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BIOMASS ENERGY POTENTIAL – GREEN ENERGY FOR THE UNIVERSITY OF WARMIA AND MAZURY IN OLSZTYN

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Abstract

The combined production of electrical and heat energy is one of the preferred, by national policy, activities associated with energy production from renewable sources. The simultaneous generation of heat and electrical or mechanical energy during the same technological process is called cogeneration or combined heat and power, CHP.

The presented methodological approach includes an analysis of the data recorded in the research stations and agricultural production stations owned and managed by the University of Warmia and Mazury (UWM) in Olsztyn, performed in order to determine the energy potential of biomass and other renewable energy sources (RES). Depending on the substrates available for UWM in Olsztyn, it is proposed to take a varied approach towards the use of RES by means of biotechnological and thermal biomass conversion. The first method is based on the production of biogas from biomass with the subsequent use of the generated biogas in the process of cogeneration. In the second method, heat energy generated by gasification in a syngas generator will be used for transformation with a Stirling's engine into mechanical energy and finally into electrical (30%) and heat (60%) energy. The concept of a "Green University" is the result of the performed analyses.

Keywords: *biomass, biogas, bio-gasworks, cogeneration, renewable energy sources, electrical energy, heat energy, gasification*

1. Introduction

The issue of alternative energy sources is currently being widely discussed in Europe and there are many reasons for it. These include the declining primary energy resources, the hazards generated by excessive emissions of harmful gases into the atmosphere, the progressive degradation of water and soil, the low efficiency of the heat energy flow systems and the demand for high quality electrical energy for industry. Therefore, new policy programmes in Europe have been formulated with an emphasis on technologies that use fuels with substantial or renewable resources.

In Poland, there has been growing interest in recent years in investments associated with the use of renewable energy sources. This situation has been prompted by the necessity to meet the requirements and assumptions of the EU energy policies (the EU Directive 2009/28/EW of June 5, 1009) which require Poland to secure a 15% share of renewable energy sources in the total energy consumption by 2020.

The use of biomass is one of the preferred activities associated with energy production from renewable sources. The Directive of the European Parliament and Council 2009/28/WE of April 23, 2009 on promoting the use of energy from renewable sources specifies biomass as a biodegradable part of products, waste materials or biological residues generated by agriculture (including plant and animal substances), forestry and associated industrial branches, including fisheries and aquaculture, as well as the biodegradable fraction of industrial and communal wastes. Biomass is particularly important for regions which are abundant in this material (for instance, the province of Warmia-Mazury, which is called "the green region") as it is characterized by a relatively low degree of carbonization at combustion and a substantial content of volatile organic compounds and a low amount of ash; these parameters determine its attractiveness as a source of fuel.

In addition, the University of Warmia and Mazury (UWM) owns and manages five locations from which it may derive biomass for biogas production and recycle it by means of gasification to generate energy. These locations include the research and teaching station situated in Łężany, the production and experimental centre in Bałcyny, the research and teaching station in Bałdy, the research station in Tomaszkowo and the "Pozorty" Spółka S. A. production and experimental station.

With reference to the aforementioned considerations, it has been concluded that, for the UWM, it is important to explore the potential of managing biomass resources, as this raw material is ideally incorporated into the concept of ecological energy. Moreover, using systems of combined heat and power production may ensure the energy security for UWM in the future and will thus allow for a reduction in the costs of electrical and heat energy.

2. Methods of biomass conversion

Depending on the type of biomass, there are two major methods of its conversion: the first is biotechnological conversion and the second involves thermal conversion (Fig. 1).

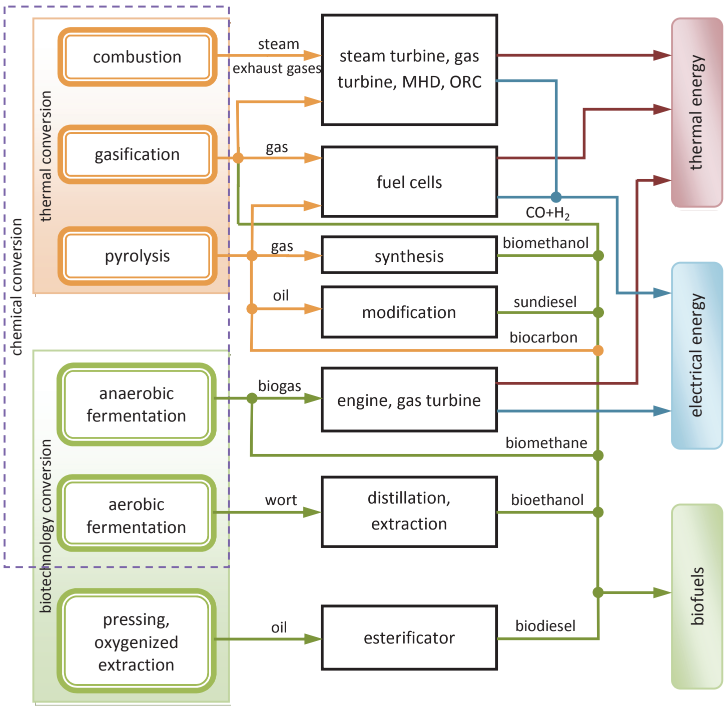

Fig 1. Methods of biomass conversion [13]

Of the biotechnological methods of biomass conversion, anaerobic fermentation is most commonly used. In the process of anaerobic fermentation, biogas is produced from organic substances (biomass) and it is an energy carrier. From a physical point of view, biogas is a gaseous solution composed mainly of methane and carbon dioxide. The composition of biogas and the specification of the biogas produced in the research station in Bałdy are presented in Tab. 1.

The concentration of the individual components, quality composition and biogas properties are determined by many factors, of which the most important are: initial composition of the substrate subjected to biodegradation, humidity of organic substance, temperature and the pressure and course of the process. It should be emphasized that the percentage of methane in biogas determines the calorific value of this fuel, i.e. the higher the proportion of methane, the higher the caloric value of biogas.

Tab. 1. The average composition of biogas [1]

Components	Concentration (ref.)	Concentration (biogas from Bałdy)
methane (CH4)	50 – 75%	62%
carbon dioxide (CO2)	25 – 45%	37%
hydrogen sulphide (H2S)	20 – 20 000 ppm	100 ppm
hydrogen (H2)	< 1%	-
carbon monoxide (CO)	0 – 2.1%	-
nitrogen (N2)	< 2%	-
oxygen (O2)	< 2%	-
others	traces	-

Agricultural organic materials (e.g. animal excrement, energy crops and agricultural waste) and industrial organic waste products are mainly used for biogas production. In animal excrement, the concentration of substances varies depending on the housing and feeding as well as the volume of utilized water. Organic substances have different rates of decomposition and yield a varied amount of biogas produced with biomass decomposition. Today, energy crops (targeted cultivations) are more commonly being used to produce biogas, i.e. grasses, clover, potato, maize, broad bean, rye, fodder beet, sugar beet, onion, mustard, pea, turnip cabbage, cabbage, cauliflower, wheat, oat, barley, sorghum, rape, pumpkin, and sunflower. These plants may be used as a whole plant or separately as fruit or tubers and leaves, seeds as well as silage or straw. In general, for purely economic reasons, organic wastes are initially used in methane fermentation and only later are they replaced with targeted crops.

Immediately after anaerobic fermentation, such undesired components as hydrogen sulphide, carbon dioxide and steam should be removed from crude biogas. The purification technology comprises a stage of desulphurization followed by a stage of carbon dioxide removal and finally the process of biogas desiccation.

The generated biogas may be used both for stationary purposes and for transportation as well as for supplying a network of natural gas. Because of the existing support mechanisms for "green energy", the most preferred technology of biogas usage is its utilization in combined heat and energy systems and selling the generated energy. The energy produced in such a process may be efficiently transformed into any other form of energy in a relatively simple way. The combined production of electrical and heat energy is called cogeneration. The concept of a cogeneration system involves simultaneous production of two energy types from one source of primary energy with simultaneous utilization of waste heat generated by the machines, which produce electrical energy. The sources of primary energy include natural gas (NG), liquefied petroleum gas (LPG), oil-derived fuels, hydrogen (fuel cells) and biogas or biomass. Cogeneration systems are usually complete modules composed of an engine, a generator, sets of heat exchangers, an exhaust system and a noise reduction system. It should be emphasized that electrical and heat energy production by means of cogeneration is one of the most effective methods of improving the efficiency of the transformation of chemical fuel energy and, thus, improving its economic efficiency in comparison with separate processes of electrical energy and heat energy production. [1-3]

Thermal conversion is the second method of biomass utilization and there are three ways of using biomass for heat production. The first involves the process of direct combustion or combustion with carbon, which consists in the conversion of the chemical energy found in carbon, hydrogen and oxygen compounds into heat energy. This is the simplest, yet least efficient and least economical process [13]. The two other methods of biomass conversion, i.e. pyrolysis and gasification, have higher capacities. In the process of pyrolysis, biomass is exposed to high temperatures without any contact with oxygen or other oxygenating factors. The solid fuel is transformed into two different forms: gas fuel and liquid fuel. The proportion of the individual forms and their composition is determined by the type and composition of biomass as well as by the course of the process. Gasification includes a series of thermodynamic processes, heat and mass exchange and multidirectional exothermic and endothermic chemical reactions which occur at high temperature and result in the conversion of solid fuel into a gaseous form. The process of gasification requires, apart from the material that is gasified, a gasifying factor such as steam, air, oxygen or carbon dioxide [11]. Each of these processes has different dynamics of transformation of the chemical structure of solid fuel. Investigation of the nature of the transformations in the individual processes constitutes the first step towards limiting their negative impact on the environment. Biomass alone, as well as a mixture of biomass and carbon, can be used in each of these processes.

The most efficient, both economically and technologically, method of thermal conversion of biomass is its gasification to produce gaseous fuels. The transformation of biomass in a gasifying reactor generates a gaseous product, which after purification can be used to produce electrical and heat energy. The efficiency of gasification in simple installations is around 20% although it can be as high as 90% for advanced installations [14]. The concept of "efficiency of gasification" means the ratio of chemical energy of the produced gas to the chemical energy in the fuel. This process may be divided into several areas with diversified temperatures, namely drying, degasification, pyrolysis and gasification, which occur in the zone of combustion and reduction of temperature (Fig. 2) [15].

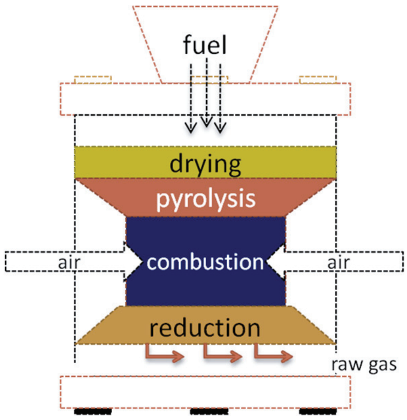

Fig. 2. Gasification

The actual process of biomass gasification generates synthesis gas which contains flammable compounds, mainly hydrogen, carbon monoxide and a small amount of methane and inflammable substances, mainly carbon dioxide, steam and nitrogen. The quantity and composition of synthetic gas generated using biomass gasification depends mainly on the type of biomass and a gasifying factor and the temperature, pressure and method of gasification. [10, 12, 16, 17].

3. The "Green University" concept

Kortowo is a location which encompasses the majority of university buildings. The teaching facilities, dormitories, sport facilities (including the swimming pool) and the internal university transportation system that will be developed in the future consume a substantial volume of energy. Therefore, one of the most important strategic targets set by the University is to ensure the energy self-sufficiency of UWM based on its own renewable energy sources (RES). Apart from collecting solar energy (photovoltaics, solar collectors) and the energy savings achieved by insulating the buildings, the UWM plans to use the potential of targeted agriculture as well as the production and processing of raw materials accumulated in RES. The energy potential of biomass will allow us to satisfy, to a large extent, the demands of the campus. The diagram of energy management is presented in the Fig. 3.

Based on the solutions discussed in the present publication and the analysis of the data from the research and teaching stations and agricultural production stations owned by UWM, the concept of the "Green University" has been constructed and is graphically depicted on Fig. 4.

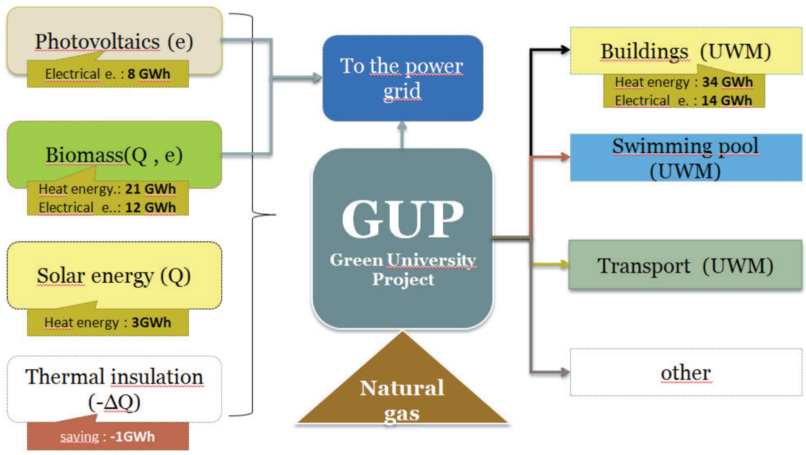

Fig. 3. Diagram of the "Green University" system

The substrates derived from the arable lands and animal husbandry managed by UWM in Olsztyn may be used in a dual mode. The methods of thermal and biotechnological conversion are carried out simultaneously and the degree of their utilization is determined by the amount of raw materials necessary to accomplish a given process. Thermal conversion generates heat energy by means of gasification in a syngas generator and in a subsequent stage it is transformed with a Stirling engine into electrical and heat energy. Biotechnological conversion generates biogas from biomass and the produced biogas is used in the process of cogeneration.

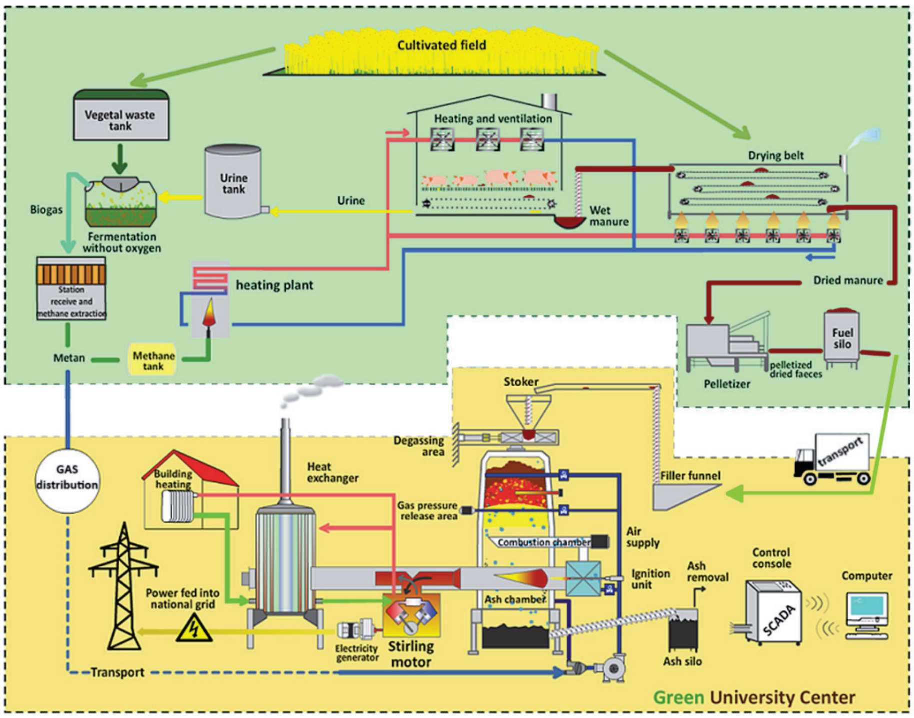

Fig. 4. "Green University" concept

The analysis of the data obtained from the research and teaching stations and agricultural production stations owned by UWM in Olsztyn indicates that three locations (the stations in Bałdy, Bałcyny and Łężany), excluding the research station in Tomaszkowo and the "Pozorty" Spółka S. A. production and research station, are the most representative units for performing estimate calculations of the average and theoretical energy production potential for the University. The results of these calculations are presented in Tab. 2 and 3.

Tab. 2. Biotechnological conversion of the biomass from the research and teaching stations and production stations owned by the UWM in Olsztyn

Biomass	Farm	Average acreage	Average yield	Quantity	In total	Energy potential	Energy conversion factor	Energy conversion factor	Energy consumption	Final
		[ha]	[t/ha]	[pcs]	[t]	[GJ]	[GJ/t]	[GJ/psc]	[%]	[GJ]
Sugar beat	Bałcyny	71	40	-	2840	8854	3	-	100	8854
Grass	Bałcyny	264	12	-	3168	10312	3	-	50	5156
Maize – silage	Bałdy	100	30	-	3000	7397	2	-	100	7397
Grass	Bałdy	395	12	-	4740	15429	3	-	50	7715
Grass	Łężany	300	12	-	3600	11718	3	-	50	5859
Bovine manure	Bałcyny	-	-	1141	6275	5703	-	5	50	2852
Bovine manure	Bałdy	-	-	387	2500	2272	-	6	50	1136
									Total	**38968**

Tab. 3. Thermal conversion of the biomass from the research and teaching stations and production stations owned by the UWM in Olsztyn

Biomass	Farm	Average acreage	Average yield	In total	Energy potential	Energy conversion factor	Energy consumption	Final
		[ha]	[t/ha]	[t]	[GJ]	[GJ/t]	[%]	[GJ]
Wheat straw	Bałcyny	575	4.4	2530	43516	17	50	21758
Triticale straw	Bałcyny	15,03	4.9	74	1259	17	50	630
Corn straw	Bałcyny	176	13.9	2446	43301	18	50	21651
Triticale straw	Bałdy	103	4.9	505	8630	17	50	4315
Wheat straw	Łężany	600	4.4	2640	45408	17	50	22704
Rape straw	Łężany	300	2.2	660	11286	17	50	5643
Oat straw	Łężany	150	4.4	660	11352	17	50	5676
Common osier	Łężany	55	30	1650	13628	8	100	13628
							Total	**96004**

4. Summary

Using the potential of biomass energy has numerous advantages, especially when the associated technologies are implemented in the region of Warmia and Mazury. The substantial resources of renewable raw materials used in the processes, which generate "green energy", create the possibility for the UWM to ensure its energy security in the future.

The concept of a "Green University" will contribute to the improvement of energy efficiency, will positively impact the savings of primary energy and will limit the emissions of harmful substances to the environment. The benefit of cogeneration systems lies in the universal nature of planning the location of such an investment. Therefore, the technologies of combined heat and power production may be used in all places where there is a simultaneous demand for heat and electrical energy or where it is impossible or economically unjustified to invest in a large heat and power station system.

The subject area of biogas generation and utilization and development of agricultural biogasworks in UWM is extensive and covers:

– the generation of biomass,

- transport, storage and preparation of biomass,
- development of a fermentation technology depending on the type and composition of substrates,
- selection of the optimal process parameters, efficiency evaluation and a cost assessment of biogas generation,
- evaluation of biogas supply fluctuations over time,
- analysis of the composition and properties of biogas,
- development of a biogas purification technology,
- analysis of the potential for using the generated energy carriers in the place of installation and outside it; possible types and configurations of arrangements, selection and analysis of operational parameters,
- environmental aspects,
- management of post-reaction residues,
- analysis of both local and global economic effects,
- legal regulations and others.

By engaging in numerous activities in the field of renewable energy sources, the University has gained considerable experience in acquiring and processing these energy sources. Moreover, it has the large staff and the equipment necessary for basic procedures in this subject area. The presented "Green University" concept is an attempt at synergic management of this potential.

Based on the simulative calculation of the utilization of biomass obtained by UWM (including 50% usage of straw and manure for biogas production) and on the concept presented on Fig. 3, the current consumption of energy by the UWM has been balanced against the potential of the Green University project.

Tab. 4. Demands and energy potential of the UWM

	Heat [GWh]	**Electrical energy** [GWh]
Balance for 2011	**34**	**14**
Biomass	21-37	12-21
Solar collectors	3	
Photovoltaics	-	8
Thermal insulation	1	-
Total	**25-41**	**20-29**

The total consumption of energy by the University of Warmia and Mazury in Olsztyn in 2011 was 14.83 GWh, whereas the consumption of heat energy amounted to 125,388 GJ (34.83 GWh).

The calculations have demonstrated that by using the selected substrates it is theoretically possible to generate 22.5 GWh of electrical energy and 143,778.84 GJ of heat energy, which constitutes 151.7% and 114.7%, respectively, of the energy demands for UWM. This data is, however, theoretical and it would be necessary to include the consumption of energy for processing and the impact of other random parameters.

To achieve this effect, it is indispensable to construct three bio-gasworks with cogeneration systems on the farms owned by UWM. It is also important to develop a process for collecting and storing these waste materials. In addition, it would be necessary to construct a facility equipped with a syngas generator that could be used for gasification of biomass obtained from common osier cultivations and straw.

Furthermore, a stable and productive natural fertilizer generated in the bio-gasworks ensures recycling of nutrients in the soil and reduces the need for chemical fertilizers. By eliminating the fertilization with manure, the risk of spreading biological hazards and pollution of ground waters and soil can be reduced.

These bio-gasworks will became part of the concept of ecological (sustainable) agriculture thereby creating the potential for meeting the energy demands (and eventually selling the surplus to the network) and for reusing the nutrients for soil fertilization (by recycling the waste products). It is simultaneously possible to obtain economic benefits through the effects of the aforementioned savings, production of high quality products (electrical energy, fertilizing concentrate), commercial provision of waste recycling services and others, such as selling CO_2 emission limits.

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