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# Experience with the production of electricity from biogas at sewage treatment plant in the Czech Republic

***Abstract**. The paper deals with using biogas produced by sewage treatment plants for electricity production. Biogas is used for its uncomplicated burning and further conversion of the energy it carries into heat. Formerly, anaerobic sludge stabilization was considered necessary evil connected with sewage treatment with as much as 50% share on operating costs. Biogas burning in cogeneration units in sewage treatment plants means a significant opportunity for the water treatment companies.*

**Streszczenie.** *Artykuł zajmuje się wykorzystaniem biogazu produkowanego w oczyszczalni ścieków do produkcji energii elektrycznej. Biogaz jest wykorzystywany dzięki możliwości jego nieskomplikowanego spalania i dalszego przekształcania energii. Dawniej stabilizacja beztlenowa osadów była uznawana za konieczne zło związane z oczyszczaniem ścieków co zwiększało koszty o 50%. Dziś biogaz jest spalany w kogeneratorach w oczyszczalniach ścieków i oznacza wielką szansę dla firm wodociągowo-kanalizacyjnych. (**Doświadczenie z produkcją energii elektrycznej z biogazu w oczyszczalniach ścieków w republice Czeskiej**).*

**Keywords:** biogas, sewage treatment plant, biogas station, electricity, renewable source of energy
**Słowa kluczowe**: biogaz, oczyszczalnia ścieków, stacja biogazowa, energia elektryczna, odnawialne źródła energii

**Biogas**

Biogas and biogas systems are sources of electricity which are highly beneficial for environmental protection and development. Despite the fact that biogas systems are incapable of replacing fossil fuels yet which dominate the energy market, there are unlimited possibilities of their future use.

Biogas is a gas mixture of mainly methane and carbon dioxide (of which there is 25 - 40 %) and small amounts of other gases, such as hydrogen, nitrogen and sulphone. It develops in bacterial anaerobic decomposition of organic matter. This process is called anaerobic fermentation. The main holders of energy are methane and small amount of hydrogen; carbon dioxide and other gases are ballast.

It is a colourless mixture of mainly methane and small amount of hydrogen which are the main energy carriers. Other gases, such as nitrogen, ammonia and sulphone are only ballast. The heating value of biogas is between 18 and 25 MJ/m$^3$.

Anaerobic decomposition was discovered by an Italian physicist A. Volta who ran the first laboratory anaerobic fermentation in 1776. In the course of the 20th century anaerobic technologies were developed especially for anaerobic treatment of sewage sludge. The sewage treatment plant (STP) in Essen produced and supplied biogas to municipal gasworks as early as in 1922.

Biogas is used for production of electrical electricity, heat and gaseous biofuel. Mostly, biogas is burnt in cogeneration units at STPs to produce electricity and heat on site.

The data in Table 1 and 2 show a visible growth in biogas-based production of electricity and heat.

Within the statistics for the Ministry of Industry and Trade, all the entities using biogas technology are monitored. The energy produced in cogeneration units is recorded separately.

Table 1 Rough production of electricity using biogas [MWh]

| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|
| Biogas total | 107 856 | 138 793 | 160 858 | 175 839 | 215 223 | 266 868 | 441 267 | 634 662 | 928 715 |
| Sewage treatment plants | 55 810 | 65 592 | 74 316 | 69 732 | 74 157 | 78 052 | 82 807 | 89 973 | 95 202 |
| Biogas stations | 6 519 | 7 130 | 8 243 | 19 211 | 43 248 | 91 580 | 262 622 | 447 424 | 724 802 |
| Landfill gas | 45 527 | 66 071 | 78 299 | 86 896 | 97 818 | 97 236 | 95 838 | 97 265 | 108 711 |
| Renewables total | 1 878 960 | 2 742 932 | 3 133 325 | 3 518 883 | 3 412 097 | 3 731 013 | 4 654 969 | 5 903 156 | 7 245 651 |

Table 2 Rough production of heat using biogas [GJ]

| | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|
| Biogas total | 780 639 | 968 452 | 1 009 902 | 918 511 | 1 009 221 | 1 065 390 | 1 210 969 | 1 610 361 | 1 910 636 |
| Sewage treatment plants | 633 583 | 797 328 | 851 540 | 760 047 | 749 055 | 752 484 | 736 819 | 777 489 | 817 340 |
| Biogas stations | 57 324 | 67 553 | 67 223 | 80 270 | 167 776 | 226 452 | 397 616 | 752 400 | 1 015 821 |
| Landfill gas | 89 732 | 103 572 | 91 140 | 78 193 | 92 390 | 86 454 | 76 534 | 80 473 | 77 474 |
| Renewables total | 39 059 434 | 44 351 757 | 45 397 225 | 46 301 315 | 50 562 917 | 48 777 184 | 48 714 951 | 53 235 131 | 53 023 795 |

Also, biogas from STPs, farm-based biogas stations and landfill gas are differentiated. However, the numbers in statistics are lower than the actual ones, as not all the entities using biogas are licensed and supply electricity to the grid. More and more biogas plants are built and the growth is so dynamic it has exceeded the use of landfill gas which dominated several years ago.

Compared to other renewables, plants using biogas for electricity production have the most favourable efficiency of installed output utilization.

Table 3 Efficiency of utilization of installed output - renewables

| Renewable type | Average time of yearly utilization of installed output (h/year) | Average time of yearly utilization of installed output (%) |
|---|---|---|
| Wind electricity plants | 2 100 | 24 |
| Small hydroelectricity plants | 4 000 | 46 |
| Biomass plants | 5 000 | 57 |
| Biogas plants | 7 500 | 86 |
| Geothermal plants | 5 700 | 65 |
| Photovoltaic plants | 980 | 11 |

**Production of Biogas in Sewage Treatment Plants – the Czech Republic**

The first biogas stations were built in big agricultural plants and in STPs for anaerobic stabilization of sewage sludge. The first STPs with anaerobic stabilization of sewage sludge were built in the CR as early as in the 1960's. Today this technology is used in every plant with over 50 000 ER (equivalent residents). Sewage is treated mechanically in primary treatment and biologically in secondary treatment. Raw water is pretreated and pumped into the primary clarifiers where primary sludge can settle. The primary sludge plus the residual active sludge form the raw sludge which is processed in methanation. The sludge is pumped into pre-heated methanation chambers where it is processed in anaerobic digestion and biogas is produced and collected in gasholders.

Treatment of sewage sludge is becoming a critical issue for sewage treatment as the yearly production of sewage sludge in the CR is approx. 184,000 tons. The sludge represents approx. 2 % of total amount of sewage but concentrates as much as 80% of original pollution.

Biogas in STPs is used in cogeneration whereby electricity and heat are produced. The heat is used for heating and the electricity is used to support energy demanding technologies in the STPs on site. Total efficiency in conversion of biogas energy is about 86 % (36% electricity a 50% heat). Differences can be found concerning different producers.

The electricity range of cogeneration units is from hundreds of kW to units of MW. Maintenance and repair costs decrease and electricity efficiency of a cogeneration unit increase with increasing electricity. On the contrary, total efficiency (sum of electricity and heat efficiency) stays more or less constant. Hence, it is more convenient to use only one unit running on full output, which is the most common solution of using biogas in cogeneration units. The lifespan of the cogeneration engine is within 6-8 years of uninterrupted operation, but it is affected by the number of startups.

Formerly, anaerobic sludge stabilization was considered necessary evil connected with sewage treatment with as much as 50% share on operating costs. Produced biogas was used to heat the chambers and buildings on site. However, after the purchase prices were increased, such activities have become much more advantageous.

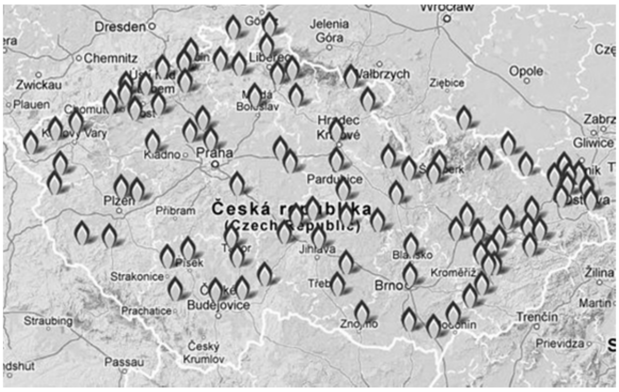


Fig 1 Localization of sewage treatment plants with anaerobic stabilization of sludge

*Table 4 Electricity production using biogas in sewage treatment plants in 2003 - 2011*

| | Number of facilities producing electricity | Installed electricity output [kW] | Electricity production [MWh] | Self-consumption including losses [MWh] | Supply to grid [MWh] |
|---|---|---|---|---|---|
| 2003 | 53 | 14 184 | 55 810 | 49 157 | 6 653 |
| 2004 | 69 | 16 989 | 65 592 | 49 885 | 15 707 |
| 2005 | 72 | 17 389 | 74 316 | 58 956 | 15 360 |
| 2006 | 72 | 17 156 | 69 731 | 53 198 | 16 233 |
| 2007 | 76 | 17 306 | 74 157 | 58 842 | 15 315 |
| 2008 | 81 | 18 236 | 78 053 | 62 489 | 15 564 |
| 2009 | 83 | 19 031 | 82 807 | 67 914 | 15 564 |
| 2010 | 85 | 19 116 | 89 973 | 73 297 | 16 676 |
| 2011 | 92 | 19 934 | 95 202 | 78 769 | 16 433 |

Table. 5 Heat production using biogas in sewage treatment plants in 2003 - 2011

| | Number of facilities producing electricity | Installed heat output [kW] | Heat production [GJ] | Self-consumption including losses [GJ] | Direct supply [GJ] |
|---|---|---|---|---|---|
| 2003 | 168 | 136 967 | 633 583 | 630 787 | 2 796 |
| 2004 | 206 | 160 638 | 797 328 | 793 758 | 3 569 |
| 2005 | 222 | 156 568 | 851 540 | 847 261 | 4 279 |
| 2006 | 208 | 154 885 | 760 047 | 757 669 | 2 377 |
| 2007 | 207 | 120 121 | 749 055 | 745 063 | 3 992 |
| 2008 | 214 | 98 865 | 752 484 | 748 484 | 4 000 |
| 2009 | 228 | 100 217 | 736 818 | 721 321 | 15 497 |
| 2010 | 227 | 101 347 | 777 488 | 762 611 | 14 877 |
| 2011 | 246 | 98 105 | 817 340 | 813 796 | 3 544 |

Today approximately 15% of total amount of biogas used for energy purposes is produced in municipal STPs with anaerobic stabilization of sludge (Fig.1). According to the statistics of the Ministry of Industry and Trade, 92.2 GWh of electrical electricity were produced in such a way. However, the aerobic sewage treatment consumes a lot of electrical electricity and so the proportion of electricity self-consumption is around 80%. Also, much of heat produced in STPs is used for heating fermentation chambers. When gasholders are filled, residual biogas can be burnt off on gas burners.

Table 4. and 5. show production of electricity and heat using biogas in STPs in the CR in 2003 – 2011.

Output of big sources where other fuel (natural gas) is burnt together with biogas is not counted in the statistics since 2008. Clearly, the numbers are low. The production of electrical electricity using biogas is not essential for the grid operators, yet it is critical for the operators/owners of STPs, especially because of the financial aid of electricity produced by renewable energy sources. Moreover, in terms of energy consumption, leftover materials are used effectively to provide some degree of self-reliance to the STPs and help to promote environmentally sustainable development.

Most STPs have optimized the process of biogas use since the 'Energy Act' – the act on government support of electrical electricity from renewables – was approved.

From the latest point of view of electricity consumption, many STPs are not operated in optimum energy mode. There are several ways to improve their electricity consumption: optimisation of electricity consumption of electrical appliances (pumps, blowers, etc.), enhancement of technology, using heat energy for heating buildings with help of heat pumps, drying of sludge, or increasing biogas production.

The combined generation of electricity and heat using biogas in the CR is supported by fixed purchase prices and green bonuses by the Act no. 165/2012 Coll.

These fixed purchase prices and green bonuses for biogas production show a rising trend. The biogas stations were up to 2008 differentiated according to the date of putting into operation. From 2009 they are sorted in two categories depending on the type of biomass used. In contrast, the plants using landfill and sludge gases were united into one category and then divided according to the date of putting into operation.

The fixed purchase price and green bonuses stay basically the same, see Tab. 6.

Table 6 Fixed purchase prices and yearly green bonuses for electricity – landfill and sludge gases

| The start of facility operation | | Purchase price [EUR/MWh] | Green bonuses [EUR/MWh] |
|---|---|---|---|
| 1. 1. 2004 | 31. 12. 2005 | 115 | 76 |
| 1. 1. 2006 | 31. 12. 2012 | 102 | 63 |
| 1. 1. 2013 | 31. 12. 2013 | 73 | 35 |

The new Act. No. 165/2012 Coll. on supported energy sources and amendments modifies the way in which financial support on electricity of secondary sources is paid. So far all support, fixed purchase price or green bonus, was paid by the regional distribution grid operator. Now the electricity traders are responsible for purchasing electricity and the system of billing and paying off support is more complicated. A new subject enters the financial transactions and information flows – a market operator.

The law in energetics stated that every biogas station (BGS) operator must be registered for this particular market. Each registered participant then has the opportunity to participate in the equalizing market and offer its control capacity within short-term electric power trading transactions. Those are simple transactions between producers and the power grid operator. As it is mostly negative control energy, this is a good opportunity for BGS. The disadvantage of overall shut-down is mainly the increased heat load on certain parts resulting in substantial reduction of their service life. It is therefore better to reduce the output to approximately 30 % of the installed output. Even though the minimum output is not limited, the BGS would be more convenient when connected into a virtual block with higher output.

**Co-generation unit**

The co-generation units currently used within biogas stations are mostly represented by diesel combustions engines modified for biogas combustion purposes. This modification lies in replacement of the fuel system. There are two methods of fuel ignition used, with adding of diesel into fuel to ensure its ignition upon achievement of certain compression and resultant heat-up of fuel to the ignition point. The disadvantage of this system is large consumption of diesel during higher performance operation, when the diesel content might exceed 10 % of the fuel volume. Another option deals with fitting a glow plug in the motor associated with certain technical problems as these motors are not designed for such solutions.

BGS can actually use three different storage types:

*Storage of produced biogas* is dependent on capacity of the gas container; the existing stations are designed for shot downtimes only (approx. 6 hours) with subsequent forced combustion of the produced gas by means of safety burner. Construction modifications are basically very simple, when the existing fermenter is just extended by a few meters to enlarge the gas container space. There is no need to build up any further areas and that prevents consequence negative impact on the living environment. Biogas in storage can be then used in times of increased demand for electric power or heat. However, the output of CHPU has to be increased to an extent adequate to the size of gas container.

*Heat energy* can be accumulated in the linked heat distribution network that is able to store great volume of heat. This concept can make use of certain momentum, when the stored energy will be utilised during periods of high consumption of hot water. Another option is to use a storage tank. The storage tank may be of non-pressure design that is simpler yet requires a large space or any pressure tank with the ability to store the same amount of energy within a smaller space. The stored energy can be used for heating within premises of the BGS. Both options for heat storage can be mutually combined.

*Storage of electric* can be achieved using all the classic storage technologies available. The most common elements are lead batteries disadvantaged by the fairly low density of stored energy, so these require large space and are fairly heavy. Another option would be using the more expensive batteries of NaS type with 10-times higher energy density per unit of weight compared to lead batteries. Those are approximately three times smaller and excellent short-term overload capacity.

Another option for storage is to connect a specific BGS into the electric power grid as a peak power supply to balance grid fluctuations especially at the low voltage level at the end of grid, where these are mostly installed. That prevents additional losses in transfer from large centralised supply units. However, they are disadvantaged by the relatively low output of several hundreds of kilowatts or a few megawatts at maximum.

One of the options to utilise controlled BGS is to connect it on the same line as a non-controlled, stochastic power supply, e.g. photovoltaic or wind power plant. The BGS serves as a compensation supply in this case and it produces electric power and heat during periods of reduced supply from the primary source only. The specific area would then experience reduction of peak output and achievement of better production stability. As far as their control is concerned, both supply units would have to cooperate together and the BGS would require a larger gas container. For up to half a day production of biogas and with double output motor. It is more convenient rather for collaboration with a photovoltaic power plant that ensures better operation stability compared to wind power plants, which might incur several days of downtime period due to zero wind.

## Conclusion

As per the European directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, the Czech Republic is obliged to achieve the overall objectives stipulated for the year 2020. These mandatory national targets endorse a 13% share of energy from renewable sources on the final energy consumption by 2020. The share of renewables on primary energy sources was 7% in 2011.

Biogas is used for its uncomplicated burning and further conversion of the energy it carries into heat. It can be used as a fuel for combustion engine to generate mechanical energy which can be converted to electricity and heat via generator. Biogas is also tested for electricity generation in fuel cells. Moreover, it has a great potential for transportation. Biomethane, which is acquired after removing $CO_2$ from biogas, is identical with natural gas and it can be used to fuel CNG vehicles. However, there are no stations that can purify biogas to biomethane in the CR.

Today, the Czech Republic is one of top ten producers of biogas is Europe. There are 495 biogas stations of total installed output 244.46 MW. The total yearly production of electricity in 2011 was 928.7 MWh. All biogas produced in the CR is used on site for combined generation of electricity and heat. The biogas share on renewables has reached the value of 13%.

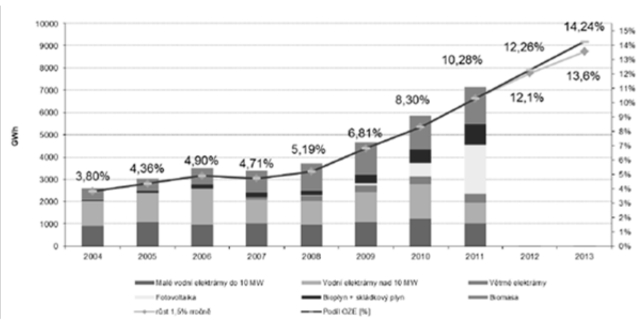


Fig. 2 Expected development of power production from renewables and its share on gross domestic consumption

The expenses on promoting the renewables are going to increase in 2013. In the long term supported prices for power distribution are going to rise as well. At the same time the government has decreased the support from the state budget which decreases the effect of renewables support on electricity costs. The current renewables support is costly being the inheritance of the past and burdens domestic industry. Now consumers contribute 16 EUR from every paid megawatthour to support renewables. Without the state financial support the contribution would be 26 EUR. The government decided to increase the contribution to about 23 EUR/MWh for the next year.

In 2013 and the following years a decline in building not only biogas but all the renewable energy sources is expected. It is due to the fact that the objectives of the National Action Plan will be reached in the following years. It is probable that the power fixed purchase price will be reduced, or even that the ERÚ (Energy Regulatory Office) will cease the support for the newly built plants of renewable energy sources by 2014. The expected development of power production from the renewables and its share on the gross domestic consumption is shown in Fig.2

Biogas burning in cogeneration units in sewage treatment plants means a significant opportunity for the water treatment companies. Biogas, a by-product of sludge disposal, is used for combined generation of electricity and heat. This will lead to diversification of resources for energy consumption in sewage treatment plants.

The planned return on investment of biogas systems is expected to drop sharply from 2014. However, biogas as a renewable source of energy will help to promote positive environmental awareness of sewage treatment plants in the CR.

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