Marzena Smol
Mineral and Energy Economy Research Institute, Polish Academy of Sciences
Wybickiego 7 str., 31-261 Kraków, Poland, smol@meeri.pl

Joanna Kulczycka
AGH University of Science and Technology
Gramatyka 10 str., 30-067 Kraków, Poland, kulczycka@meeri.pl

ASSESSMENT OF MANAGEMENT PATHWAYS OF BY-PRODUCTS FROM BIOMASS COMBUSTION USING BATNEEC OPTIONS

Abstract
The paper presents a methodology for evaluating the Best Available Techniques Not Entailing Excessive Costs (BATNEEC) options for the management of by-products from biomass combustion - ash. Biomass ash BA was collected from Green Energy Block in Połaniec (Poland). Four variant of BA disposal were analysed: 1st - the storage of BA on conventional municipal waste landfills; 2nd, 3rd, 4th - use of BA for fertilisers production (2nd – 70% of BA, 3rd - 45% of BA, 4th - 90% of BA). Technical, environmental and economic consequences of the actions in the field of waste management technology were considered. BATNEEC evaluation indicated that the collected BA on dump (1st variant) is technical, environmental and economic inefficient, this solution has received lowest score - 29 points. The 2nd, 3rd and 4th variants have received 124, 113 and 30 points, respectively. This indicates that there are quantitative restrictions on substitution of nutrients in mineral fertilisers. Due to the possibility of secondary pollution during waste usage in agriculture, the use of BA in fertiliser products requires compliance with environmental rules - only the nutrient rich and rather heavy metal poor fractions of BA shall be used for fertilising and soil improvement purposes.

Key words
renewable energy sources (RES), biomass ash (BA), Best Available Techniques Not Entailing Excessive Costs (BATNEEC)

Introduction

One of the primary objectives of a country's economy is providing energy security, guaranteeing no risk of interruption of fuel and energy supplies. Such activities are mainly based on the supply diversification of imported fuel (alternative sources) and the development of production capacity from deposits located on own territory. The fulfilment of this objective leads to enable the economic and civilization development. Moreover, the environmental requirements and the European Union (EU) decision to decrease the share of the imported fuels in the Europe’s energy balance promote the possibilities in the usage of local energy sources in accordance with the best practice of the environmental protection technologies [1].

In Poland, according to current legislation, energy policy is defined in the Act on Energy Law [2], which specifies it as a rules of energy policy, a terms and conditions for supply and fuels and energy usage, including heat, and activities of energy companies, an indication of the authorities responsible for fuel and energy (Journal of Laws 2006. No 89, item 625). In recent years, an expert team (representatives of science, economic chambers, businesses and consumers) has developed a draft “Polish Energy Policy until 2050" (PEP 2050). In the energy balance, an increase in percent of the energy usage coming from renewable sources: 15% in 2020 and 20% in 2030 is indicated.

Renewable energy sources (RES) are becoming popular worldwide [3]. Currently, energy from renewable sources in Poland comes mainly from solid biofuels (80.03%), liquid biofuels (8.20%), wind energy (6.05%) water energy (2.46%) and biogas (2.12%) [4]. Under the Polish conditions, one of the most important and promising RES is biomass. According to European Union (EU) legalisation [5], biomass is a biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste (Directive

2001/77 / EC 2001). In recent years, constant growth in the use of biomass for energy purposes is observed. Permanent renewable sources (wood and other solid biomass) are increasingly used in conventional power plants, mainly in the regions of Northern and Eastern Europe, thanks to the extensive district heating network, combined with the relatively high demand for heat in the winter period and a sufficient supply of biomass. The main advantage of biomass compared to other RES is the availability of it. Despite wind and solar which their availability depends on weather, environmental, technological conditions, biomass is local RES that using its energy does not need any complex technology. Moreover, biomass is compatible with most of current fossil fuel power plants [6]. The use of biomass as energy sources has some other advantages, like [7]:

- disposal of a huge amount of organic waste and recovering energy from it;
- animal manure could also be utilized as fertilizer in agriculture;
- political issues related to fuel dependency of countries;
- decrease of the odour problem;
- economic and social development in rural areas;
- provides new job opportunities.

It should be noted that a consequence of increasing biomass combustion is an increase in the amount of waste generated during this process - combustion residues, mainly in the form of biomass ash (BA). The properties of ash from the biomass combustion, if they are well understood, allow for BA usage for industrial purposes or agricultural [8]. Therefore, an important problem is the analysis and development of modern technologies of BA handling [9], with particular reference to its natural usage. BA is a valuable source of nutrients for plants and it could be an alternative to mineral fertilisers.

In Poland, an example of the power plant fired in 100% by biomass in Green Energy Block (ZBE) in Połaniec. However, there are 35 other installations for thermal conversion of biomass, which generated more than 200 thousand tons of BA per year. This is a huge potential feedstock for use it in the fertiliser industry, according to assumptions of circular economy (CE) model (COM 614, 2015) [10] and ‘A zero waste programme for Europe’ (COM 398, 2014) [11]. Research and development of sustainable utilisation paths for BA, focused on an optimization and expansion of ash utilisation techniques are required in this area.

This paper presents a methodology for evaluating the Best Available Techniques Not Entailing Excessive Costs (BATNEEC) options for the management of by-products (BA) from biomass combustion in a dedicated fluidized bed boiler from Green Energy Block in Power Plant Połaniec (eastern Poland).

Innovative technology for biomass ash (BA) disposal

In June 2013, power plant Green Energy Block in 100% fired by biomass was opened in Połaniec, eastern Poland. Currently the energy produced in the boiler with power 250 MW is 25% of the total national production of electricity from biomass fuel. It should be emphasized that during the energy production, a large amount of by-products from biomass combustion in a dedicated fluidized bed boiler is generated. The main product of biomass combustion is biomass ash with code 10 01 01 (Journal of Laws 2014, item 1923) [12]. According to the EU [13] and polish regulations [14, 15] that waste must subsequently be disposed of. In view of this fact, there is a large and pressing need for the development of innovative technology for the management of BA. Due to the possibility of disposal of this waste for agriculture purposes, fertiliser production technology based on combustion by-products of biomass was invented in ZBE. Under the project, one production line with following components was created:

- feeding system - belt conveyors, feeders;
- preparatory system - mixer buffer grinder, a homogenizer;
- agglomerating system: granulator with conditioner;
- stabilization system: cooler with a sieve shaker;
- receiving system: belt conveyors, scales and packaging machine.

Technological scheme of the analyzed system is shown in Figure 1.

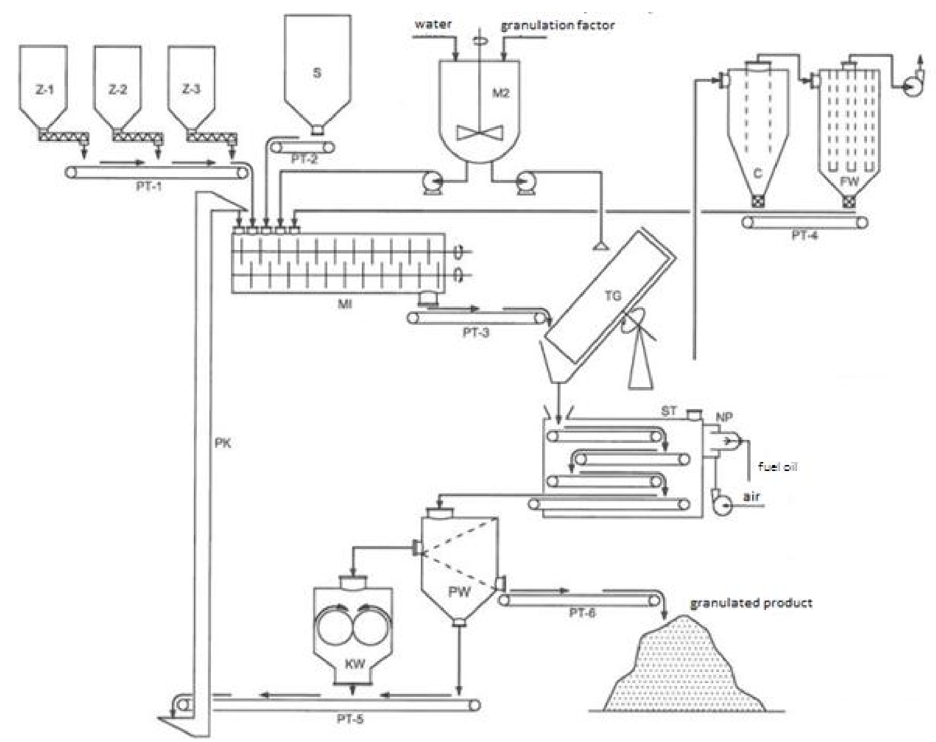

Fig. 1. Technological scheme for the production of fertilizers based on BA (Z-1, Z-2, Z-3 - reservoirs of raw materials, S – silo, MI - intensive mixer, P-1, P-2, P-3, P-4, P-5, P-6 - belt conveyors, PK – bucket conveyor, TG – granulation plate, ST – belt dryer, NP - air heater, PW - vibrating sieve, KW - roll crusher, C – cyclone, FW - bag filter, M2 - mixer of granulation liquid)
Source: Author's

The construction stage of a prototype production line was preceded by performing computer simulations using the application to engineering design CAD (SolidWORKS, AutoCAD, Inventor). The main target of such activities was the elimination of errors and complications, which could have a negative impact on the design of the prototype and the real production process.

Methodology

In order to evaluate methods of BA management, Best Available Techniques Not Entailing Excessive Costs (BATNEEC) options was used. Best Available Techniques (BAT) is most commonly selected and evaluated at the level of the production system and evaluated using expert methods in which the criteria most frequently applied are the technical feasibility of implementation, environmental benefits and economic profitability [16]. BAT include:

- "techniques" - both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
- "available" means those developed on a scale which allows implementation in the relevant industrial sector;
- "best" means most effective in achieving a high general level of protection of the environment as a whole.

As BAT plays a key role in industrial sustainability improvement through an increase in energy efficiency, pollution reduction and increasing economic and environmental benefits [17], BATNEEC (which is connected with BAT) methodology was chosen for the assessment of fertilisers production technologies [18]. BATNEEC are the best technologies that represent the minimum hazard for the natural environment, while at the same time maintaining the economic profitability of production, i.e. emissions from installations to the environment should be reduced as much as possible and in the most economically efficient way. The evaluated management technology should be the best in the field of pollution prevention and possible usage for the industrial purposes. Generally BATNEEC concerns the balance between environmental benefits and the incurred costs. In the current study, the technical, environmental and economic consequences of the actions in the field of waste management technology for BA disposal were considered. The methodology for evaluating the technical, environmental and economic effects of new production process with BATNEEC options included: preparing the topics and areas for action, creation of a problem-approach team, identifying feasible options that can be implemented, defining their specifications, and the evaluation of proposed technological variants according to evaluated options [16].

The first step of the research was to define the criteria for the evaluation of the selected options: technical, environmental and economic consequences. In second step, fourteen evaluation criteria options were indicated:

- Reducing the cost of processing and/or storage of waste;
- Reducing the amount of waste;
- Consistency with the objectives of sustainable development,
- Consistency with the programs of the national economy;
- Consistency with EU programs;
- The degree of adaptation to local conditions;
- Improved relations with consumers;
- Improved relations with the public;
- The investment volume;
- Time and ease of implementation;
- The required legal permits;
- Availability of technologies;
- Ecological assessment method of analysis of the process in terms of cumulative account;
- Assessment of quality technology.

Taking into account the professional knowledge about waste management technologies, an evaluating team of four experts was selected. The experience of BATNEEC evaluation team is presented in Figure 2.

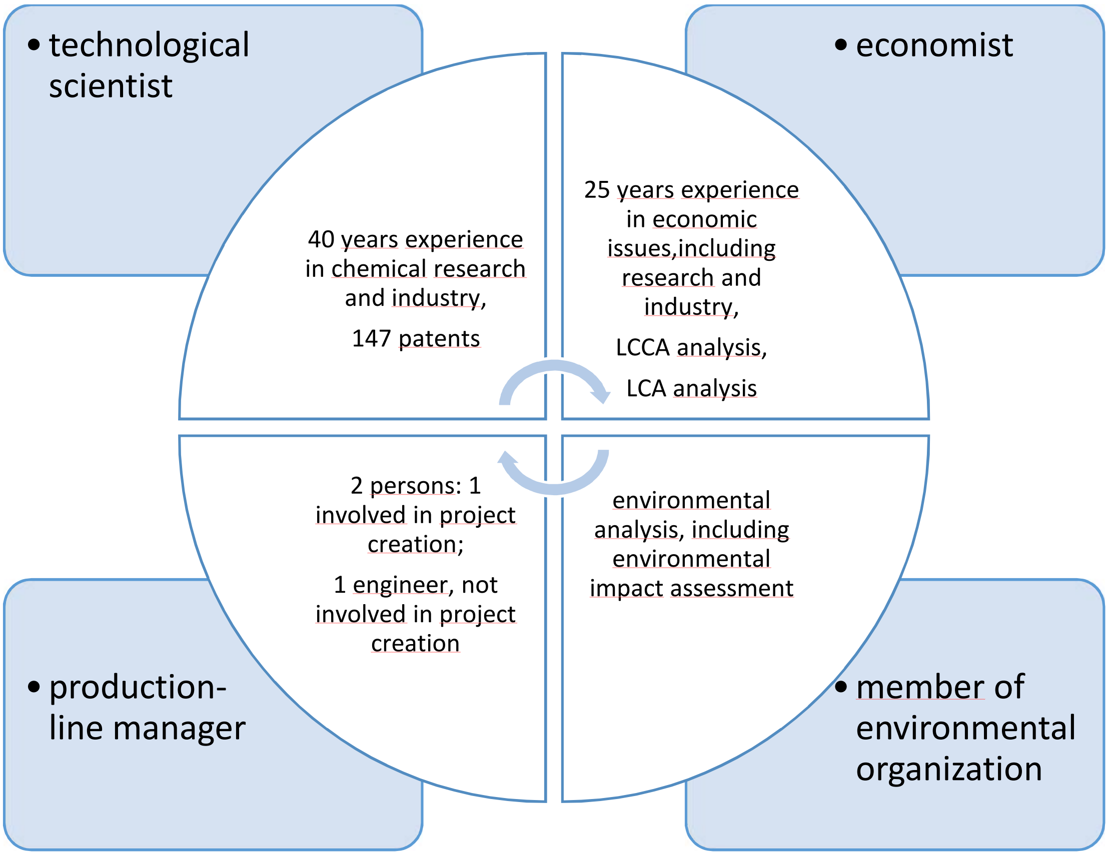

Fig. 2. BATNEEC evaluating team
Source: Author's

The evaluating team included one technological scientist, an economist, a production-line manager, and a representative from an environmental organization. The options studied were scored by the experts on a scale of 0 to 10 points within a given criterion. The maximum rating of one analysed options was 140 points. To facilitate the evaluation, the scoring system was divided into five levels of effect: no effect (0 points), small effect (1–2 points), medium effect (3–5 points), large effect (6–8 points) and very large effect (9–10 points). From the total score, the an average score was calculated for each criterion (summing up the points and dividing the sum by the number of members awarding points). Total scores of the criteria allowed evaluating and ranking the variants. Ranking of fertiliser production variants permits a proper evaluation and ranking of the technologies used.

The paper presents a methodology for evaluation of the BATNEEC options for the management of by-products from biomass combustion in a dedicated fluidized bed boiler. The main objective of this work was to compare base situation - lack of production with three variants of fertilisers production based on BA. The control situation (disposal of BA on dump) was compared to three variants of fertiliser production, with varying content of nutrients in manufactured products. The following variants were taken into account:
1st variant - a management of BA on conventional municipal waste landfill;
2nd variant – a fertilisers production based on BA: 70% of BA in mass of fertiliser product;
3rd variant – a fertilisers production based on BA: 45% of BA in mass of fertiliser product;
4th variant – a fertilisers production based on BA: 90% of BA in mass of fertiliser product.

Results and discussion
This paper presents the methodology for evaluating the options BATNEEC storage of ashes from the biomass burning and production fertiliser based on BA. The scope of work included the selection of options and criteria for their evaluation. This methodology of assessing of BA management variants with use the BATNEEC options provided the basis for the selection of the options and defined the criteria for their evaluation. The BATNEEC options for the assessment of the BA storage and fertilisers production are described in Table 1.

Table 1. The waste management solutions for biomass ash criteria and evaluation of each option BATNEEC

		Consequences		
Variant	**Solutions**	**Technical**	**Environmental**	**Economic**
1st	Storage of ash from biomass combustion (BA)	A non-refundable loss of raw materials	Storage of BA. The negative impact on the local environment	High costs of BA storage
2nd	Production of fertiliser no. 1 based on ash from biomass combustion (BA)	Use all the products of biomass combustion. Recovery - recycling of raw materials from the BA	Out-of-process recycling of combustion products. Recycling and re-use of raw materials from combustion products. The substitution of natural resources by waste. Elimination of BA storage	Elimination of the high cost of storage. Reduction of energy costs. Income from the sale of fertiliser product
3rd	Production of fertiliser no. 2 based on ash from biomass combustion (BA)	Use all the products of biomass combustion. Recovery - recycling of raw materials from the BA	Out-of-process recycling of combustion products. Recycling and re-use of raw materials from combustion products. The substitution of natural resources by waste. Elimination of BA storage	Elimination of the high cost of storage. Reduction of energy costs. Income from the sale of fertiliser product
4th	Production of fertiliser no. 3 based on ash from biomass combustion (BA)	The use of micro-elements affects a higher solubility in water. Irretrievable loss of raw materials	An adverse impact on the environment through BA storage	Minimizing the cost of BA transport and storage

Source: Author's

The next step in the procedure was the selection of criteria for the evaluation of selected options. This evaluation has a qualitative character. In order to facilitate the assessment of the options, the scoring division on five levels including the zero effects (0 points), small effects (1-2 points), medium effects (3-5 points), large effects (6-8 points) and very large effects (9-10 points) was introduced. The maximum score for each option can reach 140 points. This criteria are universal and can be used after appropriate adaptation to the needs of any process. The results for 1st and 2nd variants are shown in Table 2.

Table 2. Criteria and evaluation of BATNEEC options for analysed variants

		Variants			
No.	**Criteria ratings**	1st	2nd	3rd	4th
1	Reducing the cost of processing and/or storage of waste	0	9	10	0
2	Reducing the amount of waste	0	10	10	0
3	Consistency with the objectives of sustainable development	0	10	10	2
4	Consistency with the programs of the national economy	0	10	10	0
5	Consistency with EU programs	0	10	10	4
6	Degree of adaptation to local conditions	1	9	9	2
7	Improved relations with consumers	1	9	9	2
8	Improved relations with the public	1	9	9	2
9	The investment volume	10	4	4	0
10	Time and ease of implementation	3	4	4	10
11	The required legal permits	3	4	4	0
12	Availability of technologies	10	10	10	4
13	Ecological assessment method of analysis of the process in terms of cumulative account	0	8	7	2
14	Quality technology assessment	0	8	7	2
Total score [points]		**29**	**124**	**113**	**30**

Source: Author's

The highest rated options refer to solutions with very high environmental and economic efficiency, consistent with the objectives of sustainable development (SD). The 2nd and 3rd variants related to the fertiliser production based on biomass ashes have received 124 and 113 points, respectively. This two variants can be regarded as the best available techniques from the analysed solutions. The 4th variant received only 30 points. This indicates that there are quantitative restrictions on substitution of nutrients in mineral fertilisers. The evaluation indicated that the collected biomass ashes on dump (1st variant) is technical, environmental and economic inefficient, this solution has received lowest score - 29 points. It should be also mentioned that due to the possibility of secondary pollution, as in the case of sewage sludge usage in agriculture, the use of BA in fertiliser products requires compliance with environmental rules. That's including the monitoring of heavy metals content - only the nutrient rich and rather heavy metal poor fractions of BA shall be used for fertilising and soil improvement purposes. Moreover, the technology of BA management must comply with legal requirements and be economically viable for the producer of fertilisers. Potential investors should use the BATNEEC options results for evaluation of technological solutions in waste management, especially as the results obtained conform to those proposed in the EU waste hierarchy (Directive 2008/98/EC) [13] and circular economy model (COM 614, 2015) [10].

The proposed technology of BA management could be considered as eco-innovativeness. In EU countries for years there have been grants or loans for environmental project available from the national funds (such as the

National Fund for Environmental Protection and Water Management in Poland), and, recently, also from the EU funds (e.g. Structural Funds) [19], the business operators fund the majority of such projects with their own resources. Supporting eco-innovative projects designed to reduce negative environmental impacts, at every stage of the product life cycle, requires the development and implementation of rules for their evaluation, taking into account the technical feasibility, economic and ecological efficiency, and consideration to social aspects [20] potential beneficiaries which will take into account whole life cycle in the investments projects, in accordance with the 'zero waste' strategy will be in the first place supported by European funds at the national and international level in new programming period 2014-2020.

The results obtained in study are easy to interpret and could be used as a tool for communicating with the public, supporting Corporate Social Reasonability (CSR) of the company. However, due to the fact that the ash from the combustion of biomass is a waste, its safety application in agricultural industry requires extensive knowledge based on the results of experimental research, taking into account environmental and technical aspects as well as legal regulations.

Conclusions

BATNEEC option methodology is a useful tool for comparing the methods of waste management, including biomass ash (BA). The result of BATNEEC analysis was the ranking of the alternative types of waste management technologies analysed, from the most to the least favourable variants, taking into account technical, environmental and economic aspects.

All studied variants (2nd, 3rd, 4th) related to the production of fertilisers based on BA were selected as much more beneficial than collection biomass ashes on dump (1st variant). Among the assessed variants, two options (2nd and 3rd) related to the production of fertilizers (respectively 89% and 81% of the maximum 140 points) were highest rated. This two variants can be regarded as the best available techniques from the analysed solutions.

The assessment of 1st variant related to the BA storage on dump was the lowest (21% of maximum score) - this solution should be avoided. Due to the possibility of secondary pollution of environment, the use of BA for fertiliser purposes requires compliance with environmental rules. The disposal of BA is a problem of secondary waste treatment and there is a large and pressing need for the development of methods for the disposal of this waste.

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