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Review

Bioethanol production from agricultural wastes: An overview

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ABSTRACT

Due to rapid growth in population and industrialization, worldwide ethanol demand is increasing continuously. Conventional crops such as corn and sugarcane are unable to meet the global demand of bioethanol production due to their primary value of food and feed. Therefore, lignocellulosic substances such as agricultural wastes are attractive feedstocks for bioethanol production. Agricultural wastes are cost effective, renewable and abundant. Bioethanol from agricultural waste could be a promising technology though the process has several challenges and limitations such as biomass transport and handling, and efficient pretreatment methods for total delignification of lignocellulosics. Proper pretreatment methods can increase concentrations of fermentable sugars after enzymatic saccharification, thereby improving the efficiency of the whole process. Conversion of glucose as well as xylose to ethanol needs some new fermentation technologies, to make the whole process cost effective. In this review, available technologies for bioethanol production from agricultural wastes are discussed.

1. Introduction

The world's present economy is highly dependent on various fossil energy sources such as oil, coal, natural gas, etc. These are being used for the production of fuel, electricity and other goods [1]. Excessive consumption of fossil fuels, particularly in large urban areas, has resulted in generation of high levels of pollution during the last few decades. The level of greenhouse gasses in the earth's atmosphere has drastically increased [2]. With the expansion of human population and increase of industrial prosperity, global energy consumption also has increased gradually. Import of transport fuel is affected by limited reserves of fossil fuel. Annual global oil production will begin to decline within the near future [3]. In this scenario, renewable sources might serve as an alternative. Wind, water, sun, biomass, geothermal heat can be the renewable sources for the energy industry whereas fuel production and the chemical industry may depend on biomass as an alternative source in the near future [4]. All petroleum-based fuels can be replaced by renewable biomass fuels such as bioethanol, bio-diesel, bio-hydrogen, etc., derived from sugarcane, corn, switchgrass, algae, etc. Requirements of electricity may be supplied by solar- and wind-farms. The energy consumption rate includes each person's share of electricity and fuel used in making foods and goods and their transport. Biogas has also been identified as a possible motor fuel on organic farms in the short and medium terms. Biogas is produced by anaerobic digestion of organic material. When used as biofuel, CO_2 is removed from the gas to increase the energy content and the gaseous fuel can be stored at high pressure. Biogas can be substituted for natural gas or propane as fuel for boilers and for electricity generation in rural areas. Approximately 1281 mega watt biogas is potentially produced from agrowastes in India [5]. Annual methane production in Sweden from organic waste is about 38 PJ, catering to 11% of the domestic energy requirement for transportation in 2007 and projected to be sufficient for fulfilling the EU target for 2020 [6].

Countries across the globe have considered and directed state policies toward the increased and economic utilization of biomass for meeting their future energy demands in order to meet carbon dioxide reduction targets as specified in the Kyoto Protocol as well as to decrease reliance and dependence on the supply of fossil fuels. Although biomass can be a huge source of transport fuels such as bioethanol, biomass is commonly used to generate both power and heat, generally through combustion. Ethanol is at present the most widely used liquid biofuel for motor vehicles [7,8]. The importance of ethanol is increasing due to a number of reasons such as global warming and climate change. Bioethanol has been receiving widespread interest at the international, national and regional levels. The global market for bioethanol has entered a phase of rapid, transitional growth. Many countries around the world are shifting their focus toward renewable sources for power production because of depleting crude oil reserves. The trend is extending to transport fuel as well. Ethanol has potential as a valuable

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replacement of gasoline in the transport fuel market. However, the cost of bioethanol production is more compared to fossil fuels. The world bioethanol production in 2001 was 31 billion liters [19]. It has grown to 39 billion liters in 2006 and is expected to reach 100 billion liters in 2015 [9]. Brazil and the USA are the two major ethanol producers accounting for 62% of the world production [18]. Large scale production of fuel ethanol is mainly based on sucrose from sugarcane in Brazil or starch, mainly from corn, in the USA. Current ethanol production based on corn, starch and sugar substances may not be desirable due to their food and feed value. Economy of the ethanol production process from grains is dependent on the market of its by-product – distillers' dried grains with solubles (DDGS) – as animal food. The market of DDGS may not expand like that of ethanol in the future [9]. Cost is an important factor for large scale expansion of bioethanol production. The green gold fuel from lignocellulosic wastes avoids the existing competition of food versus fuel caused by grain based bioethanol production [20]. It has been estimated that 442 billion liters of bioethanol can be produced from lignocellulosic biomass and that total crop residues and wasted crops can produce 491 billion liters of bioethanol per year, about 16 times higher than the actual world bioethanol production [18]. Lignocellulosic materials are renewable, low cost and are abundantly available. It includes crop residues, grasses, sawdust, wood chips, etc. Extensive research has been carried out on ethanol production from lignocellulosics in the past two decades [10–12]. Hence bioethanol production could be the route to the effective utilization of agricultural wastes. Rice straw, wheat straw, corn straw, and sugarcane bagasse are the major agricultural wastes in terms of quantity of biomass available [18]. This review aims to present a brief overview of the available and accessible technologies for bioethanol production using these major agrowastes.

2. Raw material

The four major agrowastes mentioned in the preceding section are the most favorable feedstocks for bioethanol production due to their availability throughout the year. Worldwide production of these agrowastes is given in Table 1. Asia is the major producer of rice straw and wheat straw, whereas corn straw and bagasse are mostly produced in America (Table 1). They also vary in chemical composition (Table 2), cellulose being the major component.

These agro-residues are also utilized as animal fodder, as domestic fuel, and as fuel to run boilers. The utilization fraction of wheat straw, rice straw and corn straw is too low and varies with geographic region [18]. Each year a large portion of agricultural residues is disposed of as waste. For instance, approximately 600–900 million tons per year rice straw is produced globally [13]. The options for the disposal of rice straw are limited by the great bulk of material, slow degradation in the soil, harboring of rice stem diseases, and high mineral content. Only a small portion of globally produced rice straw is used as animal feed, the rest is removed from the field by burning, a common practice all over the world, increasing air pollution and affecting human health [14–17]. Open field burning is already banned in many countries in Western Europe and some other countries have considered it seriously. Less than 1% of corn straw is collected for industrial processing and about 5% is used as animal feed and bedding. More than 90% of corn straw in United States is left in the fields [22]. Sugarcane bagasse has its prominent use as a fuel for boilers and for cogeneration of electricity [23]. Globally, bioethanol production from rice straw, wheat straw, corn straw and sugarcane bagasse is now a matter of interest (Table 3). Rice straw is the most abundant waste compared to the other major wastes (Table 1) and rice straw can potentially produce 205 billion liters bioethanol per year, which is the highest among these four mentioned agricultural wastes.

Lignocellulose is a complex carbohydrate polymer of cellulose, hemicellulose and lignin. Cellulose is linear and crystalline. It is a homopolymer of repeating sugar units of glucose linked by β-1,4 glycosidic bonds. Hemicellulose is a short and highly branched polymer. It is a heteropolymer of D-xylose, D-arabinose, D-glucose, D-galactose, and D-mannose. Lignin is hydrophobic in nature and is tightly bound to these two carbohydrate polymers. It thus protects these polymers from microbial attack [24]. It is a three-dimensional aromatic polymer of p, hydroxyphenylpropanoid units connected by C–C and C–O–C links. Sugar compositions of various agrowastes (rice straw, wheat straw, corn straw, bagasse) are given in Table 4 [25].

Lignocellulosics are processed for bioethanol production through three major operations: pretreatment for delignification is necessary to liberate cellulose and hemicellulose before hydrolysis; hydrolysis of cellulose and hemicellulose to produce fermentable sugars including glucose, xylose, arabinose, galactose, mannose and fermentation of reducing sugars. The non-carbohydrate components of lignin also have value added applications [21].

3. Pretreatment

The most important processing challenge in the production of biofuel is pretreatment of the biomass. Lignocellulosic biomass is composed of three main constituents namely hemicellulose, lignin and cellulose. Pretreatment methods refer to the solubilization and separation of one or more of these components of biomass. It makes the remaining solid biomass more accessible to further chemical or biological treatment [7]. The lignocellulosic complex is made up of a matrix of cellulose and lignin bound by hemicellulose chains. The pretreatment is done to break the matrix in order to reduce the degree of crystallinity of the cellulose and increase the fraction of amorphous cellulose, the most suitable form for enzymatic attack [26]. Pretreatment is undertaken to bring about

Table 1
Quantities of agricultural waste (million tons) reportedly available for bioethanol production.

Agrowaste	Africa	Asia	Europe	America	Oceania	Reference
Rice straw	20.9	667.6	3.9	37.2	1.7	[18,21]
Wheat straw	5.34	145.20	132.59	62.64	8.57	[18]
Corn straw	0.00	33.90	28.61	140.86	0.24	[18]
Bagasse	11.73	74.88	0.01	87.62	6.49	[18]

Table 2
Chemical composition of agricultural wastes.

Substrate	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Protein (%)	Ash (%)	Reference (%)
Rice straw	32–47	19–27	5–24	–	12.4	[13,25]
Wheat straw	35–45	20–30	8–15	3.1	10.1	[24,75]
Corn straw	42.6	21.3	8.2	5.1	4.3	[75]
Baggase	65 (total carbohydrate)		18.4	3	2.4	[48,85]

Table 3
Worldwide potential bioethanol production from agricultural wastes.

Agricultural residue	Potential annual bioethanol production (globally) (giga liter)	Reference
Rice straw	205	[18]
Wheat straw	104	[85]
Corn straw	58.6	[18]
Sugarcane bagasse	51.3	[18]