

Cassava Mill Effluents Recycling through Bioenergy Production: A Review


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ISSN: 2578-0336



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Submission:  June 5, 2018

Published:  May 09, 2019

Volume 5 - Issue 4

How to cite this article: Izah SC. Cassava Mill Effluents Recycling through Bioenergy Production: A Review. *Environ Anal Eco stud.* 5(4). EAES.000618.2019. DOI: [10.31031/EAES.2019.05.000618](https://doi.org/10.31031/EAES.2019.05.000618)

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Abstract

The processing of cassava tuber into finished products such as gari generates large wastes water. The effluents are known to contain cyanide and acidic pH in addition to other chemical characteristics such as heavy metals, chemical oxygen demand among others. The effluents have toxicological impacts on the receiving ecosystem (Soil and Surface Water) as well as some of its associated fauna and flora. During degradation processes by the indigenous microbes in the soil, the effluents emits odour that are offensive to human. This study reviews recycling options of cassava mill effluents through bioenergy production. The study found that cassava mill effluents have demonstrated positive potentials for biogas, biohydrogen, bioethanol, bioelectricity using varying technologies. During bioenergy production, the characteristics of the raw effluents is improved upon in some of the parameters such as chemical oxygen demand, total solid, pH etc probably due to the activities of some microorganisms. As such, there is the need for research to focus on other possible utilization of the sludge generated such as bio-fertilizer production as an option for reuse.

Keywords: Bioenergy; Biotechnology; Cassava wastewater; Environmental contamination; Reuse; Toxicology

Introduction

Environmental degradation associated with greenhouse gases mainly include methane and Carbon Dioxide and to lesser extent Hydrofluorocarbons, Perfluorocarbons and Sulphur Hexafluoride have been implicated to cause global warming [1]. Combustion of petroleum products also release diversity of emissions depending on its physical constituents. Combustion of biomass also release particulates and gaseous emissions [2,3]. Typically, some greenhouse gases can also be emitted from unsustainable discharge of wastes resulting from food processing under anaerobic conditions. To these effects, Ohimain Izah [1] reported the potential contribution of palm oil mill effluents to climate change in Nigeria. Studies have also shown that most biomass have bioenergy potentials.

According to Jekanyinfa and Bamgboye [4]; Ohimain and Izah [5], energy is a vital resource required by human for the survival of the economy. Energy is used in different forms including heat, electrical, mechanical and human energy [5]. Till date natural gas and petroleum are the most widely utilized energy sources accounting for over 50% of world energy requirements [6]. Ohimain [7] also reported that no other energy sources are as flexible as petroleum products. As such most of the global energy is meant through petroleum products. According to Atadashi et al. [8], approximately 86% of global transportation fuel is provided by non-renewable energy sources such as petroleum. Furthermore, the demand of energy has been on the increasing trend probably due to an upsurge on global population [9,10].

Probably due to the challenges of fossil fuels including its environmental impacts, several countries including Nigeria have embarked on suitable alternative for the petroleum-based fuel. Biomass has emerged as possible replacement [10,11]. Several biofuels has demonstrated good prospects for optimization and possibly commercialization. To this effects Bioethanol, Biogas, Biohydrogen etc have yielded possible results though research and development. In many parts of the world, bioethanol and biogas have been commercialized but they are also challenged by choice of feedstocks. For instance, in the production of bioethanol first generational feedstock which are basically food crops has food versus fuel crises. Hence research focused on the use of non-edible grasses and lignocellulosic wastes materials for production.

Several grasses such as elephant grass [12] wild Sorghum [13] etc have demonstrated possible potentials for bioethanol. Several wastes materials have been demonstrated for Biohydrogen, Bioethanol, Biogas, Bioelectricity production under varying conditions. Nigeria is the leading cassava producer in the world accounting for over 20% of total output on global scale [14-25]. Typically, cassava is a staple food in Africa [23,26]. Cassava is among the widely consumed food in West African region in addition to maize and rice. Zhang et al. [14] reported that cassava is the 4th source of dietary carbohydrate energy crop with energy content of 720 x10¹²KJ/day. The authors reported that cassava ranked 5th and 3rd among starch crop on global production and source of carbohydrate for human consumption, respectively.

Approximately 60%, 33% and 7% of cassava produced on global scale is consumed as food (Gari, Fufu), animal feed and industrial purposes (viz: textile, paper, food, and fermentation industries, among others) respectively [14,26-28]. But in developing country like Nigeria, about 80% of cassava tubers produced are predominantly used for production of food especially gari (about 60%) and to lesser extent fufu, Lafon, etc (about 20%), while the rest 20% are used industrially. Some of the notable areas of utilization include Livestock Feeds, Confectionaries, Monosodium Glutamate, Sweeteners, Alcohol, Adhesive, Glues, Textiles, Soup Thickener, Laundry and Pharmaceuticals [29-31].

Cassava has also been utilized for the production of bread at certain percentages [32,33]. Cassava has also gained attention for bioethanol production [34-37]. Though, the utilization has not yielded the desired result. During processing of cassava tuber into gari three major wastes streams including seiviate, peels (Solid), gaseous emission (Air Pollutants) and cassava mill effluents (Liquid Wastes). The solid wastes such as cassava peels seiviates are source of food to some domestic animals such as goat. Though Ubalua [38] considered cassava processing wastes especially the waste water to contribute to environmental pollution and aesthetic nuisance.

The cassava mill effluents are toxic to the environment and has the tendency to alter the receiving soil characteristics [16-18,23,24]. The impacts have been widely documented in literatures. Hence there is need for sustainable management practices of this waste stream. Therefore, this study focused on the bioenergy potentials of cassava mill effluents as sustainable options for avoiding the toxicological impacts associated with cassava mill effluents.

Environmental Impacts of Cassava Mill Effluents

Cassava mill effluents contain total solids, heavy metals, total suspended solid, cyanide, acidic pH, high chemical oxygen demand, total dissolved solid and conductivity. Studies have indicated that the physiochemical characteristics of the effluents sometimes exceed the limits specified by Federal Environmental Protection Agency, Nigeria for effluents to be discharged into the environment [19,20,23]. The characteristics of the effluents are known to be injurious to the environment and some of its associated fauna. The cassava mill effluents are known to impacts of the three major components of the environment including air [39,40], soil [16-18,23,24,41,42] and water quality [43-46].

Ero and Okponmwense [40], Derek [47] reported some of the challenges of odour pollution to include breathing and sleeping difficulty, coughing, stomach discomfort and loss of appetite, eye, nose and throat irritation, disturbance from external environment, annoyance etc. Furthermore, cassava mill effluents could cause an alteration in the quality of receiving soil and surface water with regard to their physicochemical and microbial characteristics. According to Uhegbu et al. [48], cassava mill effluents with leads to alteration on some food crops (viz: *Dioscorea dumetorum* (Domestic Yam), *Dioscorea dumetorum* (Wild Yeam), *Dioscorea rotundata* (White Yam), *Dioscorea alata* (Water Yam), *Xanthosoma sagittifolium* (Red Cocoyam), *Colocasia esculenta* (White Cocoyam), *Ipomea batatas* (Red sweet potato), *Ipomeabatatas* (White sweet potato) with regard to the cyanide content.

Hence the consumption of food resources cultivated it cassava mill effluents contaminated soil may have some health implication because of the lethal nature of cyanide in soil. On aquatic ecosystem, cassava mill effluents are known to affects histopathological, haematological, enzymes, behavioural response, mortality etc in exposed fish [13,49,50]. The toxicity potentials of cassava mill effluents may be associated with the cyanide content [23], which have been described as respiratory poison that could kill fisheries [49]. In soil, raw cassava mill effluents have been reported to kill some vegetation cover (viz: *Sida acuta*, *Mimosa pudica*, *Euphorbia hirata*, *Tridax procumbens*, *Chromelaena odorata*) to some extent [51].

Authors have also reported that cassava mill effluents could inhibit plant germination and growth [52-54]. Probably due to nutrient potentials of cassava mill effluents on surface water it could lead to eutrophication [23], thereby enhancing the growth of aquatic plants and marsh transformation [40]. The eutrophication could reduce oxygen content in water thereby causing behavioural response and enhancing mortality rate of aquatic organisms. Soil receiving cassava mill effluents have been reported to have lower microbial load [15,23,55].

This could be due to the cyanide content of the cassava which is lethal to some microbes. Environmental risk have been carried out in soil receiving cassava mill effluents in a rural community and result showed low to moderate contamination level in wet and dry seasons apart from lead that had considerable pollution in one of the locations for wet season for contamination factor and degree of contamination for iron, chromium, zinc, copper, cobalt, nickel, manganese, lead and cadmium [18]. The authors further reported that the pollution load index for these metals were within no pollution to moderate pollution, Nemerov integrated pollution index were within warning line of pollution to low level of pollution during the dry season and warning line of pollution to high pollution in wet season, while the metal pollution index and average pollution index showed slight pollution.

Enerijiofi et al. [55] reported that Potassium, Sodium, Copper and Calcium showed high contamination; Magnesium, Iron and lead showed considerable contamination, Zinc, Manganese, Nickel, Cadmium, Vanadium and Chromium showed moderate contamination for contamination factor; and Potassium, Sodium,

Copper and Calcium showed high contamination, Zinc, Manganese, Nickel, Cadmium, Vanadium and Chromium showed moderate pollution and Magnesium, Iron and lead showed low pollution status based on index of geo-accumulation in cassava mill effluents contaminated soil.

Izah et al. [17] also reported iron, chromium, zinc, copper, cobalt, nickel, manganese, lead and cadmium in soil receiving cassava mill effluents to show un-contamination to moderate contamination for Index of geo accumulation, background rank to significant enrichment for enrichment factor and no enrichment to moderate enrichment for metal enrichment index, and pollution based on quantification of contamination. Izah et al. [24] showed low ecological risk in the soil for both wet and dry season.

Bioenergy Potentials of Cassava Mill Effluents

Several technologies have been demonstrated potentials toward effective management of cassava mill effluents through biotechnological advancement. To this effect, cassava mill effluents have been shown to be used for bio-surfactant production [56,57]. The effluents are used as source of medium for the cultivation of *Saccharomyces cerevisiae* biomass [21,22,25,58,59], volatile fatty acids [60], enzymes, organic acids, bioenergy etc. Energy is typically one of the fundamental requirements for human existence. Biofuel from biomass is gaining prominence as many countries in including

Table 1: Bioethanol production from cassava mill effluents.

Aim/Methodology	Findings	Implication	Reference
Ethanol production potential of cassava waste water using <i>Saccharomyces cerevisiae</i> in acid and enzyme hydrolysis	Hydrolysate of 3.60 and 1.88% (v/w) ethanol in acid and enzyme process was observed when the pH was adjusted. Ethanol yield of 3.61 and 2.91% (v/w) for acid and enzymatic process respectively was generated in 3 days old cultures	CME can be used for bioethanol production	[66]
Ethanol production from cassava waste water using <i>Zymomonas mobilis</i> and <i>Saccharomyces cerevisiae</i> isolated from rafia palm sap.	Results showed maximum ethanol was produced after 48h of fermentation using <i>Zymomonas mobilis</i> for acid (15.0% v/wt) and enzymatic (16.5% v/wt) hydrolysates. Similarly, 2.9 and 2.84(%v/wt) ethanol were produced in acid and enzyme hydrolysates respectively using <i>Saccharomyces cerevisiae</i>	CME can be used for bioethanol production and	[67]
Bioethanol production from CME using Bakers' yeast (<i>Saccharomyces cerevisiae</i>) through separate hydrolysis and fermentation techniques.	Results should ethanol concentration, yield, density and fermentation efficiency of 0.28-0.46%. 0.11-0.25 Yp/s, 0.9172-0.9562 and 22.33-48.55% respectively for 1-7 days fermentation period	Ethanol can be produced from CME	[35]
Ethanol produced from cassava waste water as a potential source of gasoline blend (7%, 10%, 20% and 30%) for automobile fuel	Results showed that the ethanol blend processes conform to the American Standard of Testing and Material. Ethanol yield was 19.96% with specific gravity of 0.8638. The blending showed varying volumetric ratios which generally increased the volatility of the fuel.	Ethanol produced from cassava waste water as a potential source of gasoline blend for automobile fuel through fermentation and distillation.	[68]

Recently, the use of waste for ethanol production have been encouraged as a sustainable means of preventing the attendant environmental impacts associated with them. Bioethanol production offers a sustainable approach to manage cassava mill effluents [35,66-68]. Bioethanol production from cassava mill effluents could be through direct microbial conversion using acid resistant strain of yeast. Table 1 presents finding from ethanol production from cassava mill effluents. The conversion of cassava and its processing wastes have been established in literatures.

Nigeria is seeking to substitute conventional fuel with biofuels such as biodiesel, bioethanol and biogas.

In recent time energy is produced from biomass including animal and plant resources. Food and agricultural processing activities lead to generation of several wastes stream, which have been reported to have bioenergy potentials [35]. For instance, cassava mill effluents which is one of the largest food processing wastes in Nigeria has bioenergy potentials. As such the organization of this section of the paper is mainly on different bioenergy products that could be generated from cassava mill effluents.

Bioethanol

Ethanol is a typically example of an oxygenated fuel that has tendency to replace gasoline [61,62]. This is probably due to its high-octane number [63] and low emission with regard to pollutant gases. Furthermore, due to its environmental benefits its used as blend for gasoline. Many nations have approved certain ethanol blend in conventional fuel including Nigeria (E10) [37]. Bioethanol is produced via different technology depending on the nature of the feedstock. According to Brooks [64], Dhabeekar and Chandak [65] bioethanol production from agricultural feedstock depends largely on the use of ideal microbial strain, suitable fermentation substrate and process technology.

Specifically, several technologies for conversion of carbohydrate crops such as cassava to ethanol have evolved.

But to this regard several attempt to produce ethanol with high yield following hydrolysis and fermentation of carbohydrate from cassava waste water have been made [14]. The production of ethanol from cassava mill effluents has been widely carried out using *Saccharomyces cerevisiae* [11]. In addition, studies have suggested that several internal conditions (constituents of the effluents, choice of microbes, sugar contents of the waste,

configuration among others) and environmental factors (time, temperature, pH etc) affects yield of ethanol from wastes feedstock.

Biobutanol

Biobutanol have been reported to be a promising fuel for vehicles. This could be due to their high-octane number and energy content, low volatility, and improved air-to-fuel ratio similar to gasoline [14]. Like ethanol, butanol production through fermentation has a long historical origin. According to Zhang et al. [14], cassava tuber and its processing waste water is a promising lignocellulosic feedstock for acetone-butanol-ethanol production. The authors further reported that cassava bagasse hydrolysate is also a good substrate for n-butanol during acetone-butanol-ethanol fermentation processes.

Ouephanit et al. [69] reported that biobutanol and ethanol can be produced from tapioca starch wastewater using *Clostridium spp*

Table 2: Biogas production from cassava mill effluents.

Raw Material and Duration	Findings	Implication	References
Biogas and biofertilizer production from cassava wastewater and cassava peel in a ratio of 3:1 after 21 days of fermentation	Biogas was produced after 3 days of charging. In addition, a rich bio-fertilizer (nitrogen, phosphorus, potash and potassium) was produced due to increase as fermentation continues and a significant reduction of odour level within the <i>gari</i> processing	Cassava mill effluents is a suitable raw material for biogas production while generating biofertilizer	[76]
Biogas Production from Cassava Starch Effluent Using Microalgae as Biostabilisator in a semi-continuous process	Result showed biogas production from cassava wastewater with microalgae enhanced after yeast, ruminant bacteria and was added.	Total solid from cassava mill effluents stabilized with microalgae increase. Biogas increase with addition of biostabilisator	[77]
Biogas production from cassava mill effluents supplemented with biodiesel processing waste using anaerobic hybrid reactor	Result showed that supplementation of biodiesel processing waste water to cassava mill effluents at 0.5-2.0% can elevate to 19.4-96.2% and 13.4-56.7% for biogas and methane production respectively.	Cassava mill effluents can generate biogas when biodiesel producing wastes in added	[78]
Specific Methanogenic Activities and Biogas Production of cassava granules Size and wastewater	Result showed that granules size ranged of 1.5-1.7 mm and Specific methanogenic activities of 0.28 gCOD/gVSSd. The methane potential of cassava wastewater 161.12 mlCH ₄ /gCOD	Cassava mill effluents is a potential substrate for biogas production	[79]

Cassava mill effluents are also a good substrate for biogas production [76-79], with or without the use of bio stabilator. Table 2 present the findings of authors for biogas production using cassava mill effluents substrate. In addition, Paixao et al. [80] reported methane yield of 14.4l/d at temperature of 25 °C in hybrid reactor under certain conditions. Auphimai et al. [81] reported methane yield of 271.0-290.0ml CH₄/g COD using batch reactor at temperature of 37 °C. During biogas production from cassava mill effluents, the resultant sludge is rich in potash, nitrogen, phosphorus and potassium. As such they can be used as biofertilizer [76].

According to Zhang et al. [14], co-digestion with manure can aid in maintaining an optimum pH for the methanogenic microbes, reduction in free ammonia/ammonium inhibition, enhancing optimal Carbon to Nitrogen ratio for effective digestion. To this regard, Ren et al. [82] reported that co-digestion of pig manure and cassava dregs enhance the population and diversity of methanogens during biogas production. Working conditions are affected by pH and temperature (environmental factors), organic loading rate, hydraulic retention time, microbial activity, pressure, nutrient level and composition, chemical equilibrium, mixing of effluent etc (internal factors) [1,9,70,73].

through fermentation processes. The authors also reported that the butanol (and combined butanol plus ethanol) production level was improved at pH 5.5 for both strain of bacteria (*Clostridium butyricum* TISTR 1032 and *Clostridium acetobutylicum* ATCC 824).

Biogas

Biogas is produced from several technologies that principally involve either aerobic or anaerobic digestion. Biogas production using anaerobic digester has gain prominence and has been widely studied. For instance, different configuration of digester used for biogas using palm oil mill effluents has been recently reviewed by Ohimain and Izah [70]. Biogas approximately consists of about 65% methane and 35% carbon dioxide under anaerobic system [9]. Biogas is a colourless, odourless, inflammable and combustible fuel [70-72] Biogas is produced by four major steps like hydrolysis, acidogenesis, acetogenesis and methanogenesis [1,9,70,73-75].

Studies have shown that biogas produced from wastewater has combustion characteristics. In addition, biogas is environmental, economic and socially sustainable. Biogas produced from cassava mill effluents could be used for both heat and power generation. The utilization of cassava mill effluents for biogas production could prevent the attendant environmental impacts associated with the wastewater.

Biohydrogen

Hydrogen has been regarding as fuel for the future. Biohydrogen can be diversely applied in different sectors including power generation and as transportation fuel. Hydrogen from can be produced from biomass through several technologies including fermentation (with the aid of photosynthetic and chemosynthetic bacteria), electrolysis of water, steam reformation of methane, thermocatalytic reformation [83-85]. Through fermentation, biohydrogen can be produced through light depended (photo) and light independent (dark) processes [83].

Microbes such as phototrophic indigenous purple non-sulphur bacteria (*Rhodospseudomonas palustris* PBUM001) [86],

Thermoanaerobacterium species [87,88], *Clostridium butyricum* EB6 [89,90], *Clostridium acetobutylicum* [14] have been employed for biohydrogen production at varying fermentation processes. According to Lam & Lee [74], light independent fermentation processes are favorable due to the utilization of Bacillus, Enterobacter, Clostridium species during acidogenesis. Typically, biohydrogen typically involves acidogenesis (conversion of monomers to intermediaries such as volatile fatty acids) and methanogenesis (conversion of volatile fatty acids to methane).

Carbohydrate-rich substrate have been widely reported as potential feedstock for biohydrogen production through fermentation [14,83]. The potentials of cassava feedstock for biohydrogen production have been reported in literature. In addition, waste rich in carbohydrate is ideal substrate for the fermentative hydrogen production. Thong et al. [91] reported hydrogen yield of 124.9-287mLH₂/g starch at thermophilic temperature of 60 °C using continuous stirred tank reactor. Sreethawong et al. [92] reported hydrogen yield of 438mL H₂/g COD removed at 37 °C under anaerobic sequencing batch reactor. Amorim et al. [93] reported hydrogen yield of 1.91mol H₂/mol glucose at approximately 28 °C using anaerobic fluidized bed reactor.

Like biogas, several environmental parameters such as temperature, pH, and other operational conditions affects the yield [94-96], carbon to nitrogen and carbon to phosphorus ratios [14],

in addition pre-treatment such as acidic and alkaline conditions enhance the yield of hydrogen [14,97]. Specifically, acidic condition enhance the release of soluble carbohydrate while alkali condition stimulate soluble total organic carbon [14,97].

Bioelectricity using microbial fuel cells

Microbial fuel cell is a bio-electrochemical device that utilizes microorganisms to general electrical current from waste water i.e., effluents. Microbial fuel cell has the ability to transform chemical energy found in organic compounds into electricity via the catalysis of microorganisms [98,99]. As such it's a promising alternative energy source and wastewater treatment [100-105]. Due to the architectural design of microbial fuel cells it has received attention in other field including engineering (mechanical, chemical and environmental biotechnologist in addition to microbiologist [98]. Over the years, significant improvement has been made on the optimization of microbial fuel cell technology for the treatment of effluent while generating electrical current.

Several substrates can produce electricity using Microbial fuel cell technology, while reducing the pollution potential of such wastewater. Cassava mill effluents is a potential substrate for electricity generation using microbial fuel cells [106-108]. Table 3 present electricity generation from cassava waste. During electricity generation from the wastewater, the chemical oxygen demand is reduced.

Table 3: Bioelectricity generation from cassava mill effluents using microbial fuel cells technology.

Aim/ Methodology	Findings	Implication	Reference
Treatment of cassava waste water while generating electricity using mixed culture sludge in a sediment battery technique of microbial fuel cells	The results revealed that the microbial fuel cells could generate electricity from full-strength wastewater (975mg-COD/L) with the maximum voltage and power density of 174.17mV and 1820.10mW/m ² when the feeding rate of 5ml/min	Cassava waste water is a potential substrate for bioelectricity generation	[106]
Mixed culture sludge was used as inoculum at the bottom chamber in microbial fuel cells to treat cassava waste water while generating electrical current	Results showed that the microbial fuel cells could generate electricity from full-strength cyanide laden wastewater (16000mg-COD/L, 86mg/L cyanide) with a maximum power density of 1771mW/m ² .	Cassava waste water could generate electricity while reducing the chemical oxygen demand content	[109]
Solid-liquid separation, ultrasonication, pre-fermentation and anode-aeration were used to enhance the efficiency of power generation and pollutants removal from cassava waste water.	Results showed that pre-fermentation has superior efficiency with maximum power density of 437.13mW/m ² and TCOD removal of 62.5%.	Pre-fermentation coupled with halfway anode aeration is a viable approach for power generation and pollutants removal from the cassava wastewater	*[107]
Cassava wastewater with a chemical oxygen demand value of 32,000mg/L was subjected to pretreatment using sonication and α -amylase in a double chamber microbial fuel cell.	Results showed average maximum power output from cassava wastewater subjected to pretreatment with α -amylase and no treatment has voltage of 9861mV and 7159mV respectively. Higher chemical oxygen demand reduction was observed in both sonication and α -amylase compared to the control	Cassava waste water can generate electricity and reduces it chemical oxygen demand values using microbial fuel cells	[108]
Electricity generation from cassava waste water in a flour factory using single chamber microbial fuel cell in a batch mode, with chemical oxygen demand value of 1,086 - 50.06mg/L at alkaline pH and temperature at 30 °C.	Results showed maximum power density of 22.19 W/m ³ and 16.70W/m ³ at pH 9.0 and 8.0 respectively. Also maximum of coulombic efficiency of 47.8% was achieved at pH of 9.0.	Cassava waste water could generate electrical current at alkaline condition while reducing the chemical oxygen demand value	[110]
Electricity generation from cassava mother liquid using potassium ferricyanide as electron acceptor in a mediator-less double chamber microbial fuel cell.	Result showed maximum current of 2.28A with a potential difference of 1.32V.	Cassava mother liquid can generate electricity and a sustainable approach for its management	[105]

Conclusion and the Way Forward

Cassava mill effluents is a liquid waste generated during cassava processing into gari. In Nigeria, over 80% percent of cassava processing are handles by small-scale processors that typically use hydraulic presser to remove the water from the bagged mashed cassava. The effluents are discharged in the environment with little or no treatment. The toxicological impacts of cassava mill effluents have been reported to affects some domestic animals (sheep and goats), fisheries, plant growth and productivity. Furthermore, environmental risk assessment has shown that cassava mill effluents have some level of contamination in the receiving soil [108-110].

Hence, there is the need for sustainable management practices, this study found that bioenergy is a potential means through which the attendant environmental impacts of the waste can be curtailed. As such, there is the need for research to focus on means for collecting all the cassava mill effluents from the various processing mills for bioenergy production. In addition, the sludge generated during bioenergy production biohydrogen, bioelectricity, bioethanol, biogas should also be studied for other downstream applications such as bio-fertilizer.

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