

# Utilization of Agro-Industrial Residues and Municipal Waste of Plant Origin for Cellulosic Ethanol Production

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## ABSTRACT

*Today's search for alternative sources of energy to reduce the use of fossil fuels is motivated by environmental, socio-economic and political reasons. The use of agro-industrial and municipal wastes of plant origin for ethanol production appears to be the best option to solve the dilemma of using food sources to produce biofuels, since it adds value to these wastes in eco-efficient processes. This paper highlights the potential of agro-industrial and municipal wastes for cellulosic ethanol production.*

**Keywords:** Bioethanol, Agro-Industrial Byproducts, Environmental Preservation, Eco-Efficiency

## 1. Introduction

The interest in alternative sources of energy from plant biomass to replace the dwindling reserves of fossil fuel and petroleum derivatives has been influenced by the constant increase in world crude oil prices. This was evidenced as recently as early 2011, when uncertainties in the political situation of some countries in the Middle East and North Africa drove the price of crude oil to over US\$ 120 per barrel on the London Stock Exchange [1]. Moreover, the combustion of petrochemical fuels has influenced climate change and aggravated global warming, mainly due the emission of greenhouse gases (GHG). Attempts to mitigate environmental impacts have led to the search for renewable and clean sources of energy. These sources include sugarcane ethanol and corn starch ethanol, which represent alternatives to overcome economic problems and environmental impacts.

However, in some countries, the sharp increase in the production of ethanol from starch may lead to controversies regarding the use of this raw material for biofuel or food production, not to mention the high demand for tillable land and agricultural inputs [2]. In this context, an alternative to starch and sucrose-based biofuels has been the production of ethanol from plant biomass (cellulosic ethanol) derived from agro-industrial wastes [2-5] and mu-

nicipal waste [2,6-10]. The conversion of cellulose into fermentable sugars for ethanol production is a promising alternative to meet the global demand for biofuels.

This paper offers a review of the available sources of plant biomass used for the production of cellulosic ethanol, and the environmental, socioeconomic and political policies involved in cellulosic ethanol production.

## 2. Plant Biomass

Plant biomass, the most abundant source of organic matter on earth, is biodegradable and renewable [5]. This biomass is found in forests, agro-industrial residues and municipal waste [11], and is a potential source of material for the production of ethanol [2], which can replace gasoline due to its high energy efficiency [5].

The structure of plant cell walls consists of polysaccharides, proteins, phenolic compounds and minerals. Polysaccharides, which represent about 90% of the dry weight of the cell wall, consist of cellulose (20% - 40%), hemicellulose (15% - 25%) and pectin (30%), while lignin, a non-polysaccharide, gives the cell wall its rigidity [12].

Cellulose, the main constituent of plants [13], is a linear homopolysaccharide with 8000 - 12000 glucose units linked by 1,4-beta-glycosidic bonds. Hemicellulose is a complex heteropolysaccharide composed of glucose, ga-

lactose, mannose, xylose, arabinose, uronic acids and acetyl groups. The branched chain presents a degree of polymerization of less than 200 units [14]. Pectin is a complex heteropolysaccharide constituted of axial connections of  $\alpha$ -1,4-D-galacturonic acid units composed of rhamnose, arabinose and galactose [15]. Lignin is a phenolic polymer that contributes to the structural rigidity of plant tissues [12]. It is composed of macromolecules synthesized by radicals from three *p*-hydroxycinnamic precursor alcohols: *p*-coumaryl, coniferyl and sinapyl [14].

Glucose molecules are joined by glycosidic bonds to form linear chains (cellulose) that interact with each other through hydrogen bonds, forming a structure of elementary fibrils that are water-insoluble and highly crystalline. Four elementary fibrils are grouped in a hemicellulose monolayer, surrounded by a hemicellulose and lignin matrix, called cellulose microfibrils [14,16, 17].

Lignocellulosic material is a generic term that describes the main constituents of plants, *i.e.*, cellulose, hemicellulose and lignin [18], as indicated in **Figure 1**. Its composition depends not only on the type of plant (**Table 1**), but also on the selected part of the plant [19], and on growth conditions [20,21]. This material differs from products with high sugar and starch content [5,22-24].

### 3. Global Scenario

Global ethanol production is monopolized by two major producers, the USA, which uses corn starch, and Brazil, which uses sugarcane sucrose [25]. In both cases, this production is based on food sources. According to Pimentel *et al.* [26], the allocation of food sources for the production of biofuels reaches a critical point when an impasse is reached between the production of raw material for fuel ethanol or for food. This impasse represents a bottleneck in the maintenance and expansion of the biofuels market. One of the short-term alternatives would be to use these plants solely for food and use only their lignocellulosic materials for the production of ethanol. This would help mitigate environmental pollution and mini-

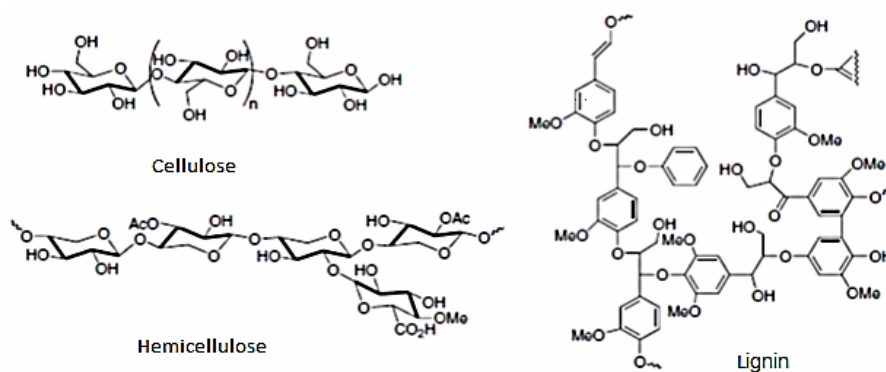
mize the use of food sources for ethanol production [10].

Based on this idea, the Chinese government encourages the production of ethanol only from non-food substrates, *e.g.*, perennial grasses, and plant husks and chaff [27], and strictly controls the territorial expansion of food substrates used in ethanol production [28]. Currently, China

**Table 1. Cellulose, hemicellulose and lignin contents of some agro-industrial and urban residues of plant origin.**

Plant biomass	Compound (%)		
	Cellulose	Hemicellulose	Lignin
Sugarcane bagasse	33	30	29
Wheat straw	30	24	18
Sorghum straw	33	18	15
Rice straw	32	24	13
Oat straw	41	16	11
Maize ear	42	39	14
Maize stalk	35	15	19
Barley straw	40	20	15
Alfalfa stalk	48.5	6.5	16.6
Rice husk	36	15	19
<i>Eucalyptus grandis</i>	38	13	37
<i>Eucalyptus saligna</i>	45	12	25
<i>Pinus sp.</i>	44	26	29
Journal	61	16	21
Processed paper	47	25	12
Angiosperm wood	40 - 50	24 - 40	18 - 25
Gymnosperm wood	45 - 50	25 - 35	20 - 30
Nuts husk	25 - 30	25 - 30	30 - 40
White paper	85 - 99	0	0 - 15
Grasses	25 - 40	35 - 50	19 - 25
Leafs	15 - 20	80 - 85	0
Cottonseed lint	80 - 90	0 - 15	0

Source: [29-34].



**Figure 1. Structural chains of lignocellulosic materials.**

is the world's largest rice and wheat producer. The country generates huge amounts of agro-industrial residues, which may be used alternatively for ethanol production instead of impacting the environment [35,36].

Brazil's sugarcane production seeks to meet domestic and export market demands for ethanol and sugar. However, this economic dependence has serious negative consequences for the population. In early 2011, there was a shortage of ethanol as a result of the higher demand for sucrose for sugar production (due to rising sugar export prices), allied to the sugarcane off-season, which resulted in an average price increase of 20.5%.

Another prospect is ethanol production in Brazil driven by the incorporation of sugarcane bagasse ethanol produced at the same industrial plant, resulting in lower production costs. This proposal would increase the availability of ethanol during the sugarcane off-season, and represent higher economic and ecological efficiencies in the process. This concept is strengthened by data from Brazil's 2010/2011 sugarcane harvest. Although it was a bumper crop, it did not suffice to meet the demand for ethanol and sugar production. In the 2011 season, Brazil's sugarcane production volume will fall short of industrial demand by 23%. This volume is expected to be approximately 632 million tons, while the volume needed to meet current domestic and export demand is 775.6 million tons. The projections for 2020 are that Brazil's sugarcane production will fall 34% below demand, with an estimated supply of 974 million tons to meet a demand exceeding 1.3 billion tons [37].

All around the world, new alternatives are being investigated for the production of cellulosic ethanol based on crops as the source of raw materials. These alternatives include eucalyptus (*Eucalyptus* sp.) and leucaena (*Leucaena* sp.) as well as fast-growing grasses of high productivity, e.g., elephant-grass (*Pennisetum purpureum*), used as forage in South America, switchgrass (*Panicum virgatum*), a species native to North America, and tall grass of the genus *Miscanthus*, which is of greater interest in Europe [38]. Although cultivated plant biomass represents an advance in cellulosic ethanol production, agro-industrial residues and municipal waste of plant origin are priorities for use as substrates for cellulosic ethanol production [30,39-43].

#### 4. Socioenvironmental, Economic and Political Policies

Changes in the global energy matrix have been driven by fuels derived from animal, plant and microbial organic matter. The search for cheaper fuels in developing countries has fostered a growth in the economic activity of biofuel production, facilitated by the fact that most of these countries have large tracts of land, available water

supplies and favorable weather conditions, which may lead to regional development (employment and income generation, population devolution and an increase in foreign exchange reserves). However, it is important to underline the need for strategic agricultural zoning studies to avoid environmental and socioeconomic disasters promoted by huge green deserts, as well as the use of biofuels as an extra energy supply and not merely to replace non-renewable sources of energy.

Renewable sources of energy are desirable because they represent a safe and sustainable energy supply, and lower GHG emissions [3,44]. Ethanol production using lignocellulosic biomass is one of the most important technologies for an ecologically feasible [45] and sustainable production of renewable fuels [44,46-48] to minimize the environmental impact caused by GHG. The six main GHGs are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride [49]. The carbon dioxide produced by burning biofuels is partially recycled in the process of photosynthesis, which is when plant biomass is formed [50,51]. Ethanol has a positive carbon balance [52], and also releases low amounts of nitrous oxide and sulfur dioxide during combustion [53].

The use of municipal waste of plant origin as a substrate for ethanol production can lead to a temporary increase in organic compounds and toxic substances in the environment [54]. However, this amount is small when compared to that produced by liquid fossil fuels [55]. According to the Intergovernmental Panel on Climate Change [49], climate change is caused by the excessive increase of GHGs in the atmosphere, intensified by human activities, which is the case of fossil fuels that have been in use since the pre-industrial age. Significant amounts of carbon dioxide are released into the atmosphere annually. In 2002, about 24 billion metric tons of carbon dioxide would be produced by burning fossil fuels. This number is estimated to reach 33 billion by 2015 [51].

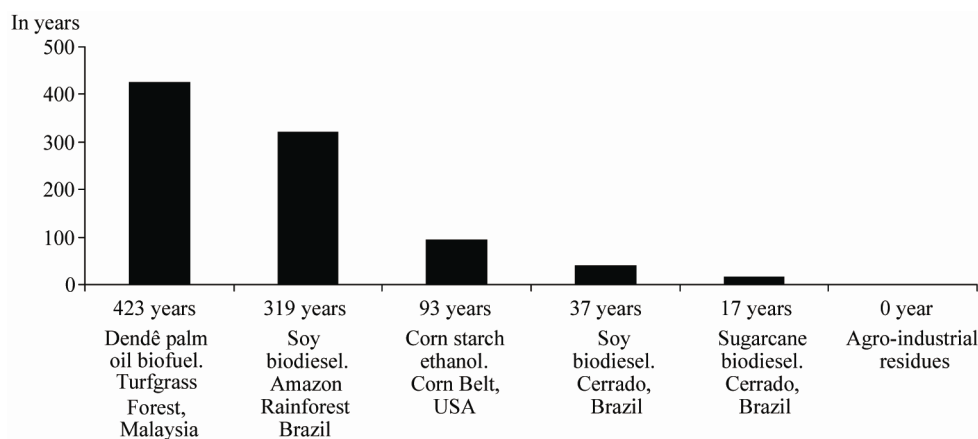
Studies on biofuel by Sukimaran *et al.* [56] demonstrated that the potential of ethanol is comparable to that of petroleum, making it economically feasible for commercial purposes. Moreover, these authors emphasize that the octane rating of ethanol is higher than that of gasoline and that it produces lower air pollutant emissions. In the 1990s, the Tennessee Valley Authority (USA) developed an efficient technology for converting vegetable waste into ethanol [57]. The material was composed of 45% glucose and 9% hemicellulose [2,58,59] and allowed for the production of cellulosic ethanol. According to Shi *et al.* [9], the use of municipal waste of plant origin for ethanol production is a promising strategy to supply the world's energy needs and reduce GHG emissions. Their estimates of the socioeconomic development of

173 countries point to a global production of 82.9 billion liters of ethanol from municipal waste, replacing the consumption of 5.36% of gasoline.

In a comparison of the eco-efficiency of liquid fuels, *i.e.*, gasoline, corn starch ethanol and cellulosic ethanol, Hill *et al.* [55] found that cellulosic ethanol is the most eco-efficient. These authors reported the following costs to produce 1 billion gallons of fuel: gasoline—US\$ 416 million, corn starch ethanol—US\$ 614 million, and cellulosic ethanol—US\$ 208 million. **Figure 2** indicates the time required to eliminate CO<sub>2</sub> emissions produced by deforestation, harvesting and production of some biofuels. These findings emphasize the importance of producing cellulosic ethanol, which not only adds value to plant biomass for biofuel production but also requires no expansion of farmland.

The International Energy Agency’s projections for the global biofuel demand reveal a drastic growth in the com-

ing decades, with a strong contribution from the road transport sector up to 2030 [60]. The growing use of biofuels is influenced mainly by the Montreal (1987), Kyoto (1997) and Copenhagen (2009) Protocols. However, the UN Climate Change Conference (COP-16) held in Mexico in 2010 pointed to uncertainties for the second phase of the Kyoto Protocol, which sets mandatory and voluntary targets for the reduction of global emission caps (GEC) in industrialized countries. Nevertheless, there is a tendency for a period without mandatory targets for environmental preservation from 2012. The increase in biofuel consumption is influenced by voluntary and mandatory targets adopted by some countries (**Table 2**). According to the World Energy Assessment [61] and Goldenberg [62], projections for the world energy scenario up to 2100 are optimistic, with an increase in renewable sources and the consequent reduction of non-renewable sources [61].



**Figure 2. Time required to eliminate carbon dioxide emissions caused by deforestation, harvesting and production of some biofuels [63].**

**Table 2. Voluntary and mandatory biofuel targets of some countries.**

Country	Target	Condition
Germany	Addition of 6.75% of anhydrous ethanol to gasoline in 2010; increase to 8% in 2015 and 10% in 2020.	Mandatory
Brazil	Mixture of 20% to 25% of anhydrous ethanol in gasoline and 5% of biodiesel in diesel in 2010; expansion of the use of hydrated ethanol.	Mandatory
Canada	Addition of 5% of anhydrous ethanol in gasoline in 2010; addition of 2% of biodiesel in diesel in 2012.	Mandatory
China	Utilization of 15% of biofuels in the transport sector.	Voluntary
France	Addition of 7% of anhydrous ethanol in gasoline in 2010 <sup>a</sup> and increase to 10% in 2015 <sup>b</sup> .	<sup>a</sup> Voluntary and <sup>b</sup> mandatory
Italy	Addition of 5.75 % of anhydrous ethanol in gasoline in 2010 and increase to 10% in 2010.	Mandatory
European Union	Utilization of 10% of biofuels in 2010.	Mandatory
United Kingdom	Utilization of 5% of biofuels in 2010.	Mandatory

Source: [64].

## 5. Final Remarks

The environmental changes influenced by greenhouse gas emissions and global warming, the rising prices of crude oil and its derivatives, and the ever growing global demand for fuels, have led to the development of numerous biotechnological processes to minimize the use of fossil fuels in the late 20<sup>th</sup> and early 21<sup>st</sup> centuries

These innovations include the development of biofuels, such as ethanol, which started in Brazil in 1920 and was strongly boosted by Brazil's Pro-Alcohol Program established in 1975. Since then, ethanol participates effectively in Brazil's energy matrix and is one of the cleanest technologies in the world. Population growth, an expanding agribusiness sector and the search for sustainable development have resulted in the eco-efficient production of cellulosic ethanol from low-cost agro-industrial residues and municipal waste of plant origin.

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