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POSSIBILITIES OF USING BIOMASS FOR ENERGY PURPOSES[1]

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ABSTRACT

Energy consumption demand, which is constantly growing along with civilization development facing depletion of traditional resources - mainly fossil fuels (coal, petroleum, natural gas), and accompanying increase of pollution of natural environment have resulted in the increase of interest in the use of energy from renewable sources. This paper presents the significance of renewable energy sources in the domestic energy balance. Special attention has been paid to the basic source of renewable energy in Poland, that is to biomass. Types of biomass are described and general energy properties as well as physical and chemical features of the basic plant materials obtained for energy purposes. Possibilities of using biomass for production of electric energy and heat as well as the applied methods of its conversion into biofuels are discussed. The advantages and threats related to the use of plant biomass for energy purposes are pointed out.

Introduction

The term biomass is used for solid or liquid substances of plant and animal origin derived from products, waste and residues from agriculture, forestry and related industries as well as, partially, other types of biodegradable waste. Biomass resources for energy purposes, estimated in different scenarios and strategic documents, are the highest among all the available renewable energy sources in Poland. Their use, compared to other RES, is dominant in all the energy sectors of our country (Janowicz, 2006).

In recent years, the resources of fossil fuels have been rapidly diminishing. The conventional energy uses of these fuels have contributed significantly to the pollution of the environment. For these reasons, the use of renewable energy sources has become an indispensable solution. They provide an alternative to traditional non-renewable energy sources. Their resources are complementary in natural processes, which practically allows treating them as inexhaustible. Moreover, obtaining energy from these sources is more

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environmentally friendly compared to the conventional sources. The use of renewable energy sources significantly reduces the harmful impact of energy on the environment, notably by reducing emissions, especially greenhouse gases (Grzybek, 2003).

Plant biomass is rather difficult to use as a fuel and it requires suitable treatment. First of all, it is a fuel of local importance, which is a heterogeneous material, often damp and with low energy potential relatively to the unit volume. Therefore, in comparison to other commonly used energy carriers, biomass may seem a troublesome energy source. However, due to the universality of its occurrence and general availability, it enjoys constant interest of the agricultural producers, potential consumers of electricity and heat as well as environmentalists. It is also an opportunity for the creation and development of local businesses that can use raw materials from local farmers and allocate them for energy purposes (Frączek, 2010; Kuś and Matyka, 2008; Piotrowski et al., 2004; Terlikowski, 2012).

Plant biomass in its natural form is characterized by a relatively low density, hindering the transport, storage and use in practice. Hence, it has to be thickened, for example as pellets or briquettes. They are prepared from dry particulate biomass under high pressure at elevated temperature, usually without the addition of binders. During the agglomeration the forces and temperatures cause the concentration of a large quantity of material into a small volume. This results in a decrease of water content, at the same time increasing the concentration of mass and energy and thus the distribution and use of this biofuel is facilitated (Hejft, 2013; Kołodziej and Matyka, 2012; Szyszlak-Bargłowicz and Piekarski, 2009).

The energy value of plant biomass depends on both the type and condition of raw material, and especially its moisture content. A high water content causes reduction in the calorific value and hence the amount of heat obtained during the biomass combustion. The largest item in the balance sheet of renewable energy in Poland is the energy of solid biofuels. The share of other renewable energy carriers has been changing, showing a clear upward trend for energy from liquid biofuels, wind, biogas and solar. The share of renewable energy carriers in the total energy from renewable sources is presented in Table 1 (GUS, 2013).

Table 1
Participation of particular renewable energy carriers in the total energy production from renewable sources in 2012 (GUS, 2013)

Type of RES	Participation (%)
Solid biofuels	82.16
Fluid biofuels	7.97
Wind energy	4.80
Water energy	2.06
Biogas	1.98
Municipal waste	0.38
Heat pumps	0.31
Geothermal energy	0.19
Solar energy	0.15

Solid biofuels accounted for the highest share (56.45%) in total electricity production from renewable energy sources in 2012. Further energy carriers used to produce electricity were wind, water and biogas (fig. 1). Electricity generated from biogas was derived mainly from landfill biogas (41.8%) and wastewater treatment plants biogas (34.3%). In contrast, liquid biofuels and solar power accounted for a small share in the total electricity production (GUS, 2013).

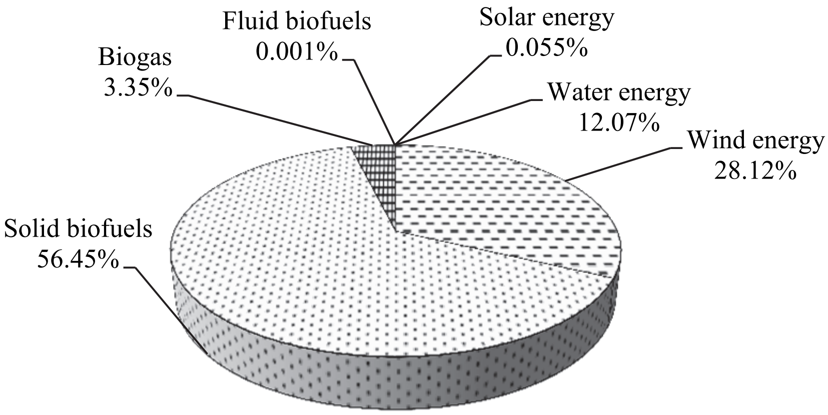

Figure 1. Participation of renewable energy in production of electricity in 2012 (GUS, 2013)

Types of biomass

Plant biomass is formed as a result of photosynthesis, in which the energy of solar radiation converts CO_2 and H_2O into organic compounds. It is considered a major renewable energy source because its resources reproduce in a short time. Biomass for biofuel use is extracted from various sources such as: forestry, agriculture, industry (mainly agri-food), public utilities and other sources. The energy contained in biomass can be processed into other, very convenient, forms of biofuels. The main components of plant biomass energy are: cellulose, hemicellulose and lignin, which are multi-particulate biopolymers. The contents of these ingredients in the selected types of biomass are presented in table 2.

Solid biofuels include organic, non-fossil substances of biological origin, which can be used as fuels to produce heat or electricity. The main solid biofuels are: firewood occurring in various forms, briquettes or pellets produced from plant waste materials and waste from timber and paper industries. A separate group of fuels are those from energy crops plantations (fast-growing trees, perennial dicotyledonous plants, perennial grasses, energy crops) as well as organic residues from agriculture and horticulture (Denisiuk, 2006; Kościk, 2007; Kołodziej and Matyka, 2012).

The following types of biomass can be mentioned according to their origin:
1. Wood biomass (dendromass):
   - Shrub biomass,
   - Deciduous and coniferous fast-growing trees biomass,
   - Residues and waste from wood biomass processing industry.
2. Agricultural biomass (agrimass):
   - Biomass from crop production waste and residues,
   - Biomass from energy crops,
   - Biomass from agri-food production waste,
   - Biomass coming from other biodegradable waste.
3. Biomass of animal origin (zoomass):
   - Animal manure, solid and liquid (manure, slurry),
   - Side waste of slaughtering animals (e.g. stomach content),
   - Products from animal processing (e.g. fats).

Table 2
Composition of polymers in the selected types of plant biomass (Klimiuk et al., 2012)

Type of biomass	Cellulose (%)	Hemicelluloses (%)	Lignin (%)
Wheat straw	38.0	30.0	16.5
Rye straw	28.8	27.6	2.8
Maize stover	12.4	30.8	1.4
Grasses	39.7	16.9	17.6
Energy plants	45.0	30.0	15.0
Soft timber	35-40	25-30	27-30
Wood waste	50.0	23.0	22.0
Municipal waste	45.0	9.0	10.0

The primary source of biomass obtained from crop production is straw from cereals and other crops. An important role of potential biomass resource is also played by energy plants, which include: fast-growing shrubs and trees (*willow*, *Rosa multiflora*, *Robinia pseudoacacia*, *poplar*, *Acer negundo*), long-lasting perennials (*Virginia mallow*, *Jerusalem artichokes*, *Silphium-perfoliatum*, *Sakhalin knotweed*), perennial grasses (*reed canarygrass*, *Miscanthus giganteus* and *Miscanthus sacchariflorus*, *Andropogon gerardi*, *Spartina pectinata*, *Panicum virgatum*), annuals (energy crops: maize, beet, rape, rye) and others (Majtkowski, 2007; Stolarski et al., 2008; Terlikowski, 2012).

Methods of biomass conversion

Plant biomass obtained in varying weather conditions is usually characterized by increased moisture and it needs drying. The drying process of biomass is carried out prior to its storage in order to get rid of water contained in the material and to avoid the problems associated with:
– Decay of plant material (loss of dry weight and energy),
– Processes that cause mold growth and cause risk to human health and the environment,
– Risks arising from self-ignition (self-heating),

– Microbiological processes resulting in emissions of greenhouse gases,
– Reduction of calorific value.

A commonly used method of mechanical biomass processing is its grinding (cutting, chipping) and pressing, briquetting or pelleting (fig. 2). Shredding is usually used before transporting biomass, to increase its bulk density and reduce transport costs. In turn, pressing, briquetting and pelleting of biomass is the process of fuel densification in order to improve its physical and energy properties. Densification most commonly applies to solid biomass, i.e. sawdust, wood chips, straw, hay, husks etc. This type of biomass conversion increases its energy density, defined as the ratio of calorific value per unit volume (GJ·m^{-3}), reduces moisture content and also causes standardized sizes and shapes of the derived biofuels, so that they can both be used in the power industry and distributed. Table 3 shows some of the energy, physical and chemical properties of solid biofuels produced from selected types of straw.

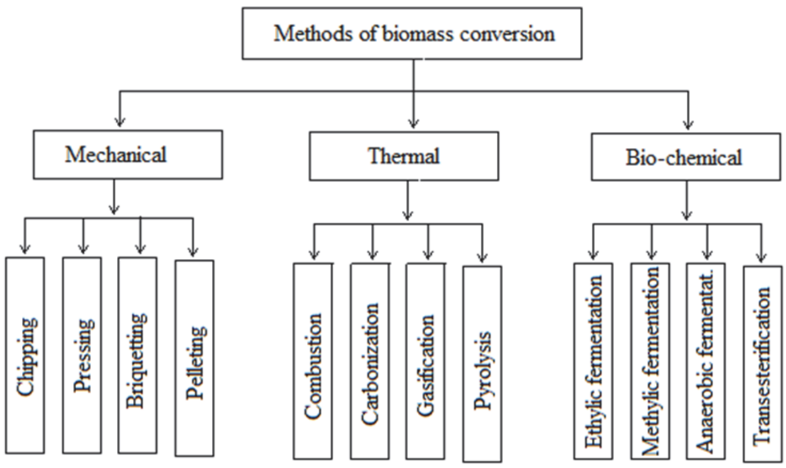

Figure 2. Methods of biomass conversion into biofuels

Table 3
Energy, physical and chemical properties of solid biofuels produced from straw (Lewandowski and Ryms, 2013)

Specification	Measure unit	Briquettes		Pellets	
		Wheat straw	Rape straw	Wheat straw	Rye straw
Calorific value	(MJ·kg^{-1})	15.2	20.1	18.2	19.2
Moisture	(% mass)	15.1	9.6	8.3	6.6
Bulk density	(kg·m^{-3})	320	310	540	580
Diameter	(mm)	50.0	50.0	9.0	9.0
Chloride content (Cl)	(% mass)	0.047	0.013	0.270	0.263
Sulfur content (S)	(% mass)	0.160	0.592	0.130	0.390
Carbon content (C)	(% mass)	45.5	50.0	45.5	40.1

Thermal biomass conversion methods, in addition to combustion, include carbonization, gasification and pyrolysis. The biomass used as a fuel in power industry can be burnt in different ways. The most common way is direct combustion in special fluidized bed boilers that are characterized by a very high efficiency of the combustion process and stable working conditions. Another way is the biomass co-incineration with coal in power boilers designed for the combustion of coal or charcoal

Direct co-incineration of biomass is carried out in the combustion chamber into which the biomass and coal are supplied either separately or as a previously prepared mixture of biomass and coal. Indirect co-incineration is carried out after the biomass gasification in a special gasifier, when the resulting gas is transported to the combustion chamber where it is burnt in special burners. And in the parallel incineration the coal and biomass are burnt in separate combustion chambers in which both the combustion processes are individually prepared and controlled.

The thermal carbonization of biomass is carried out under anaerobic conditions, at the temperature of 200 to 300ºC under the near atmospheric pressure. It is actually the process of high-temperature drying of biomass for processing into biofuel with properties similar to carbon.

As a result of biomass carbonization the obtained fuel is characterized by:

– Similar physical and energy properties,
– Higher calorific value,
– Hydrophobic nature,
– High resistance to biological processes,
– Increased milling properties,
– Higher melting temperature of ashes.

Pellets made from char are characterized by high energy density, they are resistant to moisture absorption and do not require special equipment for storage, as is the case with conventional pellets. The combination of biomass pelletizing with carbonization process gives good results for these biofuels which in the future may become a substitute for coal. After this process the lignocellulosic biomass becomes more carbon-like. Milling properties are improved, whereby there is a reduction in energy expenditure for grinding. Also the hydrophobic properties are upgraded, which make storage of biomass safer as the risk of its biological degradation is lower.

Pyrolysis is a process of thermal decomposition of biomass occurring in oxygen-free atmosphere or in the presence of a small amount of oxygen relatively to the amount of oxygen needed for combustion. The main products of pyrolysis are pyrolysis gas, bio-oil (called pyrolytic oil) and char (solid form with a high degree of oxidation). Pyrolysis can be fast or slow. During the fast pyrolysis biomass is decomposed under the influence of elevated temperature (approx. 500ºC) to form a vapor and an amount of the char. Upon cooling some of the products are condensed to generate a dark brown oily liquid with a high calorific value. The slow pyrolysis is traditionally used in the production of charcoal by wood de-oxidation (dry distillation). Currently, the slow pyrolysis is used for the production of char characterized by greater stability and energy density as well as very low moisture.

Gasification of biomass includes a series of thermal processes, wherein the treated solid fuel is delivered to a device called a gas generator, reactor or gasifier. This method of converting biomass is appropriate when it is to be used in dispersed, small or medium-sized cogeneration systems. During biomass gasification the wood gas (holzgas) is produced. In the gasification process the following steps can be identified: the biomass drying at the temperature of approx. 150ºC, the isolating from the fuel of volatiles at the temperature of 200-600ºC, i.e. oxidation, in other words formation of oxide and carbon dioxide and water vapor at the temperature above 600ºC and the reduction of carbon dioxide and steam to carbon monoxide and hydrogen. In the process of biomass gasification the following types of products are obtained: gas, liquid (condensing ones, steam, alcohols, acids), tar (heavy hydrocarbons condensing to a solid form) and solid (ash).

Among the biochemical methods of biomass conversion there are anaerobic fermentation, during which alcohols or biogas are obtained, as well as vegetable oils and animal fats transesterification for the production of biodiesel. Biomass which is composed of cellulose, hemicelluloses and lignin is biochemically conversed to liquid biofuels. After hydrolysis it becomes a material rich in sugars, from which in the process of the subsequent biochemical process ethanol or biogas is produced. Virtually each of biomass types is a potential raw material for the production of first-generation biofuels. There are the following processes of biomass hydrolysis: thermal hydrolysis, wherein the long chains of cellulose and hemicellulose molecules are reduced in an aqueous medium by the input of thermal energy, and anaerobic digestion, during which the cellulose is converted to sugars, and these in turn are converted to liquid biofuels.

Benefits and risks associated with the use of biomass

The use of biomass for energy purposes has both a lot of advantages and numerous disadvantages. First of all, its application as a biofuel is fairly harmless to the environment. This is due to the fact that during the combustion of biomass the CO_2 emissions are balanced with the CO_2 amount absorbed by plants in the process of photosynthesis. In some cases, for example, perennials can take from the atmosphere more CO_2 than they emit during combustion in boilers. In addition, biomass contains significantly lower amounts of sulfur, so there is no need for flue gas desulfurization which takes place during coal combustion. Also, the use of biomass for heating is very cost-effective because its prices are lower than those of other fuels. Another advantage is finding use for uncultivated land and waste (Romanowska-Słomka, 2009).

Among the benefits associated with the use of biomass there are, e.g.:
- Protection of the environment,
- Management of degraded land unsuitable for agriculture,
- Increasing the share of renewables in the overall balance of raw materials,
- Ensuring the energy security of the country,
- Management of surplus food on the market,
- Ensuring revenues from agricultural production carried out for non-food purposes,
- Creating conditions for the restructuring of the Polish countryside and agriculture,
- Development of the industry in terms of resources for the production and processing of biomass,
- Providing a cheap source of heat for industrial and municipal customers.

In contrast, the physical and biological hazards are associated primarily with the way the preparation and storage of biomass are performed. Storage of wet plant biomass is associated with the growth of microorganisms whose metabolic activity increases its temperature. In extreme cases, the temperature rise may lead to self-ignition. Biomass exposed to adverse weather conditions quickly becomes damp. Such an action leads to an intensive growth of microorganisms. The resulting fungi and bacteria may be a serious threat to the health of workers and can cause allergic reactions. Harmful micro-organisms include the toxin-producing fungi as well as viruses and parasites that can promote cancers, and even cause death. The most exposed to infections and allergies are people serving boilers because they do the loading and unloading work. Also, people employed in waste incineration are additionally exposed to contact with microorganisms carried by rodents (mice and rats), and even with parasites (Romanowska-Słomka, 2009).

In addition, the risks associated with the use of biomass include e.g.:

- Greater demand for large energy plants plantations and thus reduction or even elimination of biodiversity,
- Formation of large-scale monocultures and soil exhaustion,
- Possibility of a fire hazard in the accumulated biomass resources,
- Reducing the performance and efficiency of boilers,
- Destruction of heating devices associated with the so-called high-temperature corrosion,
- Sintering and agglomeration of ash (defluidization of the fluidized bed),
- Formation of deposits on the convection surfaces.

Conclusion

Environmental protection issues related to the operation and depletion of conventional fuels, as well as the growth of polluting emissions, contribute to the wider use of renewable energy sources. It results from the growing environmental awareness in societies and the desire to counteract the greenhouse effect and global warming. A significant reduction in the amount of emitted substances believed to be particularly harmful to the environment can be achieved by the use of biomass for energy purposes. However, energy production from biomass should be done without any risk to the acquisition of adequate resources for human food and animal feed.

Given the trends in new technologies concerning the use of biomass for energy purposes (relatively low conversion efficiency), it can be assumed that in the future the solutions applied on a larger scale will be cogeneration (production of electricity and heat in a single process) and trigeneration (production of electricity, heat and cooling in a single process). These solutions can significantly upgrade the management and use of available biomass resources in Poland and greatly contribute to the achievement of desired objectives in the field of climate and energy policy of this country.

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MOŻLIWOŚCI WYKORZYSTANIA BIOMASY NA CELE ENERGETYCZNE

Streszczenie. Stale rosnące wraz z rozwojem cywilizacyjnym zapotrzebowanie na energię, przy wyczerpywaniu się jej tradycyjnych zasobów – głównie paliw kopalnych (węgiel, ropa naftowa, gaz ziemny) oraz towarzyszący ich zużyciu wzrost zanieczyszczenia środowiska naturalnego, powodują zwiększenie zainteresowania wykorzystaniem energii ze źródeł odnawialnych. W pracy przedstawiono znaczenie odnawialnych źródeł energii w bilansie energetycznym kraju. Szczególną uwagę zwrócono na podstawowe źródło energii odnawialnej w Polsce, jakim jest biomasa. Opisano rodzaje biomasy oraz podano ogólne właściwości energetyczne i fizyczno-chemiczne podstawowych surowców roślinnych pozyskiwanych do celów energetycznych. Omówiono możliwości wykorzystania biomasy do produkcji energii elektrycznej i ciepła oraz stosowane sposoby jej konwersji na biopaliwa. Podkreślono także korzyści i zagrożenia związane z wykorzystaniem biomasy roślinnej na cele energetyczne.

Słowa kluczowe: biomasa, produkcja energii, sposoby konwersji, korzyści i zagrożenia