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Biogas as engine fuel

The article presents the current state and prospects for development of biogas in Poland. It presents the potential for biogas production in Poland from agricultural biogas plants, biogas recovery in landfills and biogas recovery plant at the sewage treatment plants. The potential of biogas production in Sweden is described as well. The status and prospects for development of biogas in Poland in relation to the Swedish experience were presented. The results of ecological studies on the use of biogas (biomethane) to power city buses engines were identified.

Key words: *biogas, agricultural biogas plant*

Biogaz jako paliwo silnikowe

W artykule przedstawiono stan aktualny i perspektywy rozwoju biogazu w Polsce, a także potencjał produkcji biogazu w Polsce z biogazowni rolniczych, instalacji odzysku biogazu przy wysypiskach odpadów oraz z instalacji odzysku biogazu przy oczyszczalniach ścieków. Określono również potencjał produkcyjny biogazu w Szwecji. Zaprezentowano stan i perspektywy rozwoju biogazu w Polsce w odniesieniu do szwedzkich doświadczeń. Przedstawiono wyniki badań ekologicznych nad zastosowaniem biogazu (biometanu) do zasilania silników autobusów miejskich.

Słowa kluczowe: *biogaz, biogazownia rolnicza*

1. Introduction

According to Directive 2003/30/EC [1] of the European Parliament and of the Council biogas is "a fuel gas produced from biomass and/or from the biodegradable fraction of waste, that can be purified to natural gas quality, to be used as biofuel, or wood gas". Feedstock for biogas production is mostly derived from agricultural, municipal and industry wastes.

Biogas can be produced by the anaerobic digestion (AD) of a range of organic wastes, with the key wastes being [2, 3]:
- sewage sludge,
- wet manure slurries from intensive styles of agriculture,
- dry manures from animal beddings, known as farm yard manure (FYM),
- waste from food processing,
- food and organic waste from restaurants and other commercial operations,
- household kitchen and garden wastes.

Biogas can also be produced by thermal gasification, which is a process where the biomass or organic waste is heated under limited amounts of oxygen. The heat decomposes the organic material and gases as carbon dioxide, hydrogen, stream, carbon monoxide and methane are produced. Biogas produced this way is called SNG, Synthetic Natural Gas [2]. Table 1 presents for instance average composition of landfill biogas in comparison for average composition of natural gas [4].

Biogas upgrading technologies are enabled for cleaning and removing: water, hydrogen sulfide, oxygen, nitrogen, ammonia, siloxanes, particles; increasing energy content by removing carbon dioxide; conditioning for distribution e.g.: odorization, compression [4].

Biogas upgrading technologies are presently following: water scrubbing, PSA (*Pressure Swing Adsorption*), chemical absorption, membrane and cryogenic [4]. In result of these processes emerge biomethane. Table 2 presents Swedish Standard for biogas as a fuel for SI engines [4].

Table 1. Average composition of biogas in comparison for average composition of natural gas [4]

		Biogas	Landfill gas	Natural gas (Danish)
Compounds	Methane (vol-%)	60-70	35-65	89
	Other hydro carbons (vol-%)	0	0	9.4
	Hydrogen (vol-%)	0	0-3	0
	Carbon dioxide (vol-%)	30-40	15-50	0.67
	Nitrogen (vol-%)	~0.2	5-40	0.28
	Oxygen (vol-%)	0	0-5	0
	Hydrogen sulphide (ppm)	0-4000	0-100	2.9
	Ammonia (ppm)	~100	~5	0
	Lower heating value (kWh/Nm³)	6.5	4.4	11.0

Biomethane can be used by SI engines of vehicles directly (as CBG or LBG for instance: terracastus technologies [5]) or can be injected as upgraded biogas into grid.

European Project Baltic Biogas Bus (BBB) stimulate the use of biogas (biomethane) as fuel of city buses aiming to reduce environmental impact. Desk study on wider range of biogas production options and experiences including production potential scenarios for Baltic Sea Region (for Poland, Sweden etc.) is one of purpose of this project.

Table 2. Swedish Standard for biogas as fuel for SI engines [4]

• Particles < 1 μm
• Methane 97+/- 2 %
• Water < 32 mg/Nm^3
• CO_2, O_2, N_2 < 5%
• Oxygen < 1 vol %
• Sulphur < 23 mg/Nm^3
• N (except for N_2) expressed as NH_3 < 20 mg/Nm^3
• Odorised
• Compressed to 200 bar
For grid injection: Addition of propane (around 7–9 vol%)

New market opportunities for the development of biogas have created an European Union Directive 2009/28/EC [6] of 5 June 2009 on promotion of renewable energy sources, requiring from Poland to achieve 15% share of RES in final energy consumption in 2020. The construction of a new quantity target in relation to "energy consumption" offers the opportunities for biogas sector development, which can be direct or indirect used of all three end-markets of energy carriers, such as electricity, heat and transport.

Document prepared by the government titled “A Roadmap for renewable energy by 2020” as a plan for implementation of the Directive, has to specify the individual shares of energy carriers from renewable energy sources and technology in achieving the national target and their participation in general, national energy use balance. In the current year it is expected to introduce a new support system, including a new system of certification under the amendment to the Energy Law, which will determine the profitability of biogas investment in coming years.

According to the Energy Regulatory Office, on the beginning of the 2010 there were 124 biogas plants in Poland, including:

– 6 agricultural biogas plants;
– 46 biogas plants that produce biogas from sewage treatment plants;
– 72 biogas plants that produce biogas from landfills [7].

It is assumed that in 2020 Poland will produce 2 bln m^3 of biogas [8].

From the biogas manufactured in Poland in 2008 there were received 251,8 GWh of electricity and 925 TJ of heat, however in 2010 the total power of the biogas plants was 70,777 MW [7].

Utilization share of biogas by vehicle for example in Sweden is approximately 26 %. This type of utilization of biogas do not exist in Poland.

2. Biogas in Poland – actual condition and perspective of development

2.1. Biogas production potential from the agricultural biogas plants in Poland

The area of Poland covers 31 269 thous. ha, of which 55% of the area is used for agricultural purposes, and 29% is woodland. The total potential of biomass has been calculated at 160,9 PJ, and future scenarios foresee the reduction to 155.3 PJ (scenario 1) and 139.5 PJ (scenario 2). First scenario predicts to maximize the production of biofuels (including biogas) by 2020, while the second scenario assumes a sustainable production of biofuels (including biogas) with a special observance of minimum impact on the environment. The potential of the forest is now almost 26% of the total capacity and is expected to grow to the level of 31% in both scenarios. In all scenarios, from a technical point of view, thin wood fraction is the most important part and will be equal to 53-55% of the total potential of forest biomass. The potential for the wood industry will not have a significant impact on the amount of calculation and will not vary significantly among scenarios (2-3%) [9].

Straw potential specifies the largest proportion of the total potential of biomass in the current assessments. Currently, its potential is estimated at 115,8 PJ, that is 72% of total capacity. It was estimated, that in scenarios 1 and 2, the potential of biomass will be reduced to 66% of the total potential. Most of the full potential of straw from the cereal straw and grain is estimated at over 62% of the total harvested straw. In second place there is corn straw 20% share. Rapeseed straw is 17% of all the straw. In the current vision of future scenario for maximizing the production of biofuels, the amount of surplus straw reaches 31% of the fully assembled straw, while in the second future scenario is 28% [9].

According to data of the Energy Market Agency in Poland, covering approximately 50% of the Polish market as of January 1st, 2010, agricultural biogas production potential is estimated at 3 629 000 m^3, which corresponds to 78 438,4 GJ of energy, heating value equal to 21 614 kJ/m^3 [10].

The intention of the Polish government is to create such mechanisms, that by the 2020 there was founded about 2500 agricultural biogas plants with total capacity of 2000-3000 MW in Poland [11].

Currently in Poland there are about 1300 holdings of cattle, 3000 holdings pigs, 3500 holdings of poultry – in total 7,800 farms with an animal cast of more than 100 livestock units [12], which is a large enough potential to intensify the agricultural production of biogas.

The production potential of biomass as a feedstock for the production of biogas, in permanent pastures (after the security of fodder needs at the current level of livestock production) is total: 2 278 thous. Mg per year at a minimal level. With extensive production, while at the maximum level for intensive production is 3 418 thous. Mg per year [13].

In Poland energy crops in the 2007/2008 season are occupied by area of 180,5 thous. ha. Oilseeds occupied 63,6% of total area of planted energy crops, cereals 20,4%, while the corn 11%, remaining area occupied permanent crops (willow and others), and grasses, roots and other [13].

Currently straw, as raw material, is mainly used to produce heat or electricity as a solid fuel, and can also be used for biogas production and the production of second-generation biofuels. Estimated quantity of straw possible to use for energy purposes in Poland amounts to 4,866 thous. Mg [13].

Assuming that for energy purposes (biogas) will be used remains from agricultural production only in 25%, this potential is approximately 125 thous. Mg of dry mass (0.5 t/ha) which is equivalent to about 50 mln m^3 biogas. This represents 10% of the amount of natural gas consumed in rural areas [13].

Considering, as a raw material, also residues from cattle, swine and poultry, the potential of available raw materials for the manufacture of agricultural biogas is estimated by the Ministry of Agriculture and Rural Development 5 500 mln m^3 in total, of which:
– from the special crops and residues 1 962 mln m^3,
– the residue of the meadows and pastures 1 700 mln m^3,
– from the by-products fermentation from agricultural production 1 540 mln m^3.

The potential for biogas production in the distinction between types of raw materials is shown in Fig. 3. Figure 1 shows that the special crops and residues, as well as meadows and pastures and agricultural by-products have a high potential for agricultural biogas production.

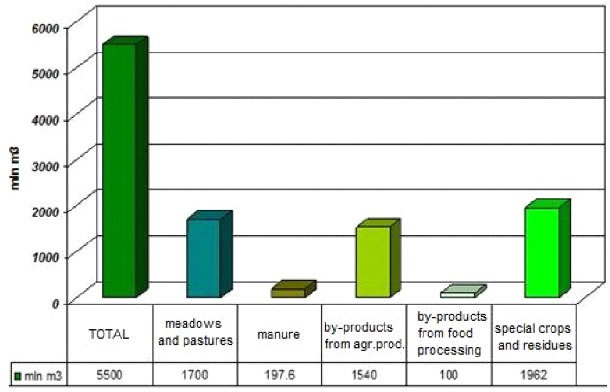

Fig. 1. Production potential of agricultural biogas (in mln m^3) [2]

2.2 Biogas production potential from the land-fills plants in Poland

In Poland is produced about 10–12 mln Mg of unsorted municipal waste a year, and in the group of mixed waste fraction, biodegradable fraction is dominant (50%). In addition, a significant amount of green waste from gardens and parks (leaves, grass) and waste from markets also are deposited in landfills. Biodegradation, and therefore the distribution of those waste has a place on landfill, and one of the products of decomposition is methane. Assuming a biogas yield for 200 m^3/Mg was calculated that the production of biogas from biodegradable waste in Poland could reach 1 bln m^3, assuming 50% methane content in derived biogas, gives the theoretical amount of 500 million m^3. The biogas heating value is 36 MJ/m^3, thus waiving the recovery of biogas from biodegradable waste means a loss of 18 thous. TJ of energy in the country [14].

In optimal conditions, from the one Mg of municipal waste about 400-500 m^3 of landfill gas. However, in reality, not all organic wastes are fully decomposed, and the fermentation process depends on several factors. Therefore, it is assumed that from the one Mg of waste can win up to 200 m^3 of landfill gas [15].

Currently on Poland there is about 700 registered and active landfills. It was estimated that each year they produce over 600 million m^3 of methane. In practice, the landfill gas resources possible to derive not exceed 30-45% of the total potential in the landfills. In such circumstances, reasonably possible to derive methane sources from the same municipal waste landfills are estimated at 135-145 million m^3 of methane per year, equivalent to 5 235 TJ of energy. This potential is being used only marginally.

Number of landfills in Poland, equipped with a degassing installations is growing permanently and in 2007 reached 304 units [16]. Part of the landfill installation is equipped with facilities for the production of heat and/or electricity.

According to the data of Energy Market Agency in Poland, covering approximately 50% of the Polish market as of January 1st, 2010, the productive potential of biogas from landfills is estimated on 33 927 500 m^3, equivalent to 565 953 GJ of energy, by the heating value, equal to 16 681 kJ/m^3 [10].

Data from the Energy Regulatory Office on January 1st, 2010 shows that currently there are 72 plants for the production of biogas from landfills with total capacity of 7 245 MW [7]. These installations are built on a landfill site.

From the manufactured biogas from landfills in 2008 in, there was received 14.4 GWh of electricity and 142 TJ of heat [10].

2.3. Biogas production potential from the wastewater treatment plants in Poland

Poland has more than 4000 sewage treatment plants and industrial plants. In many such systems are formed large quantities of sediment, which may constitute the raw material for biogas production because they do not contain toxic substances, and dry matter content of 4-5%, including more than 90% organic matter, allows them to be anaerobic. These deposits in Poland, are mostly deposited in landfills, which is becoming an increasing problem, particularly in light of EU law. Legal regulations limit the storage of sludge, and therefore it is necessary to disseminate appropriate methods of disposal of sewage sludge and their optimal use [17].

Technical potential for the use of biogas from wastewater treatment plants for energy purposes is very high. Poland has 1759 industrial and 1471 municipal wastewater treatment plants and this number increases (for the year 2003). At present only at 72 sewage treatment plants, there are biogas plants. Standard from 1 m^3 of sediment (4–5% dry weight) could be obtained from 10 to 20 m^3 of biogas containing 60% methane. For the direct production of biogas are best adapted biological sewage treatment plants, which apply in all municipal wastewater treatment plants and some industrial plants. Due to the fact that sewage treatment plants have a relatively high demand on both their own heat and electricity, the energy use of biogas from the fermentation of sewage sludge can significantly improve the profitability of these municipal services. For economic reasons, the acquisition of biogas for energy purposes is justified only to the larger sewage treatment plants receiving on average over 8000 – 10000 m^3/day [18].

Eurostat data show that the total production of sewage sludge in Poland amounts to 533,4 thous. Mg of dry solids per year (in year 2007) [19]. Given the data that the yield of biogas from dry organic matter of sewage sludge is 63 m^3 per Mg of dry organic matter, and the fact that it contains 80% of dry organic matter and organic in the dry matter, it can be concluded, that the potential of biogas from sewage sludge is 26 883 360 m^3 per year.

According to the data of Polish Energy Market Agency, the biogas production potential from sewage treatment plants is estimated at 96 930 200 m^3, which corresponds to 2 078 755 GJ of energy, equal to the heating value 21 446 kJ/m^3 [10].

Data from the Energy Regulatory Office on January 1st, 2010 show that there are currently 46 installations for the production of biogas from wastewater treatment plants with total capacity of 7245 MW. These installations are built at the wastewater treatment plants.

From the wastewater treatment biogas manufactured in 2008 in Poland there was received 94.9 GWh of electricity and 733 TJ [10].

Poland as a country of industry and agriculture has a relatively large potential for biogas production. Depending on the degree of purity of agricultural biogas, namely methane content, produced biogas can be an important energy carrier in CHP systems, and to use in transport.

National waste management in Poland is not very efficient, which means that significant amounts of potential energy resources as waste substances are deposited in landfills.

Alignment of the national fuel and energy economy to the requirements of European directives, in particular Directive 2009/28/EC [6] promoting renewable energy sources, imposes the need for significant change to increase the potential energy derived from renewable sources and waste substances.

The degree of dispersion and relatively low potential of individual farms may hinder the creation of agricultural biogas plants complexes, covering the whole of Polish territory. Nevertheless, the possibility of building about 2500 agricultural biogas plants in Poland, reported for the first time at the conference WIREC 2008 in Washington, seems to be real in the period up to 2020

Started research on the possibility of purification and use of biogas for transport purposes may create the possibility to use purified biogas as a fuel initially in agricultural machinery and equipment, and next by fueling vehicle engines. In this field work is being carried out, which aim is to use the existing Polish natural gas distribution network (currently in Poland there are 31 CNG refueling stations).

3. Production potential of biogas in Sweden

At present, in Sweden there are about 233 biogas plants with a total biogas production of 1.3 TWh/year. Most of these installations, as many as 139 is located at municipal wastewater treatment plants (WWTP). In these plants produce almost 43% of the Swedish biogas [19, 20, 21].

The theoretical potential of biogas production in Sweden is about 14 to 17 TWh/year, representing more than ten times the current production of biogas. Biomass from agriculture represent the largest part of the potential of biogas. Currently, almost 80% of the capacity of the agricultural sector remains unused.

According to the Swedish Association of Gas production potential of biogas in Sweden is very large, and a value of 35-40 TWh/year.

4. Biogas actual condition and perspective of development in Poland versus Sweden

Data of production potential of biogas indicate huge capability use in Poland of biogas as transport fuel particular for city buses. In Sweden a lot of city buses is presently supply of biogas (biomethane). For example in Stockholm are in service in this year about 150 city buses. Division of biogas production potencial (Poland and Sweden) according to data of BBB Project presents Table 3.

Table 3. Division of biogas production potencial (Poland and Sweden) according to data of BBB Project

Biogas type		Country: Poland	Country: Sweden
Agriculture biogas	According to data	3 629 000 m^3	76%
	Converted value [m^3]	3 629 000	1,82-2,20 bln
Landfill biogas	According to data	33 927 500 m^3	10%
	Converted value [m^3]	33 927 500	0,24-0,29 bln
Biogas from wastewater treatment plants	According to data	96 930 200 m^3	14%
	Converted value [m^3]	96 930 200	0,34-0,41 bln
TOTAL	According to data	153-486 PJ	14-17 TWh[1] *35-40 TWh[1]*
	Converted value [m^3]	7,2-22,8 bln	2,4-2,9 bln[1] *6-6,9 bln[1]*

[1] depend on scenario for the development of renewable energy sources

5. Ecological results of application of biogas (biomethane) for supplying city buses

Biogas (biomethane) is inter alia similar to compressed natural gas (CNG) but renewable.

Results of research (VTT Technical Research Center of Finland) introduce in indicate that (Table 4, Fig. 2):

– currently EEV (*Enhanced Environmentally Friendly Vehicle*) certified methane buses clearly outperform EEV certified diesel vehicles for NO_x as well as PM,
– methane vehicles provide true EEV performance over time,
– all methane fuelled vehicles deliver very low PM emissions,
– clear benefit for methane also for PM numbers, aldehydes, direct NO_2 emissions and unregulated emissions (PAH),
– main drawback of spark-ignited methane compared to diesel is higher energy consumption.
– best diesel and CNG buses can have a tailpipe CO_2 emission 1,100 g/km (Braunschweig city bus – cycle).

However, it is necessary to remember that biomethane is renewable fuel and if we use biomethane CO_2 emission from well to wheel is near zero.

Table 4. Results research of exhaust emissions from EEV buses (diesel and CNG) [22]

City bus-cycle	CO g/km	HC g/km	CH_4* g/km	NO_x g/km	PM g/km	CO_2 g/km	CO_2eqv g/km
Diesel Euro III	0,80	0,14	0,00	8,64	0,195	1189	1189
Diesel Euro IV	2,84	0,10	0,00	8,35	0,112	1194	1194
Diesel Euro V**	2,84	0,10	0,00	8,35	0,087	1194	1194
Diesel EEV	1,12	0,02	0,00	5,87	0,062	1116	1116
CNG Euro III	0,14	1,67	1,14	9,36	0,011	1257	1295
CNG EEV	2,27	1,04	0,87	3,18	0,007	1275	1294
* for diesel CH_4 = 0; ** euro V emission factors are estimated by euro IV results							

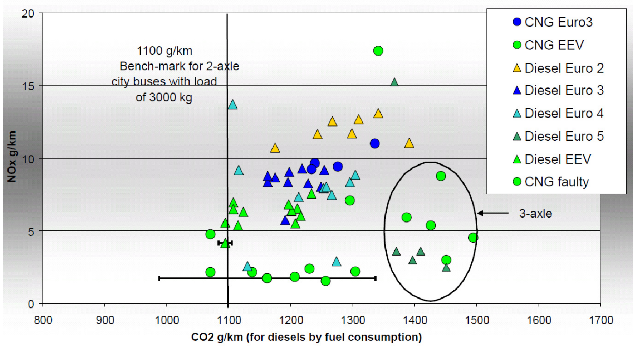

Fig. 2. NO_x and CO_2 emissions over the Braunschweig city bus – cycle [22]

To verify these data are studies carried out in real traffic conditions in Rzeszow (Fig. 3, Fig. 4).

6. Conclusions

The EU 20-20-20 climate and energy goals can be summaries as follows:
– reduction greenhouse gas emissions at least by 20% up to 2020,
– improving the EV's energy efficiency by 20% up to 2020,
– increasing the share of renewable energy up to 20% in 2020, in particular a 10% share of renewable energy in the transport sector.

The new transport White Paper recommends an ambitions target of 60% reduction of greenhouse gas emissions from transport up to 2050 in comparison to 1990.

Fig. 3. Research CNG and diesel buses in real traffic conditions in Rzeszow

Fig. 4. Research apparatus used in the study exhaust emission buses in real traffic conditions in Rzeszow

In this publication is forecasted that biomethane will be alternative road transport fuel for passenger/light duty cars, heavy duty (city) vehicles and heavy duty (long distance) vehicles in short term period (2020), mid term period (2030) and long term period (2050 – only for passenger /light duty cars and heavy duty (city) vehicles [23].

Prospect of application of biogas (biomethane) as a vehicle fuel is significant.

Bibliography

[1] Directive 2003/30/EC – Official Journal of the European Union L123/42, 17.5.2003.

[2] Biernat K., Dziołak P., Gis W., Żółtowski A.: Summary elaboration on the production and potential production of biogas in the Baltic Sea Region Countries today and in the perspective of the next years. Baltic Biogas Bus Project.

[3] Biernat K.: Nowe technologie wytwarzania biokomponentów i biopaliw pierwszej i drugiej generacji. Międzynarodowa Konferencja – Jakość paliw w Polsce i Unii Europejskiej. Warszawa 2007.

[4] Petersson A.: Overview of upgrading technologies. 2010 Nordic Biogas Conference.

[5] Beyer J., Brown B.: Terracastus technologies. Technology for cleaning and upgrading biogas, www.businessregion.se

[6] Directive 2009/28/EC – Official Journal of the European Union L 110/16, 5.6.2009

[7] Mapa Odnawialnych Źródeł Energii, opracowana przez Urząd Regulacji Energetyki, dane aktualne na dzień 31 grudnia 2009 r.: http://www.ure.gov.pl/uremapoze/mapa.html;

[8] Ministerstwo Rolnictwa i Rozwoju Wsi, Założenia Programu rozwoju biogazowni rolniczych, stanowiące propozycję Ministra Rolnictwa i Rozwoju Wsi przekazaną Ministrowi Gospodarki do programu „Innowacyjna Energetyka, Rolnictwo Energetyczne", Warszawa, maj 2009;

[9] Opracowanie pt. Residue biomass potential inventory results (Deliverable D5.01.03) w projekcie Renewable fuels for advanced power-trains (RENEW)

[10] Informacja z Agencji Rynku Energii – Iwona Gogacz, wiadomość elektroniczna z dnia 15 stycznia 2010r.;

[11] Ministerstwo Rolnictwa i Rozwoju Wsi, Założenia Programu rozwoju biogazowni rolniczych stanowiące propozycję Ministra Rolnictwa i Rozwoju Wsi przekazaną Ministrowi Gospodarki do programu „Innowacyjna Energetyka, Rolnictwo Energetyczne", Warszawa, maj 2009;

[12] Rembowski Ł.: Potencjał ilości biomasy ze źródeł rolniczych i przemysłowych w Polsce, Redakcja agroenergetyka.pl: http://agroenergetyka.pl/?a=article&id=512;

[13] Żmuda K.: Ministerstwo Rolnictwa i Rozwoju Wsi, Energetyka odnawialna w polityce Ministerstwa Rolnictwa i Rozwoju Wsi, Bydgoszcz, 24 czerwca 2009 r.;

[14] Pozyskiwanie biogazu z odpadów komunalnych, Redakcja agroenergetyka.pl: http://agroenergetyka.pl/?a=article&idd=149;

[15] EC BREC, 2003. Odnawialne źródła energii jako element rozwoju lokalnego;

[16] Ochrona Środowiska 2008, Główny Urząd Statystyczny, Informacje i Opracowania Statystyczne, Warszawa;

[17] Produkcja biogazu w oczyszczalni ścieków, Redakcja aeroenergetyka.pl: http://agroenergetyka.pl/?a=article&id=529;

[18] EC BREC, 2003. Odnawialne źródła energii jako element rozwoju lokalnego;

[19] Yohaness M. T. : Biogas potential from cow manure – Influence of diet, Uppsala BioCenter, Swedish University of Agricultural Sciences, Master thesis 2010:3;

[20] DahlgrenS.: Swedish Biogas Association and Swedish Gas Association, Biogas State of the art – Sweden;

[21] Avfall Sverige – Swedish Waste Management 2009;

[22] Nylund Nils-Olof: Environmental benefits with biogas buses, Nordic Biogas Conference Oslo, 10 – 12 March 2010;

[23] European alternative fuel strategy in the Clean Transport System Interactive. JEG "Transport & Enviromental".

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