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Biomass Renewable Energy Production from Corn Cobs Feedstock Gasifier as Energy Constituent in Internal Combustion Engines (ICEs)

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Abstract: Biomass gasification is a chemical conversion of solid biomass renewable energy constituents into a gaseous combustible substance often regarded as producer gas through progressive thermochemical synthesis. The gasification method produces gas fuels required for power generation which is considered the best alternative to fossil fuels that accounted for 80% of domestic energy and industrial consumption with consequential impressions on global warming and greenhouse effects. In the current research, the biomass gasification system were used to produce electricity from the chemical energy contained in organic recyclable agricultural waste (Corn Cob) used as feedstock gasifier in the energy conversion process. Corn Cob feedstocks renewable organic materials produced from plants were used to synthesize the syngas that contained the electrical energy required to power the internal combustion engine. The utilization of pure hydrous or anhydrous ethanol in internal combustion engines is the direct lignocellulose bioconversion of Corn Cob requiring microbial fermentation, thermochemical pre-treatment test, designed to accelerate enzymatic hydrolysis of cellulose into fermentable sugars, varying the temperature conditions to produce maximum production of biofuel on an industrial scale to drive the internal combustion engine. The current research utilized biomass energy to generate 150 KW worth of electricity from biomass gasification process, utilizing Corn Cob feedstock gasifier to generate electric power for rural electrification.

Keywords: Biomass Gasification, Corn Cob Feedstock, Bioenergy, Renewable Energy, Syngas, Internal Combustion Engine

1. Introduction

The desire to reinvent new energy mix in the current twenty first century digital economy had pushed the world to commence gradually the move from consumption of fossil fuel to sustainable renewable energy resources [1]. The 26th United Nations Climate Change Conference (COP26) held at Glasgow 2021, proposed measures towards securing the global net zero carbon emissions, sustaining the 1.5°C temperature increase target towards protecting the environmental ecosystems and resource mobilisation, comprising 197 signatories made up of government officials, businesses and environmental activists, reemphasizing the goals of the 2015 Paris Agreement on environmental protection. Combating the threatening climate change, requires taking measures to counterbalance the emission of carbonaceous substances and reinventing alternatives to fossil fuels globally [2]. To that effect, so many countries have formally shown commitment to 2015 Paris Climate Agreement towards lowering the carbon emissions by setting up new standards and formulating new energy policies to ensure compliance. Pre-emptive measures will require reduction of global carbon emissions by 40 percent before 2030, as countries policy makers recognized such vulnerability situations of energy use and greenhouse gas emissions for them to take proper and timely actions to cope with the threats of climate change which can occur anytime in the nearest future [3]. The global warming account for the mounting global temperatures in line with increase in the concentrations of greenhouse gases in the atmosphere, which include carbon dioxide, methane, nitrous oxide, water vapour and fluorinated synthetic gases [4]. The consequences of global warming are straightforwardly attributable to human activities with respect to burning of fossil fuels like natural gas, coal, oil and gasoline which had promptly resulted into greenhouse gas effect.

The intensification in energy related carbon dioxide emissions have been on the increase in the United States of America's transportation sector with 29 percent gaseous emission, followed by electricity production 28 percent and industrial activity 22 percent, which is significantly high pollutant emissions from the global perspective [5]. The global deliberations over the climate change had predominantly focused on the developed countries where the activities responsible for global warming and greenhouse gas effect are prevalent, when compared with the emission levels permissible for the world assessment goals of the Paris Agreement [6]. In the international deliberations over the management of the climate change effects, the developing countries so far have shouldered a small number of responsibilities when juxtaposed with its counterpart in the developed countries. In the Kyoto Protocol which was implemented on 11 December 1997, the agreement operationalized the United Nations Framework Convention on Climate Change by obligating the developed countries and economies in transition to moderate greenhouse gases emission in harmony with acceptable country-wide peculiarities [7]. Along with the causes of global warming, and the obligations which were adopted at the Kyoto Conference, it was recognized that individual countries have diverse experiences in contending climate change, on the premise of varied economic developments and therefore placed priorities of reducing the current gaseous emissions on the industrialized countries for being responsible for the current levels of greenhouse gases atmospheric pollution [8]. In addition to Kyotol Protocol, the Paris Agreement was adopted by approximately 190 countries and the European Union (EU) in 2015 to address the undesirable consequences of the global climate changes. The Paris agreement covered approximately 97% of global greenhouse gas emissions as commitments were made from all major greenhouse gaseous emitting countries with the mandate to lower their carbonaceous gas emissions, together with the intending obligations [9].

Consumption of fossil fuel and gaseous substances amounted to over 75% of energy demand in Nigeria, which also pointed that the country is at risk of greenhouse gaseous effects vulnerability [10]. Taking into consideration the dependency on fossil fuel and possibility of it running out in the nearest future, coupled with the environmental and atmospheric pollution, there is need for urgent reinforcement to harness other sustainable alternatives toward generating energy in Nigeria. Rural electricity generation and distribution have been unsatisfactory in Nigeria ever since independence, which have been among the major factors hindering economic growth and industrial sustainability [11]. The limited electricity generation and distribution have constrained human development potentials, commercial business activities, industrial productivity and economic growth of several resourceful expansion programmes and projects introduced by United Nations Industrial Development Organization (UNIDO) in Nigeria [12]. The UNIDO is a specialized agency of the United Nations that assists countries in economic and industrial development plans which the successive administrations in Nigeria had partnered to revitalize the industrial landscape in line with the government's goal of evolving among the topmost 20 developed economies in the world by 2020 which unfortunately had failed to meet target due to certain unattainable objectives including rural electricity deficiencies [13].

To that effect, the current research have approached the development in two ways through inventing a sustainable biomass renewable energy for rural electrification which will also counterbalance the greenhouse gaseous emission effects. Biomass gasification is a renewable energy technology conduit that utilized a coordinated processes requiring heat energy, steam and oxygen to convert biomass solid waste into syngas, methane, water, nitrogen and other bye products without combustion [14]. Ideally, gasification process transforms organic or fossil-based carbonaceous constituents at high temperatures greater than 700°C (1292°F) into carbon monoxide (CO), hydrogen, and carbon dioxide (CO_2) without combustible gaseous emissions [15]. The CO then oxidizes with water (H_2O) to form CO_2 and more hydrogen passing through a water-gas shift reaction. The carbon adsorber, a pollution control equipment used to abate volatile organic compounds in low concentration gas streams were utilized to separate the hydrogen from the gas stream [16]. In this research, the rural community mini-grids biomass power generation with capacity of 150KW was produced using Corn Cob feedstock gasifier to supply energy to the internal combustion engine used to generate electricity to meet 75% energy requirements of the rural citizens in the community where it was hosted.

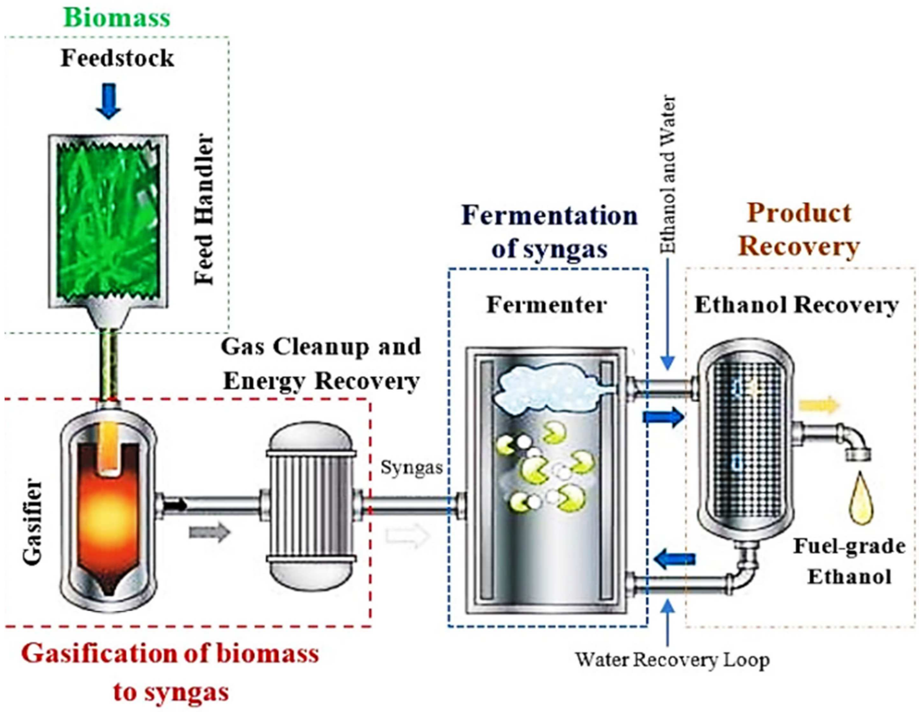

Figure 1. *Conversion of Syngas into biofuel and chemicals product through fermentation [17].*

In Figure 1 above, the biomass gasification process produced synthetic gas called syngas which further undergoes fermentation. The syngas fermentation is the chemical conversion of organic materials such as animal renewable wastes or plants into energy sources through biological synthesis to produce low-carbon biofuels and other gaseous substances without combustion [18]. The fermentation procedure relied on the microbial decomposition of diverse organic substances as a source of energy, carbon dioxide (CO_2), water and resynthesized organic carbon compounds using acetogen as microorganism that generates acetate as an end product of the fermentation [19]. Acetogens are used in the varieties of compounds as sources of energy and carbon in which the acetogenic metabolism required the utilization of CO_2 as a carbon source and hydrogen as an energy source [20]. Several laboratory findings confirmed that utilization of acetogens in the process convert various synthetic gas components like CO, CO_2, and H_2 into multicarbon compounds such as ethanol, 2,3-butanediol, acetate, butyrate, butanol and lactate. The ethanol is an essential final product of the chemical process, in addition to 2,3-butanediol which its bioconversion process occurs under moderate atmospheric temperature and pressure for biofuels and chemicals manufactures [21].

2. Objectives of the Study

The global objectives of the renewable energy schemes are to establish a carbon free economy that will replace the use of fossil fuel in generating electricity and to contribute to the National Action Plan on Climate Change. The National Action Plan on Climate Change is a global strategic policy instrument that is subject to periodic evaluation, renewal and improvement, in attending to the situations affecting the global ecosystem sustainability. To that effect, the current research has been designed to:

i. Increase renewable energy contribution in the national power generation mix.
ii. Facilitate the growth of the renewable energy industry as an alternative to fossil fuel consumption.
iii. Ensure economical renewable energy generation costs using biomass gasification methodology.
iv. Conserve the environmental ecosystem sustainability for future renewable energy generation and performance optimization.
v. Enhance responsiveness on the roles and importance of mitigating the alternative source of electricity generation through biomass gasification technology.
vi. Appropriate renewable energy mix and energy efficiency technologies through semi renewable energy-based hybrid systems and mini-grids.
vii. Mitigate biofuel and biogas synthesis for household requirements due to its high relevance for low-income citizens/populace.

Moreover, the Nigeria Renewable Energy Master Plan (REMP) being a policy instrument from the Federal Ministry of Environment has been put in place to intensify production of renewable energy to account for 10% of Nigerian total energy utilization by 2025 [22]. The REMP for Nigeria was articulated in 2006 in partnership with United Nations Development Programme (UNDP) which has the mandate to assist countries in achieving sustainable economic growth and human capital development [23]. The REMP evolves to principally address the Nigeria electricity demands and improve the grid reliability and energy security.

3. Statement of Problem

The activities of human beings are progressively influencing the climate and the earth's temperature has been unstable through burning of fossil fuels, cutting down forests and farming livestock. Those activities have added enormously to the amount of greenhouse gases to those naturally occurring in the atmosphere, thereby snowballing the global warming and greenhouse effect. The climate change were conceived as the long-term urtication in temperatures and weather patterns. Those urtication could be a natural polarization or humanly induced from the activities that promoted climate change, predominantly due to the burning of fossil fuels that engenders heat-trapping gases. A considerable amount of plant and animal species are possibly going to be at jeopardy of extinction, provided the global standard temperatures rises from 1.5°C to 2.5°C (2.7°F to 4.5°F). The ecological loss estimations will escalate to as much as 40 percent for a warming in excess of 4.5°C (8.1°F) which can only be attained in the Intergovernmental Panel on Climate Change (IPCC) higher emissions circumstances [24]. The precipitous human prompted alterations in the environment at global, regional and local scales appear to be contributing to population declines and extinctions, resulting in an unprecedented biodiversity crisis with consequential destructive impressions on the environmental ecosystem sustainability. To that effect, the current research synthesized several findings that will enable low fossil fuel consumptions through biomass renewable energy technology.

4. Literature Review

Renewable energy are developed through natural courses which replenishes constantly from various forms which it derives directly from the sun energy or from heat energy produced deep within the earth crust [25]. The renewable electricity generation in 2021 and beyond are set to expand progressively, which include electricity and heat energy produced from solar, wind, hydropower, biomass, biofuels, geothermal resources and hydrogen derived from renewable resources [26]. The Renewable Energy Policy Network for the 21st Century (REN21) has publicised its 2017 report, which highlighted some technical plans for 2018 and beyond [27]. The REN21 report focussed on the 2017 International Renewable Energy Conference, which was jointly hosted by REN21 and the Mexican government (MEXIREC) that assembled the government officials and its partners to deliberate the advancement in renewable energy policy framework [28]. The REN21 programme was planned within the methodological approaches towards renewable energy mix, concentrating on the issues of global importance, such as comprehensive world-wide energy access, socio-economic benefits and emancipation of marginalized social groups. The REN21 collaborated with various stakeholders which include the G20, the World Bank and the International Renewable Energy Agency (IRENA) to formulate frameworks and analysis of the renewable energy market, industry and policy trends [29]. The REN21 contributors had comprehended the renewable energy future potential policy solutions, through expanding network of partnership organizations to develop regional partnerships with Southern Africa and Asia and to work in synergy with South Korea on future International Renewable Energy Conferences [30].

According to REN21’s 2017 report, the renewable energy contributed 19.3% to humans' global energy requirements and 24.5% generation of electricity in 2015 and 2016 respectively were drawn from the renewable energy sources [31]. The distribution of the renewable energy consumption were apportioned as 8.9% coming from conventional biomass gasification, 4.2% as heat energy (modern biomass gasification, geothermal and solar heat), 3.9% from hydroelectricity and the remaining 2.2% is electricity from wind, solar, geothermal and other forms of biomass gasification designs [32]. According to Andreosso et al., (2020), the worldwide investments in renewable energy in 2017 amounted to US$279.8 billion with China accounting for 45% of the global renewable energy investments and United States and Europe both accounting for 15% of the global renewable energy development [33]. From the global perspective, there exist possibility of 10.5 million jobs associated with the renewable energy investments with solar photovoltaics being the largest renewable employer due to its efficient and cheaper energy reusability in addition to biomass gasification renewable energy technology [34]. The speedy implementation of renewable energy and energy efficiency technologies have given rise to more considerable climate change mitigation, energy security and socio-economic benefits based on the country’s energy peculiarities. According to Boudet (2019), a certain global survey shows that energy issues are widely in support of expansive renewable solar system, wind power, hydroelectricity and biomass gasification, but more thoroughly differentiated when it comes to expanding fossil fuel energies such as coal mining, offshore oil and gas drilling and hydraulic fracturing for oil and natural gases [35].

The biomass gasification power systems delivers electricity from the chemical energy contained in organic materials such as agricultural residue, wood waste, animal waste and energy crops [36]. Considering the biomass gasification resources utilization in the electricity grid modelling, the quantification, availability, price and physical properties of the feedstock gasifier is of great importance. There are several factors that distinguished the use of biomass gasification resources in electricity generation from every other renewable energy sources, among which are the human actions within the environmental ecosystem, because the energy source (feedstock) must be planted, harvested, transported and processed into an applicable biomass renewable energy constituent. However, the quantifications of the biomass gasifier depends on natural factors such as growing season and annual rainfall, in addition to certain unpredictability that characterized the other renewable resources, as such do not apply to the biomass gasification renewable energy system. The biomass gasification feedstock is readily stored to ensure increasingly supply and often processed into liquid or gaseous fuel for industrial application and electricity generation demand [37]. Biomass being the plant derivable organic materials which are distinctively known as lignocellulosic biomass, are extracted from maize corn cob [38]. According to Zoghlami & Paes (2019), the lignocellulosic biomass is an abundant renewable energy resources from maize plant, mainly composed of polysaccharides molecules (cellulose and hemicelluloses) and an aromatic polymer called lignin which are usually hydrolysed into fermentable sugar through an enzymatic processes to produce biofuels without compromising the global food security [39]. The lignocellulosic biomass possessed an extraordinary energy potential as an alternative to fossil fuel required in the production of second-generation biofuels and biogas chemical constituents as part of requirements for attaining sustainable and environmental friendly energy based renewable necessities. Biomass gasification can be synthesized straightforwardly by way of combustion to produce heat or indirectly after converting it to various forms of biofuel energy through thermal, chemical and biochemical processes [40].

However, biomass feedstock gasification can be converted to other usable forms of energy such as methane used as a replacement for natural gas or transportation fuels such as ethanol and biodiesel [40]. Biomass is the only renewable energy source that can be converted into liquid biofuels such as ethanol and biodiesel utilized to drive the internal combustion engine. The ethanol is manufactured by fermenting the biomass feedstocks richly in content with carbohydrates, such as maize corn, sugar cane and wheat. The biodiesel were produced from combining ethanol with animal fat, recycled cooking fat or vegetable oil which do not function much proficiently when compared with gasoline, although both are usually combined to produce a highly gaseous compound used in driving the internal combustion engine which do not release the emissions associated with fossil fuels that pollute the environment [41]. The Corn ethanol is ethanol produced from Corn biomass and it is the main source of bioethanol fuel in the United States of America [42]. Commercially, the Corn ethanol is produced by ethanol fermentation and distillation to enable bioethanol production at higher temperatures, whereas optimal temperature for maximum productivity occurs at 32°C. Ethanol are mixed into more than 98% of United States of America gasoline to reduce air pollution [43]. According to Bajpai (2020), modifications are required depending on the percentage blend of ethanol with gasoline mixtures denoted as "E" numbers which describe the percentage of ethanol fuel in the mixture by volume, for example, E85 is 85 percent anhydrous ethanol and 15 percent gasoline [44]. The Corn ethanol is mainly used in combinations with gasoline to create mixtures such as E10, E15 and E85 in which E10 and E15 can be used in all combustible engines without modification [45]. On the other hand, blends like E85, with much ethanol concentration requires significant modifications to be made before an engine can run on the mixture without damaging the engine [46]. According to Verhelst et al., (2019), the utilization of pure hydrous or anhydrous ethanol in internal combustion engines is only possible if the engines are designed or modified for that purpose and used only in the automobiles, light-duty trucks and motorcycles [47]. Contemporaneously, China's biomass direct combustion power generation technology had become relatively matured and has become an ostensible technology innovation for the consumption and utilization of crop growth in regions with these resources. The biomass energy utilization are transforming into biomass power grid, biomass gasification (including biogas), biomass briquette fuel and biological liquid fuel for regional and rural electrification as credible alternative to fossil fuels [48].

Figure 2. *A heap of disposable Corn Cob harvested from the Maize Field.*

The Figure 2 above is the Corn Cob feedstock, a waste agricultural maize product containing substantial amount of sugars that can be further processed into numerous organic and inorganic chemical compounds [49]. The enzymatic fermentation of lignocelluloses at considerable temperatures (46°C and 50°C) will favour cellulase activities to enable yeast produce substantial amounts of ethanol from cheap non-edible materials such as Corn Cob feedstock for renewal energy generation [50]. In this manner, altering the temperature conditions during the fermentation process will enable extreme production of biofuel on industrialized commercial quantity for several other process optimization. During the industrial brewing manufactures, the production of ethanol is supported through fermentation of starchy constituents from Corn Cob, in this situation, sugars are transformed into bioethanol with carbon dioxide and water as by-products of the reaction [51]. The bioethanol manufactured from Corn Cob utilizes only a limited proportion of the disposable agricultural materials, through simultaneous saccharification and fermentation of lignocelluloses agricultural wastes [52].

5. Design Methodology

Thermodynamic equilibrium technique were applied to formulate the mathematical methodology for predicting the producer gas composition from the biomass gasification mixture. The technique was adopted to establish the biomass composition that could be appropriate to whatever biomass gasification system installation now and in the future. To that effect, the thermodynamic equilibrium technique formulated on chemical balance and mass balance are applied which has negligible problematical constructions and can be employed to several other biomass gasification systems and reactor inputs [53]. Thermodynamic equilibrium technique are generally classified into two methodologies; stoichiometric methodology (model based on equilibrium constant) and non-stoichiometric methodology (model base on decreasing Gibbs free energy). According to Okolie et al., (2020), the stoichiometric methodology is generally of negligible complexity on the account of its extensively adoption in studying the outcomes of process parameters on biomass gasification system development [54]. Several researchers have used stoichiometric methodology to predict gasification performances which have demonstrated reasonable conformity with experimental data in the biomass gasification system installations. The predicted feedstock in the current research is Corn Cobs biomass gasifier, which its experimental investigation results are shown in Table 1 below.

Table 1. *Essential investigation of Corn Cob Feedstock Gasifier.*

Biomass Type	Experimental Analysis (wt.%)			
	C	H	O	N
Corn Cob	45.5	6.2	47.0	1.3

The results of the biomass feedstock equivalent ratio (0.55-0.85) and oxygen sufficient air, together with oxygen supply of 22%-51% based on the characterized separation techniques (membrane technology) were anticipated and the expected products were measured up with the experimental data to ascertain maximum compliance. In the experiment, the equivalent ratio were described to be the ratio of the actual fuel/air ratio to the stoichiometric fuel/air ratio. The stoichiometric thermodynamic equilibrium combustion happened when all the oxygen is combusted in the process and there is no more molecular oxygen left in the products. The gasification temperature were maintained at 400°C - 900°C as every further operation specifications were modified for the gasification in a fixed bed gasifier. While the biomass feedstock gasification constituents migrate downward through the fixed-bed gasifiers, it move into zones of increased temperature intensity and varied gas constituents, refer to Figure 3.

This approach involved the design of commercial gasification system that can produce a high quality biofuel syngas for internal combustion engines, turbines and heat applications in a well-coordinated scientific arrangement, refer to Figure 3. The biomass gasification presents an alternative to conventional ways of converting feedstocks like Corn Cob biomass gasifier to produce electric energy and other serviceable gaseous commodities without combustion. The benefits of biomass gasification technology, its applications and conditions, particularly in the renewable clean energy generation, made it increasingly important part of the Nigerian energy and industrial power demand. The unchanging price and plentiful supply of Corn Cob feedstock as an agricultural waste product throughout the supply chain makes it the leading feedstock gasifier. The diagrammatical representation of a gasification process involving Corn Cob feedstock gasifier is portrayed both on the feedstock flexibility, inherent in the gasification system together with the wide scale gaseous product lines of the gasification technology installation.

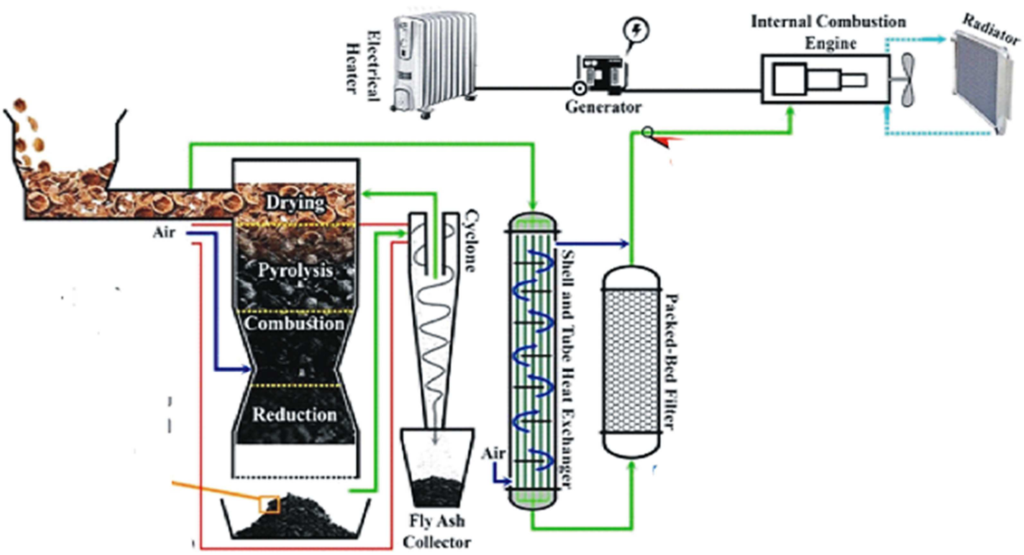

Figure 3. *Downdraft Biomass Gasifier Integrated with an Internal Combustion Engine [55].*

In the current research, a medium scale downdraft biomass gasification system using Corn Cob feedstock gasifier and connected to an internal combustion engine in anticipation for sustainable bioenergy conversion to generate electricity to meet the rural community energy requirements using lower heating value of 18.07 MJ/kg were realized. Several quantifications and assessments were conducted, together with biomass properties, syngas constituents, flue gas emission, bottom ash evaluation and temperature activities were presented to observe and estimate the characteristics of feedstock in the product formations. The temperature initially increases alongside the gasifier height, attaining the topmost extend in the oxidization zone of the gasification system. To that effect, the temperature degenerates step by step in the reduction zone and lowered substantially in the pyrolysis zone, refer to Figure 3. The temperature hit the highest rise within the oxidization zone of the gasification system on the account that the char oxidation happens as soon as there is plentiful availability of oxygen at the bottom of the gasifier [56]. Similarly, on top of the oxidization layer, the oxygen concentration diminishes as several reactions taking place within the layer were endothermic activities which potentially lowers the temperature. In the same way, air from top to bottom used in the reduction layer, within the pyrolysis layer and organic constituents are chemically combusted by heat in non-attendance of oxygen.

5.1. Theoretical Gasification Formulation

The current biomass gasification system employed thermochemical synthetic techniques which converted carbonaceous substances into serviceable gas fuel or chemical raw material [57]. The synthetic technique as a rule entails four sequential step as reported in the diagram above, refer to Figure 3, which include (i.) Drying Zone Reaction (ii.) Pyrolysis Zone Reaction (iii.) Oxidation Zone Reaction and (vi.) Reduction Zone Reaction.

i. Drying Zone Reaction

The drying zone reaction took effect at the temperature of 100°C which will persist until the temperature is adjusted to 50°C [58]. The reaction will vaporize nearly all the water composition in the Corn Cob biomass gasification feedstock. There is no substantial chemical reaction in the zone, except water evaporation.

$$\text{Biomass} + \text{Hot} = \text{Dry biomass} + \text{Steam} \quad (1)$$

ii. Pyrolysis Zone Reaction

The pyrolysis zone reaction represented an incomplete gasification and combustive reactions, characterizing a distributive sequence of chemical and physical reactions taking effects at the pyrolysis stage. The temperature of 250-500°C marks the commencement of pyrolysis process when thermally unstable components like lignin in biomass, break-up and vaporized in combination with other components [58]. Those evaporating pyrolysis products are composed of polycyclic aromatic hydrocarbon, a chemical compound comprising of carbon and hydrogen with aromatic rings and tar.

$$\text{Biomass} \rightarrow \text{Water vapour} + \text{Charcoal} + \text{Gas} + \text{Tar} \quad (2)$$

iii. Oxidation or Combustion Zone Reaction

Following the activities of the gas from the pyrolysis reactions which are readily oxidized by the oxygen from the intermediate gasification processes. The lower layers temperature surpasses the carbon ignition temperature to enable the exothermic combustion reaction on the account of the excessive oxygen release to heat the moving gas up and solid down [58].

$$C + O_2 \rightarrow CO_2 \ (\Delta H = -\ 394 \text{ kJ / mol}) \quad (3)$$

From equation 3, the combustion reaction occurs very speedily as the process utilized all the available oxygen in the system. On the account that all the available oxygen are reduced, the combustion reaction turns to incomplete combustion, liberating CO and relatively quantity of heat energy [58].

$$C + \tfrac{1}{2} O_2 \rightarrow CO \ (\Delta H = -\ 111 \text{ kJ / mol}) \quad (4)$$

iv. Reduction Zone Reaction

While the mixture of CO, CO_2, steam and hot gas from the feed through the gasification channel, migrates through the gasification reduction zone, char from the gasifier bed being categorised in conjunction with CO_2 move into the reduction zone, which will result into a diminishing CO_2 intensity in the gasification zone of the system [58].

$$C + CO_2 \rightarrow 2CO \ (\Delta H = +172 \text{ kJ / mol}) \quad (5)$$

The endothermic gasification reaction releases a mixture of gases called the producer gas (syngas) from the reaction which include carbon monoxide and hydrogen from carbon.

$$C + H_2O \rightarrow CO + H_2 \ (\Delta H = +131 \text{ kJ / mol}) \quad (6)$$

The biomass gasification process stages are temperature controlled with effect to different layers of the gasification system arrangement, indicated as follows:

1. Drying Zone: Temperature greater than 100°C
2. Pyrolysis Zone: 250°C greater than Temperature = 500°C
3. Oxidation Zone: Temperature equal to 1200°C
4. Reduction Zone: 600°C less than Temperature and Temperature less than 1000°C.

The Temperature is exceptionally instrumental on the biomass gasification reaction activation, the rate of air and combustion speed of the oxidation process of the feedstock raw material in the gasification system [59]. At the instance of steam gasification, the chemical processes evolves rapidly at the temperature bound of 900°C -1200°C. In every gasification processes, the temperature of the reactor significantly influences the manufacture of the product syngas and other chemical commodities. To that effect, the biomass gasification system demands total insulation to balance the internal temperature equilibrium of the reactor from arbitrary rise or fall [60]. The biomass system temperature is of great parametric essence on the account that it influences the chemical reactions that took place. To that effect, an examination of temperature modification between 700°C, 800°C and 900°C together with the results achieved throughout the gasification reactions that yielded (H_2, CO, and CH_4) were represented in Figure 4. On the temperature 700°C, the production of CO were more prominent than the yield at the temperature 800°C and 900°C respectively. When the reaction temperature was 700°C, the volume of CO yield was 23.60% vol, on the other hand, the volume declined to 16.83% when the temperature was increased to 800°C and subsequently improved to 17.42% at the temperature of 900°C. This happens because the Boudouard reaction suggests that on the reduced temperatures the equilibrium is on the exothermic CO_2 favour and on higher temperatures the endothermic formation of CO is the dominant product, as propounded by the Le Chatelier's Principle [61], while the H_2 formation witnessed a reduction from 27.82 vol% when the temperature was 700°C to 23.47% vol and 14.55 vol% when the temperatures were 800°C and 900°C. The increase in temperature promoted a higher yield of hydrogen gas on the account that energy for hydrogen production is endothermic reactions, in this manner increases the hydrogen content of the gas yield [62]. On the other hand, increasing the reaction temperature of water-gas reaction has significant involvement than the Boudouard reaction which activates the water-gas shift reaction ($CO + H_2O \rightarrow CO_2$ and H_2) to cause intensification in H_2 concentration in the producer gas as extreme temperatures inclination promotes steam modification of methane to CO and H_2 [63].

The volume of methane collected at the temperatures of 800°C and 900°C were 1.82% vol and 1.40% vol respectively, minimal to the methane concentration at 700°C at 7.09 vol%. The methane concentration declined along with increase in the gasification temperature, on the account that greater temperature inclination will intensify methane steam modification which potentially lowers the methane yield whereas increase in temperature intensifies the concentration of hydrogen and carbon monoxide [62].

$$CH_4 + H_2O \rightarrow CO + 3H_2 \ (+206 \text{ kJ / mol}) \quad (7)$$

$$CH_4 + CO_2 \rightarrow 2H_2 + 2CO \ (+247 \text{ kJ / mol}) \quad (8)$$

5.2. Model Validation and Modification

According to Sittisun et al., (2019), the thermodynamic equilibrium technique experimental results and gas composition model calculation were contrasted to cross examine its deviation by root mean square error computation [64]. The non-equilibrium conditions are usually present in the actual gasification system, for that reason, the model was formed by increasing the non-equilibrium coefficients A and B to K1 and K2 to decrease computational imperfections. Several scholars on biomass gasification technology often prioritized the exigencies of the methodology in developing their models which had resulted in better energy estimations. On the general note, the correctness of the technique is cross examined through contrasting the projected gas composition from the technique with the experimental results. In the current design, errors were computed using arithmetical variables called root mean square (RMS).

$$\text{RMS} = \text{Square Root } ((\sum X_e - X_p)^2 / N) \quad (9)$$

Where N is the number of observations, X_p is the predicted value and X_e is the experimental data respectively which must correspond with the theoretical predictions.

6. Discussion of Findings

The percentage of H_2, CO and CH_4 were computed applying the technologically advanced model which centred on the thermodynamic stoichiometric equilibrium computation. The Figure 4 represented the gas manufactured composition and LHV with particular emphasis to the biomass gasification temperature variations. The intensification in oxygen concentration from 22% to 51% increases the intensity of the combustible gas composition, which can equally be understood by the lower nitrogen dilution at the same equivalent ratio. The reduced amount of nitrogen dilution in the enriched air have an effect on the increased concentration of other gases, including CH_4, H_2 and CO composition. The intensification in the combustible gas concentrations correspondingly build up the LHV performances. The improved oxygen air with 50% oxygen concentration contributed to the maximum LHV output in the experimental setting.

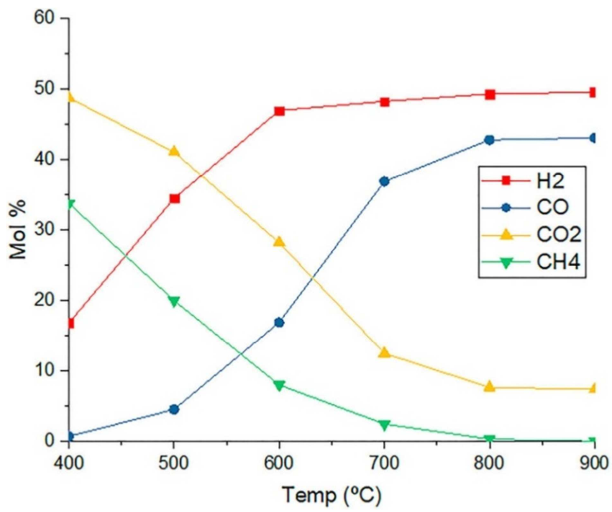

Figure 4. *Effect of gasification temperature on gas production.*

The comparative study of several gaseous characteristics together with the temperature changes have been demonstrated in Figure 4, which shows that CO formation rate and hydrogen production rate become more intense as the temperature increases. However, the CH_4 formation decreases along with temperature increase. The LHV computations have equally been done for several other biomass gasification systems alongside temperature adjustment. The LHV of the experimented model was observed to reduce with increase in temperature, therefore during the gasification process, it will be technically favourable to maintain constant temperature when significant changes have started taking effect. The temperature of the gasification system has considerable effects on the gaseous formation and gaseous composition from the current research development.

7. Conclusion

The current research on biomass renewable energy production from corn cobs feedstock gasifier as an energy constituent in internal combustible engines provided an insightful analysis into the sustainability performances of bioenergy systems for providing cooking gas and electricity generated energy services for the rural communities in Nigeria where national grid electrification is in short supply. It was accomplished through modelling an optimizable bioenergy supply chain required for the consistent provision of serviceable gas commodities and associating its sustainability performances to the prevailing energy systems aimed at reducing carbon dioxide emission which is responsible for global warming and greenhouse gaseous effects. The results indicated that employing biomass oriented gasifier internal combustion engines as an alternative to diesel generators for the establishment of electrification system which may perhaps result in reduction of greenhouse gas effect, global warning, SO_2 and CO_2 emission. Considering the biomass gasification resources utilization in the electricity grid modelling, the quantification, availability, price and physical properties of the feedstock gasifier is of great importance in the performance evaluation. The bioenergy systems establishment have better performances than the existing fossil based power plants in delivering the most cleanest energy services with regard to environmental ecosystem sustainability. For this reason, the country policymakers should contemplate investment into renewable energy adoption to foster sustainable development geared towards condensing the environmental effects of global warming.

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Availability of Data and Materials

The data and materials for the research were available and interpreted within the body of the work.

Authors' Contributions

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Consent for Publication

All the authors consented to the publication.

Conflict of Interests

The authors declare that they have no competing interests.

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