Journal of KONES Powertrain and Transport, Vol. 25, No. 2 2018

ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0012.2815

POTENTIAL OF BIOMASS-TO-FUEL CONVERSION TECHNOLOGIES FOR POWER AND MEANS OF TRANSPORT

Rafał Prusak, Zbigniew Skuza

Czestochowa University of Technology
Faculty of Production Engineering and Materials Technology
Department of Production Management and Logistic
Armii Krajowej Av. 19, 42-200 Czestochowa, Poland
tel.: +48 34 3250725, +48 34 3250771, fax: +48 34 3250753
e-mail: prusak.rafal@wip.pcz.pl, skuza.zbigniew@wip.pcz.pl

Marek Kurtyka, Zbigniew Rembiesa

Bioelektrownie Świętokrzyskie MK-Stoki Duże sp. z o.o.
Tartaczna 12, 40-749 Katowice, Poland

Abstract

Reduction of CO_2 emissions in Poland (excluding transport) should be related to a change in the structure of electricity production sources. Similar actions have been taken by many European countries. In 2017, in the European Union's power industry, the largest emitters were dominated by coal-fired power plants in Germany (seven power plants). However, the leader of this ranking turned out to be the Belchatów power plant owned by the Polish Energy Group (PGE). Renewable energy is energy obtained from natural processes. It should be obtained in a way that would not cause a deficit of natural resources (renewed in a short time) to have a limited impact on the environment. The purpose of promoting and using renewable energy sources (RES) is to reduce the harmful effects of energy on the natural environment, primarily by limiting greenhouse gas emissions (water vapour, CO_2, CH_4, CFC, N_2O, halon, ozone and industrial gases HFC, PFC, SF6). Biomass is the most widely used renewable energy source currently used. The study of the literature and comparison of the set parameters for different types of biomass in the given order shows that Virginia mallow has the highest usefulness for energy purposes. Considering the fact that both cashew and coconut (shells) cannot be grown due to the climate prevailing in Poland, Virginia mallow seems to be the best alternative for traditional fuels used in the energy sector in the analysed group. Virginia mallow has competitive properties to wood biomass and hard coal only significantly supercedes in terms of calorific value. The energy properties of Virginia mallow can additionally be improved as a result of the torrefaction process. In addition, in the literature on the subject, attention is paid to the fact that mallow may be grown on less-favoured soils and the process of its collection – in contrast to other such plants – does not require the use of specialized agricultural machinery.

Keywords: *renewable energy sources, biomass, sida hermaphrodita, torrefaction, renewable fuel*

1. Introduction

The priorities of the European Union (EU) ecological policy were included in the general EU's seventh program "Good quality of life, taking into account the limitations of our planet" adopted on November 20, 2013. One of the goals set and defined is to transform the Union into a resource-efficient, green and competitive low-carbon economy by 2020. The area thus defined requires the following measures [1]:

– full implementation of the climate and energy package in order to achieve the 20-20-20 targets (i.e. to reduce the emission of carbon dioxide by at least 20% in relation to the 1990 level; increase the share of renewable energy sources to 20%; increase the efficiency of energy use by 20%) and to agree on further stages of climate policy development after 2020;
– significant improvement in the effectiveness of ecological products throughout their period of use;

– limiting the impact of consumption on the environment, among other by a reduction in food waste and sustainable use of biomass.

These goals have been accepted by many European countries, e.g. on March 27, 2018, the President of the Republic of Poland, Andrzej Duda, signed a law that would allow him to ratify the Doha Amendment on carbon dioxide emissions. Thus, Poland confirmed on the international arena that by 2020 it would reduce CO_2 emissions by 20% [2].

The data presented in Fig. 1 shows that in the coming decades the amount of electricity generated in Poland will grow and, according to forecasts, in 2050 its production, compared to 2015, will increase by 40%. In the same period, the share of energy from renewable sources (RES) will increase from 13% to 33% with a simultaneous decrease in the share of energy production from brown coal (from 37% to 5%) and hard coal (from 46% to 33%). This forecast was based, among others on the assumption that in 2025 energy from nuclear power plants will appear and its share will increase from 6% to 19% (currently, however, there is still no unambiguous and operational decision regarding the construction of the first Polish nuclear power plant) [2].

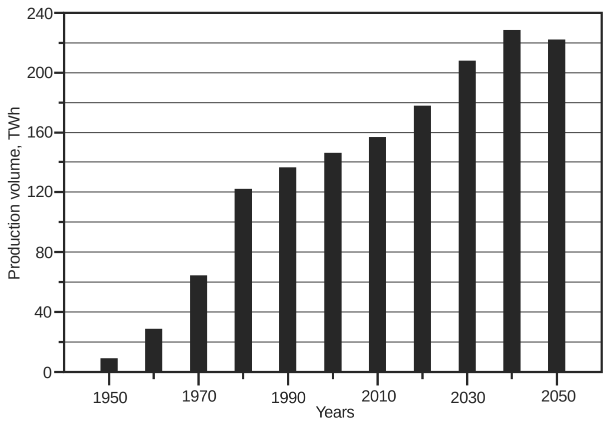

Fig. 1. Amount of electricity generated in Poland and forecast of its production by 2050 [4, 5]

The structure of electricity production sources is particularly important in connection with the plans to reduce CO_2 emissions. Generally, heavy transport accounts for 5% of emissions of this harmful gas, the remaining transport are 25%, industry is 9%, and energy production is as much as 30% [3]. More detailed data were included in the annual report covering installations and aircraft operators (excluding transport) participating in the EU Emissions Trading Scheme (EU ETS). The CO_2 emissions recorded in Poland for 2017 amounted to 203,101,411 Mg and increased until the previous year by 2.17%. The largest share was in the case of power plants (55%), which together with heat and power plants accounted for 75% of the annual emissions. Among the industrial sectors, the main emitter was metallurgy (iron and steel, non-ferrous metals) with a share of 5.4%.

The presented data shows that the reduction of CO_2 emissions in Poland (excluding transport) should be related to a change in the structure of electricity production sources. Similar actions have been taken by many European countries. The withdrawal from energy production from coal has already been announced among others by: Italy (2025), France (2022), the Netherlands (2030), Portugal (2030), Great Britain (2025), Sweden (2022), and Finland (2030). The country that no longer produces energy from coal is Norway, based almost exclusively on hydropower.

In 2017, in the European Union's power industry, the largest emitters were dominated by coal-fired power plants in Germany (seven power plants). However, the leader of this ranking turned out to be the Bełchatów power plant owned by the Polish Energy Group (PGE), which increased its emissions by 9% compared to the previous year, reaching 37.6 million Mg (the second in the ranking, the Neurath power station issued 29.9 million Mg). The top ten included the Kozienice power plant (ENEA) with emissions of 11.2 million Mg (the only one on the list that uses hard coal instead of brown coal as fuel).

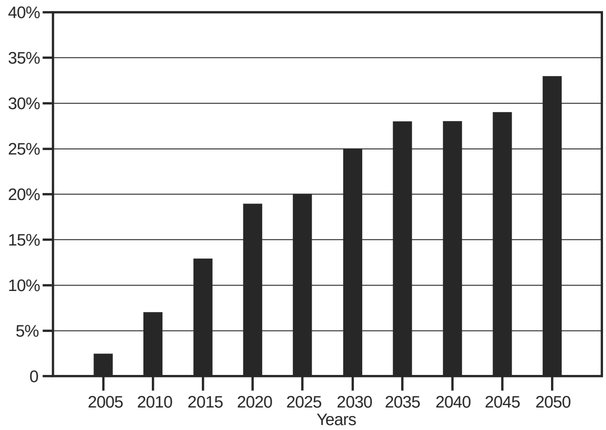

Fig. 2. Percentage share of RES in electricity production – current status and according to Polish Energy Policy forecast until 2050 [4, 5]

2. Renewable energy sources

Renewable energy is energy obtained from natural processes. It should be obtained in a way that would not cause a deficit of natural resources (renewed in a short time) to have a limited impact on the environment. The following types of energy can be distinguished in this area:
– solar energy (solar collectors and photovoltaic cells),
– water energy (water turbines),
– wind energy (wind turbines),
– ground energy, or geothermal energy (heat pumps),
– biomass energy (incinerators, biogas plants).

The purpose of promoting and using renewable energy sources (RES) is to reduce the harmful effects of energy on the natural environment, primarily by limiting greenhouse gas emissions (water vapour, CO_2, CH_4, CFC, N_2O, halon, ozone and industrial gases HFC, PFC, SF_6). The development of the use of renewable energy sources is focused on heat and power generation, but among others, it is carried out in the following areas:
– bio-components used in liquid fuels and liquid biofuels [6, 7],
– fuels for means of transport [8-10].

The issue of renewable energy in the European Union has been regulated by the Directive of the European Parliament and Council 2009/28/WE of April 23, 2009 on the promoting the use of energy from renewable sources. In Poland, the RES issue is governed by the provisions of the Act of 20 February 2015 on renewable energy sources (Journal of Laws item 478) [11]. Recently, i.e. on 16 June 2018, the Commission, the European Parliament, and the Council of the European Union agreed on new goals from which it emerges that in 2030 in the EU, 32% of energy will come from renewable sources. Member States have 18 months to transpose European law into their national legal systems from the moment the directive comes into force.

Until the introduction of new regulations in the EU, the RES share targets set for 2020 are still valid. The highest share of renewable sources in consumption is in Sweden (53.8%), Finland (38.7%), Latvia (37.2%), Austria (33.5%) and Denmark (32.2%) – the lowest in Luxembourg (5.4%), Malta and the Netherlands (6% each). Each EU Member State has its own RES share goal established (Poland 15%). The national targets for 2020 have already been achieved by Bulgaria, the Czech Republic, Denmark, Estonia, Croatia, Italy, Lithuania, Hungary, Romania, Finland and Sweden. The Netherlands (8% to achieve the target), France (7%), Ireland (6.5%), the United Kingdom (5.7%) and Luxembourg (5.6%) [12] are the farthest from the set RES share levels.

In Poland on March 6, 2018, the Council of Ministers adopted a draft amendment to the act on renewable energy sources. The proposed changes are to contribute to efficient use of renewable energy, fulfil international obligations, as well as to increase the use of by-products from agriculture and industry using agricultural raw materials for energy purposes. These activities are in line with trends in the use of various renewable energy carriers observed on the Polish market in recent years [13] (a significant share of biofuels – Fig. 3).

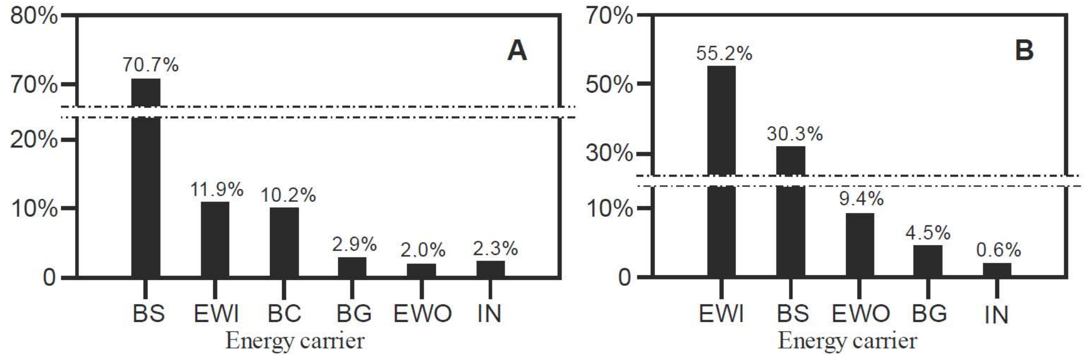

Fig. 3. Structure for obtaining energy from RES in Poland by carrier in 2016 (A). Share of RES in electricity production in Poland, by carrier in 2016 (B) [13]. Energy carriers: BS – solid biofuels, EWI – wind energy BC – liquid biofuels, BG – biogas, EWO – water energy, IN – other

3. Solid biofuels

Biomass is the most widely used renewable energy source currently used. According to the European Union definition, biomass means biodegradable fractions of products, waste and residues of the agricultural industry (including plant and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste. As reviewed, it is confirmed, that biomass crops can be thermally converted to higher quality fuels [14]. Biofuel produced from biomass may occur in various states of aggregation, i.e.:

– solid biofuels – firewood (wood splinters, wood chips, sawdust, cuttings), energy crops, agricultural residues (straw), briquettes, pellets, biocarbon, peat, dehydrated sewage sludge, waste from the processing industry (seeds and pits, seed husks, molasses, pulp, pomace), other (e.g. waste paper),
– gas biofuels – agricultural biogas (fermentation of slurry, manure, plant biomass), biogas from fermentation of food processing waste, biogas from fermentation of sewage sludge, landfill gas, wood gas, hydrogen,
– liquid biofuels – biodiesel (rapeseed fuel), ethanol (cereals, corn, beets, potatoes), methanol, liquid fuels from cellulose (petrol, bio-oils).

Jagustyn, Bątorek-Giesa, and Wilk [15] for 14 different Agro biomass (biomass from energy crops, as well as waste or residues from agricultural production and the processing industry of its products) compiled the basic parameters characterizing the usefulness of these biomasses as fuels for energy purposes. The following were assessed: total moisture content in the working condition; calorific value in working state; dry content of ash, total carbon, chlorine, total sulphur and nitrogen. The biomass group consisted of: energetic willow, Virginia mallow, miscanthus, sorghum, oil palm, corn – cob, rape straw, sunflower husks, dried fruit, olive pomace, beet pulp, cocoa shells, coconut husk, and cashew. A comparison of the set parameters (without prioritizing them) indicated that in the given order, cashew, coconut shells, and Virginia mallow show the highest usefulness for energy purposes. Considering the fact that both cashew and coconut (shells) cannot be grown due to the climate prevailing in Poland, Virginia mallow seems to be the best alternative for traditional fuels used in the energy sector in the analysed group. The data contained in Tab. 1 also shows that Virginia mallow has competitive properties to wood biomass and hard coal only significantly supercedes in terms of calorific value.

It should be noted, however, that analysis of the literature on the subject indicates the existence of some discrepancies in the assessment of the ash content in the context of Virginia mallow. These values according to different authors range from 2.5-5.9% [16] to 14.7-16.6% dry matter (these discrepancies may result from different agro-ecological conditions and the age of the mallow – the time of cultivation). This is a very important parameter, because ash negatively affects the calorific value of fuel and the course of the combustion process. Additionally, in the case of using biomass in high-powered boilers, the process of so-called co-firing with it and coal or culm is used, and then the mineral part of the biomass increases the amount of general ash, which is a troublesome waste in the energy sector. The chemical composition of ash from biomass is also important for energy units, because a high content of alkali and chemically aggressive chlorine can cause corrosion of power equipment and the formation of deposits on the heating surfaces of the boiler. The proportions between alkaline components (Fe_2O_3, CaO, MgO, Na_2O, K_2O and P_2O_5) and acidic (SiO_2, Al_2O_3 and TiO_2), contained in the ash from biomass, are an index characterizing the tendency of ash to form sediments. In addition, ashes from the combustion of biomass have a low melting point, which can consequently lead to boiler slagging. The advantage of ash from Virginia mallow, against the background of other energy plants, is undoubtedly the high melting temperature, exceeding 1500ºC [17, 18].

Tab. 1. Properties of coal and selected types of solid biomass [15]

Parameter	Coal	Brown coal	Wood biomass	Virginia mallow
W, %	3.2-19.1	10.9-54.6	4.9-68.5	6.9-13.6
A, %	3.5-27.9	7.8-20.3	0.3-6.9	2.2-4.5
S, %	0.32-1.17	0.69-1.10	0.02-0.08	0.03-0.08
Q, MJ/kg	21.1-27.7	7.8-18.4	4.4-18.4	14.5-16.1
Cl, %	0.020-0.159	0.005-0.029	0.005-0.057	0.019-0.166
C, %	49.7-78.4	41.7-56.8	45.2-51.7	47.8-49.9
N, %	0.54-1.51	0.31-0.98	0.12-0.92	0.24-0.64
where: W – total moisture content in working state, A – ash content in dry state, S – total sulphur content in dry state, Q – heating value in working condition, Cl – chlorine content in dry state, C – total carbon content in dry state, N – nitrogen content in the dry state				

The large-scale production of energy from solid biomass is associated with the occurrence of technological limitations, which increase with an increasing share of biomass in the fuel stream fed to the boiler. It can especially in direct co-firing systems, negatively affect the functioning of the installation, especially when using low-quality biomass. In addition, the high amount of combustible components in the biomass changes the ignition and combustion conditions of the coal-biomass mixture in the boiler. Restrictions related to co-firing of biomass contributed, among others, to the development of methods of its initial preparation before energy use, including drying, briquetting, pelleting, rinsing, and torrefaction [19].

Torrefaction consists in drying at a temperature of 250 to 350ºC in an inert gas atmosphere. This process eliminates most of the unfavourable features of biomass. The product (so-called biochar) obtained as a result of the torrefaction process is a homogeneous material with cumulated chemical energy, contributes to increased stability of the co-firing process with coal, has a low moisture content, very good milling properties, possesses hydrophobic properties which allow safe storage free from the risk of environmental degradation, is characterized by a lack of biological activity and a reduced content of tar precursors as well as an increased carbon content in relation to raw biomass [19]. Thanks to the torrefaction process, biomass gains new properties, which are particularly beneficial in the case of its use for energy purposes, for example in the combustion process or gasification. The product obtained as a result of torrefaction has physicochemical properties similar to low caloric coals rather than to raw biomass. It can therefore successfully replace coal, e.g. as fuel for energy purposes, both domestic and industrial [20]. The torrefaction process leads, especially at higher process temperatures, unfortunately to an increase in the ash content [21].

Virginia mallow, also called Virginia fanpetals (Sida hermaphrodita), was brought to Poland from North America. It forms compact shrubs with several dozen stems up to 4 cm in diameter and up to 4 m high. However, this plant requires proper care due to its susceptibility to diseases and pests. It is harvested from the second year of cultivation; the shoots are pruned above the ground, and then chopped into wood chips. It is suitable for growing in the climate of Poland, on medium and poorly graded soils, including sandy fifth grade soil and wasteland (except for flooded and over-dried ones). It tolerates frost well and can also be used to reclamation chemically degraded areas and those excluded from agricultural use. The forms of Virginia mallow with less foliage are more useful for burning, while more leafy forms are preferred for biogas production. A Virginia mallow plantation can be used for a period of 15-20 years. Depending on the agro-ecological conditions, dry matter yields of mallow stems are varied – on sewage sludge 9 Mg/ha, on mineral soil class III 17 Mg/ha, in very favourable conditions 20 to 25 Mg/ha. An extremely beneficial feature of this cultivated plant is the possibility of obtaining biomass with different humidity depending on the demand. This humidity can be regulated by the harvesting date. Biomass harvested in the autumn, at the end of the growing season, may contain significant amounts of moisture, but during the winter season, it reduces the water content to twenty percent. For this reason, it can be burned directly after the harvest, without drying, which reduces the costs of obtaining energy.

4. Conclusions

The development of the use of energy crops requires a long-term economic policy that clearly defines the directions of action and development in the area of renewable energy sources. This is particularly important due to the fact that the cultivation of energy crops is a long-term activity. Such an investment should be based on long-term contracts that give the manufacturer an increased sense of economic stability.

Energy crops play a huge role in the protection of the natural environment. They for example can be used for land reclamation purposes. Biofuels obtained from energy crops are also a serious alternative to woody biomass, which contribute to reducing the exploitation of forests (affects forest management positively). In addition, in the process of biomass burning, less CO_2 is generated than in the analogous process of burning coal or other fossil fuels (e.g. oil, gas). The emission of SO_2, NO_X and CO is also lower than for fossil fuels. Another significant advantage is that the amount of carbon dioxide emitted to the atmosphere during its combustion is balanced by the amount of CO_2 absorbed by plants that restore biomass in the photosynthesis process (closed CO_2 cycle) – an effective way to compensate for anthropogenic (man-made) CO_2 emissions.

In Polish conditions, the use of biomass as an energy fuel may contribute to the diversification of sources required in the processes of acquiring energy. Taking into account different agro-ecological conditions, the diversity of energy crops and the parameters characterizing the usefulness of various biomasses as fuels for energy purposes, Among others, Virginia mallow, with respect to its high annual yield by mass, seems to be a promising source for producing charcoal as well as liquid fuel based on a bio-oil, which is by-product from torrefaction process. The physical-chemical properties of fuels from Virginia mallow can additionally be improved as a result of post processing the products from torrefaction process. In addition, attention is paid to the fact that mallow may be grown on less-favoured soils and the process of its collection – in contrast to other such plants – does not require the use of specialized agricultural machinery.

Summing up, there is satisfactory potential for production of liquid fuels for internal combustion engines under requirements of low specific costs for the following: harvesting, thermal conversion (torrefaction goes at relatively low temperature of 300-350ºC) and post processing to obtain valuable fuels.

Acknowledgments

The present research was conducted in the frame of the project No. BIOSTRATEG1/270745/2/NCBR/2015, entitled "Dietary, Power and Economic Potential of Sida Hermaphrodita Cultivation on Fallow Land" supported by the Polish National Centre for Research and Development.

References

[1] Komisja Europejska, *Dobra jakość życia z uwzględnieniem ograniczeń naszej planety* [online] Available at: ec.europa.eu/environment/pubs/pdf/factsheets/7eap/pl.pdf, accessed 28 May 2018.
[2] WNP.PL (ICH), *Bilans emisji CO_2 Polski w EU ETS. 70 proc. z energetyki zawodowej* [online] Available at: energetyka.wnp.pl/bilans-emisji-co2-polski-w-eu-ets-70-proc-z-energetyki zawodowej, 300476_1_0_0.html, accessed 28 June 2018.
[3] [online] Available at: http://reducingco2together.eu/#trucks-one [Accessed 26 June 2018].
[4] Dmowski, S., *Przemysł energetyczny w* Polsce, online available at: www.geografia24.eu/geo_prezentacje_rozsz_3/383_4_przemysl/r3_4_03a.pdf, accessed 25 June 2018.
[5] [online] Available at: www.wysokienapięcie.pl/991-prognoza-prudukcja-energii-polsce-2050-2030, accessed 28 June 2018.
[6] Abdelfattah, O. Y, Allam, S., Youssef, I., Mourad, M., El-Tawwab, A., *Influence of biodiesel from Egyptian used cooking oil on performance and emissions of small diesel engine*, Journal of KONES Powertrain and Transport, Vol. 24, No. 1, pp. 7-21, 2017.
[7] Kaźmierczak, U., Kulczycki, A., *Method of preliminary evaluation of biocomponents influence on the process of biofuels combustion in aviation turbine engines,* Journal of KONES Powertrain and Transport, Vol. 24, No. 4, pp. 83-90, 2017.
[8] Kowalewicz, A., Wojtyniak, M., *New alternative fuels for I.C. engines – review*, Journal of KONES Powertrain and Transport, Vol. 11, No. 1, pp. 358-368, 2004.
[9] Bereczky, A., *Alternative fuels and technologies for compression ignition internal combustion engines*, Journal of KONES Powertrain and Transport, Vol. 19, No. 4, pp. 43-51, 2012.
[10] Piętak, A., Duda, K., Chraplewska, N., *Possibilities of supplying internal combustion engines by wood gas*, Journal of KONES Powertrain and Transport, Vol. 17, No. 3, pp. 369-376, 2010.
[11] www.mos.gov.pl/srodowisko/odnawialne-zrodla-energii, accessed 26 June 2018.
[12] [online] Available at: energetyka.wnp.pl/eurostat-udzial-oze-w-konsumpcji-energii-w-europie, 316118_1_0_0.html, accessed 01 July 2018.
[13] [online] Available at: www.green-projects.pl/2017/12/energia-oze-wytwarzanie-polska-statystyki, accessed 01 July 2018.
[14] Rostek, E., Biernat, K., *Thermogravimetric biomass-to-liquid processes*, Journal of KONES Powertrain and Transport, Vol. 18, No. 2, pp. 377-383, 2011.
[15] Jagustyn, B., Bątorek-Giesa, N., Wilk, B, *Ocena właściwości biomasy wykorzystywanej do celów energetycznych*, Chemik, Vol. 65 (6), pp. 557-563, 2011.
[16] Tworkowski, J., Szczukowski, S., Stolarski, M. J., Kwiatkowski, J., Graban, L., *Produkcyjność i właściwości biomasy ślazowca pensylwańskiego jako paliwa w zależności od materiału siewnego i obsady roślin*, Fragm. Agron., Vol. 31 (2), pp. 115-125, 2014.
[17] Jablonowski, N. D., Kollmann, T., Nabel, M., Damm, T., et al., *Valorization of Sida (Sida hermaphrodita) biomass for multiple energy purposes*, GCB Bioenergy, Vol. 9, pp. 202-214, 2017.
[18] Kowalczyk-Jusko, A., *Ash from different energy crops*, Proceedings of EC Opole, Vol. 3, No. 1, 2009.
[19] Kopczyński, M., Zuwała, J., *Biomasa toryfikowana – nowe paliwo dla energetyki*, Chemik, Vol. 67 (6), pp. 540-551, 2013.

[20] Szwaja, S., Poskart, A., Magdziarz, A., Musiał, D., Zajemska, M., *Rola biomasy toryfikowanej na rynku tradycyjnych paliw kopalnych*, Rynek Energii, 1 (134), pp. 65-71, 2018.
[21] Borkowska, H., Styk, B., *Ślazowiec pensylwański. Uprawa i wykorzystywanie*, Wydawnictwo Akademii Rolniczej w Lublinie, Lublin 2006.

Manuscript received 02 January 2018; approved for printing 23 May 2018