

Review Article

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

ABSTRACT

The Government of Ghana has introduced into its energy mix hosts of 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 biofuel feedstock for power generation. This paper gives an overview of the potential use of *Pennisetum purpureum* K. Schumach as a cheap and readily available source of biomass or biofuel for electric power generation in Ghana.

Keywords: Elephant grass, biomass, biofuel, electric power

1. INTRODUCTION

Pennisetum purpureum K. Schumach (Common names: Elephant grass, Napier grass, Uganda grass) is robust perennial grass belonging to the family *Gramineae*. Elephant grass is a tropical C4 bunchgrass with high growth rate and biomass production [1]. The plant has wider geographic distributional range in the tropics and the 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 predominate grass in dry semideciduous zone (Figure 1). It is endemic to tropical Africa. The grass was introduced to North America in 1913, as forage grass [2]. Elephant grass is now considered as an invasive species in United States, due to absence of natural enemies to control its growth and population dynamics. It requires comprehensive environmental impact assessment for large scale deployment as cellulosic bioenergy resource or fodder in some countries particularly in United States [3]. It has been utilized as folder, as a cover material for soil erosion control, as bedding for mushrooms cultivation and as raw material in the production of paper [4], [5]. Nonetheless, in South America is considered as new alternative form of animal feed [6], [7]. Brazil has taken up the challenge and the leading role to extensively conduct research into use of Elephant grass biomass for electric power generation and production of derivatives of biofuels through process of gasification and pyrolysis. This initiative has led to establishment of thermoelectric power plant by Sykue Bioenergia of Brazil to generate 30 megawatts of electricity from elephant grass biomass at a cost of 43 million dollars [8]. Ghana has comparative advantage over Brazil in the sense that elephant grass is a native grass species

that grows in the wild extensively on the range lands in the dry semideciduous ecosystems (see Figure 1). Whereas in the case of Brazil the species has been domesticated and it requires intensive agronomic packages. To achieve high growth rate in nonnative environment, most often elephant grass requires large amount 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 native species and it is highly adapted to the local environmental conditions, given the necessary breeding and selection for improvement with added improve agronomic practices; high biomass yields can 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, 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]. The dry semideciduous 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 constitute 8% of high forest zone in the country [10]. The potential as cellulosic biomass for energy generation particularly thermoelectricity in Ghana is very high. In fact, the short life cycle and high growth rate makes it most 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 heat energy in oven as much as the amount of fossil fuel used to produce it, with less carbon foot print whilst sugarcane converted into ethanol only produces nine times as much heat energy [11],[8]. A unique attribute of cellulosic biomass from grasses and wood in general, 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 process of pyrolysis [12]. It can be gasified and liquefied to produce syngas or bio-oil [13], [14], [15]. 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 sequesterate carbon dioxide ([14]). 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 [11]. Elephant grass as perennial crop with low input requirement and potential biomass production for energy generation particularly electricity has not yet been fully exploited in the 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.

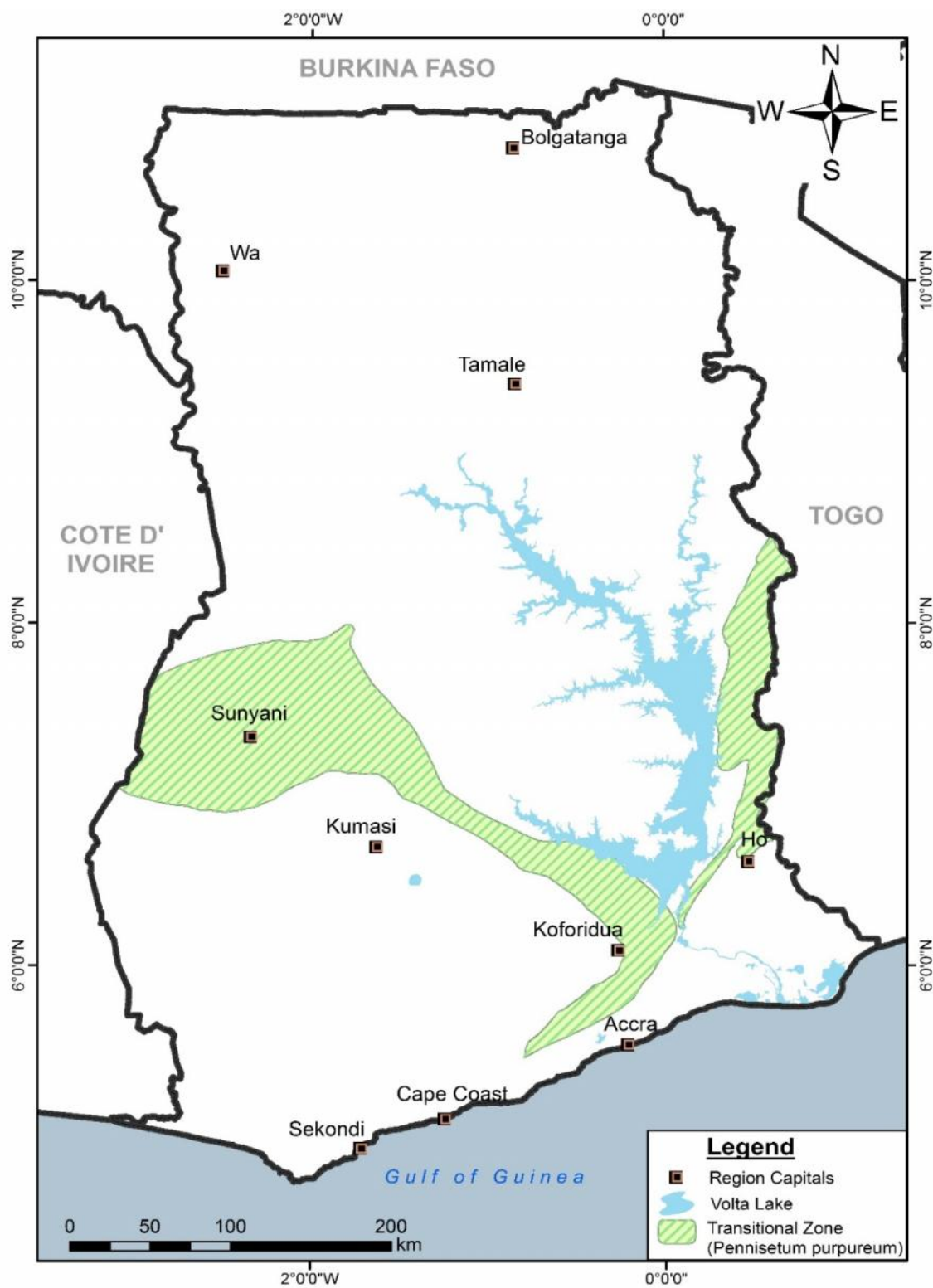
1.1 Demand and supply dynamics of electricity in Ghana

Ghana generates proximately 64% of her electric power from hydro sources [16]. The hydro is currently subject to the vagaries of the weather due to climate change [17]. The rest is of the country's electric power needs is obtained from thermal that lacks secured proven source of fuel (Natural gas and light crude oil) and dependent on dynamics of world crude prices [17]. In order to ensure energy security,

there is more agent 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 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 76891 hectares of biomass [18]. Nonetheless, high value of 30MW per 1600 ha have been reported [19]. This fuel material can be readily produced locally and it offers flexibility, reliability and security needed for energy generation. In addition, it is relatively cheaper and windfall to Ghanaian economy is very huge, 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 corresponding expansion of industrial sector particularly mining and manufacturing, the on-going rural electrification scheme and the new oil find with corresponding up-stream and mid-stream activities [20]. In addition, the other latent factors associated with rapid urbanization and population growth accounting for huge proportion of non-commercial residential consumers (see Figure 2). The demand for electricity is estimated to have year-on-year average growth rate of about 10 % [16].

However, 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 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 bulk electricity purchases from VRA and other independent power producers respectively. These losses emanate from technical (e.g. obsolete equipment) and commercial (illegal connection and nonpayment of bills) causes. Moreover, country exported 329 GWh of electricity to the neighboring countries [21].

89



90

91

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

92

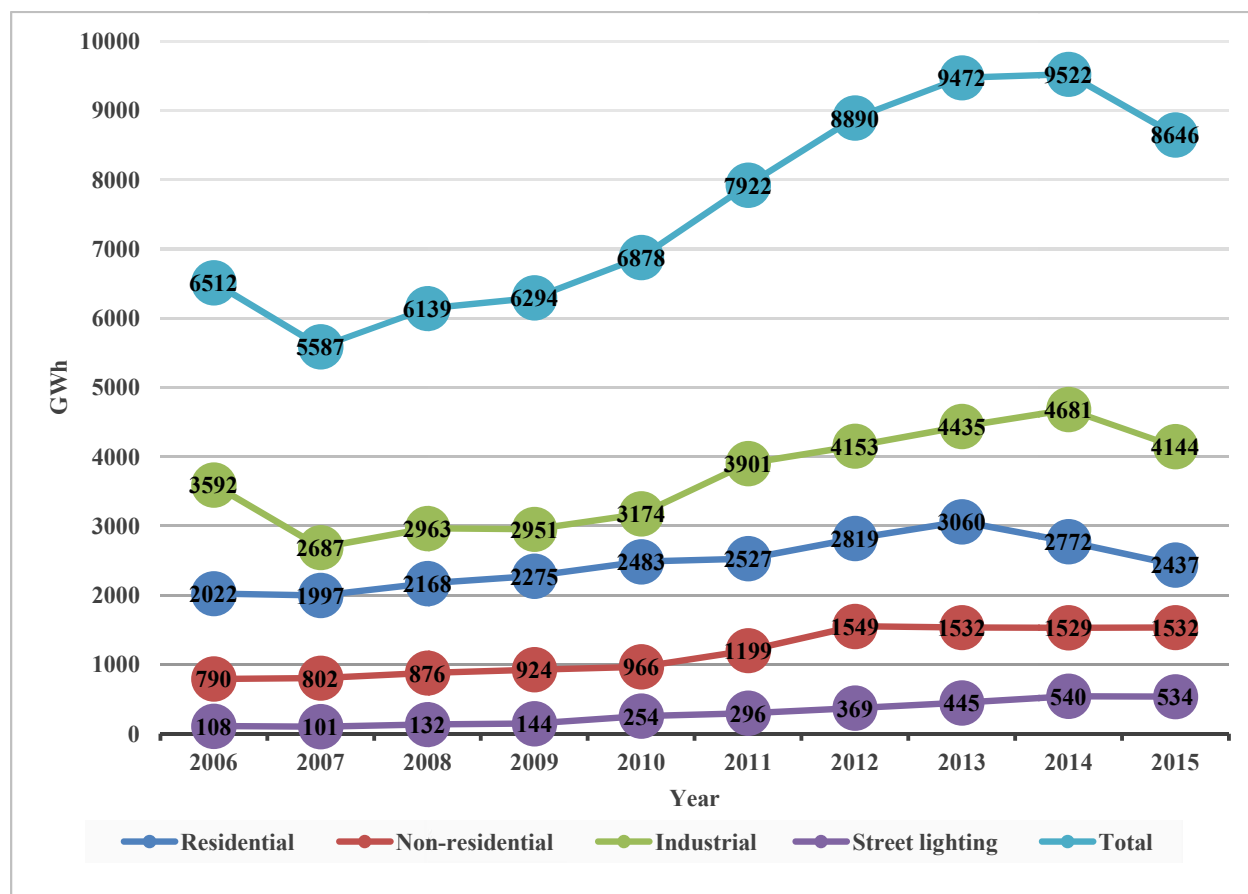


Figure 2. Drivers of electricity consumption in Ghana

2. BIOMASS ENERGY AND COST OF PRODUCTION

The current average cost of generating electricity utilizing biomass in US employing conventional combustion technology(biomass-fired) without cogeneration is estimated to range from 0.08 \$ to 0.26 \$ per kilowatt-hour [22],[23]. However, the cost could vary depend on the interest rate on the investment, location, system design and fuel cost taking into consideration logistical constraint in terms of transport and harvest [22]. Moreover, with advancement in technology the cost is expected to go down; particularly with introduction of new gasification technologies the cost of generating power from waste wood and other biomass feedstock may go down.

As at 2013, in Northern Europe, the cost of producing electricity from biomass ranges from 19.58 to 23.50 dollar per MWh (1.95 to 2.35 cents per kWh) for co-firing plant. The spot market price was

approximately 24.15 to 25.46 dollar per MWh (2.415 to 2.546 cents per kWh) [24]. Presently, the cost of electric power generation from biomass has come down due to technological advancement and technical efficiency.

Table 2. Estimated LCOE of North America and European Union

PLANT TYPE	North America	European Union
	Total System LCOE* (\$/KWh)	Total System LCOE* (\$/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: [25], [30], # [31]

The levelized cost of power from biomass using despatchable technology is comparatively lower than technologies such as coal and nuclear in both North America and within European Union [25] (Table 2). 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 are 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 [26].

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 [10]. However, for continuous assured supply of elephant grass biomass as feed stock, 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 (Figure 3). Co-firing generating plant that could utilize elephant grass alone or in combination with sawdust from saw mills and municipal solid waste or both (Figure 3).

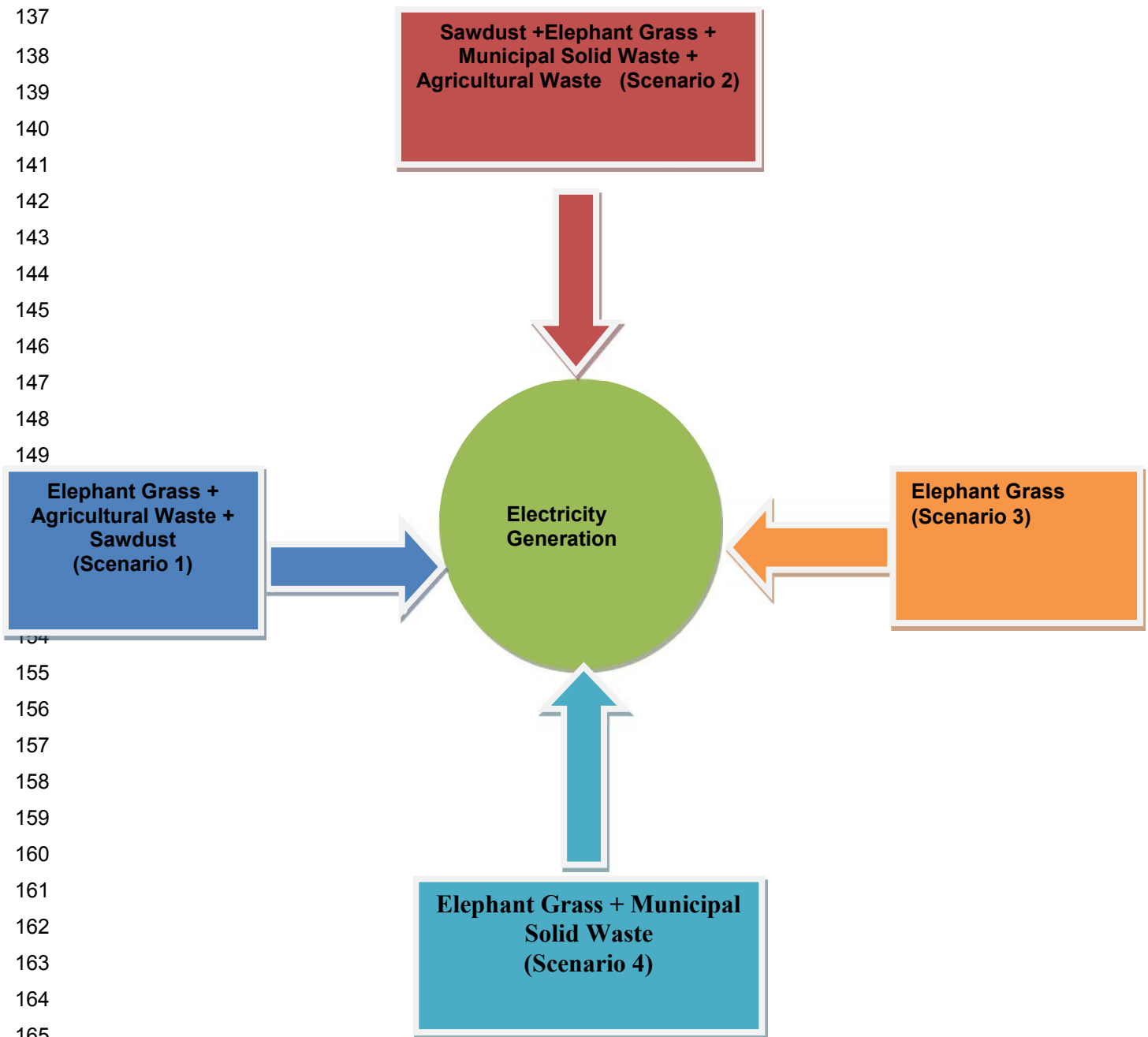


Figure 3. Various scenarios for using elephant grass (*Pennisetum purpureum*) biomass in combination with other feed stocks for electricity generation in Ghana.

In general mixed biomass fuel feedstock in power generation are more cost efficient and reliable [32]. In 2008, the total dry biomass of agricultural residues generated in Ghana was approximately 4,159,550 ton [33]. During the same period it was estimated that the total waste generated from sawn or processed timber was 256,000 m³ equivalents to 128,250 tons of waste in wood milling industry in the country [33],[34]. However, the quality of waste material or sawdust generated varies with tree species and kind of processing mechanism employed and maintenance of the plant [34]. Moreover it is estimated that each households in Ghana generate per capital municipal solid of approximately 150 kg to 200 kg per annum. However, the 10 regional capitals all together generate about 2 million ton municipal solid waste per annum, and Accra alone generates 760,000 tons municipal solid waste per annum [35],[36]). These figures are expected to go up with increase in urbanization and population growth. Thus, suggesting potential availability of biomass for power generation if this feedstock resource is well managed. It will be reasonable for the Ghana to establish pilot biomass power generating plant in the regional capitals. In addition, this will help to address the problem of waste management in the regional capitals. The potential use of available native plants biomass and waste biomass material will ensure sustainable bioenergy deployment [37].

2.2 Yields, energy and economics

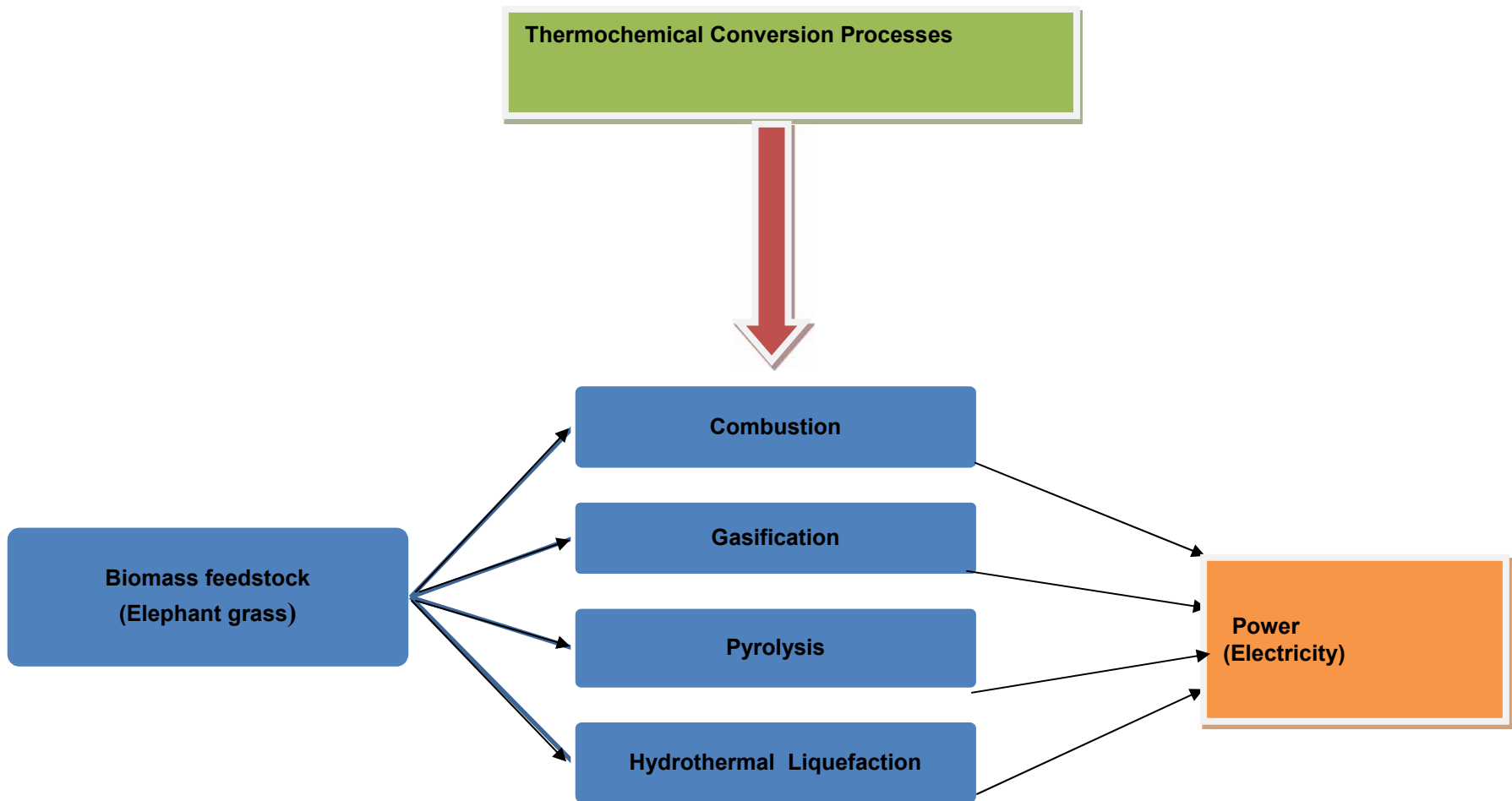
Elephant grass has highest biomass yield per hectare than any know short rotation wood crop (harvest 2-10 years) meant for bioenergy [9]. A referenced research reported oven dry biomass yield of 0.0 25kgm⁻¹day⁻¹ based on linear growth in elephant grass [9]. In related studies a dry biomass amounts between the range of 27.3 to 37.1 MT/ha were reported in regions with precipitation amount over 1250mm per annum [38]. This annual rainfall amounts is comparable as pertaining to dry semideciduous ecological zone in Ghana [39]. 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 [40]. However, higher biomass yields can be achieved if the species is allowed to grow beyond 200 days before harvest [41]. The yield of dry matter increase with advancing in age, 50 and 91.3 MT/ha at 200 and 365 days of continuous growth respectively [41],[9],[42],[38]. A typical oven dried yield of about 25–35 metric tons per hectare in a year is usually not uncommon. This yield amount is equivalent to 100 barrels of crude oil per hectare [43]. The biomass yields that can be achieved under standard agronomic conditions depend on the species or cultivar of the elephant grass in question [44], [40]. The biomass of elephant grass has higher heating value, lower ash, nitrogen and sulphur content. Structurally, biomass of elephant grass contains high levels of cellulose and lignin, thus making it an ideal candidate for bio-oil (biodiesel) production [43]. Thus, the potential for elephant grass as next generation feedstock for power generation particularly electricity is very huge in Ghana and rest of tropical Africa. This is under premise that

research and development in the country will address issue related to technical, logistics, economic, social and agronomic in more holistic and comprehensive manner.

3. ELEPHANT GRASS BIOMASS POWER CONVERSION TECHNOLOGIES

The transformation of biomass to energy involves wide range of different technologies depending on the sources of biomass, end-use application and available infrastructure [12], [45]. 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 under 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 process can be used in power generation (electricity) (Figure 4). The most common processes are the formal three processes due to the fact that liquefaction is complicated engineering and expensive [45]. Combustion technologies rely on direct burning of biomass to release the stored chemical energy into heat, mechanical power or electricity. These involve the application of varieties of process equipment such as steam turbines coupled with dynamos, furnaces, turbo-generators, boilers etc. e.g. [46], [45], [47]. Direct combustion of biomass produces temperatures in the neighborhood of about 800-1000°C. Biomass combustion systems are available in the size range from a few kW up to more than 100 MW. The efficiency for heat production is considerably high and heat from biomass is economically feasible particularly co-fire system with coal [48], [49], [46],[37]. 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 [46]. Gasification is the process of turning biomass into 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 [50],[51]. The producer gas mixture can be used to run internal combustion engines (both compression) and spark ignition) and as substitute for furnace oil in direct heat applications. In addition, it is economically viable way of producing methanol, an industrial chemical useful as fuel for heat engines and chemical feedstock (syngas) [52]. The producer gases can be burnt directly as fuel in gas engines and gas turbines for electricity generation [53]. The current conventional method which has added advantage is biomass integrated gasification or combined cycle, this system is more efficient in converting clean producer gaseous fuel to electricity [45];[3]. Pyrolysis practically involves conversion of biomass to liquid by thermal destruction or through heating under inert environmental condition at temperature of about 500°C or higher [54].

239
240
241
242
243
244
245



246
247

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

248
249
250 The resulting products are mainly charcoal, liquid (biodiesel) and fuel gas [55]. The biodiesel
251 (bio-oil) and fuel gas can be used by turbines or engines to produce electricity or combine
252 heat and power (CHP) [55], [56]. Hydrothermal liquefaction of biomass is conversion of solid
253 biomass to into liquid biofuel under high pressures (4 –22 MPa) and extreme temperatures
254 (523–647 K) in water medium (steam). The process breaks down the complex polymers of
255 monomers of biomass usually lignocellulosic material into liquid form [57], [58].

256
257

258 **3.1 Bioenergy, Environment and Food Security Nexus**

259 There is growing concern of arable land meant for food crop cultivation being converted into
260 production of short rotation biofuel crop such as elephant grass for biomass. Globally, rising
261 cost of energy and paradigm shift in energy and environmental policies that favour
262 production of renewable energy have contributed to demand for biofuels to the detriment of
263 food crops [59]. This has created a situation whereby arable lands for food crop cultivation
264 are being converted into production of biofuels. This condition has led to high food prices a
265 situation which is beneficial to food crop farmers and disadvantage to average consumer
266 [60]. The use of arable land for biofuel production usually offset the balance that ensures
267 food security particularly in developing countries. The production of biofuel crops for energy
268 usually requires large amount of land [61].The Government of Ghana releasing the link
269 between food security and biofuel production has emphasized the need to strike the balance
270 between sustainable food security and land allocation for biofuel crops in the bioenergy
271 policy document. However, one of the unique attributes of elephant grass as a native grass
272 species is its ability to thrive very well in degraded ecosystems and marginal lands that are
273 not suitable for meaningful agriculture. Elephant grass being a native species, the usually
274 externalities associated with producing biofuel (biomass) from exotic grasses in terms of
275 inputs like nitrogen, phosphorous and pesticide are absent (see, 62). Moreover,
276 phosphorous is deficient in most tropical soils and Ghana is no exception [63]. Power
277 generation using elephant grass is carbon neutral with minimal environmental impact in
278 terms of carbon dioxide emissions. Elephant grass and grasses in general have ability to
279 sequester carbon dioxide [64].

280

281 **4. CONCLUSION**

282 The use of elephant grass as short rotation biofuel feedstock holds great potential for the
283 country. Elephant grass is suitable as a fuel for direct combustion or through series of
284 thermochemical conversion to generate electric power. It offers secure and reliable source of

285 fuel as compared to fossils currently being used to generate power in the country. The
 286 biomass from the elephant grass plantation can be integrated with agriculture and urban
 287 waste in direct combustion process to produce power. This offers advantage in the nation's
 288 drive to manage huge pile of solid waste engulfing our major urban centers. The leveled
 289 cost of generating power from biomass particularly from elephant grass is relatively lower
 290 and competitive to other forms of dispatchable power technologies. The economic benefit of
 291 incorporate elephant grass biomass based bioenergy into our energy mix as nation is very
 292 huge in terms of employment to the youth and reducing rural poverty by providing additional
 293 income. The other positive side for using biomass in power generation is the fact that is
 294 clean electricity and carbon neutral, hence environmental friendly. In addition, elephant
 295 grass is a native plant species and highly adapted to local ecological and environmental
 296 condition. The use of elephant grass as bioenergy resource will ensure long term
 297 environmental sustainability. It is imperative for us as a nation to harness the potential of this
 298 renewable natural resource to address our energy needs. Policymakers and researchers
 299 need to have second look at potential use of elephant grass biomass for power generation
 300 and as part of energy mix to ensure electric power security in the country.

301

302 REFERENCES

- 303 1. Wang D, Poss JA., Donovan TJ, Shannon MC, Lesch SM. Biophysical properties and
 304 biomass production of elephant grass under saline conditions. J. Arid. Environ. 2002;
 305 52(4); 447-456.
 306
- 307 2. Thompson JB. Napier and merker grasses. Florida Agric. Exp. Stat Bull. 1919;153:136-
 308 249
 309
- 310 3. Lane J. EPA OK's arundo, Napier grass for renewable fuels. Biofuels Digest
 311 [http://www.biofuelsdigest.com/bdigest/2013/07/05/epa-oks-arundo-napier-grass-for-](http://www.biofuelsdigest.com/bdigest/2013/07/05/epa-oks-arundo-napier-grass-for-renewable-fuels)
 312 [renewable-fuels](http://www.biofuelsdigest.com/bdigest/2013/07/05/epa-oks-arundo-napier-grass-for-renewable-fuels), 2013 (accessed 20 July, 2018).
 313
- 314 4. Kabi F, Bareeba FB, Havrevoll Q, Mpofo IDT. Evaluation of protein degradation
 315 characteristics and metabolisable protein of elephant grass (*Pennisetum purpureum*)
 316 and locally available protein supplements. Livest. Prod. Sci. 2005; 95:143-53.
 317
- 318 5. Adekalu KO, Olorunfemi IA, Osunbitan JA. Grass mulching effect on infiltration, surface
 319 run off and soil loss of three agricultural soils in Nigeria. Bioresour.Technol. 2007; 98:
 320 912-917.
 321
- 322 6. Aroeira LJM, Lopes FCF, Deresz F, Verneque RS, M Dayrell MS, de Matos LL,
 323 Maldonado-Vasquez H, Vittori A. Pasture availability and dry matter intake of lactating

- crossbred cows grazing elephant grass (*Pennisetum purpureum*, Schum.). *Anim. Feed Sci. Technol.* 1999; 78: 313-324.
7. Ebong C, Byenkya SG., Ndikumana J. Effects of substituting Calliandra leaf meal for soybean meal on intake, digestibility, growth and feed efficiency in goats. *J. Appl. Anim. Res.* 1990; 16:211–216.
8. Osava M. Energy-Brazil: Elephant grass for biomass. Inter Press Service New Agency.<http://www.ipsnews.net/2007/10/energy-brazil-elephant-grass-forbiomass> 2013(accessed 15 October, 2017)
9. Prine GM, Rockwood DL, Stricker JA. Many *Short Rotation Trees and Herbaceous* Plants Available as Energy Crops in Humid Lower South. In *Proceedings of Bioenergy 2000, Northeast Regional Bioenergy Program*. October 15-19, 2000. Buffalo. NY, 2000.
10. FAO. Hardwood plantations in Ghana by F. Odoom. Forest plantations working paper 24. Forest resources Development Service, Forest Resources Division, FAO, Rome (unpublished). 2002.
11. Jansen AR. Second generation biofuels and biomass. Essential guide for investors, scientist and decision makers. Wiley-VCH Verlag GmbH & Co, KGaA, Weinheim, Germany, 2012.
12. McKendry P. Energy production from biomass (part 1): overview of biomass. *Bioresour. Technol.* 2002a; 83:37-46.
13. Lin D. The development and prospective of bioenergy technology in China. *Biomass Bioenergy* 1998; 15:181–186.
14. Moore KJ, Fales SL, Heaton EA. Biorenewable energy: new opportunities for grassland agriculture. *Multifunctional Grasslands in a Changing World*, 2008 IGC /IRC Conference Hohhot, China, 2008, pp. 1023-1030,2008.
15. Liu X, Shen Y, Lou L, Ding Cai C. Copper tolerance of the biomass crops Elephant grass (*Pennisetum purpureum* Schumach), Vetiver grass (*Vetiveria zizanioides*) and the upland reed (*Phragmites australis*) in soil culture, *Biotechnol. Adv.* 2009; 27: 633-640.
16. Eshun ME, Amoako-Tuffour J. A review of the trends in Ghana's power sector. *Energy Sustain. Soc.* 2016; 5:1-9.
17. Energy Commission, National energy statistics 2006 – 2016. Strategic Planning and Policy Division, Energy Commission, Ghana. April, 2017.
18. Vivanpatarakij S, Wangjiraniran W, Nidhiritdhikrai R, Wiwattanadat D. Potential Study of Electricity Generation 1000 MW with Biogas in Thailand. *Adv. Mater. Res.* 2013; 622(623): 1209-1212.

- 371 19. Bioenergy International. Giant King Grass. Bioenergy International No 69, 7 -2013
372 www.bioenergyinternational.com, 2013, (accessed 20 December, 2017)
373
- 374 20. Energy Commission, 2016 Energy (Supply and Demand) Outlook for Ghana. Final
375 Report, April, 2016, Energy Commission, Ghana, 2016a.
376
- 377 21. Energy Commission, *National energy statistics 2006 – 2015*. Strategic Planning and
378 Policy Division, Energy Commission, Ghana. April, 2016, 2016b.
379
- 380 22. ODOE, *Biomass energy: Cost of production*. Bioenergy in Oregon. www.Oregon.gov
381 /energy/RENEW/Biomass/Pages/Cost.aspx, 2013, (accessed 1 January, 2018)
382
- 383 23. WBDG, *Biomass for electricity generation*. https://www.wbdg.org/resource/biomass-
384 electricity-generation, 2016, (accessed 15 December, 2017)
385
- 386 24. M. Hogan, J. Otterstedt, R. Morin, S Wilde, *Biomass for heat and power-opportunity and*
387 *economics*. http://www.europeanclimate.org/documents/Biomass_report_-_Final.pdf,
388 2013, (accessed 20 December, 2017)
389
- 390 25. U.S. Energy Information Administration, Annual Energy Outlook 2016, April 2016,
391 DOE/EIA 0383(2016) VGP, 2016.
392
- 393 26. Kenney KL, Ovard LP. Advanced feedstock for advanced biofuels: transforming biomass
394 to feedstock. *Biofuels* 2013; 4: 1-3.
395
- 396 27. Quist E. Value for Money: Ghana's electricity cost highest in West Africa-
397 ACEP.[www.pulse.com.gh/oil-gas/value-for-money-ghanas-electricity-cost-highest-in-](http://www.pulse.com.gh/oil-gas/value-for-money-ghanas-electricity-cost-highest-in-west-africa-acep-id4389656.html)
398 [west-africa-acep-id4389656.html](http://www.pulse.com.gh/oil-gas/value-for-money-ghanas-electricity-cost-highest-in-west-africa-acep-id4389656.html), 2015(accessed 15 December, 2017)
399
- 400 28. Energy Commission, Market watch: Monthly market data analysis. Wholesale electricity
401 market bulletin. Issue No. 6: 1st June 2016 to 30th June 2016, 2016 c
402
- 403 29. Myjoyonline.com. Electricity tariffs to be reduced-Agyarko. [www.myjoyonline](http://www.myjoyonline.com/politics/2017/January-23/electricity-tariffs-to-be-reducedifagyarko.php)
404 [.com/politics/2017/January-23/electricity-tariffs-to-be-reducedifagyarko.php](http://www.myjoyonline.com/politics/2017/January-23/electricity-tariffs-to-be-reducedifagyarko.php),2017
405 (accessed 30 July, 2018)
406
- 407 30. Powertech, Levelized cost of electricity. Issue 2015.VGB-B-031, 2015
408
- 409 31. Askja Energy Partners. The Wish-list of Icelandic energy industry. [https:](https://askjaenergybdotcom.bfiles.wordpress.com/2016/08/iceland-new-powerprojects-utilizationcategory_askja-energypartners-august-2016.jpg)
410 [//askjaenergybdotcom.bfiles.wordpress.com/2016/08/iceland-new-powerprojects-](https://askjaenergybdotcom.bfiles.wordpress.com/2016/08/iceland-new-powerprojects-utilizationcategory_askja-energypartners-august-2016.jpg)
411 [utilizationcategory_askja-energypartners-august-2016.jpg](https://askjaenergybdotcom.bfiles.wordpress.com/2016/08/iceland-new-powerprojects-utilizationcategory_askja-energypartners-august-2016.jpg),2016 (accessed in December,
412 2017)
413
- 414 32. Shi J, Thompson VS, Yancey NA ,Stavile V, Simmons BA, Singh S. Impact of mixed
415 feedstock and feedstock densification on ionic liquid pretreatment efficiency. *Biofuels*
416 2013; 4(1): 63-72.
417

- 418 **33.** Duku MH, Gua S, Hagan EB. Biochar production potential in Ghana-A review. *Renew.*
419 *Sust. Energy Rev.* (2011a); 15:3539-3551.
- 420
- 421 **34.** Parikka M. Global biomass fuel resources. *Biomass and Bioenergy* 2004; 2 (7): 613–
422 620.
- 423
- 424 **35.** Kramer H, Jechimer K, Lengsfeld S, Nartey-Tokolli IB Determination of major planning
425 data for solid waste management in Accra metropolis. Accra, Ghana: Accra Metropolitan
426 Assembly, Waste Management Department. 1994.
- 427
- 428 **36.** Duku MH, Gua S, Hagan EB. A comprehensive review of biomass and biofuels potential
429 in Ghana. *Renew. Sust. Energy Rev.* (2011b); 15(1):404-415.
- 430
- 431 **37.** Van Loo S, Koppejan J. Handbook of biomass combustion and co-firing. Twente
432 University Press: Twente, Netherlands, 2002.
- 433
- 434 **38.** Bogdan AV. Tropical pasture and fodder plants. Longman, London, 1977.
- 435
- 436 **39.** Statistics, Research and information Directorate (SRID), Agriculture in Ghana. Facts and
437 Figures. Ministry of Food and Agriculture. Accra Ghana, 2001.
- 438
- 439 **40.** Duke JA, The gene revolution. Paper 1. p. 89–150. In: Office of Technology
440 Assessment, Background papers for innovative biological technologies for lesser
441 developed countries. USGPO. Washington, 1981,
- 442
- 443 **41.** Woodard KR, Prine GM. Dry matter accumulation of elephant grass, energy cane and
444 elephant millet in a subtropical climate. *Crop Sci.* 1993, 32: 818-824.
- 445
- 446 **42.** Miyagi E. The effect of planting density on yield of Napier grass (*Pennisetum*
447 *purpureum* Schumach). *Science Bulletin Collage of Agriculture, University of Ryukus*,
448 Number 1980; 27:293-301.
- 449
- 450 **43.** Mohammed IY, Abakr YA, Kazi FK, Yusup S, Alshareef I, Chin SA. Comprehensive
451 characterization of Napier grass as a feedstock for thermochemical conversion.
452 *Energies* 2015; 8(5): 3403-3417.
- 453
- 454 **44.** Vitor CMT, Fronsera DM, Coser AC, Martins CE, Nascimento JD, Ribeiro JI. Junior, Dry
455 matter production and nutritional value of elephant grass pasture under irrigation and
456 nitrogen fertilization. *Rev. Bras. Zootec.* 2009; 38(3): 435-442.
- 457
- 458 **45.** McKendry P. Energy production (part 2): conversion technologies. *Bioresour. Technol.*
459 (2002b); 83: 47-54.
- 460
- 461 **46.** Nussbaumer T. Combustion and co-combustion of biomass: Fundamentals,
462 technologies, and primary Measures for emission reduction. *Energy Fuels* 2003
463 17:1510-1521.
- 464

- 465 **47.** Szyszlak-Bargowicz J, Zajac G, Piekarski W. Energy biomass characteristics of chosen
466 plants. *Int. Agrophys.* 2012; 26:175-179.
- 467
- 468 **48.** Mitsui Babcock Ltd. Studies on thermal processing of biomass and waste materials.
469 ETSU, B/T1/00351/Rep, 1997.
- 470
- 471 **49.** EU. Biomass conversion technologies. EUR 18029 EN ISBN 92-820-5368-3, 1999.
- 472
- 473 **50.** Williams RH, Larson ED. Biomass gasifier gas turbine power generating technology,
474 *Biomass Bioenergy* 1996; 10 (2-3):149-166.
- 475
- 476 **51.** Wei L, To SDF, Pordesimo L, Batchelor W. Evaluation of micro-scale electricity
477 generation cost using biomass-derived synthetic gas through modeling. *Int. J. Energy*
478 *Research* 2011; 35:989–1003.
- 479
- 480 **52.** Reed TB, Graboski M, Markson M. The SERI high pressure oxygen gasifier, report
481 SERI/TP-234-1455R, Solar Energy Research Institute, Golden, Colorado, Feb. 1982,
482 1982.
- 483
- 484 **53.** Wang L, Weller CL, Jones DD, Hanna MA. Contemporary issues in thermal gasification
485 of biomass and its application to electricity and fuel production. *Biomass Bioenergy*
486 2008; 32 (7):573-581.
- 487
- 488 **54.** Bridgewater AV. Review of fast pyrolysis of biomass and product upgrading. *Biomass*
489 *Bioenergy* 2012; 38:68-94.
- 490
- 491 **55.** Demirbas A, Arin G, An overview of biomass pyrolysis. *Energy Source* 2002; 24:417-
492 482.
- 493
- 494 **56.** Czemik S, Bridgewater AV. Overview of application biomass fast pyrolysis oil. *Energy*
495 *Fuels* 2004; 18:590 -598.
- 496
- 497 **57.** Elliott DC, Biller P, Ross AB, Schmidt AJ, Jones SB. Hydrothermal liquefaction of
498 biomass: Developments from batch to continuous process. *Bioresour. Technol.* 2015;
499 178: 147–156.
- 500
- 501 **58.** Elliott DC, Hart TR, Schmidt AJ, Neuenschwander GG, Rotness LJ, Olarte, MV Zacher
502 AH, Albrecht KO, Hallen RT, Holladay JE, Process development for hydrothermal
503 liquefaction of algae feedstock in a continuous-flow reactor. *Algal Res.* 2013; 2:445–454.
- 504
- 505
- 506 **59.** Beckman J, Allison B, Carol AJ. Agriculture's Supply and Demand for Energy and
507 Energy Products, EIB-112, U.S. Department of Agriculture, Economic Research
508 Service, May 2013, 2013.
- 509
- 510 **60.** Huang J, Yang J, Msangi S, Rozelle S, Weersink A. Biofuels and the Poor: Global
511 Impact Pathways of Biofuels on Agricultural Markets. *Food Policy* 2012; 37(4): 439-451.
- 512

- 513 **61.** Pimentel D, Herz M, Glickstein M, Zimmerman M, Allen R, Becker K, Evans J, Hussain
514 B, Sarsfeld R, Grosfeld A, Seidel T. Renewable energy: Current and potential issues.
515 BioSci. 2002; 52(12): 1111–1120.
516
- 517 **62.** Timmons D. Social cost of biomass energy from Switchgrass in Western Massachusetts.
518 Agric. Res. Econ. Rev. 2013; 42(1): 176–195.
519
- 520 **63.** Raaimakers D, Boot RGA, Dijkstra P, Pot S. Photosynthetic rates in relation to leaf
521 phosphorus content in pioneer versus climax tropical rainforest trees. Oecol. 1995;
522 102(1):120–125.
523
- 524 **64.** Lemus R. Lal R. Bioenergy crops and carbon sequestration. Crit. Rev. Plant Sci 2005;
525 24(1), 1–21.
526