria and South Africa. Researchers have summarized the challenges faced by developing countries such as Nigeria and South Africa on waste disposal as follows:

- Lack of comprehensive legal framework and enforcement of the existing regulation.
- Low investment (private) in infrastructure.
- Inadequate human capacity for administrative and technical issues.
- Wrong attitude of the public towards solid waste disposal.
- Financing: Cost recovery is low in most states and no funding.
- Poor planning: low data management and uncontrolled urbanization.
- Uncoordinated institutional functions.
- Low academic research and industry linkages and lack of expertise.
- Lack of political interest and government support. [15,91–94].

6.1. Situation in South Africa

There have been efforts to convert corncob and sugarcane bagasse for energy generation in South Africa.

There are currently a lot of laboratory-scale studies in South Africa where corncob has been used as feedstock for bioenergy generation including production of bioethanol, bio-oil and platform chemicals in order to test its feasibility as biomass potential and most of the outcomes are promising [16,27,95,96]. South Africa could benefit greatly from utilization of corncob on a large scale.

Currently sugarcane bagasse is burnt to generate electricity and heat for own use at the sugar mills at very low efficiencies; this is basically practiced as a way to dispose surplus bagasse [97]. The power produced per sugarcane processed is estimated to about 23.5% efficiency [98]. If optimized, the sugar industry could produce 2–5 times more power, have less steam-to-higher energy efficiency and export energy to the national grid (ESKOM) [34,99]. The sugarcane produced annually for the South African Sugar Industry has the potential to produce 960 MW of energy per year [99]. Implementation of energy conservation and efficiency measures is essential for the sugar industry to generate electricity for own use and national grid [30].

South African sugar industry can improve their efficiency greatly by reducing the moisture content of the bagasse through drying and pelletization [100]. The peak season for sugarcane production in South Africa is from April to December and this indicates increased power production during peak season with enough supplies for the rural areas of Kwa-Zulu Natal and Mpumalanga. Because sugarcane cultivation is a yearly activity, this will ensure sustainable renewable energy provision to these communities [34]. Feasible cogeneration of electricity will improve also revenue generation for the sugar industry [15] that could potentially result into about 57,500 direct and 26,200 indirect job creations [101]. This could improve also the South African economy directly and indirectly because it has been estimated that the overall GDP production of ethanol from sugarcane currently contributes 0.06% to the national GDP [50].

Despite the efforts put in place to beneficiate corncob and sugarcane bagasse for energy generation in South Africa, there is need for process optimization to strike a balance between volume of waste produced and energy generated from it. Generally corncob and sugarcane bagasse are combusted to produce energy in South Africa, but the resulting ash still constitutes a waste that can be beneficiated by using the ash as reinforcement materials for the development of composite materials and of course in cement production.

6.2. Situation in Nigeria

Information on the use of corncob for bio-energy generation in Nigeria is scarce despite her position as the second largest producer of corn in Africa. Corncob is only used for domestic cooking in rural areas and substantial amount is allowed to decay in the soil. Although there have been research efforts to use corncob in the development of new materials, corncob stands as a great source of energy generation. Ogunjobi and Lajide [102] reported that bio-char produced from corncob via pyrolysis is capable of contributing 83.6 billion MJ to energy demand in Nigeria and preventing about 6.8 million tonnes of CO_2 emission into the environment. Nigeria has serious energy crisis which ensued from too much dependence on crude oil and natural gas as the sole source of energy generation. Therefore other potential energy sources must be harnessed in order to solve this problem.

7. Summary and future outlook

Nigeria and South Africa are the largest economies in Africa. The contribution of agriculture to Nigerian economy is much more significant when compared to that of South Africa. Corncob is biomass generated from both Nigeria and South Africa in large quantities and can be utilized in wastewater treatment, fuel cell, energy generation, cement and concrete industries, reinforcement materials and building materials. Sugarcane, unlike corn, is majorly produced in South Africa with Nigeria mapping out plans to increase productivity in the future. Sugarcane bagasse is used majorly in South Africa for energy generation in sugar processing companies. Few research activities carried out on the beneficiation of sugarcane bagasse in Nigeria have shown that sugarcane bagasse ash can serve as reinforcement in the development of composites materials. There is a need for extensive research to be carried out in Nigeria and South Africa on the beneficiation of corncob and sugarcane bagasse for several other applications. The few research findings that have been reported within and outside the continent on the use of corncob and sugarcane bagasse should be optimized and expanded to industrial scale. This will help solve energy crisis, waste disposal problems and environmental hazards posed by these wastes. It will also pave way for the manufacturing of affordable construction/structural materials. The problem of unemployment will be greatly alleviated as people can be engaged in the collection of waste biomass from the environment for use by industries that will transform them to valuable materials.

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