Case study

of biogas plants in Małopolska and Podkarpackie region

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1. The biogas installation of the Central Sewage Treatment Plant in Częstochowa (Cupiał and others 2003)

Since 1998, in the biogas installation of the Central Sewage Treatment Plant in Częstochowa there has been exploited a cogenerative source, producing electric energy and heat. The source consists of a gas internal-combustion engine driving an asynchronous generator as well as a set of two heat exchangers. This is a typical installation of combined power engineering CHP (Cogeneration Heat and Power), producing electric energy and heat at the source of gas fuel and at the place of requirement. (Fig. 1)

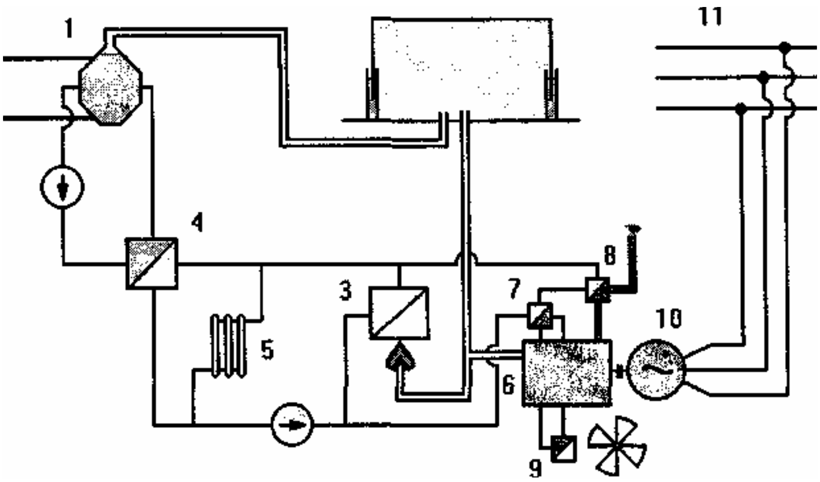

Fig. 1 Simplified scheme of implementing a thermal and electric power producing unit into a biogas thermoelectric installation of the CSTP in Częstochowa (Cupiał and others 2003): 1 - sealed fermentation chambers, 2 - an isobaric gas tank, 3 - a gas boiler room, 4 - heat exchangers: technological water - sludge, 5 - building central heating, 6 - a gas engine of the generator set, 7 - a heat exchanger: cooling liquid - technological water, 8 -a heat exchanger: exhaust gas - technological water, 9 - a back - up external cooler, 10 - an asynchronous generator, 11 - 6,3 kV electric network

The heat is delivered to the existing local heating network. Produced energy to a great degree meets the plant energy requirements. Methane fermentation with biogas production is carried out in three sealed fermentation chambers, then the biogas is sent to an isobaric gas tank with an approximate capacity of 3000 m².From the tank, the biogas is delivered through the gas network of the treatment plant to a boiler house with 3 double - fuel boilers (biogas or fuel oil) or to a biogas thermoelectric power unit. Collected gas is used mainly for heating fermentation sediment in five spiral heat exchangers (technological water - fermentation sediment) to the temperature of 35-37°C, necessary for correct conducting of the mesophilic fermentation.

In the Polish climate conditions in winter, the biogas production is sufficient only for heating the fermentation chambers. During spring - summer - autumn period there is surplus of biogas, which can be successfully used as fuel for supplying a biogas heat and power producing unit

The sewage treatment plant in Częstochowa handles about 75 000 m^3 of sewage daily, processes approximately 370 m^3 of sludge and produces up to 7000 m^3 of biogas of calorific value of 22 $MJ/m^{3.}$. Comparison of utilizing biogas in the sewage treatment plant in Częstochowa has been presented in the table 1.

Table 1 Comparison of utilizing biogas in the sewage treatment plant in Częstochowa (Cupiał and others 2003)

Intended use of biogas	Biogas consumption, [m^3]	Percentage, %
Boiler house- heat	1 122 805	72,5
Power unit - electric energy	426912	27,5
In total	1 549717	100,0

In the sewage treatment plant in Częstochowa, there is a great demand for heat as technological heat and for heating the plant buildings, and only less than 30% of biogas is a surplus, which can be used for producing electric energy and heat in a cogeneration unit with a biogas engine. It ensures producing about 10% of energy, bought during a year by the plant in the Electricity Board.

Reduction of the plant demand for technological heat can be achieved mainly by improving insulation of the fermentation chambers. In the conditions of the sewage treatment plant in Częstochowa, the biogas power producing unit with a 8A20G engine is used only at times of biogas surplus in the plant; it is from April to November. At that time, the unit can be used in a cycle up to 14 hours per day, in total of about 2000 hours with an average electrical power of about 500 kW.

The engine reaches the power level of 650 kW and maximum efficiency of 36,1 %, which corresponds to useful work per unit of 1,26 MJ/m^3 and biogas consumption per unit of 0,4 m^3/kWh. Active electric power amounts to 600 kW. The system of heat exchangers: water - water and exhaust gas - water allows to recover and transmit to the plant heating system about 260 kW of heat from the engine cooling system and about 320 kW from the exhaust system, under electric load of 600 kW. The work of the biogas thermo-electric power system is controlled by a measuring and control systems and by automatic systems of security, cutting of the gas flow and stopping the engine. The engine exhaust gases meet the TA-Luft regulations.

On the basis of experience from 2000 - 2002, it can be stated that available biogas surplus enables using the power producing unit at least 2000 h a year. This time can be considerably increased by reducing heat consumption of the treatment plant, for example by lowering minimal temperature of the sediments in the fermentation chambers to 32°C and through improving heat insulation or through increasing efficiency of the technological water - fermentation sediments heat exchangers .

Quantity and value of produced electric energy as well as the profits of Częstochowa sewage treatment plant in the years 1998 - 2002 from exploitation of the power producing unit with biogas engine have been presented in the table 2.

Table 2 Selected dates concerning exploitation of the power producing unit in the years 1998 - 2002 in the sewage treatment plant in Częstochowa (Cupiał and others, 2003)

Year	Time of work of the power producing unit [h]	Produced electric energy [MWh]	Value of produced electric energy PLN	Profits PLN*
1998	923,77	464,445	71 229,15	46 298,95
1999	795,35	371,304	67958,10	44 172,76
2000	1992,10	882,504	185446,68	120 540,34
2001	1783,90	884,295	203 695,47	132 402,06
2002	1527,00	724,194	183 863,88	110318,33
In total	7093,00	3326,742	712 193,28	453 732,44

* the Częstochowa sewage treatment plant profits after deducting costs exploiting the power producing unit

Assuming similar time of work of the power producing unit in the years 2001 - 2002 as in the year 2000, i. e. 1922 hours and average annual value of electric energy produced per one hour; between 2001 and 2002, total loss can be estimated as more than 63 000 PLN.

The hitherto positive results of an 8A20G biogas engine use, driving electricity producing unit, show that the engine is reliable, cheap in exploitation and doesn't cause any difficulties in use. The used cogeneration unit generates electric energy satisfying part of the sewage treatment plant own needs, exceeding efficiency of the unit. The rest of the energy is bought in the Electricity Board.

Comparison of selected power generating sets, manufactured in Zakłady Mechaniczne PZL-Wola S.A (Mechanical Works “PZL-Wola”) as well as the location of their installations has been presented in table 3.

Table 3. Comparison of selected gas power generating units, manufactured in Zakłady Mechaniczne PZL-Wola S.A

set power	type of fuel	location of exploitation
200 kW sets (3 items)	landfill gas	Bydgoszcz
160 kW set	landfill gas	Grudziądz
200 kW sets (2 items)	biogas from sewage treatment	Olsztyn
200 kW set	biogas from sugar-refinery	Borowiczki, Płock
100 kW set	landfill gas	Koszalin
200 kW sets (2 items)	landfill gas	Poznań
200 kW set with a heat unit	biogas from sewage treatment	Siedlce
200 kW sets (2 items)	biogas from sewage treatment	Opole
160 kW sets (2 items) with a heat unit	biogas from sewage treatment	Inowrocław
200 kW sets (2 items) with a heat unit	biogas from sewage treatment	Elbląg
200 kW sets (2 items)	landfill gas	Gdańsk-Szadułki
100 kW set with heat a unit	landfill gas	Słupsk
160 kW sets (2 items) with a heat unit	biogas from sewage treatment	Puławy
200 kW set with a heat unit	biogas from sewage treatment	Sokołów Podlaski
160 kW set with a heat unit	biogas from sewage treatment	Biała Podlaska
200 kW set with a heat unit	biogas from sewage treatment	Siedlce
170 kW container sets (2 items), suitable for building in of a heat unit	landfill gas	Bełchatów
180 kW container set, suitable for building in of a heat unit	landfill gas	Krośniewice
180 kW set with a heat unit	biogas from sewage treatment	Radzionków, Bytom

2. Biogas obtained in the Żywiec Sewage Treatment Plant

The basic objective of the Żywiec Sewage Treatment Plant is protecting waters of Żywieckie lake. The plant handles sewage from the special area of conservation - the Żywiec Landscape Park. This is a bio-mechanical sewage treatment plant. Biotreatment is carried with using the activated sludge method.

Inherent product in sewage treatment process is sludge. Sludge treatment in the plant is done in two - stage fermentation in separate fermentation chambers. Final product is sediment used as fertilizer in agriculture or as compost. Biogas, obtained in the process of mesophilic fermentation process, is stored in a gas tank and serves as a fuel for the installed cogeneration unit

The consumption of energy agents and the biogas production for the period of one year, from 15.01.2002 to 15.01.2003, have been presented (Skrzypczak 2003). Electric energy is necessary for powering technological equipment, the compound lightening, production, the administrative and auxiliary premises lightening as well as the office equipment and for heating water for communal purposes.

Annual electric energy consumption amounts to 2 807 045 kWh and average annual power consumption to 320 kW (Skrzypczak 2003).

Thermal energy is needed for warming up the sludge in fermentation chambers, warming water in the biogas tank as well as heating the plant buildings (Skrzypczak 2003).

Annual heat consumption amounts to l 253 500 kWh (4512,6 GJ), including:

- heat for technological purposes: 860 833 kWh (3099,0 GJ),
- heat for central heating: 392 666 kWh (1413,6 G J).

Thermal power consumption for the technological heat requirements: 98,3 kW

The biogas production:

- annual 406 071 m^3,
- average daily production: 1112 m^3 per day
- average hourly production: 46,4 m^3/h.

The biogas parameters (at the desulphurization reactor entry) are following:

- the average biogas composition : CH_4, 66,01%, CO_2 - 32,38%, N_2 -1,17%, O_2 - 0,44%,
- the biogas pressure: 17 mbar,
- the heating value: 21,8 MJ/m^3 (6,05 kWh/m^3),
- hydrogen sulphide content (after sulphur compounds removal process): 0,00 g/100 m^3.

When selecting type and size of a cogeneration unit, it was assumed, that the fuel (biogas) meets requirements set by the engine producer, hourly biogas consumption by the engine slightly exceeds hourly biogas production (eliminating possibility of creating surplus of biogas and necessity of burning it in a torch), the unit electric power is lower than minimal power consumed by the plan equipment (avoiding necessity for selling electric energy surplus to the Electricity Board), the unit construction allows for it fitting into the existing boiler room, the unit work cannot cause increase in payroll costs. Moreover, what is even more important, that the price and exploitation costs ensure commercial profitability of the investment.

On the basis of these criteria BHKW Vitobloc FG 114 module, manufactured by Viessmann com. with electrical output of 114 kW and thermal output of 186 kW, has been selected. Thermo - electric module BHKW Vitobloc FG 114 is equipped with MAN E2876 TE engine, a synchronic generator, a cooling water heat exchanger and an exhaust gas heat exchanger. The gas consumption at CV = 6,5 kW/Nm^3 is 51,5Nm^3/h.

The selected cogeneration unit meets all above criteria except biogas pressure; the required minimal biogas pressure is 20 mbar, whereas the supply pressure amounts to 15-17 mbar. In order to increase the pressure to required level, a ventilation blower has been used.

Additionally, making assumption, that the unit work is continuous, required solving a problem of disposal of thermal energy surplus. Thermal power accepted by the technological heat exchanger warming the solids is 98,3 kW, and the unit thermal output is 186 kW. Due to significant additional costs the idea of buying an emergency cooler has been abandoned. Instead of it, the possibility of disposing heat surplus during summertime into wastewater through the heat exchanger, being a part of the system of the lower heat source of heat pumps, has been used.

During the heating season, priority at the unit work is ensuring warming solids to the required temperature (of about 36°C) as well as water in the gas tank. In case when the solids temperature is higher than the set value, a regulating valve of the heat exchanger is opened and a heat surplus is directed to the central heating network leading to the heat pumps station. During summer time, there is a constant heat surplus, produced by the cogeneration unit. In case when total power of the cogeneration unit and the heat pumps is insufficient, the top oil boiler is switched on. The heat transmitted via network water to the heat pumps station is disposed of to wastewater through a shell and tube heat exchanger, which during heating season is an exchanger mediating in heat reception by heat pumps (the lower heat source). The work of the cogeneration unit, producing electric energy and using biogas, leads to reduction in purchase of electric energy from traditional coal using thermal-electric power stations. At the production of 734 130 kWh, annual emission reduction has been presented in the table 4.

Table 4. Reduction of pollution emission (Skrzypczak 2003)

Emission type	Specific emission limits, , kg/MWh	Annual emission limits kg/year
Sulphur dioxide SO_2	7,8	5726,14
mono-nitrogen oxides NO_x	3,2	2349,22
Carbon monoxide CO	0,2	146,83
Carbon dioxide $C0_2$	937	678 879,81
dust	1,1	807,54

Deciding factor in investment success is optimization of a unit size selection and a unit work optimisation.

A unit should be selected to ensure complete use of produced biogas and it should have the longest possible working time. When selecting an equipment of a certain type and a producer, the most important criteria is not only the cost of purchasing a unit but the costs of repairs after 20 000 and 40 000 hours of use. Successful implementations will surely encourage potential investors to use "small co-generation"

3. "Barycz" community landfill in Krakow

A good example of utilizing energy contained in biogas is a degassing installation at the "Barycz" community landfill in Krakow. In the recultivated part of the landfill there have been built forty seven degassing wells, 5 to 21 meters deep and made from 110 mm diameter perforated pipes equipped with DN 100 mm heads. In the active part of the landfill there have been drilled 21 degassing wells, 17 meters deep and made from 100 mm diameter perforated pipes. At present, 300 m^3/h of biogas is obtained from the landfill, which is used to produce electric energy transferred to the grid as well as heat used for the landfill back-up facilities needs. In the landfill site there are three container power units: two 250 kW power units and one bigger, 375 KW power unit. At the full operational load of all three units, 1279 kW of additional thermal energy is produced, both from exhaust gases and from cooling water of the engines driving the units. Total power of this system amounts to more then 2 MW. Energy produced in Barycz is mainly used for the plant own needs, which consume about 60 kW/h; A surplus is sold to the Electricity Board. Currently, the plant heat requirement, especially in winter period, amounts to between 60 and 100 kW.

Polish experiences with thermal and electric energy production justify using technological solutions of the newest generation. Reaching the most favourable parameters, such as energy efficiency, a cost of producing one unit of energy, continuity of power supply, is achieved through increasing complexity of a technological installation. Moreover, there is often the need of detailed research into local conditions so as to take full advantage of opportunities, but on the other hand not to use "overdimensed" installation, In Poland there is good access to machinery, equipment and installations with required work parameters in respect of biogas production and utilization; both of domestic production as well as from other countries.

4. Biogas obtained at the Tychy - Urbanowice Sewage Treatment Plant

Avoiding errors made at other real-life facilities is one of methods of implementing good practice. Let's not repeat someone else mistakes and ask for their advice and opinion. A biogas plant is always an individual investment. It is executed in stages. That is why the following example has been selected as a model.

In Tychy - Urbanowice, a biogas plant was built at the site of a sewage treatment plant. At a high degree of water content of the sludge and poorly functioning mixing of the batch volume, the biogas production was low and amounted to approximately 1500 m^3/24h. Small quantity of biogas and instability of the fermentation process caused that biogas hardly satisfied the requirements of the fermentation process. Biogas was produced in two sealed 2100 m^3 fermentation chambers and gathered in a one shared collector. Then, after dehydratation in the dehydrator, it was transmitted to desulphurization reactors. Desulphurization was carried out in cylindrical absorbers, 4 meters high and 2 meters in diameter, using morass ore. The technological system consisted of three parallelly connected absorbers. Contents of such desulphurization reactors should be controlled at least once a month, and spent iron oxide should be periodically removed and subjected to regeneration. The installation scheme in the initial version has been presented at fig. 2.

Only after introducing mechanical thickener, the biogas production in the fermenter has increased to approximately 2500 m^3/24h. Biogas was initially burnt in the boilers originally intended for coke firing, which after using blowpipes did not achieve high thermal efficiency. Obtained biogas was used to a small degree for producing thermal energy, which was then used for heating the fermentation chambers and the plant buildings.

The plant did not have any other option but to burn surplus gas in a torch. In the summertime, at lower demand for thermal energy, this problem was especially acute.

The composition of the biogas obtained at the Tychy- Urbanowice Sewage Treatment Plant (T. Bacza *Energetic utilization of biogas*)

CH_4 - 62,8 %

CO_2 - 35,2 %

The biogas heating value HV - 22,50 MJ/m^3

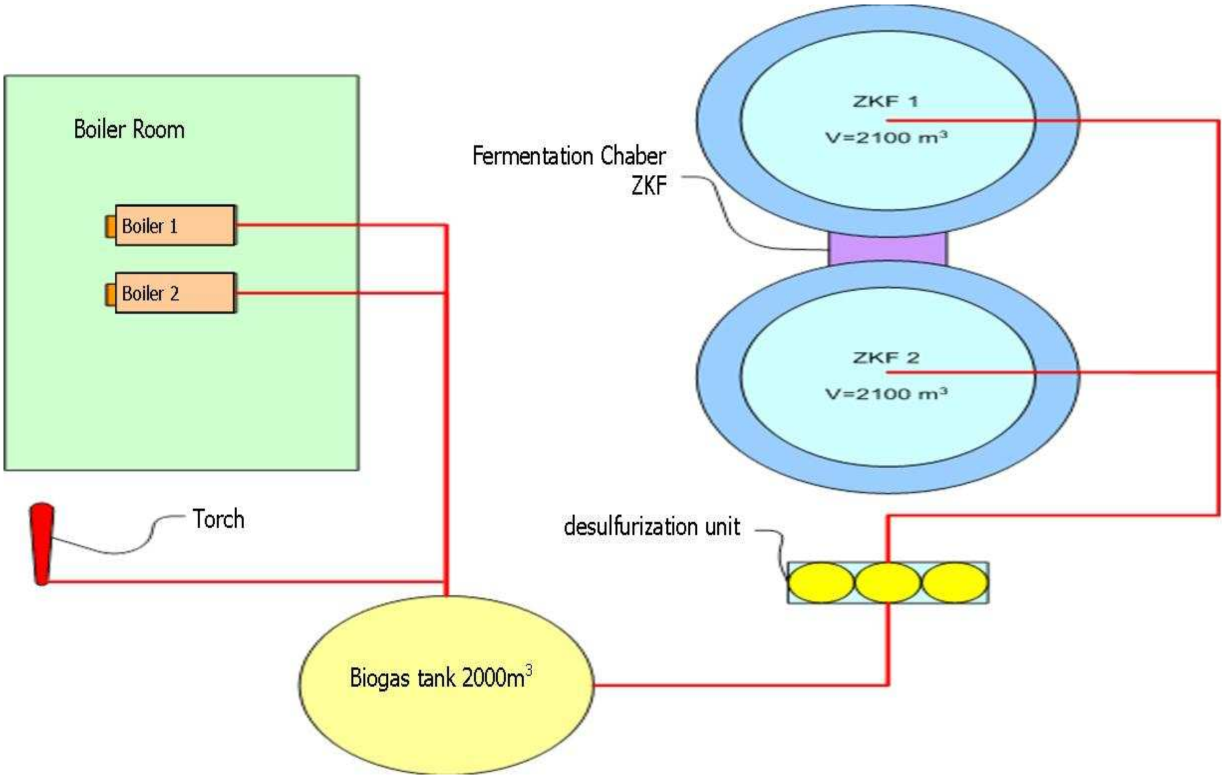

Fig. 2. The initial scheme of the biogas installation
(T. Bacza *Energetic utilization of biogas*)

After dehydration and desulphurization, biogas was transmitted to a flexible double - walled storage tank of capacity of 1720 m^3. In such a tank biogas storage takes place in the inner membrane. The biogas is then forced by the pressure, created by a ventilator pumping the air by into the space between inner and outer membrane, to flow from the inner membrane into biogas receiver tanks. The tank used was sufficient for storage of 6h production of biogas.

However, due to shortcomings listed above, several changes have been introduced. In order to improve organization of the venture and profitability of investment, a launch of biogas production at the neighbouring communal landfill was planned as well as joint utilization of biogas from the treatment plant and the communal landfill

The final version of the installation has been presented in the Fig. 3. According to the construction design, the value of work within the treatment plant, related to biogas utilization, amounted to 3 million PLN (2005).

Target biogas production, after building a new 6 000m^3 fermentation chamber in 2005, amounts to ~5500 m^3/24h. Moreover, modernized technology of Tychy - Urbanowice sewage treatment plant assumes using biogas for combined generation of thermal and electric energy. Before entering the engines, biogas is purified using a ceramic filter. The heat received from the engine cooling system and exhaust gas is transmitted to the stream of circulating water of the fermentation chambers heating system and to the plant central heating system. At the target production of 5500 m^3/24h, it is possible to produce approximately 500 kW of electric energy and 800 KW of thermal energy. Biogas is transmitted, under the pressure created in the gas tank, to the engines combined with electric energy generators. Total energy efficiency of biogas utilization amounts to 82-90%, where electric energy production share is about 35%. At the target biogas production of 5500 m^3/24h, it is possible to power approximately 500kW engine and produce about 800 KW of thermal power.

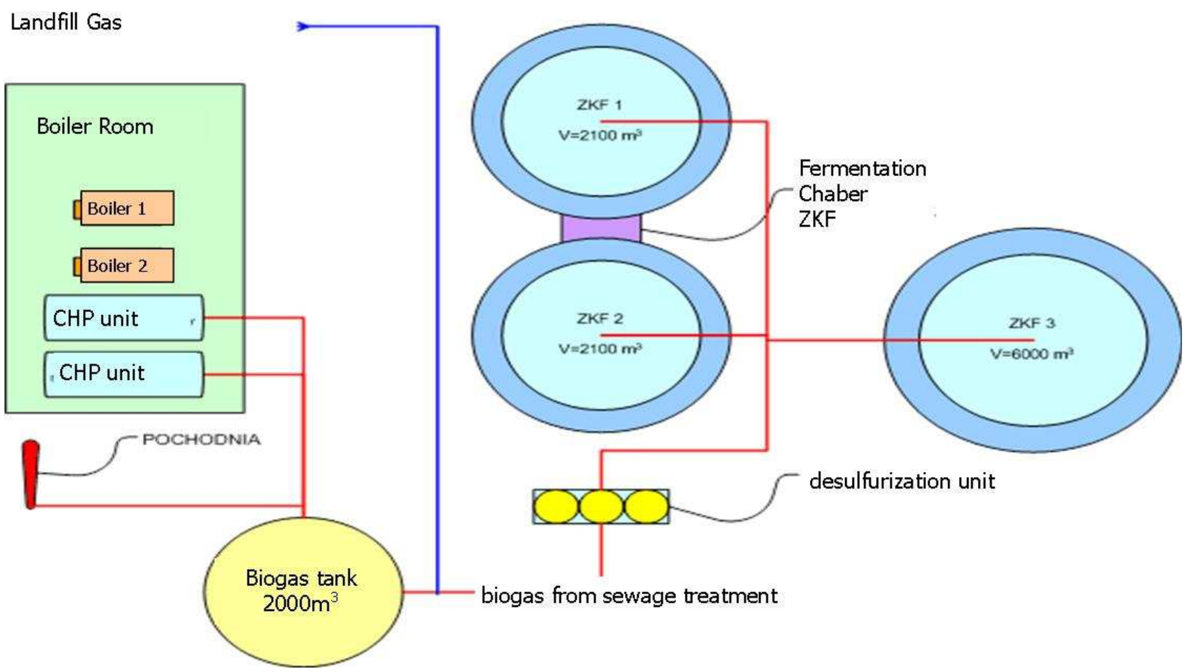

Fig. 3. The scheme of the final version of the biogas installation
(T. Bacza *Energetic utilization of biogas*)

The composition of the biogas obtained at the Tychy - Urbanowice Communal Landfill (T. Bacza *Energetic utilization of biogas*)

CH_4 - 54,0 %

CO_2 - 33,0 %

The biogas heating value HV - 19,8 MJ/m^3

Estimated investment outlays according to prices from 2004

In the biogas part:

– desulphurization - 220 thousands. PLN
– a biogas torch - 120 thousands. PLN
– a ceramic filter - 15 thousands. PLN

- equipment and accessories - 190 thousands. PLN

Electrical part:

- electrical supply lines - 110 thousands. PLN
- adjusting the main 20 kV station - 50 thousands. PLN
- thermo-electric unit (about 300 kW el + 500 kW the maximal use of 183 m^3/h) 2 items + accessories - 2200 thousands PLN.