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The Bioenergy Potentials of Lignocelluloses

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Abstract

Lignocellulosic biomass is abundant resources accrued from agricultural, municipal and other sources. Their high fermentable carbohydrate contents make them suitable candidates for bioenergy generation. The global increase in the generation of these resources is phenomenal, thus culminating in huge environmental disasters with its attendant global warming and climate change menace. Their improper management has equally been reported to cause several environmental challenges such as water, land and air pollution and the spread of pathogenic organisms which causes diverse diseases within the human and animal population. However, the proper and adequate management/utilization of these materials can improve human's living standards as well as ensuring environmental protecting via the production of environmental-friendly biofuels. In this regard, research on the use of lignocellulosic biomass as alternative energy feedstock to fossil fuels has gained considerable attention over the last few decades majorly because of their abundance and significant roles in greenhouse gas emissions reduction.

Keywords: agriculture, bioenergy, biomass, environment, pollution, resources

1. Introduction

Man has continued to exploit different sources of energy such as energy stored in plant either by burning as fuel or consuming plants for nutritional purposes. There is no doubt that energy can be converted from one form to the other and it is essential to life. However, the transformation of biomass to fossil fuel takes a long period of time and is non-renewable within the period man can utilize it. Several sources have been exploited for renewable and sustainable energy production for a short period of time [1, 2]. The hazard of fossil fuel on the environment especially in terms of greenhouse gas emission has led to the increase in demand for clean and sustainable energy. The utilization of renewable sources of energy for

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bioenergy production is a possible option in order to meet this demand. A vital point to take cognizance of is the possibility of using multiple streams of raw materials. Plant biomass is one renewable source of energy as they contain the most abundant organic material which is lignocellulose and can be considered as a credible source for bioenergy production [3]. Sadly, energy from most biomass residue is harnessed directly through combustion which is not an efficient and sustainable means. The conversion of lignocellulosic raw material to bioenergy should involve advance technologies rather than combustion in order to avoid environmental degradation [4]. The most valuable biomass sources for energy production are agricultural crops and their residues, woody plants, waste from food processing and aquatic plants [5].

Lignocellulosic biomass is structurally composed of hemicellulose, cellulose and lignin, however the complex and recalcitrant nature of lignin limits degradability by hindering enzymatic actions for energy production [6–11]. Although, lignocellulosic structure can be altered using various methods of pretreatment to break the bonds between polysaccharides and lignin which in turn aid the degradable cellulose and hemicellulose accessible for enzymatic action. Lignin which is the third most abundant polymer in nature can be removed from lignocellulosic materials using chemical pretreatment leading to an increased internal surface area, biomass enlargement and increased actions of cellulases. Although not all pretreatment brings about an ample amount of delignification, sometimes modification may occur in the structure of lignin without pretreatment which may be due to alteration in the chemical properties [12].

The yearly worldwide primary production of biomass is around 220 billion tones on the basis of dry mass which is equal to 4500EJ of energy derived from the sun annually [13]. An estimated amount of energy which is about 30EJ per year is obtained from forest and agricultural wastes in contrast to a yearly global energy requirement of more than 400EJ. Hence, the cultivation of energy crops for energy production has to be considered and encouraged in large scale. Several factors are considered when selecting good energy yielding plants and these include atmospheric and soil condition, drought resistance, minimal nutrient requirements, high production rate of biomass per hectare, minimal energy input etc. [14]. Bioenergy production can improve income rate of farmers by utilizing the byproducts from processing or storage and also contribute to rural development as energy independence, climate change and rural development are the principal drivers for promotion and application of bioenergy [15].

This focus of this paper is to address the terrestrial sources of lignocellulosic materials that can be utilized for bioenergy production, evaluate the various biofuels that can be produced from lignocellulosic feedstock and to further examine the vice and virtue of biofuel commercialization, utilization and production.

2. Terrestrial sources of lignocellulosic materials for bioenergy production

The major sources of lignocellulosic raw materials that can be exclusively utilized as feedstock for bioenergy are as follow:

1. Agricultural residue

2. Municipal solid waste
3. Woodland trees
4. Dry energy grasses

2.1. Agricultural residue

Agricultural residues are the most economic and abundant organic waste which can biologically converted to biofuels and they provides about 5% of the average amount of biomass energy [16]. They include by-products of agricultural processes such as straw, stover, bagasse, cobs, stalks, husks, etc. all of which are basically lignocellulosic in nature [17]. Although a large amount of these materials are annually produced globally but not adequately utilized [18]. Usage of these materials has been on the increase in the last few decades majorly due to the "food versus energy" debate in which most research endeavors now seek ways of producing fuels from energy crops and wastes as against the earlier practice of producing energy from food crops. Agricultural waste also includes field and processing wastes which can be utilized for bioenergy production [19, 20]. A major problem involved with utilization of agricultural waste however is the efficiency and strategy of collection. Most methods of collection involve multiple transfer of equipment over fields during which about half of the biomass is lost [21]. Yusoff [22] reported that the biomass energy potentials from the processing of wood and palm oil were about 280 TJ and 250 TJ, respectively. In another study, Peterson [23] reported the potential bioethanol and biogas production from winter rye, oilseed rape and faba bean to be 66, 70 and 52%, respectively while methane production is 0.36, 0.42 and 0.44 $l\ g^{-1}$ volatile solids, respectively. Among most agricultural materials, wheat straw has the highest potential as energy feedstock and is therefore being exploited in the industrial production of bioethanol. Similarly, rice straw has been largely used in global bioethanol production. It has been estimated that up to49.1 gallons $year^{-1}$ of global ethanol can be generated from73.9 Tg dry rice straw which is usually wasted during harvest. In total, lignocellulosic raw materials could generate up to 442 gallons $year^{-1}$ of bioethanol. Hence, the total potential generation of bioethanol from crop residues and wasted crops is higher than the world's current ethanol generation. Bagasse which is a by-product from sugarcane processing can potentially generate about 3.6% of world electricity and 2.6EJ of steam. In summary, the potential bioethanol generation agricultural resources could reduce about 32% of the global gasoline consumption when given priority [24].

2.2. Municipal solid waste

Municipal solid wastes also known as trash or garbage generally contains the usual items which includes food scraps, newspapers, furniture, grass clippings, clothing etc. These wastes can be in solid or semi-solid form and can be biodegradable, for example, food waste, green waste and paper [25]. Every person on the planet contributes about 250 kg of municipal solid waste annually [26]. In several nations, the waste is sorted into different components, which in turn enables the biodegradable portion of the waste stream also containing lignocellulosic products like papers, kitchen waste and garden trash be transformed into biofuels. The assorted variety in the municipal solid waste does not make it a perfect feedstock. In any case, it might be valuable in districts where more ideal raw materials are absent or rare. For instance, with the advances in cellulosic ethanol technologies, the Mediterranean could utilize the cellulosic constituent of municipal solid waste as a transportation fuel feedstock and at the same time decrease externalities related with land filling [27]. Some conversion technologies like pyrolysis may involve combustion of municipal solid waste before conversion to energy [28].

2.3. Woodland trees

The capacity of forest as a source of energy is expanding globally. The utilization of woody biomass for power, heat and transportation can stimulate the area of forestry and make the bond closer to energy sector territorially and globally. However, the over-usage of forest ecosystems can put at risk the sustainable improvement of forest and communities dependent on forest. Thus, forest energy strategies must be founded on the guideline of sustainable development which guarantees economic stability, environmental cleanliness and durability in the utilization of the raw material [27]. The potential flow of woody raw materials for bioenergy from forests is not definitely known and should be checked before policy intervention can be effectively executed with regards to global concession on climate change [29].

A large amount of cellulose rich biomass for bioenergy and biopolymer generation can be obtained from fast growing, short-rotation forest trees like *Eucalyptus* and *Populus* [30]. Wood and wood wastes provides about three fifths of the average amount of biomass energy. Sawdust, board ends and barks which are wastes from wood processing and forest products industry are now widely employed for energy production. This sector is partially involved in electrical power generation by the combustion of waste [6]. Energy schemes are complicated and include various factors that must be stated, including socio-economic advantages, climate change mitigation, technological effectiveness the interaction among industries and policies [12]. Researchers have made different investigations for the purpose of assessing the chances of forest energy to mitigate climate change and concluded that the technical potential of primary biomass energy obtained from the forest sector would be 12–74 EJ while the economic potential would only be 1.2–14.8EJ. Woody biomass utilized for production of energy must have the capacity to contend with different utilizations like pulp and paper. In the meantime, the energy generated from biomass must be less expensive than that created from contending energy sources [27]. The theoretical potential of the global excess wood supply in 2050 has been estimated to be 6.1 Gm^3 (71 EJ) and the technical potential to be 5.5 Gm^3 (64 EJ) on the basis of a medium demand and plantation scheme. Based on medium scale scheme, the bioenergy potential from logging, processing residues and waste was assessed to be equal to 2.4 Gm^3 $year^{-1}$ (28 EJ $year^{-1}$) wood [31]. Hypothetically, this shows that forests can be a considerable source of bioenergy and can be utilized without further deforestation and without jeopardizing the supply of wood.

2.4. Dry energy grasses

Perennial grasses have been broadly utilized as fodder crops for a considerable length of time, regularly contributing fundamentally to energy supply. The four most studied perennial rhizomatous grasses are *Panicum virgatum*, *Miscanthus* species, *Phalaris arundinacea* and

Arundodonax [32]. The use of *Miscanthus* as an energy grass has attracted attention among the perennial C4 grasses since it has been identified as a perfect energy grass and produces maximally when harvested dry. Yields of 3–10 years old plantations grown in two countries in Europe are 113–30 t/ha. This means that if a yield of 20 t/ha could be achieved; it would produce a total energy yield that is equal to 7 t/ha of oil over the life of each harvest. Switch grass has an energy value that is similar to wood yet with minimal water content [3]. After proper investigation of some crops which were perennial grasses, switch grass was observed to produce the highest potential [11]. Other than staying away from the competition between food and fuel crop usage, they are considered to have energy, financial, and ecological advantages over food crops for certain bioenergy products [10]. These grasses possess qualities and prospects as for their utilization and enhancement as lignocellulosic feedstock. In order to meet up to the large demand of biomass supply, an extensive environmental capacity is to be considered which marginal soils are included [33]. Another nutrient rich grass is Napier grass (*Pennisetum purpureum*), a grass that grows in the tropics and can withstand dry conditions. It has 30.9% total carbohydrates, 27% protein, 14.8% lipid 14.8%, and 9.1% fiber (dry weight). Thus, it is cultivated for livestock as energy crops and it is easy to cultivate with a high productivity rate of 87 ton/ha/year [32]. Sawasdee and Pisutpaisal [34] reported the feasibility of biogas production from Napier grass and observed that the methane content, yield and production rate were 53%, 122.4 mL CH 4/g TVS remove, 4.8 mL/hr. at the optimum condition.

3. Biofuels from lignocellulosic raw materials

3.1. Biobutanol

Due to the compelling need for alternatives to fossil fuel and increasing concern for environmental and health safety, biobutanol which is a second generation biofuel is now produced as a credible substitute for fossil fuel used as a blend with gasoline. Although butanol is still generated through petrochemical methods, the high demand, depletion rate and price of oil has driven the search for a sustainable source for butanol production. Biobutanol possess some better attributes which includes higher energy content, lower Reid vapor pressure, easy blending with gasoline at any ratio and ease in transportation when compared to bioethanol. Various challenges involved in lignocellulosic butanol production includes method of pretreatment, generation of unwanted solvents and the production cost, low butanol tolerance of microbes resulting in low yield, cost of raw materials. In order to enhance biobutanol production from lignocellulosic raw materials, methods in terms of inhibitors detoxification, strains improvement and process integration and optimization are be dealt with [35].

3.2. Bioethanol

Bioethanol is a first generation biofuel and is mainly produced by enzymatic fermentation using yeast to digest biodegradable raw materials with high energy content. Hydrolysis is employed when raw materials such as high energy yielding crops are utilized; this is done to breakdown the complex nature of the polymer into monomers such as simple sugar followed by conversion of the sugar to alcohol after which distillation and dehydration are used to reach the desired amount that can be utilized directly as fuel [36]. Bioethanol contributed more than 30% of the total ethanol production globally in 2006 with a significant production rate from Asia [35]. Ethanol can be mixed with petrol if appropriately purified and when utilized in modified spark ignition engines, production of toxic environmental gases will be reduced. A liter of ethanol can yield about three fifths of the energy provided by a liter of gasoline [37]. The large scale production of sugar cane in Brazil is dedicated for alcohol and sugar production. Utilization of alcohol as fuel for vehicular engines has been in existence in Brazil since 1973. The increasing demand for alcohol in Brazil led to an increase in sugar cane production in the last 5 years in Brazil [38].

3.3. Biodiesel

In 1900 during the world exhibition in Paris, a diesel engine created by the first inventor of its kind ran on 100% peanut oil and years later the inventor stated that "the diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it". In 1912 Dr. Rudolf Diesel who is the actual inventor of the diesel engine stated that "The use of vegetable oils for engine fuels may seem insignificant today, but such oils may become in course of time as important as petroleum and the coal tar products of the present time". This hypothesis is gradually becoming significant in recent days because there is a global need for sustainability and energy security. The possibility of biodiesel replacing fossil fuels as main source for power is one reason for the global research of biodiesel [39]. Biodiesel is another example of a first generation biofuel and can be produced directly from vegetable oils and other oleo chemicals via trans-esterification methods or cracking. The Trans-esterification procedure may utilize acid, enzymes and alcohol to yield the biodiesel and glycerin as by-product [40]. Oleo chemicals are chemical substances produced from fats and natural oils, they are basically fatty acids and glycerol. Hypothetically, oleo chemicals are better substitute for petrochemicals in terms of sustainability and economic viability [41]. The high price rate of biodiesel is a major constraint to its commercialization in contrast with petroleum, thus the utilization of waste oil should be considered since it is relatively available and cheap [42]. Utilization of biodiesel as a fuel is considered to have a minimal or no release of carbon dioxide since any carbon dioxide released from its combustion was beforehand caught from the atmosphere during the development of the crop used as feedstock for the generation of biodiesel. Biodiesel is considered to have a minimal flash point than gasoline derived diesel, thus its transport is more secure and efficient [43, 44]. Operationally biodiesel blends performs similarly to the conventional diesel without causing any noticeable change in the engine due to the similarity in properties of biodiesel and conventional diesel [45]. This makes biodiesel an efficient replacement for conventional diesel.

3.4. Biogas

Biogas is produced from the anaerobic digestion of biodegradable organic materials which includes lignocellulosic biomass, animal dung, carcass etc. Biogas contains methane, carbon dioxide which occupy a significant amount in terms of volume and other gases which include hydrogen sulfide and nitrogen gas [46]. Sweden is one of the pioneers of biogas production

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considering waste-based biogas technology [47]. The total potential for biogas production in Sweden is around 15 TWh per year and more than half comes from agricultural residues. About 5.8 TWh of the potential from agriculture is derived from straw as a feedstock [48]. Recently, this technology has gained so much attention and several researches are conducted regarding this technology. The multi-functional nature of this technology is one reason for its rapid expansion [48–50]. Methane which is the main energy product is generated in the final process of anaerobic digestion called methanogenesis. Naturally, methane is produced in environs such as peats, marshland, sediments and rumen [51]. Methane which is the most useful component of biogas can be utilized for the production of heat and electricity or through purification and enhancement to be utilized as vehicle fuel. Lignocellulosic materials are the most promising substrate for biogas production due to their relative abundance. Several assays have been made to ensure increase in the efficiency of biogas production using lignocellulosic feedstocks including different pretreatment techniques and codigestion with nutrient rich feedstock. However, little is known about the microbes responsible for the digestion of cellulose during biogas production. In 2014, 158 TWh biogas per year was generated from more than 14,500 biogas plants actively utilized within the European Union (EU). Germany, United Kingdom and Italy are known to have the highest primary production of biogas, which are 79.5, 21.6 and 21.5 TWh per year, respectively. In Germany, biogas production from maize, other energy crops, slurry and miscellaneous organic waste are 60, 16, 12 and 8%, respectively [48]. Even with the advancement in this technology thus far, generation and utilization of biogas is still not adequate. The industry is still young and going through challenges of low profit margins and slow return on investment [47].

3.5. The virtue and vice of biofuel commercialization, utilization and production

Recently, biofuels and gasoline have become equals in terms of cost but the total cost of benefit using biofuel is higher. Energy independence and economic stability is a major concern for any developing country and crude oil is scarcely deposited globally and developing countries without this "liquid gold" may experience a huge dent in economy if the crude oil is imported. If the use of biofuel is encouraged, countries will reduce their dependence on fossil fuel hereby creating control on monopoly of fossil rich states and also new jobs will be created with a growing biofuel industry, thus creating economic security and a less toxic environment. However some challenges associated with biofuel commercialization, utilization and production includes "food vs. fuel "crisis, future increase in price due to high demand, policies such as tax credit on production of biofuels and land use change and high cost of production which includes technology cost [8, 37, 46].

4. Conclusion

Lignocellulosic materials are viable sources of bioenergy and their usage as energy sources can play a vital role in helping the industrialized regions of the world reduce the environmental hazards of burning fossil fuel. Therefore, utilization of lignocellulosic materials as sources of energy should be promoted as one of the major routes for bioenergy production.

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Conflicts of interest

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