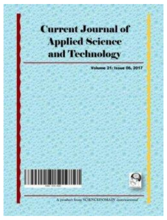

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Elephant Grass (*Pennisetum purpureum*): A Potential Source of Biomass for Power Generation in Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. Author JAD conducted literature searches and wrote the first drafted manuscript. Authors COR and MA edited the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The Government of Ghana has introduced into its energy mix many thermal generation plants, which utilize natural gas and light crude oil to augment the electric power need of the country. However, these come with high fueling cost and frequent interruption in the supply chain. One area which has not been explored is the use of biomass for electrical power generation. *Pennisetum purpureum* K. Schumach grows in the wild as grass in the dry semideciduous forest zone and the distributional range covers an area of approximately 2.1 million hectares. The grass has potential as a biofuel feedstock for power generation. This paper gives an overview of the potential use of *Pennisetum purpureum* as a cheap and readily available source of biomass or biofuel for electric power generation in Ghana.

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1. INTRODUCTION

Pennisetum purpureum K. Schumach (Common names: Elephant Grass, Napier Grass, Uganda Grass) is a robust perennial grass belonging to the family Poaceae (or Gramineae). Elephant Grass is a tropical C4 bunchgrass with a high growth rate and biomass production [1]. The plant has a wide geographic distributional range in the tropics and subtropics. Elephant Grass is usually associated with ecological zones prone to recurrent annual bushfires, particularly in transitions between forest belts and the savannah ecological zones. In Ghana, it is predominately a grass of the dry semideciduous zone (Fig. 1). It is endemic to tropical Africa. The grass was introduced to North America in 1913, as a forage grass [2]. Elephant Grass is now considered as an invasive species in the United States, due to the absence of natural enemies to control its growth and population dynamics. It requires a comprehensive environmental impact assessment for large-scale deployment as a resource for cellulosic bioenergy or fodder in some countries particularly the United States [3]. It has been utilized as folder, as a cover material for soil erosion control, as bedding for mushrooms cultivation and as a raw material in the production of paper [4,5]. Nonetheless, in South America it is considered a new alternative form of animal feed [6,7]. Brazil has taken up the challenge and a leading role to extensively conduct research into the use of Elephant Grass biomass for electric power generation and production of derivatives of biofuels through a process of gasification and pyrolysis. This initiative has led to the establishment of a thermoelectric power plant by Sykue Bioenergia of Brazil to generate 30 megawatts of electricity from Elephant Grass biomass at a cost of 43 million US dollars [8]. Ghana has a comparative advantage over Brazil in the sense that Elephant Grass is a native grass species that grows in the wild extensively on the rangelands in the dry semideciduous ecosystems (see Fig. 1). Whereas in the case of Brazil the species has been domesticated and requires intensive agronomic packages. To achieve a high growth rate in non-native environments, most often Elephant Grass requires large amounts of nutrients such as nitrogen, making it a potential border crop as a nitrogen scavenger [1]. On the contrarily, in Ghana soils colonized by Elephant Grass are considered to be marginal and less fertile and unsuitable for crop production by smallholder rural farmers. Elephant Grass is a native species and it is highly adapted to the local environmental conditions, given the necessary breeding and selection for improvement with improved agronomic practices; high biomass yields could be realized in the country. Currently, Elephant Grass produces or yields approximately 30 to 40 metric tons of biomass per hectare under local environmental and climatic conditions of Brazil [8]. Elsewhere, a biomass yield potential of 50-60 metric tons per hectare within 180 days using a linear growth rate has been reported in Elephant Grass [1,9, 10]. The dry semi-deciduous forest ecological zone (transitional zone) where Elephant Grass is widely distributed in both abandoned agricultural and secondary forest landscape covers an area of approximately 2.1 million hectares and this constitutes 8% of high forest zone in the country [11]. It's potential as cellulosic biomass for energy generation particularly thermoelectricity in Ghana is very high. In fact, it's short life cycle and high growth rate makes it a more ideal biofuel than any known short rotation tree or herbaceous biofuel feedstock. The available data indicate that the dry biomass from elephant grass can generate 25 times the heat energy in an oven compared with the same amount of fossil fuel, with less carbon footprint, whilst sugarcane converted into ethanol only produces nine times as much heat energy [12,8]. A unique attribute of cellulosic biomass from grasses and wood, in general, is that it can easily be changed into heat energy and electric power production through direct combustion or it can be used as a feedstock for conversion into liquid transportation fuel through a process of pyrolysis [13]. It can be gasified and liquefied to produce syngas or bio-oil [14,15,16]. On the other hand, biomass production of short rotation crops such as grasses, including Elephant Grass, can provide enhanced ecosystem services through their ability to sequestrate carbon dioxide [15]. For example, Elephant Grass is able to capture approximately 40 tons of carbon dioxide per hectare. The high cellulosic fiber content makes an ideal feedstock resource for ethanol production [12]. Elephant Grass as a perennial crop with low input requirements and the potential for biomass production for energy generation, particularly electricity, has not yet been fully exploited in this country. The objective of this paper is to highlight and project the potential use of *Pennisetum purpureum* as a biofuel resource for electricity generation in Ghana.

1.1 Demand and Supply Dynamics of Electricity in Ghana

Ghana generates proximately 64% of its electric power from hydro sources [17]. The hydro is currently subject to the vagaries of the weather due to climate change [18]. The rest is of the country's electric power needs are obtained from thermal that lacks a secured proven source of fuel (Natural gas and light crude oil) and dependent on the dynamics of world crude prices [18]. In order to ensure energy security, there is an urgent call for the country to explore other sources of energy notably wind, solar and use of biomass in electricity generation. Biomass from Elephant Grass offers a suitable opportunity for the country to implement small to medium scale biomass conversion to energy. Elephant Grass has huge potential as biofuel feedstock to produce 1000MW of electricity from proximately 76,891 hectares of biomass [19]. Nonetheless, high values of 30MW per 1600 ha have been reported [20]. This fuel material can be readily produced locally and it offers the flexibility, reliability and security needed for energy generation. In addition, it is relatively cheaper and the windfall to the Ghanaian economy is very large in terms of employment and other allied industries that it will be created in the process. The main drivers of demand for electricity are general economic growth with the corresponding expansion of the industrial sector particularly mining and manufacturing, the on-going rural electrification scheme and new oil discoveries with corresponding up-stream and mid-stream activities [21]. In addition, with the other latent factors associated with rapid urbanisation and population growth accounting for the huge proportion of non-commercial residential consumers (see Fig. 2), the demand for electricity is estimated to have a year-on-year average growth rate of about 10% [17].

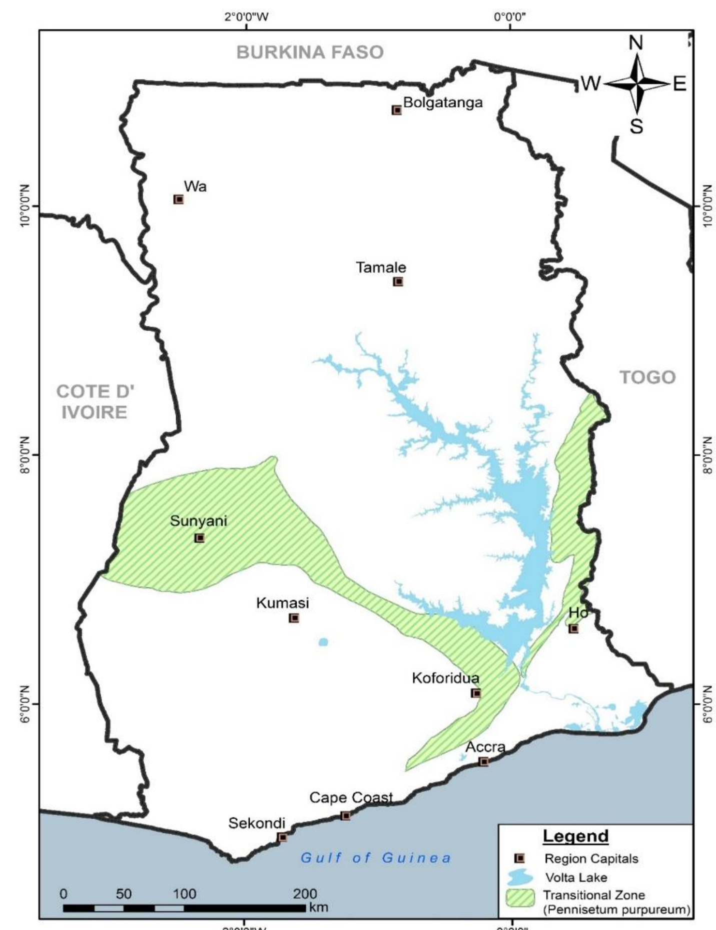

Fig. 1. The geographic range of *Pennisetum purpureum* K. Schumach in Ghana

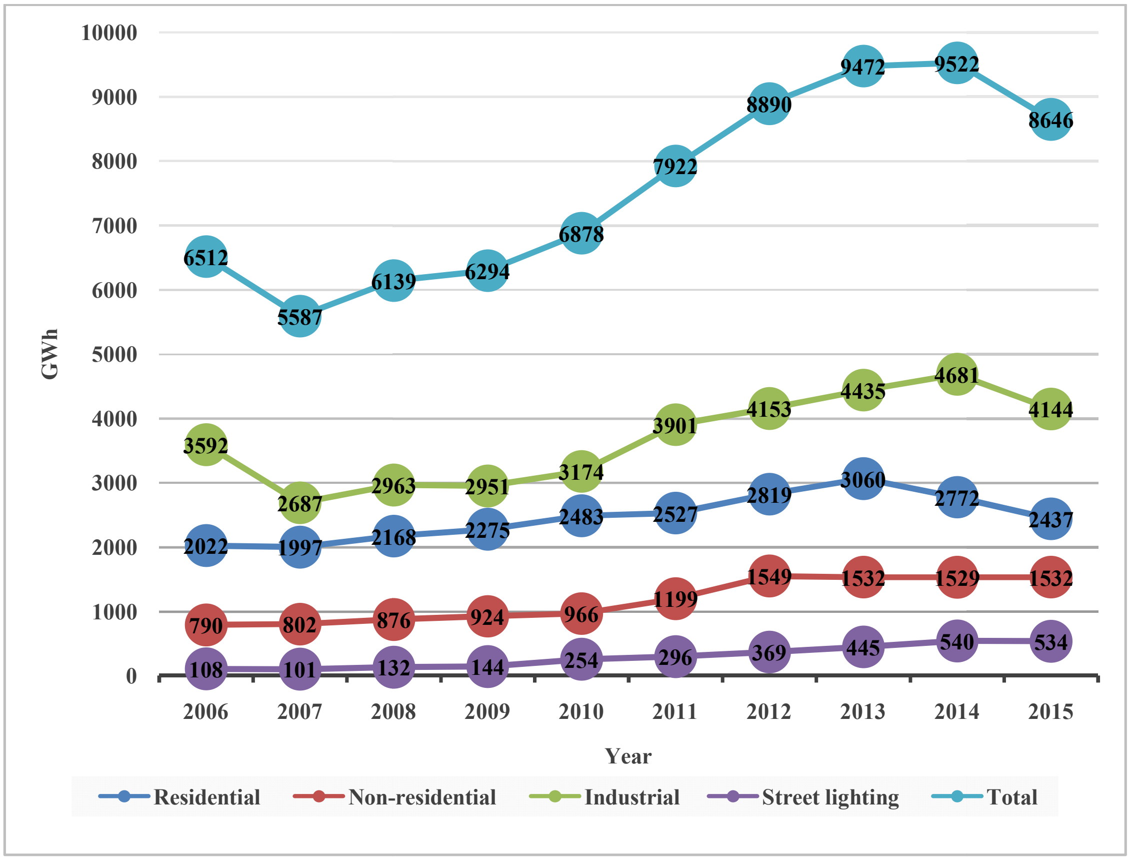

Fig. 2. Drivers of electricity consumption in Ghana

However, a substantial amount of electricity generated in the country is not accounted for due to transmission and distribution losses, these constitute 3.8 % of net electric power generation. In addition, in 2015 the two major electricity retailers in the country, Electricity Company of Ghana (ECG) and Northern Electricity Distribution Company (NEDCo), lost 22.7% and 27.5% of the total wholesale electricity purchases from Volta River Authority(VRA) and other Independent Power Producers(private power producing companies) respectively. These losses emanate from technical (e.g. obsolete equipment) and commercial (illegal connection and nonpayment of bills) causes. Moreover, the country exported 329 GWh of electricity to the neighbouring countries [22].

2. BIOMASS ENERGY AND COST OF PRODUCTION

The current average cost of generating electricity utilizing biomass in the USA employing conventional combustion technology (biomass-fired) without cogeneration is estimated to range from 0.08 US$ to 0.26 US$ per kilowatt-hour [23,24]. However, the cost could vary depending on the interest rate on the investment, location, system design and fuel cost taking into consideration logistical constraints in terms of transport and harvest [23]. Moreover, with advancements in technology the cost is expected to go down; particularly with the introduction of new gasification technologies, the cost of generating power from waste wood and other biomass feedstock may be considerably reduced. As of 2013, in Northern Europe, the cost of producing electricity from biomass ranges from 19.58 to 23.50 US$ per MWh (1.95 to 2.35 cents per kWh) for a co-firing plant. The spot market price was approximately 24.15 to 25.46 US$ per MWh (2.415 to 2.546 cents per kWh) [25]. The cost of electric power generation from biomass has come down due to technological advancement and technical efficiency.

Table 1. Estimated LCOE* of North America and European Union

Plant type	North America	European Union
	Total System LCOE* (US$/KWh)	**Total System LCOE* (US$/KWh)**
Dispatchable Technologies		
Coal	0.0951 - 0.144	0.029 - 0.116
Natural Gas	0.0752 - 0.1415	0.053 - 0.227
Nuclear	0.095	0.036 - 0.084
Geothermal	0.0395-0.0478	#0.028 - 0.045
Biomass	0.096	0.060 - 0.290
Non-Dispatchable Technologies		
Wind	0.064 - 0.158	0.029 - 0.169
Solar	0.066 - 0.179	0.035 - 0.180
Hydroelectric	0.068	0.022 - 0.108

**LCOE: Average Levelized Cost Energy: This is based on exchange rate of 1.00 EUR = 1.07 USD*
Sources: [26,27], # [28]

The levelized cost of power from biomass using dispatchable technology is comparatively lower than technologies such as coal and nuclear in both North America and within the European Union [26] (Table 1). The levelized cost of power from biomass in US is approximately 9 cent per KWh and in European Union, it ranges between 6 to 29 cents per kWh. The main drivers of the cost function are transportation, storage and handling costs, which are a significant part of the costs of biomass energy production. These challenges could be addressed through continued collaborative research and development of feedstock logistics and infrastructure [29].

2.1 Elephant Grass Biomass and Other Potential Available Biomass Feedstock

Elephant Grass growing in the wild covers large area in the dry semideciduous ecological zone. This zone covers an area of approximately 2.1 million hectares [11]. However, for the continuous assured supply of Elephant Grass biomass as feedstock, actual cultivation of the grass can be done on marginal lands and degraded ecosystems. Moreover, it can be used in combination with other feedstock for electricity generation (Fig. 3). A co-firing generating plant could utilize Elephant Grass alone or in combination with sawdust from sawmills and municipal solid waste or both (Fig. 3).

In general, mixed biomass fuel feedstock in power generation is more cost-efficient and reliable [30]. In 2008, the total dry biomass of agricultural residues generated in Ghana was approximately 4,159,550 ton [31]. During the same period, it was estimated that the total waste generated from sawn or processed timber was 256,000 m^3 equivalent to 128,250 tons of waste in the wood milling industry in the country [32,33]. However, the quality of waste material or sawdust generated varies with tree species and the kind of processing mechanism employed and the maintenance of the plant [33]. Moreover, it is estimated that each household in Ghana generates per capita municipal solid of approximately 150 kg to 200 kg per annum. However, the 10 regional capitals all together generate about 2 million tons of municipal solid waste per annum, and Accra alone generates 760,000 tons of municipal solid waste per annum [34,31]. These figures are expected to go up with increases in urbanization and population growth. Based on a current projected population of 29,614,337 million and with a growth rate of 2.39%, it is estimated that Ghana will generate about 12,710 tons of domestic and industrial waste per day [35]. Thus suggesting a potential availability of biomass for power generation if this feedstock resource is well managed, and that it would be reasonable for Ghana to establish pilot biomass power generating plants in the regional capitals. In addition, this would help to address the problem of waste management in the regional capitals.The potential use of available native plants biomass and waste biomass material would ensure sustainable bioenergy deployment [36].

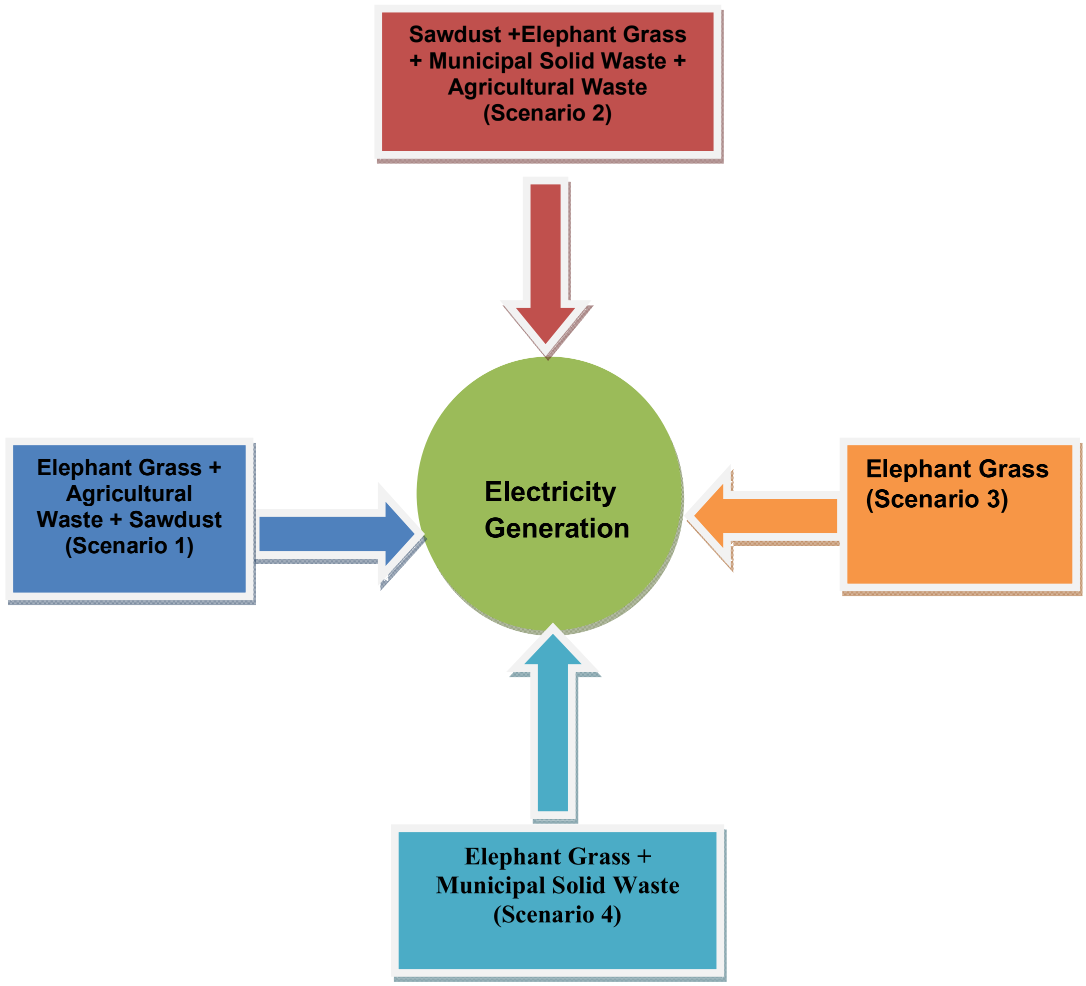

Fig. 3. Various scenarios for using Elephant Grass (*Pennisetum purpureum*) biomass in combination with other feed stocks for electricity generation in Ghana

2.2 Yields, Energy and Economics

Elephant Grass has the highest biomass yield per hectare of any know short rotation fuel crop (harvest 2-10 years) meant for bioenergy [9]. A referenced research recorded oven-dry biomass yield of 0.025kgm^{-1}day^{-1}, a measurement based on linear growth rate in Elephant Grass [9]. In related studies, dry biomass amounts in the range of 27.3 to 37.1 MT/ha were reported in regions with precipitation over 1250mm per annum [37]. This annual rainfall amount is comparable to the dry semideciduous ecological zone in Ghana [38]. Variable dry matter yields have been reported under different climatic and edaphic conditions in various countries. These are 19 MT/ha in Australia, 66 in Brazil, 58 in Costa Rica, 85 in El Salvador, 48 in Kenya, 14 in Malawi, 64 in Pakistan, 84 in Puerto Rico, 76 in Thailand, and 30 in [39]. However, higher biomass yields can be achieved if the species is allowed to grow beyond 200 days before harvest [40]. The yield of dry matter increase with advancing in age, for example 50 and 91.3 MT/ha at 200 and 365 days of continuous growth respectively [40,9,41,40]. A typical oven dried yield of about 25–35 metric tons per hectare in a year is not uncommon. This yield amount is equivalent to 100 barrels of crude oil per hectare [42]. The biomass yields that can be achieved under standard agronomic conditions depends on the species or cultivar of the Elephant Grass in question [43,42]. The biomass of Elephant Grass has higher heating value, lower ash, nitrogen and sulphur content. Structurally, the biomass of Elephant Grass contains high levels of cellulose and lignin, thus making it an ideal candidate for bio-oil (biodiesel) production [42].

Thus, the potential for Elephant Grass as next generation feedstock for power generation particularly electricity is huge in Ghana and the rest of tropical Africa. This is under the premise that research and development in the country will address an issue related to technical, logistics, economic, social and agronomic in a more holistic and comprehensive manner.

3. ELEPHANT GRASS BIOMASS POWER CONVERSION TECHNOLOGIES

The transformation of biomass to energy involves a wide range of different technologies depending on the sources of biomass, end-use application and available infrastructure [13,44]. Biomass can be transformed into three main products; these are power and/or heat as well as transportation fuels. The process of conversion can be thermo-chemical and biochemical. For the purposes of this review, the emphasis will be placed on thermo-chemical conversion technologies. These are more suitable in the context of utilizing biomass for power generation particularly electricity. The main thermo-chemical conversion processes are simple combustion of the biomass, gasification, liquefaction and pyrolysis, all these four processes can be used in power generation (electricity) (Fig. 4). The most common processes are the first three processes due to the fact that liquefaction involves complicated engineering and is expensive [44]. Combustion technologies rely on the direct burning of biomass to convert the stored chemical energy into heat, mechanical power or electricity. These involve the application of various processes and equipment such as steam turbines coupled with dynamos, furnaces, turbo-generators, boilers etc. e.g. [45,44,46]. Direct combustion of biomass produces temperatures in the neighbourhood of about 800-1000^{o}C. Biomass combustion systems are available in various size ranges from a few kW up to more than 100 MW. The efficiency for heat production is very high and heat from biomass is economically feasible particularly a co-fire system with coal [47,48,45,36]. The commercial production of electricity from direct combustion system is usually based on steam cycles connected to either steam turbines, steam engines or organic Rankine cycles [44]. Gasification is the process of turning biomass into a combustible gas mixture (Carbon monoxide, Hydrogen and traces of Methane) through partial oxidation of biomass at high temperatures, usually between the range of 800-900°C [49,50]. The producer gas mixture can be used to run internal combustion engines (both compression and spark ignition) and as a substitute for furnace oil in direct heat applications. In addition, it is an economically viable way of producing methanol, an industrial chemical useful as fuel for heat engines and chemical feedstock (syngas) [51]. The producer gases can be burnt directly as fuel in gas engines and gas turbines for electricity generation [52]. The current conventional method which has added advantages is known as biomass integrated gasification or combined cycle, this system is more efficient in converting clean producer gaseous fuel to electricity [44,3]. Pyrolysis involves the conversion of biomass to liquid by thermal destruction or through heating under an inert environmental condition at temperatures of about 500^{o}C or higher [53].

The resulting products are mainly charcoal, liquid (biodiesel) and fuel gas [54]. The biodiesel (bio-oil) and fuel gas can be used by turbines or engines to produce electricity or combine heat and power (CHP) [54,55]. Hydrothermal liquefaction of biomass is the conversion of solid biomass to into liquid biofuel under high pressures (4 –22 MPa) and extreme temperatures (523–647 K) in a water medium (steam). The process breaks down the complex polymers of monomers of biomass, usually lignocellulosic material, into a liquid form [56,57].

3.1 Bioenergy, Environment and Food Security Nexus

There is growing concern about arable land meant for food crop cultivation being converted into the production of short rotation biofuel crop such as Elephant Grass for biomass. Globally, rising costs of energy and a paradigm shift in energy and environmental policies that favour production of renewable energy have contributed to demand biofuels to the detriment of food crops [58]. This has created a situation whereby arable lands for food crop cultivation are being converted into the production of biofuels. This condition has sometimes led to higher food prices, a situation which benefited food crop farmers and disadvantaged the average consumer [59]. The use of arable land for biofuel production is usually offset by the balance that ensures food security, particularly in developing countries. The production of biofuel crops for energy usually requires a large amount of land [60]. The Government of Ghana, realizing the link

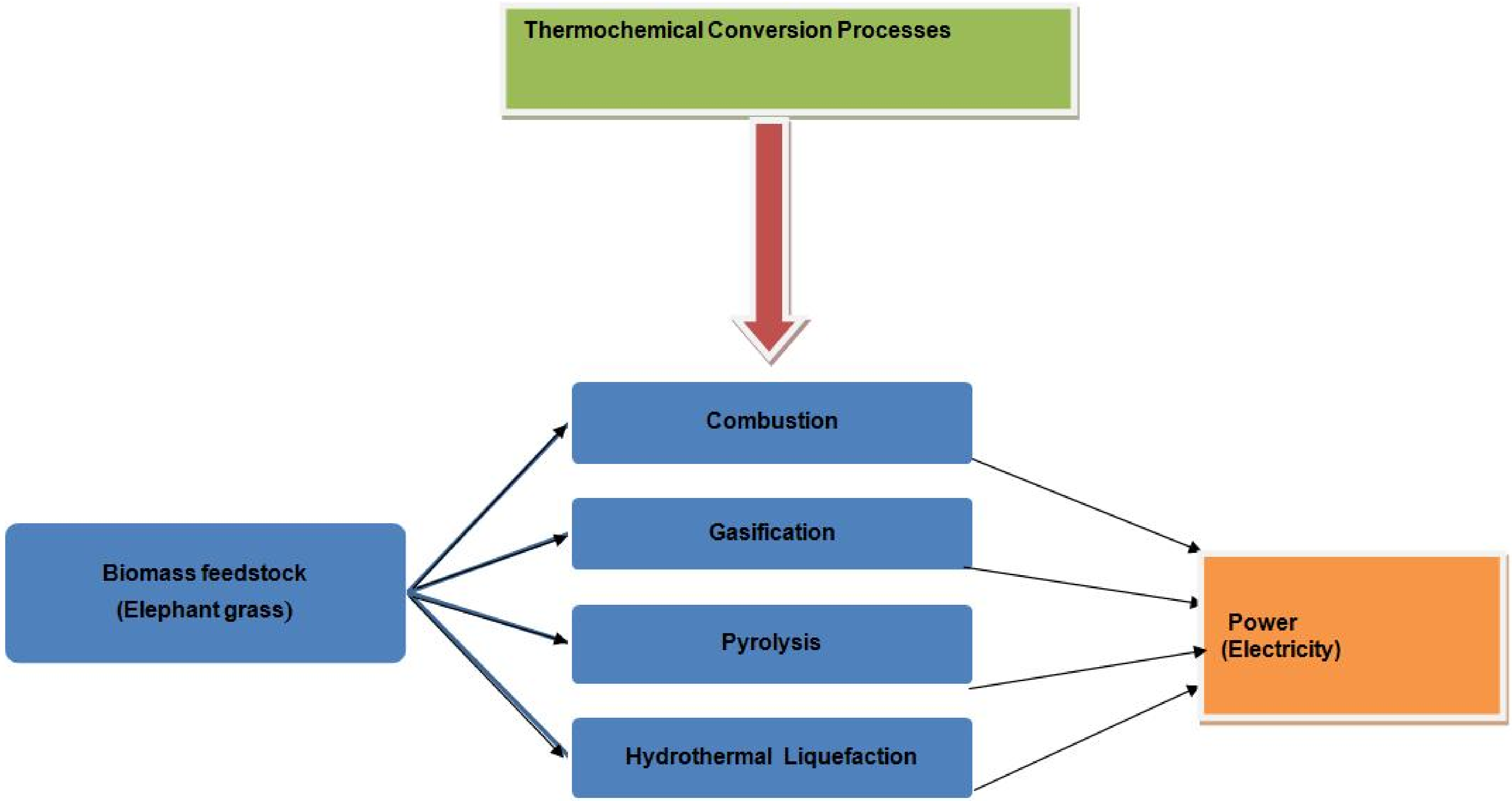

Fig. 4. Main thermochemical conversion processes of biomass to electric power

between food security and biofuel production, has emphasized the need to strike a balance between sustainable food security and land allocation for biofuel crops in its bioenergy policy document. However, one of the unique attributes of Elephant Grass as a native grass species is its ability to thrive very well in degraded ecosystems and marginal lands that are not suitable for meaningful agriculture. Because Elephant Grass is a native species, the usual externalities associated with producing biofuel (biomass) from exotic grasses in terms of inputs like nitrogen, phosphorous and pesticide are absent [see, [61]. Moreover, phosphorous is deficient in most tropical soils and Ghana is no exception [62]. Power generation using Elephant Grass is carbon neutral with minimal environmental impact in terms of carbon dioxide emissions. Elephant Grass and grasses, in general, have the ability to sequestrate carbon dioxide [63].

4. CONCLUSION

The use of Elephant Grass as a short rotation biofuel feedstock holds great potential for the country. Elephant Grass is suitable as a fuel for direct combustion or through series of thermochemical conversions to generate electric power. It offers a secure and reliable source of fuel in contrast to fossil fuels currently being used to generate power in the country. The biomass from the Elephant Grass plantation can be integrated with agriculture and urban waste in direct combustion processes to produce power. This offers advantages in the nation's drive to manage huge piles of solid waste engulfing our major urban centres. The levelized cost of generating power from biomass, particularly from Elephant Grass, is relatively lower and competitive with other forms of dispatchable power technologies. The economic benefit of incorporating Elephant Grass biomass-based bioenergy into our energy mix as a nation is huge in terms of employment for youth and reducing rural poverty by providing additional income. The other positive side for using biomass in power generation is the fact that it is clean electricity and carbon neutral, hence environmental friendly. In addition, Elephant Grass is a native plant species and highly adapted to local ecological and environmental conditions. The use of Elephant Grass as bioenergy resource will ensure long-term environmental sustainability. It is imperative for us as a nation to harness the potential of this renewable natural resource to help address our energy needs. Policymakers and researchers need to have second look at the potential use of Elephant Grass biomass for power generation and as part of the energy mix to ensure electric power security in the country.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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