Biomass: potential source of useful energy

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Abstract

Vegetal residues, cereal straws included, constitute the most abundant biomass of our planet. Some 10^{11} metric tons are produced annually in the biosphere with an energy content of 2.425×10^{18} kJ. The methods for utilizing residues of cereal crops have always been of great interest, but this interest has recently grown in Europe and the USA, due to the potential value of straws as a source of useful energy. The high cost of fossil fuels and technological progress have made possible the appearance of energy development of biomass systems that allow us to obtain energy directly or indirectly by means of combustion, pyrolysis or gasification processes. These development systems are becoming more and more efficient, reliable and clean. Due to this fact, biomass is currently being taken into account as a total or partial alternative to fossil fuels.

Key words: biomass, straw from cereals, energy development

1. Introduction

Biomass produced by vegetables is not homogeneous; sometimes proteins are abundant in it (leguminous seeds), but sometimes they are rich in lipids (oleaginous fruits), or in sugars (stem or root de sugar beet) or even in polysaccharides (cereal grains or potato tubercles). Since, in all of them, the most abundant components are carbohydrates, residual vegetable biomass is classified as follows: sugary, amylase, and lignocellulosic biomasses [1], (see table 1).

Table 1.- Types of biomass according to CH* nature

Type	Carbohydrates		Examples
Sugary	Monosaccharides	Glucose	Fruit Pulp
		Fructose	Fruit Pulp
	Disaccharides	Saccharose	Sugar cane, suit sorghum and beet
Amylase	Polysaccharides	Inulin	Potato tubercles, chicory
		Starch	Cereal grains
Lignocellulosic	Polysaccharides	Hemicellulose and cellulose	Woods

CH = Carbohydrate*

An estimation of potential residual biomass in Spain [1] can be observed in Table 2.

Table 2. - Resources of residual biomass in Spain

Type of residue	Potential residues 10^6 Tep/year
Forest and agricultural	20.2
Cattle, agricultural/industrial and mud from purifying plants	3.7
Urban solid residues	1.7
Total	25.6

Two types of residues can be distinguished in residual agricultural biomass: those coming from woody crops (olive, vine, and fruit pruning) and those coming from herbaceous (cereals and plants with mainly textile and oleic utility), for example cereal straws (figure 1).

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Figure 1 - Straw from cereal

Vegetal biomass constituted by cereal straw represents one of the most abundant vegetables residues currently generated. Residue generation represents 1 kg of straw per kg of grain harvested. This ratio grain/residue results in 400 million metric tons of crop residues yielded year in year out in the USA, and 330 million metric tons in Europe ([2] y [3]). As an example, more than 10 million metric tons of cereal straw are yearly produced in Spain, where 50% is barley straw, 40% wheat straw, and 5% oats straw. Most of these fibrous residues are burnt on the own land where they are harvested, this activity producing the emission to the atmosphere of contaminating gases, and the destruction of local micro flora [4]. Due to this harmful environmental impact, it is very interesting to value these by-products by means of treatment in such a way that they can be conveniently utilized either as energy resources or as a complement in the diet of cattle after transforming it.

2. Composition and structure of cereal straw

The general characteristics of the chemical composition of straw are the following: high fibre content (40-45%), low nitrogenous matter content (Nx6.25 less than 6%), low mineral content (except potassium), and scarce vitamin content. The most common chemical fractions of these residues are:

- Water, this coming basically from environmental conditions as well as biological fluids.
- Ashes, these coming fundamentally from mineral salts (chlorides and sulphates) and incrustations (silica).
- Proteins.
- Lignin.
- Polysaccharides, these include cellulose and hemicellulose.

The composition analysis of straws (mean values, % in dry matter) is presented in the following table:

Table. 3 - Mean composition of cereal straws [5]

Soluble		Cellular wall	
Sugars	0.5 – 1.5	Hemicellulose	15.0 – 30.0
Ethereal extract	1.0 – 3.5	Cellulose	30.0 – 45.0
Gross protein	2.0 – 6.0	Lignin	10.0 – 15.0
		Silica	3.0 – 6.0

When considering the components of cereal straw, due to their importance, the outstanding components of the cellular wall (see Table 3) are polysaccharides (cellulose and hemicellulose), lignin and silica. Cellulose, $(C_6H_{10}O_5)_n$, is a linear homogeneous polymer of β-D-glucose units in pyranose form linked by means of β-(1-4) glucosidic bonds. Hemicellulose is a heteropolymer of stemmed and short chains, formed by pentoses (xylose, arabinose, galactose) and hexoses (glucose, galactose, manosse) and a certain number of acidic sugars. Its main role consists of achieving the joining of lignin and cellulose. Lignin comes from the wooden part of plants, and it is an amorphous three-dimensional polymer constituted by units of oxygenated phenyl propane linked to each other through ether-type bonds (C-O-C) or carbon-carbon, the former being majority.

The chemical constitution of lignin responds to the biological function fulfilled by plants: protection against moisture is secured and it acts as a binding agent, thus providing structural stiffness since polysaccharide fibres are hardened and held in place [6].

3. Exploitation of residual biomass

Residual biomass, among which straw from cereals can be included, constitutes an available natural resource with unique characteristics, since it is renewable, recyclable and biodegradable. Most of this fibrous residue is used as bed for cattle or it is burnt out on the own farming soil, the latter generating the emission of contaminating gases into the atmosphere. Due to this harmful environmental impact, it is interesting to take into consideration cereal straw, by means of adequate treatment, so that it can be used either to complement the feeding diet of cattle, to produce other products, or as an energy resource.

3.1.Use of straw for feeding purposes with cattle

From the point of view of animal feeding, cereal straw is characterized by its scarce nutritional value due to its low gross protein content and to its high content of components of the cellular wall (cellulose, hemicellulose, and lignin), (see table 3). These three polymers are strongly interlaced in the vegetal cellular matrix which makes them difficult to degrade and, as a consequence, difficult to take advantage of them. This is why ruminants use these residues since their stomachs act as real fermentation chambers thanks to the bacteria living in their bellies. However, mono gastric animals are hardly able to digest cereal straw due to its scarce nutritional value.

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Several attempts to improve the nutritional value of cereal straw have been carried out, by subjecting it to different treatments (physical, chemical or biological) that hydrolyze cellulose, lignin and other hardly soluble sugars contained in cereal straw. Other ingredients can be added to straw. These can be: beet pulp, molasses, with an adequate supplement of nitrogen, sulphur and minerals. They can improve cellulose digestibility, thus increasing the level of voluntary ingestion of straw [7].

3.2. Obtaining of chemicals

Agricultural residues have low potentially-fermentative sugar contents in the form of high molecular weight polymers. The characteristics and composition of these vegetable residues let us obtain several products, provided that adequate separating techniques are used, such as ethanol, sugars,..., with different applications, as it is shown in figure 2.

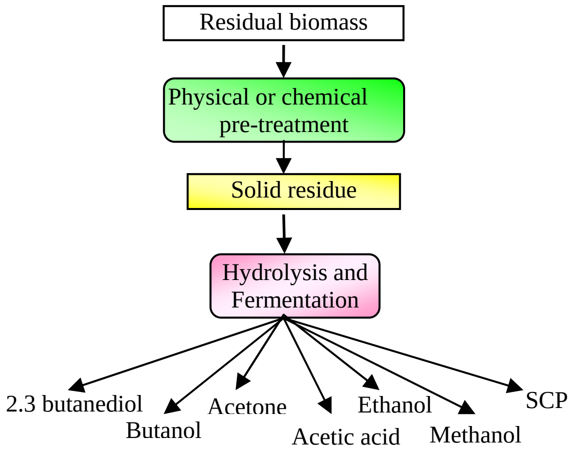

Figure 2. - Obtaining of different products from lignocellulosic residues

Currently, the processing of clean fuels such as bio diesel (obtained from vegetable oils) or bio alcohols (obtained from sugary materials) is developing rapidly. These last years, a growing interest in the study of biochemical processes has arisen, mainly those that lead us to the obtaining of ethanol and to the production of biomass (molecular microbial protein, SCP) ([8] and [9]).

3.3. Incorporation to the soil to improve its physical and chemical properties

The type of vegetable residue we are referring to cannot be directly applied to the soil as it is generated, due to a series of problems that are present. These problems are:

- Decomposition of the different components of the cellular wall (hemicellulose, cellulose and lignin) in very different times.
- Degradation of straw. It produces acetic acid (CH_3COOH), and this is harmful for the growing of new plants.
- Decomposition of straw. The soil micro organisms that decompose straw consume the oxygen needed by other seeds to germinate.

Due to this, it is necessary to subject straw to recycling by means of a treatment called composting. This treatment constitutes an exothermic oxidation process, during which the degradation of the lignocellulosic polymers are produced till they are transformed into humid acids. By inoculating specific bacteria, able to degrade the lignocellulosic residue, a rapid evolution of composting and the elimination of toxics are achieved. In the case that straw is previously used as cattle bed, it is mixed with cattle excrement and urine, so that its N contents increase. Under these conditions, it can be used as a fertilizer or good quality compost for the soil.

3.4. Energy exploitation

Vegetal biomass, residual or not, has constituted a traditional resource of fuel for mankind. Even nowadays, more than 1,500 million people depended upon these residues to meet their energy needs. Different research studies about agricultural residue palletizing for their use in heating have been carried out, the conclusion being that barley straw is the one that presents the best results [10].

With the massive use of fossil fuels, the energy development of biomass started diminishing steadily. However, during the last years, energy panorama has varied remarkably worldwide. The use of biomass as a source of energy is a possible alternative for mineral oil and, moreover, it could decrease environmental pollution [9]. Since the early 1970s, considerable research has been carried out to find sources of energy alternative to fossil fuels.

The use of biomass with energy purposes means a series of advantages over fossil fuels. The following can be underlined:

- Neutral balance of emitted carbon dioxide during combustion, since the CO_2 of the living biomass forms part of a flow of continuous circulation between atmosphere and vegetation.
- The combustion of residual biomass does not emit either sulphured or nitrogenous pollutants, or hardly solid particles, thus being much more respectful with the environment.
- The exploitation of residual biomass means to change a residue into an energy resource.
- The use of energy crops for biomass production, replacing other surplus crops, means an important social and economic improvement of the rural sector.

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- Decrease of external dependence on fuel supply.
- Technological innovation processes will let optimize the energy yield of biomass.

There are two ways of recovering energy from residues: thermo chemical and biochemical. The thermo chemical way includes treatments to high temperatures in the presence of gaseous reagents (air, O_2, N_2, H_2, H_2O,...) and, in certain cases, in the presence of catalysts. The biochemical way utilizes micro organisms (bacteria and leavens) to transform the biomass in much softer pressure and temperature conditions than in the thermo chemical ways. Biochemical processes are much more difficult, from a technological point of view, than thermo chemical ones in their design and control and require a higher investment. However, a higher energy yield is possible ([8] and [9]).

In Spain, the so-called Additional Potential of Biomass Resources in Spain (*Potencial Adicional de Recursos de Biomasa en España*), being this the annual capacity for producing energy in Spain, not being currently exploited but which could be potentially developed, is 5.7 Mtep for thermal or electric exploitation from lignocellulosic crops, 10.4 Mtep for total residual biomass, 1.2 Mtep from solid urban residues, 0.55 Mtep from biodegradable residues, and 0.64 Mtep for bio fuels from oily or sugared crops. Table 4 includes values of resources of potential residual biomass in Spain [11].

Table 4. - Resources of potential residual biomass in Spain

Type of residue	Energy potential Mtep/year	Useful resources Mt*/year
Forest resources	8.1	17
Agricultural resources	12.1	35
Agricultural/industrial and mud from purifying plants	2.5	26
Cattle and slaughterhouse residues	1.3	95
Solid urban residues	1.8	15
Totals	25.8	188

Mt = millions of metric tons*

Although the energy potential of residual biomass in Spain is about 26 Mtep/year, the resources of biomass currently used hardly reach 3.6 Mtep/year (including bio fuels and bio gas). As a consequence of this situation, the so-called Plan of Renewable Energies (*Plan de Energías Renovables-PER*) 2005-2.010 was approved (26th August 2005). The aim of the Plan is to reach in 2010 an increase of 583 ktep in the use of biomass.

By exploiting the energy potential from cereal straws, energy can be obtained, directly or indirectly, by means of combustion, pyrolysis or gasification processes.

The most widely used process has been combustion for decades, by exploiting the calorific power of such residues to produce vapour, electricity and radiant heat. There are more than ten Thermal Power Plants that burn this type of residue in the USA.

The innovations carried out in terms of direct combustion of residues are due to new technologies of combustion. This is the case of fluidized-bed furnaces, which make possible the fitting of processes to the available aims and raw materials. Gasification, a combustion with lack of air, let us obtain two energy products, SNG (Synthetic Natural Gas) and IBG (gas of mean calorific power), as a well as a series of chemical substances such as methanol, ethylene and ammonia. The gasification of lignocellulosic materials, cereal straw included, due to its own chemical composition, shows certain advantages over petroleum and coal, derived from a lower necessity of both oxygen and water. The main disadvantage consists of the limitation in the size of the necessary plant, appreciably bigger for the same production capacity, which considerably raises the cost of the whole process.

4. Plan of Renewable Energies in Spain

According to estimations carried out for the elaboration of the Renewable Energies Fostering Plan, biomass represents currently in Spain 53.8% (3,792 ktep) of the consumption of primary energy of renewable origin, including all the hydraulic energy, or 89.1% of all the renewable energies excluding it (See table 5).

Table. 5 - Consumption of renewable energies (year 2000)

	Consumption (ktep)	Total %	Relative weight Total % (w.h.)*
Biomass	3,792	56.20	89.06
Hydraulic (> 10 MW)	2,059	30.50	---
Hydraulic (< 10 MW)	0,432	6.40	---
Aeolian	0,425	6.30	9.98
Thermal solar	0,031	0.45	0.73
Geothermal	0,008	0.12	0.19
Photovoltaic solar	0,002	0.03	0.05
Total	6,749	100.00	

w.h.= without hydraulic energy*

The Renewable Energies Fostering Plan proposed for Spain, passed by the Spanish Government the 31st of December 1999, bases its proposal on an increase of 90.2 Mtep obtained from biomass, which represents 74.4% of the global increase of primary energy supplied by all renewable energies. Such Plan considers a 6,650 ktep growth with biomass between 1999 and 2010 (see table 6). For this aim to be attained, a number of public incentives and assistances are foreseen.

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Table 6.- Forecast of Spanish Plan of Renewable Energies

Forecast of the FER Plan	Situation in 1998		Growth aims 1999-2010		Target situation for 2010	
Reference unit	Ktep	%	ktep	%	ktep	%
Primary energy consumption	113,986	100			134,971	100
Contribution of FER	7,173	6.3	9,525	100	16,639	12.3
Biomass for electrical generation	169	0.2	5,100	53,5	5,269	3.9
Biogas for electrical generation	-	-	150	1,6	150	0.1
Biomass for thermal uses	3,476	3.0	900	9,4	4,376	3.2
Bio fuels			500	5,2	500	0.4
TOTAL Biomass	3,645	3.2	6,650	69,8	10,295	7.6

This Plan also considers an important participation of energy crops in the production of biomass, the utilization of more than 800,000 Ha of land used for dry farming being foreseen in order to produce 3.35 Mtep of solid bio-fuels. Nowadays, new ways of using biomass are still being discovered. One way consists of producing ethanol, a liquid alcohol fuel. Ethanol can be used in special types of cars that are manufactured for using alcohol fuel instead of gasoline. This alcohol can also be combined with gasoline. The immediate effect of its use is obvious: a dramatic reduction in our dependence on oil, a non-renewable fossil fuel [11]. Specific crops for the production of bio diesel (oleaginous crops) and bio alcohols (crops of gramineae, sugary and lignocellulosic) must be prioritized. Table 7 shows an estimation of consumption evolution for each bio fuel according to the FER (Plan of Renewable Energy Encouragement).

Table 7. – Growth proposal for several ways of energy from biomass in Spain within the Plan of Renewable Energy Encouragement for 2010.

	1998		2005		2010	
	Ktep	%	Ktep	%	Ktep	%
Electricity	169	4.3	5,269	48.0	5,100	72.0
Heat	3,476	89.3	4,376	39.9	900	12.7
Bio ethanol			500	1.4	500	7.0
Biogas			150	6.2	130	2.1
R.S.U.	247	6.4	683	4.5	436	6.2
Total	3,892	100	10,978	100	7,086	100

Source: Plan of Renewable Energy Encouragement in Spain. I.D.A.E., December 1999.

The efforts channelled towards obtaining ethanol are interesting due to the easiness that *a priori* this substance presents as a basic raw material for the Organic Chemistry Industry, and due to its potential use in internal combustion engines. Several research studies have described a process of bioconversion of straw into ethanol, where 1 kg of this fuel is obtained per kg of wheat straw ([12] y [13]).

5. Conclusions

The use of biomass for energy purposes will increase importantly in the near future. For this to take place, a number of political measures will be developed, such as to promote energy crops, to promote and improve technologies and processes for the production of biogas, bio alcohols and bio diesel, and to develop technologies for energy use of solid biomass, vegetable residues (for example, cereal straw) included.

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