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Design of Digester Biogas Tank
Part I: Biogas Calculator – Tool to Perform Biogas Energy Calculations

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Summary. The paper presents the designed biogas calculator. The parameters were analysed of substrates used in biogas production as well as the methodology of calculation of energy and heat that can be generated. Results of calculations obtained by the designed tool and the available calculators were compared. Differences in the results were discussed.
Key words: biogas, tank, converter, calculation of energy.

INTRODUCTION

The development of our civilization results in an ever increasing demand for energy. In the last years, the reserves of traditional fossil fuels such as oil, coal, and natural gas have been determined. One of the most commonly debated issues is their negative impact on the environment. All these factors have translated into growing interest in renewable energy sources. One of possibilities for increasing the share of renewable energy could be the agricultural biogas [12, 18]. In practice, biogas is most frequently used in cogeneration when creating heat and electric energy. It is becoming more and more popular as a source of biomethane [4].

Valuable nutrients obtained in the process of fermentation may be re-used as substitutes for mineral fertilisers. This process results in the lowering of CO_2 emissions, it allows for conserving fossil fuels and decreasing costs [11].

When planning to build a biogas plant the aspects that are analyzed are: location, technology and size of the facility. The most important aspect is selection of substrate from which the biogas will be produced [7, 14, 15]. Agriculture and the communal sphere produces large quantities of waste that can be used for anaerobic fermentation as an energy source [5, 20].

In Poland, according to the construction plan for agricultural biogas plants created by the Ministry of Agriculture and Rural Development, in 2020 the production of biogas will reach about 2 million m³ per year.

Tools such as biogas calculators provide the investors who wish to build an agricultural biogas plant with information on expected energy yields [17]. Biogas calculator helps to establish the basic characteristics of the facility which are necessary to model the biogas chamber. The biogas yield is dependent mostly on the type of substrate provided and its chemical composition [19].

BIOGAS CALCULATOR – USER PANEL

The Calculator was developed using the C Sharp program. The types of substrates and their parameters were chosen on the basis of [2, 3, 6, 16,]. The parameters were averaged in order to facilitate the calculations (Table 1).

The above data show that in order to increase the economic efficiency of fermentation process via increased biogas production the animal waste should be complemented by substrates with a higher content of dried organic mass per volume unit [EU Agrobiogas 2007-2010, 1].

During the first stage of utilization of the tool the choice must be made concerning the substrate type in panel I (Fig. 1). There are three substrate types to choose from: natural fertilizers, plant-based substrates and agri-food waste.

In order to perform the calculation, one has to select the available substrate type by expanding the "Typysubstratów" (EN. Substrate Types) – panel I.

Next an individual substrate should be chosen from the available substrates in panel II (Fig. 2).

In the next step, in panel III, in the field "rocznywsadsubstratu [t/rok]" (EN. "Annual substrate input [t/year]"), the available quantity of substrate should be entered and the "oblicz" (EN. "calculate") button should be pressed (Fig. 3). This way the values for a single substrate will be

Table 1. The averaged parameters of substrate used in the Calculator [own elaboration on the basis of: 2, 3, 6, 16]

Raw resources	**s.m**[%]	**d.o.m**[% sm]	**Biogas performance**		**Methane production potential**	**Methane content** [% vol.]
			[m³/t s.m]	[m³/t d.o.m]	[m³/t d.o.m]	
	Natural fertilizers					
Cattle slurry	9,5	78,5	25	350	210	60
Pig slurry	7	80,5	27,5	500	325	65
Cattle manure	25	72	45	255	153	60
Pig manure	22,5	77,5	60	360	216	60
Chicken manure	32	71,5	80	345	207	60
	Vegetal matter					
Corn silage	27,5	90	185	575	302,88	52,5
Wheat (silage from whole plants)	32,5	95	185	615	338,25	55
Sugar beet	23	92,5	175	830	444,05	53,5
Fodder beet	12	80	87,5	735	393,23	53,5
Beet leaves	16	80	70	575	313,38	54,5
Grass silage	25-37,5	82,5	185	585	318,83	54,5
	Agri-food waste					
Brewer's grains	22,5	85	117,5	665	395,68	59,5
Distillers grain stillage	7	85,5	40	565	347,48	61,5
Distillers potato stillage	6,5	90	39	550	338,25	61,5
Distillers fruit stillage	2,5	95	15	475	292,13	61,5
Fresh fruit or vegetable pulp	13	90	85	700	409,5	58,5
Run-off from processing of fruits, vegetables	3,7	72,5	63	1750	962,5	55
Process water	1,6	77,5	60	3750	2062,5	55
Pressed expeller fruits and vegetables	24	95	67,5	300	217,5	72,5
Molasses	85	87,5	315	425	308,13	72,5
Expeller apples	35	87,5	147,5	670	452,25	67,5
Expeller fruits	35	92,5	265	625	421,88	67,5

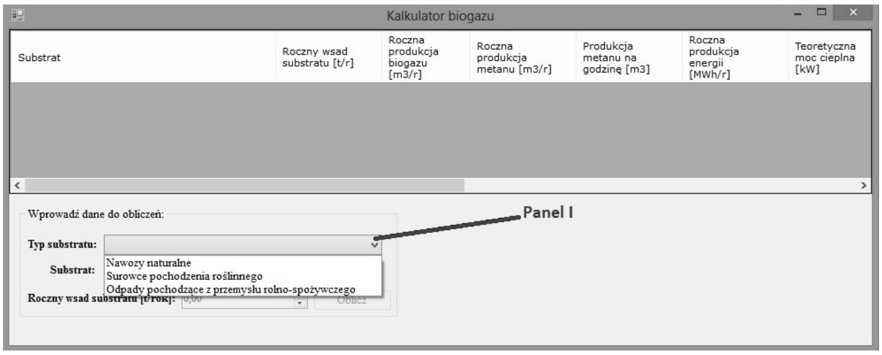


Fig. 1. Biogas calculator – substrate type selector [own elaboration]

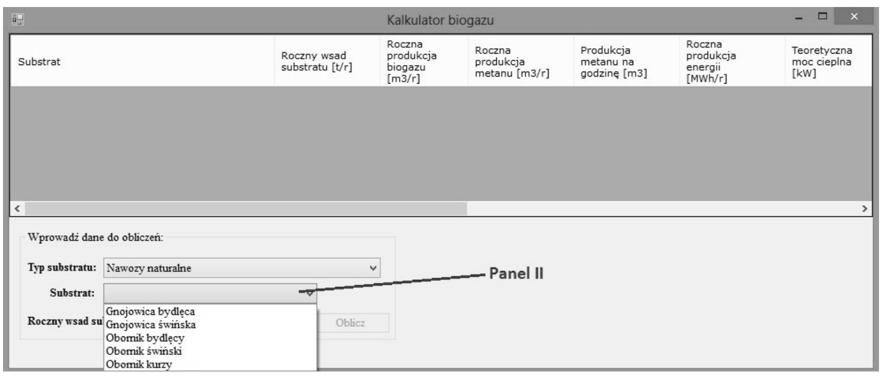


Fig. 2. Biogas calculator – selection of a specific substrate from the substrate category [own elaboration]

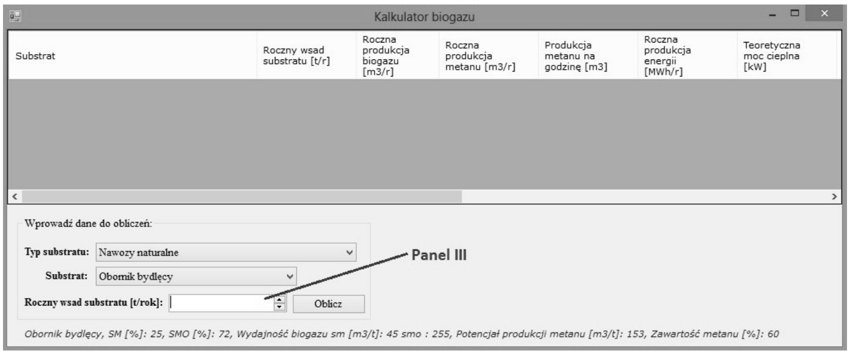


Fig. 3. Biogas calculator – entering annual quantity of substrate [own elaboration]

calculated. If the biogas plant uses more substrates, the user should re-select options in panel I, panel II and enter the value of annual substrate input in panel III. Values for individual substrates will be automatically added together in the box named "Łącznie" (EN. "Total") after clicking on the "Oblicz" (EN. "Calculate") button. After entering the boxes in the lower bar (Fig. 3) the data from the substrate table will be displayed (Tab. 1). Accessing the calculation results is possible via a slider in the middle of the program's window.

THE FIXED PARAMETERS OF THE BIOGAS CALCULATOR

The calculator uses a calorific value of 1 m³ of biogas of 9.17 kWh/m³. In order to perform energy calculations it is necessary to assume the thermal and electric efficiency of the cogeneration generator in which the biogas is burned and turned into electric energy and the heat from the combustion gases is recovered. Thermal efficiency (η_c) of the utilized cogeneration generators is from 40 to 43%. The calculator uses value: η_c= 41%. The electric efficiency (η_{el}) of the utilized generators is between 30 and 40%. The calculator uses value η_e= 37%. Another assumption was the annual working time of the generator (t), which is generally between 85-95% of a given year, i.e. 7500-8300 hours. The assumed value of this parameter is t = 8000 h.

CALCULATION METHOD

On the basis of substrate selection, its quantity and data from Table 2, calculations are made to present the energy parameters of the biogas plant according to the below equations [2, 10].

Table 2. Calculation of energy parameters of the biogas plant [own elaboration on the basis of: 2, 10]

Annual biogas production		**$R_{pb} = M_s$ s.m. d.o.m.W_b**
	R_{pm}	Annual biogas production [m³/y];
	M_s	substrate mass during a year [t/y];
	s.m	content of dry mass in 1 t of substrate [%];
	d.o.m.	content of dry organic mass in dry organic mass [%];
	W_b	biogas yield [m³/t d.o.m].
Annual methane production		**$R_{pm} = M_s$ s.m. d.o.m. P_{pm}**
	R_{pm}	annual methane production [m³/y];
	M_s	substrate mass during a year [t/y];
	s.m.	content of dry mass in 1 t of substrate [%];
	d.o.m.	content of dry organic mass in dry mass [%];
	P_{pm}	Potential for methane production [m³/t d.o.m].
Hourly methane production		**Gpm =**
	G_{pm}	Hourly methane production [m³];
	R_{pm}	annual methane production [m³y];
	t	biogas plant working time, t = 8000 [h/y].
Energy production		**R_{pe} =**
	R_{pe}	Annual energy production [MWh/y];
	R_{pm}	annual methane production [m³/y];
	W	Calorific value of methane [kWh/m³];
	1000	unit conversion.

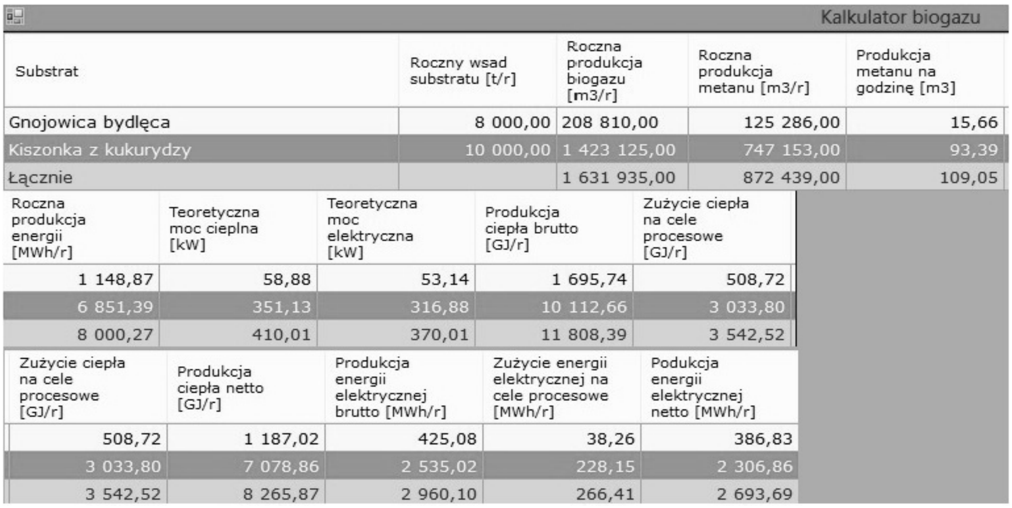
Theoretical thermal power		$\mathbf{P_{tc} = G_{pm} W \eta_c}$
	$P_{t.c}$	Theoretical thermal power [kW]
	G_{pm}	Hourly methane production [m³];
	W	Calorific value of methane [kWh/m³];
	η_c	thermal performance in cogeneration $\eta_c = 41\%$
Theorethical electric power		$\mathbf{P_{t.el} = G_{pm} W \eta_{el}}$
	$P_{t.el}$	Theorethical electric power [kW];
	G_{pm}	Hourly methane production [m³];
	W	Calorific value of methane [kWh/m³];
	η_{el}	electric performance in cogeneration $\eta_{el} = 37\%$
Gross heat production		$\mathbf{Q_{c.brutto} = P_{tc}\ t\ 3.6}$
	$Q_{c.brutto}$	Gross heat production [GJ/y];
	$P_{t.c}$	Theoretical thermal power [kW]
	t	biogas plant working time, t = 8000 [h/y];
	3,6	unit conversion.
Use of heat for process		$\mathbf{Q_{c.proc.} = Q_{c.brutto}\ z_c}$
	$Q_{c.brutto}$	Gross heat production [GJ/y];
	z_c	the process heat factor (determines what part of the generated heat is used by the biogas plant), is 0.25-0.4; $z_c = 0.3$.
Net heat production		$\mathbf{Q_{c.netto} = Q_{c.brutto} - Q_{c.proc}}$
	$\mathbf{Q_{c.netto}}$	Net heat production [GJ/y];
	$Q_{c.brutto}$	Gross heat production [GJ/y];
	$Q_{c.proc}$	Use of heat for process [GJ/y]
Gross electric energy production		$\mathbf{E_{el.brutto} = P_{t.el} t}$
	$E_{el.brutto}$	Gross electric energy [MWh/y];
	$P_{t.el}$	Theorethical electric power [kW];
	t	biogas plant working time, t = 8000 [h/y].
Use of energy for process		$\mathbf{E_{c.proc.} = E_{el.brutto} z_e}$
	$E_{c.proc}$	Use of energy for process [MWh/y];
	$E_{el.brutto}$	Gross electric energy [MWh/y];
	z_e	the energy factor determines the use of generated energy for own needs of the biogas plant $z_e = 0.09$.
Net electric energy production		$\mathbf{E_{el.netto} = E_{el.brutto} - E_{c.proc}}$
	$E_{el.netto}$	Net electric energy [MWh/y];
	$E_{el.brutto}$	Gross electric energy [MWh/y];
	$E_{c.proc}$	Use of energy for process [MWh/y];

VERIFICATION OF THE DATA OBTAINED USING THE CALCULATOR

The performance of methane fermentation processes depends on different parameters of the process [9]. The biogas yield is dependent mostly on the type of resources used that are differentiated by the content of dry organic mass, biogas production efficiency, potential of biogas production and methane content in the biogas. Substrates from the same source may be characterized by different values of the above-mentioned parameters, e.g. in corn silage the content of dry mass may be from 20 to 30%, the dry organic mass from 85 to 95%, and the biogas yield may be from 50 to 55%. This makes the results obtained from the calculator purely informative as the program makes purely theoretical calculations and uses averaged values for the substrates' parameters. These will never accurately reflect the actual yields of a biogas plant.

In order to verify the correctness of calculations made by the applied calculator the data will be used generated from the calculator available at www.mae.com.pl. The same substrate data was entered into both calculators. Entered was the same input of 8000 t/year of cattle slurry and 10000 t/year of corn silage. The data generated by the designed calculator are presented in Fig. 4.

Figure 5 shows data generated by the calculator available at www.mae.com.pl.

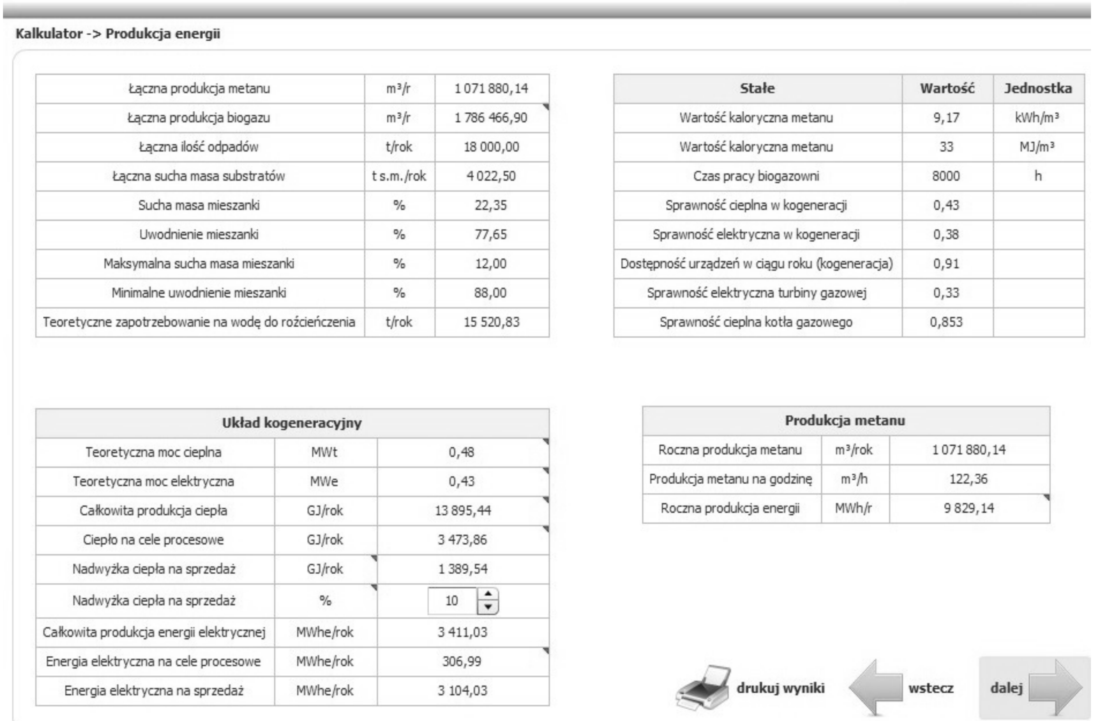

Kalkulator biogazu

Substrat	Roczny wsad substratu [t/r]	Roczna produkcja biogazu [m3/r]	Roczna produkcja metanu [m3/r]	Produkcja metanu na godzinę [m3]
Gnojowica bydlęca	8 000,00	208 810,00	125 286,00	15,66
Kiszonka z kukurydzy	10 000,00	1 423 125,00	747 153,00	93,39
Łącznie		1 631 935,00	872 439,00	109,05

Roczna produkcja energii [MWh/r]	Teoretyczna moc cieplna [kW]	Teoretyczna moc elektryczna [kW]	Produkcja ciepła brutto [GJ/r]	Zużycie ciepła na cele procesowe [GJ/r]
1 148,87	58,88	53,14	1 695,74	508,72
6 851,39	351,13	316,88	10 112,66	3 033,80
8 000,27	410,01	370,01	11 808,39	3 542,52

Zużycie ciepła na cele procesowe [GJ/r]	Produkcja ciepła netto [GJ/r]	Produkcja energii elektrycznej brutto [MWh/r]	Zużycie energii elektrycznej na cele procesowe [MWh/r]	Podukcja energii elektrycznej netto [MWh/r]
508,72	1 187,02	425,08	38,26	386,83
3 033,80	7 078,86	2 535,02	228,15	2 306,86
3 542,52	8 265,87	2 960,10	266,41	2 693,69

Fig. 4. Calculations using the designed biogas calculator [own elaboration]


Kalkulator -> Produkcja energii

Łączna produkcja metanu	m³/r	1 071 880,14
Łączna produkcja biogazu	m³/r	1 786 466,90
Łączna ilość odpadów	t/rok	18 000,00
Łączna sucha masa substratów	t s.m./rok	4 022,50
Sucha masa mieszanki	%	22,35
Uwodnienie mieszanki	%	77,65
Maksymalna sucha masa mieszanki	%	12,00
Minimalne uwodnienie mieszanki	%	88,00
Teoretyczne zapotrzebowanie na wodę do rozcieńczenia	t/rok	15 520,83

Stałe	Wartość	Jednostka
Wartość kaloryczna metanu	9,17	kWh/m³
Wartość kaloryczna metanu	33	MJ/m³
Czas pracy biogazowni	8000	h
Sprawność cieplna w kogeneracji	0,43	
Sprawność elektryczna w kogeneracji	0,38	
Dostępność urządzeń w ciągu roku (kogeneracja)	0,91	
Sprawność elektryczna turbiny gazowej	0,33	
Sprawność cieplna kotła gazowego	0,853	

Układ kogeneracyjny		
Teoretyczna moc cieplna	MWt	0,48
Teoretyczna moc elektryczna	MWe	0,43
Całkowita produkcja ciepła	GJ/rok	13 895,44
Ciepło na cele procesowe	GJ/rok	3 473,86
Nadwyżka ciepła na sprzedaż	GJ/rok	1 389,54
Nadwyżka ciepła na sprzedaż	%	10
Całkowita produkcja energii elektrycznej	MWhe/rok	3 411,03
Energia elektryczna na cele procesowe	MWhe/rok	306,99
Energia elektryczna na sprzedaż	MWhe/rok	3 104,03

Produkcja metanu		
Roczna produkcja metanu	m³/rok	1 071 880,14
Produkcja metanu na godzinę	m³/h	122,36
Roczna produkcja energii	MWh/r	9 829,14

drukuj wyniki wstecz dalej

Fig. 5. Data generated by the calculator available at www.mae.com.pl

The next step presents the data calculated by the compared calculators (Tab. 3).

Table 3. Comparison of calculations made by the two compared calculators [own elaboration]

Parameter	Unit	Value	
Annual input	[t/year]	– Cattle slurry 8000 – Corn silage 10000	
Calculator used		Calculator designed	Internet calculator
Total annual biogas production	[m³/year]	1631935	1786466,90
Total annual methane production	[m³/year]	872439	1071880,14
Hourly methane production	[m³]	109,05	122,36
Annual working time	[h]	8000	8000
Annual energy production	[MWh/y]	8000,27	9829,14
Theoretical thermal power	[MW]	0,41	0,48
Theoretical electric power	[MW]	0,37	0,43
Gross heat production	[GJ/year]	11808,39	13 895.44

Parameter	Unit	Value	
Annual input	[t/year]	– Cattle slurry 8000 – Corn silage 10000	
Calculator used		Calculator designed	Internet calculator
Use of heat for process	[GJ/year]	3542,52	3473,86
Net heat production	[GJ/year]	8265,87	10421,58
Gross electric energy production	[MWh/y]	2960,10	3411,03
Use of energy for process	[MWh/y]	266,41	306,99
Net electric energy production	[MWh/y]	2693,69	3104,04

The data comparison shows that the calculations made by the designed calculator showed values at similar level. The calculated values for production of biogas, methane and energy yields may be considered very similar for both calculators. Small differences in calculated values of biogas production may be due to qualitative assessment of raw materials' parameters used by the calculators. Difference in energy yield is due to differences in efficiency of the assumed generators and different factors for individual usage of electric energy and heat for processing needs.

CONCLUSIONS

The designed calculator performs its calculations in a correct way. The generated data may aid the investor in forecasting the amount of biogas that can be produced from the available substrates and the amount of electric and heat energy can be gained from the combustion of the said biogas. It should be taken into consideration that the data are of informational character. Before the commencement of the design stage of the facility, the parameters of the planned technology should be analyzed and the substrate should be tested for the possible biogas yield and its calorific value.

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PROJEKTOWANIE ZBIORNIKA KOMORY BIOGAZOWEJ CZ. 1.: KALKULATOR BIOGAZU NARZĘDZIE UMOŻLIWIAJĄCE PRZEPROWADZENIE OBLICZEŃ ENERGETYCZNYCH BIOGAZOWNI

Streszczenie. Opisano zaprojektowany kalkulator biogazu. Przeanalizowano parametry substratów wykorzystywanych do produkcji biogazu oraz metodykę kalkulacji możliwej do pozyskania z nich energii elektrycznej i ciepła. Porównano wyniki kalkulacji uzyskane przez zaprojektowane narzędzie obliczeniowe z powszechnie dostępnymi kalkulatorami. Omówionoróżnice w uzyskanychwynikach.

Słowa kluczowe: biogaz, zbiornik,kalkulator, obliczenia energetyczne.