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Technical Economic Analysis of a 0,8MW Agricultural Biogas Plant

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Summary. The article focuses on selected aspects of the technical and economic analysis of the 0.8 MW agricultural biogas plant. The electrical power, generated in a cogeneration system, fed power to the neighbouring overhead power grid, Węgrów – Sokołów Podlaski, while the heat energy recovered from combustion gases and liquids cooling the engine was used to heat digesters, a residential building, drying room and farm buildings. The planned annual production equals c.a. 6400 MWh per year given the 8000 h of engine operation. The substrates used as input for the digestive chambers were as follows: fermented maize, pig slurry and liquid digestate pulp.
Key words: engine, digestive chamber, biogas, electrical power.

INTRODUCTION

Conventional energy sources, such as coal, crude oil or natural gas, shall be exhausted, which is the reason why other energy carriers are being searched for in developed countries, like renewable energy sources [2, 19]. The energy is environmentally friendly, as it comes from non-exhaustible sources. Next to the basic sources of green energy, including sun or wind, there is also the biomass [11, 12, 13]. The use of biofuels reduces the emission of CO_2 and other liquids and gases, like SO_2, CO or dinitrogen monoxide, which are hazardous to humans. Furthermore, there is yet another issue concerning agricultural waste management, where ecology and economy are crucial [7, 8, 14]. Next to municipal wastes, among factors affecting the rural environment are animal faeces and emission of hazardous compounds contained therein to the atmosphere [16, 17]. For some time now, the problems referred to above have been solved with the use of methanogenesis [1, 3, 15]. The studied agricultural biogas plant is located app. 100 km from Warsaw. Based on the data obtained from the investor, the technical and economic aspects of the investment have been characterized.

GENERAL CHARACTERISTICS OF THE DISTRIBUTION OF DEVICES

All the elements of the biogas plant are located within the plot of the area of 2.67 ha, according to the instructions set forth in applicable regulations [5, 18, 20]. Among the key elements of the biogas plant are: weighbridge, fermented maize silos, substrate stacking bin, two digesters, pumping station, digestate pulp container, cogeneration unit, pig slurry container, quick release coupling for pumping in liquid substrate, stacking bin scales, grating for silage leachate, flare.

Table 1 shows the requirements concerning the spacing of digestive chambers and biogas tanks.

Table 1. Distance from biogas tanks and digestive chambers to other agricultural structures [5]

Item	Criterion	Min. distance [m]
1	From other buildings	16
2	From the border of adjacent plot	10
3	From livestock buildings	30
4	From other biogas tanks and digestive chambers	30
5	From coal and coke depot	30
6	From other building structures not qualified as buildings	10
7	From grain silos and animal feed silos the capacity of which exceeds 100 tons	30

Yet another requirement is the size of the safety zone around the biogas plant, which was also included in the biogas plant design. Under item 1, table 2 shows the specific value for the biogas plant in question, taking into account different dimensions of the biogas tank.

Table 2. Sizes of safety zones around the biogas plant [5]

Item	Tank capacity [m³]	Safety zone [m]
1	above 100	8
2	50–100	5
3	below 50	3

CHARACTERISTICS OF SELECTED ELEMENTS OF THE BIOGAS PLANT

The order of the described elements of the biogas plant is connected with the beginning of the "path" of the substrates, through their partial processing and digestion, until the digestate pulp is obtained.

Weighbridge – the first action needed to obtain biogas is the delivery of substrate. Before the substrate (e.g. maize) gets to the stock pile, it is weighed on a special weighbridge of the area of 42 m². The above serves as a basis to settle the amounts due to farmers who deliver the green mass. The weighbridge accuracy of 10 kg permits a very thorough control of the amounts of the substrate obtained.

Bunker silos – trailers with maize, after weighed, are emptied in two silos of the total area exceeding 6000 m². Currently, they are used to store 10,000 tons of fermented maize. The fermented maize storage possibilities have been elaborated according to the requirements set forth in the "Traunstein Silo" system. The subbase has been made from asphalt with a component neutralizing the negative impact caused by contact of the subbase with the aggressive activity of the leachate. Therefore, structure of the soil corresponds to the structure of a wear course with a high usage coefficient. Side walls have been lined with reinforced concrete, while the inner side has been covered with protective PE foil (up to the height of 1 meter) for protection against contact with the aggressive area. Dimensions of the bunker silos are presented in table 3.

Table 3. Silo dimensions [10]

Bunker silo	Value	Unit
Length	118	m
Width	2 x 26	m
Height	3	m
Volume	18,330	m³

Liquid substrate tank is a concrete tank for liquid substrate, which consists of an intermediate tank and a bulk silage tank – each of the capacity of 25 m³ (Table 4). The intermediate tank is used for storing pig slurry obtained from the local farmer. The bulk element absorbs silage from the bunker silo. The silage is immediately transported by the high-efficiency pump installed in the tank (power: 11 kW) directly to the digestive chamber. The tank is re-filled with the use of the quick release coupling installed. The chamber is protected against overfilling with a special warning system. The system consists of a float installed in the tank and three lamps mounted on the board next to the tank. Depending on the level of fill-up and the resultant location of the float, the appropriate number of lamps is activated.

Table 4. Characteristics of the liquid substrate tank [10]

Substrate tank	Value	Unit
Capacity	2 x 25	m³
Depth	2,5	m
Width	2	m
Length	5	m
Fittings		
High-efficiency HRP 3000 E chopper mix pump	11	kW

Fliegl PolyPro 40t biomass feeder is a stacking bin by the world leading producer of agricultural equipment, Fliegl, based on the structure of agricultural monocoque trailer. Nominal load of the feeder, given the capacity of c.a. 120 m³ equals app. 50 tons. The loading process is performed with the use of an efficient telescopic loader. The input dose is established based on the readings of an electronic scale placed on the side of the flume. The material loaded inside is transported along a sliding wall to the mixer which puts the substrate smoothly into the charging hopper. Then, the biomass gets to the mixing system with a liquid substrate from where it gets to the pumping station through the 15 kW pump.

Pumping station and technical room – there is a technical room between digestive chambers (dimensions: 8.87 m x 12.21 m). It is used for supervision of the operation of individual assemblies and for installation control. The room houses a pumping station (Figure 1) and a control panel in charge of the operation of the biogas plant. The control panel is used to define the volumes of the substrate charged, overall air content in the biogas and temperature in the digestive chambers. The pumping station consists of an RPM 3000E 18 kW emptying pump and a welded pumping system, DA 50 – 160, conveying the substrate under the pressure of 10 bar. The system contains an additional connection, should a new digestive chamber be connected to the substrate power feeding system.

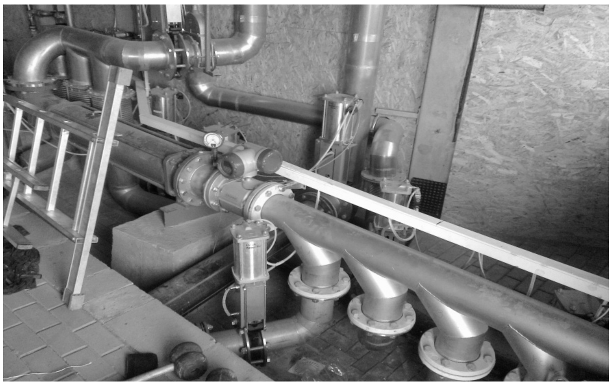

Fig. 1. Substrate-to-digestive chamber pumping system [author's study]

Digestive chambers and digestate pulp tank – the respective capacity of the tanks (diameters: 21, 23, 30 m) equals 2 100, 2 500 and 3 000 m³. All tanks have been built as conventional round RCC tanks. They are fitted with gas caps which lock them tightly. The caps serve the function of biogas tanks. The tanks are composed of a supporting structure with overlaying PE and PVC foil, which serves as protection against air. The biogas produced escapes to the upper part of the shell, from where it is transported through a piping system to the carbon filter. There is a pass in the wall used for repairs, maintenance works and removal of deposited sand sediments. The digestive chambers are fitted with a set of three hydraulic stirrers, which prevent one-sided and quick substrate sedimentation. Heating coils are installed on the walls, maintaining the temperature of 38°C inside the tanks. This is a necessary procedure in the mesophilic process, as biogas starts to hover above the silage as soon as after 5 hours. Moreover, the walls are heat-insulated with a B2 grade material of the minimum thickness of 60 mm. The digested mass gets to the pulp container. The content of the container also emits biogas (5 % of the overall production). The substrate retention period, from its application to digestive chambers until removal from the last container, equals approximately 70 days. In practice, it is 2 or 3 months due to the established times of outpour of the digested fertilizer into the fields. A portion of the pump returns to circulation thus diluting the dry biomass with water, while the other part is received by farmers. The tank is emptied through a high-efficiency 30 kW pump.

Cogeneration system – cogeneration unit is placed in a container of the area of 36 m². Before biogas gets to the engine, it is subjected to desulfurization in a tank filled with active coal, placed outside of the container. This process is necessary to prepare the biogas for further circulation. After the process, purified gas is tested for its composition, meaning methane content. The aforementioned tests are monitored on a touch sensitive display in the container. Table 5 shows a report on the content of individual ingredients in biogas of November 2014.

Table 5. Results of the produced biogas measurement [author's study]

Biogas	Methane	Carbon dioxide	Oxygen	Hydrogen sulfide
10.11.2014	65%	34%	0.20%	90 ppm
11.11.2014	64%	35%	0.20%	88 ppm
12.11.2014	65%	34%	0.20%	90 ppm
13.11.2014	62%	37%	0.20%	95 ppm
14.11.2014	59%	40%	0.20%	94 ppm
15.11.2014	60%	39%	0.20%	92 ppm

Treated fuel, in the form of a mixture of biogas and oxygen, gets to the flow control system through the container walls. This is where it comes into contact with the cogeneration unit composed of: the engine, current generator and heat exchanger. A four-stroke, 16-cylinder MWM spark ignition engine generates the power of 800 kW. The exchanger thermal power is estimated to equal app. 800 kW. After the fuel mixture has been combusted, the engine generates mechanical energy. A generator is connected to the crankshaft with a clutch. The generator transforms mechanical energy into electrical power. The energy s transported to the 15 kV transporter and, then, to the transmission grid. At the same time, the heat exchanger recovers heat from combustion gases engine-cooling water and transfers it to heat digestive chambers. The other portion of the heat flows through the piping to the household of the biogas plant owners, where it will be used to heat the house and dry the grains. The temperature at the heat exchanger outlet equals 80°C, while the return temperature equals 30°C. Due to technical issues, the current biogas production fluctuates around 2000 m³ per day, with a planned increase in production within the next three months up to 8000 m³ in 24 hours.

CHARACTERISTICS OF SUBSTRATES USED IN PRODUCTION

According to the initial conceptual design, the following products shall be used as input to the digestive chamber: fermented maize, pig slurry, broad production waste, maize leachate and water (as the substrate diluting agent).

The basic substrate currently used for biogas production is silage maize – possibly the best and most available substrate in the area of the investment. The said material is stored in two bunker silos placed directly by the stacking bin. In the biogas plant analysed maize is obtained from two sources: purchase from the neighbouring farmers and collection of materials from own crops. Daily maize input equals 40 tons, while the annual consumption is planned at the level of c.a. 12,000 tons of green mass. To liquefy the substrate used, with dry mass at the level of 325, pig slurry was used as the second component of the input mass. It is obtained from a local pig farmer. The content of dry mass for this type of substrate equals 6%, which supports the liquefaction and digestion process.

The farmers who deliver substrates to the biogas plant, in the form of maize and pig slurry, obtain natural fertilizer in the form of digestate pulp. The pig slurry is poured over fields with the use of slurry tanks. This is beneficial to both parties. For farmers who sell maize, this is a source of additional income and an opportunity to fertilize their fields with a free-of-charge natural fertilizer of much better quality than the slurry alone. In this way they will be able to supplement shortages of nutritive substances within fields that require intense fertilization due to high soil requirements of maize intended for biogas production. For a pigsty owner, in turn,

the above serves as a way to obtain good quality liquid fertilizer and solves the problem of excess slurry in the tanks. As set forth in the agreement with the biogas plant, the farmer is supposed to deliver app. 6000 m³ of slurry per year. To reduce slurry consumption and to prevent the necessity to use water as a diluting agent, silage leachate and liquid digestate pulp are put into the tanks as well. Figure 2 shows interdependence between the uses of individual substrates.

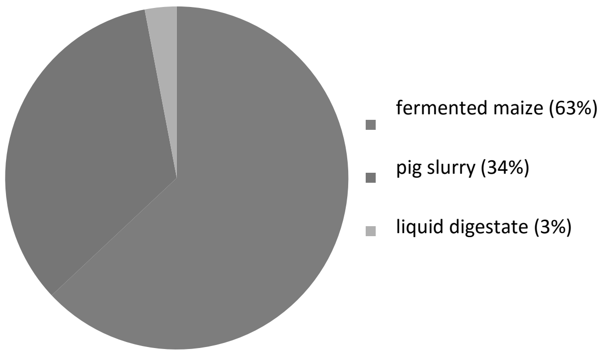

Fig. 2. Consumption of individual substrates in daily production [author's study]

FUNDS ALLOCATED TOWARDS THE CONSTRUCTION OF THE BIOGAS PLANT UNDER ANALYSIS

Table 6 contains a presentation of financial resources for the construction of biogas plant under analysis.

Table 6. Percentage volume of own funds and funds obtained from the National Fund of Environmental Protection [author's study]

Item	Type of financial contribution	%
1	Non-refundable grant from the National Fund of Environmental Protection and Water Management	30
2	Preferential borrowing	45
3	Bank loan + own funds	25

The project analysed in the present document was awarded a non-refundable grant from the National Fund of Environmental Protection and Water Management (NFOŚiGW), which, beyond doubt, was a success in terms of the investors' endeavours, as the maximum funds were obtained. The above shortened the period of reimbursement of own capital and the funds obtained under the borrowing and the loan. This very same institution granted a preferential borrowing to the company, which covered almost half of the costs of construction. The aforementioned borrowing was allocated as part of the Green Investment System for 15 years, with interest rate at the level of 4.5%. This is another success as, again, the maximum borrowing obtainable in the project was granted. The last, third part, was own capital amounting to 500,000 and the loan incurred for 20 years at the rate of 5.5%.

COSTS OF CONSTRUCTION AND UTILIZATION OF THE INSTALLATION

When designing the facility, the owners focused on the quality first. The overall cost of construction was relatively high and amounted to app. PLN 10.5 million. This is due to the best quality of materials used for the construction and the elements of renowned producers mounted in the installation. The annual costs of maintenance of the biogas plant, without loan repayment, have been presented in Table 7.

Table 7. Annual costs of maintenance of the biogas plant subject to analysis [author's study]

Item	Cost type	Cost [PLN/year]
1	Obtaining maize	720 thousand
2	Tax for the municipality	20 thousand
3	Income tax	260 thousand
4	Renovations	80 thousand
5	Insurance	100 thousand
6	Installation operation	20 thousand
	IN TOTAL	**PLN 1.2 million**

Annual expenses of the biogas plant, with annual costs of loan and borrowing repayment included, are presented in Table 8.

Table 8. Annual expenses of the biogas plant, including repayment of liabilities [author's study]

Item	Cost items	Cost [PLN/year]
1	Maintenance of the biogas plant	1.2 million
2	Preferential borrowing repayment	329,175
3	Loan repayment	110,775
	IN TOTAL	**1,639,950**

REVENUE FROM THE BIOGAS PLANT INVESTMENT UNDER ANALYSIS

During the annual cycle of operation of the biogas plant, it is necessary to ensure time for servicing and repair of failures, if any [4, 6]. Therefore, the average number of hours of operation of the generating unit in the investment analysed equals 8,000 hours per year. The power capacity equals 800 kW, of which 50 kW is allocated towards auxiliary needs of the installation. The price for production of 1 MWh was reduced by the quality fee amounting to 7% of its value, which was initially established at the level of PLN 181. There is a further bonus to the sales of green energy, i.e. "Green Certificates", which provide additional PLN 160-190 for each MWh produced [9]. After all costs have been deducted from the aforementioned amount, the approximate annual profit of the company equals PLN 390,000.

CONCLUSIONS

Production of biogas from agricultural waste is the best way to obtain green energy. This is confirmed by production stability throughout the year, regardless of the weather. The only condition of such stability is the appropriate composition of the substrates selected, as well as regular periodic inspections that prevent unexpected failures. Apart from stable energy supply, the biogas analysed in the present article provides local farmers with an opportunity to generate additional income. Next to electricity production for the public grid, sales of heat to the local school and residential houses are also planned.

Changes in the market of 'colour certificates' have entailed changes in income from green energy production, which significantly extended the return-on-investment period.

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ANALIZA TECHNICZNO-EKONOMICZNA BIOGAZOWNI ROLNICZEJ O MOCY 0,8MW

Streszczenie. W artykule przedstawiono wybrane aspekty analizy techniczno – ekonomicznej biogazowni rolniczej o mocy 0,8 MW. Produkowana energia elektryczna w układzie kogeneracyjnym zasilała pobliską energetyczną sieć napowietrzną Węgrów – Sokołów Podlaski, natomiast odzyskiwana energia cieplna ze spalin oraz cieczy chłodzącej silnik wykorzystywana była do ogrzewania fermentatorów, domu mieszkalnego, suszarni i budynków gospodarczych. Planowana roczna produkcja ma wynosić ok. 6 400 MWh rocznie przy 8 000 h pracy silnika. Substratem używanym jako wsad do komór fermentacyjnych były kiszonka z kukurydzy, gnojowica świńska oraz płynna postać pulpy pofermentacyjnej.
Słowa kluczowe: silnik, komora fermentacyjna, biogaz, energia elektryczna.