ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1181710

OPERATION OF URBAN BUSES POWERED BIOMETHANE

Wojciech Gis

Motor Transport Institute
Jagiellonska Street 80, 03-301 Warsaw, Poland
tel.:+48 22 438 54 00, fax: +48 22 438 54 01
e-mail: wojciech.gis @ its.waw.pl

Agnieszka Merkisz-Guranowska, Jacek Pielecha

Poznan University of Technology
Faculty of Machines and Transportation
Piotrowo Street 3, 60-965 Poznan, Poland
tel.:+48 61 6475958, +48 22 665 21 18
e-mail: agnieszka.merkisz-guranowska@put.poznan.pl
jacek.pielecha@put.poznan.pl

Maciej Gis

Warsaw University of Technology
The Faculty of Automotive and Construction Machinery Engineering
Narbutta Street 84, 02-524 Warsaw, Poland
tel.: +48 606 740 357
e-mail: maciek.gis@gmail.com

Abstract

The article presents the advantages of using biomethane to power city buses. Given the current possibilities for the production of biomethane in the country. They are very limited, but established the country's first mobile installation biogas purification to natural gas quality. Presented the results of comparative testing exhaust emissions and fuel consumption of city buses: CNG (biomethane) and diesel. The study was conducted in the national real traffic conditions. Reference was also the issue of eco - driving buses power CNG or biomethane. Presented used to test devices eco - driving Sagasystem company. The Sagasystem collects main information from the FMS gate in the vehicle: speed of the bus, fuel consumption, fuel consumption when in idle gear, work time when in idle gear, number of braking. Additional information from the FMS gate is the speed of vehicle (and individual wheels), speed of vehicle (according to the GPS), use of clutch (on/off) etc. Test results of emission standards and fuel consumption of CNG-powered bus (biomethane) in the national real traffic conditions were presented. Tests were carried out using and without the use of the above equipment.

Keywords: *transport, road transport, combustion engines, biomethane, CNG, environmental protection*

1. Introduction

Raw biogas is the mixture of methane (app. 65%), carbon dioxide (app. 35%) and other additives. It is formed through the methane fermentation in anaerobic conditions. Possible substrates for biogas production are agricultural waste (biomass), municipal waste from landfills, industrial waste and sewage sludge from the sewage treatment plants.

Biogas can be used as a fuel to produce electricity and heat, and biomethane in its upgraded form, can be used as a fuel for internal combustion engines [1, 3-5, 7, 8].

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

Results of research introduce in indicate that [5, 6]:

- currently EEV 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,
- stoichiometric vehicles deliver lower NO_x and lower fuel consumption,
- clear benefit for methane also for unregulated emissions (PM numbers, aldehydes, PAH, direct NO_2 emissions etc.),
- main drawback of spark-ignited methane compared to diesel is higher energy consumption.

It is necessary to remember that biomethane is renewable fuel and therefore CO_2 emission from well to wheel is near zero [6].

Total biogas potential in Poland is 6.4 bn m^3, for example in Germany 24 bn m^3 [5, 9]. In Germany was 7470 biogas plants (2012) and 80 biomethane plants (2012) [2]. In Poland was 178 biogas plants (2012) and there was not biomethane plants (2012) [2].

2. First in Poland mobile installation for purifying biogas to the quality of natural gas – biomethane

In carried by international consortium (including Motor Transport Institute) of the European project Mare Baltic Biogas Bus was need to implement in the aspect of [5]:

- upgrading of biogas,
- small scale biogas upgrading facility in Poland,
- social-environmental-economic analysis on biogas as fuel in Poland,
- energy efficiency of biogas buses,
- hybrid electric biogas buses in Västerås, Sweden and Bergen, Norway,
- eco-driving system and training to raise fuel efficiency in project partner countries,

General information upgrading about installation in Poland:

- the owner of installation: Motor Transport Institute (ITS),
- installation contractor: NGV Autogas Ltd. from Krakow,
- source of funding: European project More Baltic Biogas Bus and financial means of ITS,
- duration: 2013-2014,
- place of foundation: area inactive landfill in Niepołomice near Krakow, managed by the Company "Waterworks Niepołomice".

The scope of operation of the installation: to dry the biogas, removal of excess carbon dioxide, sulphur compounds, and other undesirable contaminations, and then compressing and storing biomethane at a pressure of 250 bar in the cylinders.

Installations: on the basis of two twenty-foot containers. In one container mounted device for the upgrading of biogas to the parameters of motor fuel (natural gas) – biomethane. Quality control in the process of upgrading biomethane is automatically. The solution is protected by patent rights.

In the second container mounted compressor, absorber absorbing residual water from biomethane and biomethane storage cylinders. On the outer wall of the second container mounted distributor-serving biomethane refuelling tank of car. Average hourly capacity of biomethane fuel sourcing of the installation is limited by the capacity of the compressor biomethane and is 50 Nm^3/h. On the Fig. 1 below is presented, described installation for purify biogas to biomethane.

Due to the necessary tests for verifying installations, planned at the same time as comparative tests exhaust emissions of pollutants buses: diesel-powered and compressed natural gas and tests eco-driving device, these recent study was conducted using compressed natural gas.

Fig. 1. Installation for purifying biogas to the quality of natural gas – biomethane

3. The tests and result analysis of the ecological properties of vehicles refuelled with natural gas and diesel

Tests on the emissions and the consumption of fuel were conducted on two vehicles (buses):

- Vehicle I – refuelled with CNG – included tests on the fuel consumption and the emission of pollutants; the tests conducted on November 11, 2014, using the Jelcz bus M121 M/4, equipped with a combustion engine , meeting the emission standard Euro III (production year 2006), with the cylinder capacity of 11967 cm^3, 180 kW.
- Vehicle II – refuelled with diesel – included identical tests (vehicle make Jelcz M121 MB, engine’s cylinder capacity 11970 cm^3, maximum power 180 kW, production year 2000; such tests were also performed on November 29, 2014 on the same driving distance and comparable road conditions (test were performed simultaneously on two buses, which were driven directly one after the other).

The scope of work:

The measurement of the emissions and the fuel consumption under real traffic conditions

The analysis of the tests relating to the study:

a) photographic documentation from the tests (Fig. 2 and 3),
b) report on the tests for the vehicle refuelled with CNG and refuelled with diesel,
c) characteristics of the test driving distance (Fig. 4),
d) characteristics of the concentration and the intensity of the emission of harmful compounds of the exhaust,
e) characteristics of instantaneous fuel consumption and road fuel consumption,
f) two-dimensional histograms related to the vehicle (in coordinates of the bus speed-acceleration) participation of operation time and the intensity of the emission of harmful compounds,
g) two-dimensional histograms of hourly and road fuel consumption related to the bus,
h) summary of results – road consumption of fuels and the road emission of harmful compounds.

Fig. 2. Tested buses

Fig. 3. One of two devices used to measurement exhaust pollutants under real conditions

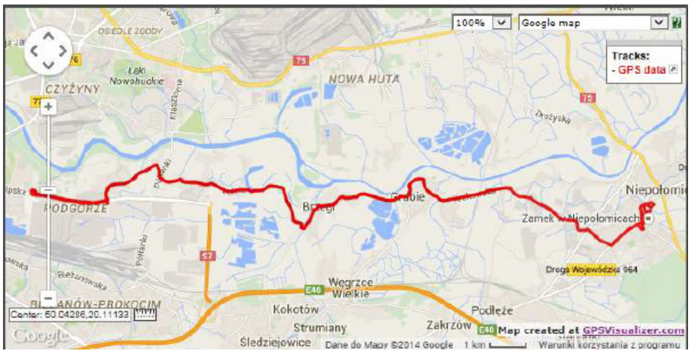


Fig. 4. Characteristics of the test route

The characteristic of the obtained results

The comparison of the results was possible thanks to the positive result of comparing the driving routes and their large percentage time consistency, being the effect of defining the participation of the phases time of the vehicle operation during the test (Fig. 5):

- acceleration: 44% (CNG bus) and 43% (diesel bus),
- constant speed: 6% (CNG bus) and 5% (diesel bus),
- breaking the vehicle: 36% (CNG bus) and 45% (diesel bus),
- stationary vehicle: 14% (CNG bus) and 8% (diesel bus).

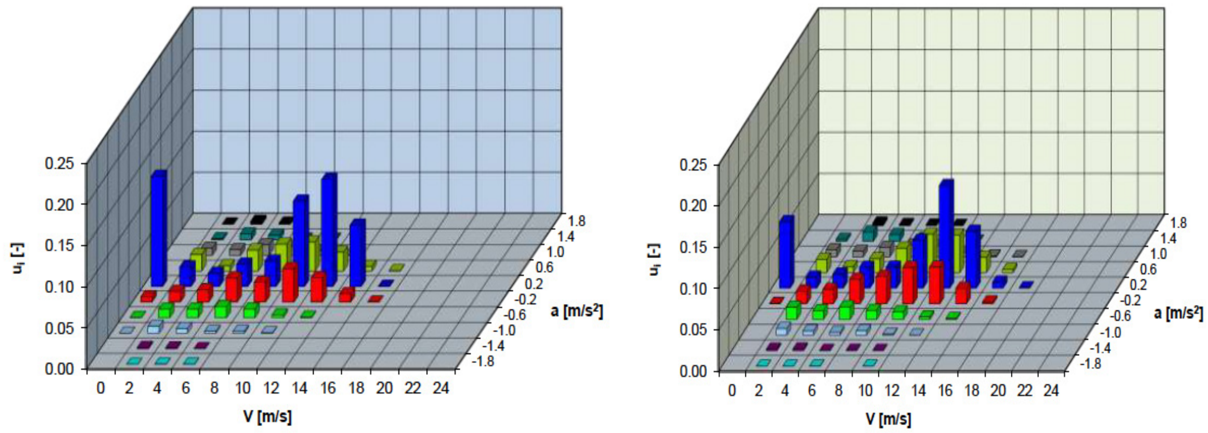
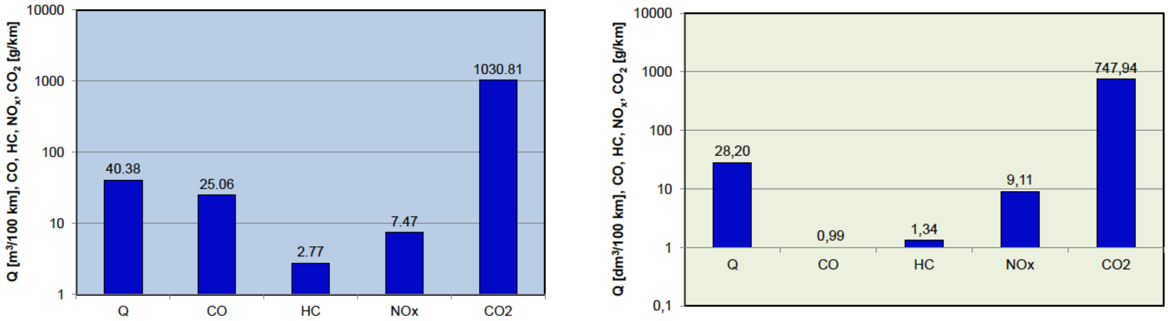


Fig. 5. Two-dimensional histograms of participation of the vehicle operation time during testing in coordinates of the vehicle speed - acceleration: – vehicle I (CNG), – vehicle II (diesel)

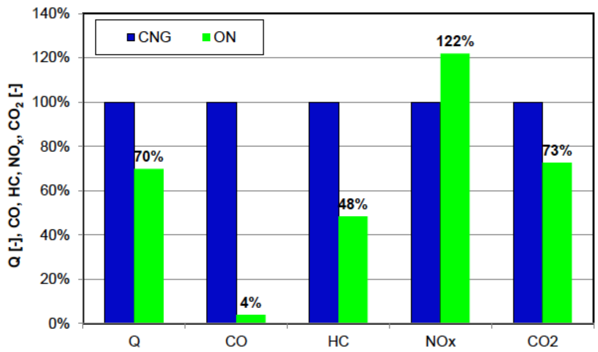
From the performed tests in the real road traffic conditions, the conclusions are as follows (Fig. 6, 7):

- the road fuel consumption (natural gas): 40.38 m^3/100 km (CNG bus) and 28.2 dm^3/100 km (diesel bus),
- the road emission of carbon monoxide (CO): 25.06 g/km (CNG bus) and 0.99 g/km (diesel bus) – reduction by 96%,
- the road emission of hydrocarbons (HC): 2.77 g/km (CNG bus) and 1.34 g/km (diesel bus) – reduction by 52%,
- the road emission of nitric oxide (NO_x): 7.47 g/km (CNG bus) and 9.11 g/km (diesel bus) – increased by 22%,
- the road emission of carbon dioxide (CO_2): 1030 g/km (CNG bus) and 748 g/km (diesel bus) – reduction by 27%.



Fuel consumption, harmful compounds *Fuel consumption, harmful compounds*

Fig. 6. The results of the mileage consumption of fuel and the road emission of pollutants, obtained during testing: – vehicle I (CNG), – vehicle II (diesel)



Fuel consumption, harmful compounds

Fig. 7. Comparison of the road consumption of fuel and the road emission of pollutants, obtained during testing

The conducted tests indicate that the road emission of nitric oxides (NO_x) of the bus with an engine refuelled with CNG is lower than the road emission of NO_x of the bus with the compression ignition engine (CI). Considering the fact, that excess emission of nitric oxides from CI engines is a serious problem, especially in urban traffic, the benefit of utilizing buses with engines refuelled with CNG is obvious here.

Also, the emission of particulates, the second most significant component of the exhaust gases in the CI engines (in the presented tests it was not measured due to lack of such possibility, using the PEMS type measuring devices), in case of using engines refuelled with CNG it is lower than the one occurring in the CI engines (without utilizing expensive purifying systems).

In case of the emission of the carbon dioxide (CO_2) by the bus with the engine refuelled with CNG, therefore with the spark-ignition engine (SI), it is greater than the one occurring in the bus with the engine refuelled with diesel. When using biomethane, though, which is nearly entirely renewable, during life cycle (from well to wheel), the bus with the engine refuelled with biomethane will be a better solution than utilizing a bus with the CI engine for the reason of the CO_2 emission, which is smaller during the life cycle of the CNG engine, comparing to the CI engine.

There is an advantage in the bus with the CI engine over the one with the SI engine, refuelled with CNG (biomethane) in relation to the emission of carbon monoxide (CO), and in the case of the emission of the hydrocarbons, the measurements, performed with the devices, allowed for defining their total value (non-methane hydrocarbons and methane), hence the higher values for the bus with the SI engine. It needs to be emphasized, that methane is not toxic, although it is a greenhouse gas. The utilization of the more efficient catalytic systems will allow for the reduction of the road emission of CO and HC.

The presented tests and analysis indicate the appropriateness of utilizing city buses with engines refuelled with biomethane, more so, that the first installation, described in this study, was constructed in the Country for the purpose of purifying biogas to the form of biomethane. With the popularization of this production of biomethane across the country, certain reduction in the dependency on the natural gas import, being the fossil fuel, therefore non-renewable, is undoubtedly possible.

4. Ecological assessment of city buses powered by natural gas

The aim of the study was to evaluate the ecological properties of the municipal public transport buses powered by natural gas for varied operating conditions: standard one and using eco-driving.

The studies on the exhaust emissions and fuel consumption have been performed in two phases:

- Phase I – standard - included the studies on the fuel consumption and pollutants emissions without equipment supporting the fuel economy
- Phase II – eco – included conducting the identical tests using the device that supports reduced fuel consumption.

Within the More Baltic Biogas Bus project purchased the equipment for eco-driving of Sagasystem, Norwegian company (Fig. 8). The system collects main information from the FMS gate in the vehicle:

- Speed of the bus,
- Fuel consumption,
- Fuel consumption when in idle gear,
- Work time when in idle gear,
- Number of braking.

Additional information from the FMS gate:

- The speed of vehicle (and individual wheels),
- Speed of vehicle (according to the GPS),
- Use of clutch (on/off),
- Total fuel consumption etc.

Fig. 8. The eco-panel of Sagasystem informing the driver in regards to the driving style: Green LEDs indicate ecological driving. Yellow LEDs indicate driving which strays away from the economical characteristics. Red LEDs indicate uneconomical driving

Research was carried out on a bus powered by CNG (Tab. 1). For the measurement of exhaust emission pollutants used mobile device Semtech DS (Fig. 9).

Tab. 1. CNG bus parameters

Parameters	**CNG bus**
Engine type	SI
Engine capacity	7.8 dm^3
Number of cylinders	6
Max power/engine speed	200 kW/ 2000 min^{-1}
Max torque/engine speed	1100 Nm 1100 – 1650 min^{-1}
Emission level	Euro IV
Catalytic converter	TWC
Max mass of bus	18 000 kg
Length of bus	12 m

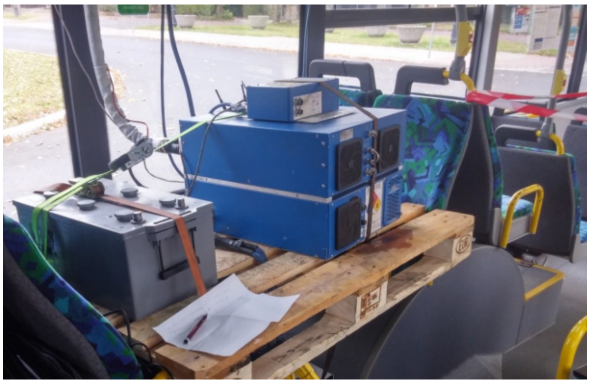


Fig. 9. Mobile device Semtech DS to measurement of exhaust emission pollutants under real conditions

The test route was selected based on the load along a bus route, which in this case was an average passenger congestion one (Fig. 10).

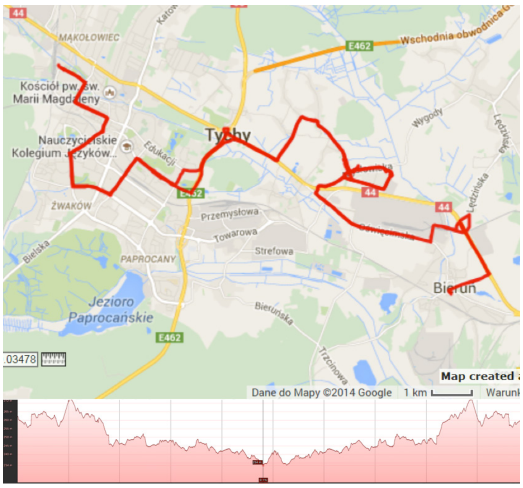


Fig. 10. Test route

The comparison of the results, in all, was possible thanks to the positive result of comparing the route distances and their considerable time consistency, which was the effect of defining the participation of time phases of the vehicle work in the test (the values have been rounded to the full units):

– Acceleration: 34% (I phase) and 31% (II phase),
– Constant speed: 18% (I phase) and 22% (II phase),
– Braking the vehicle: 31% (I phase) and 27% (II phase),
– Standstill of the vehicle: 17% (I phase) and 19% (II phase).

Results of the road fuel consumption and the road emission of substances obtained during testing shown on Fig. 11.

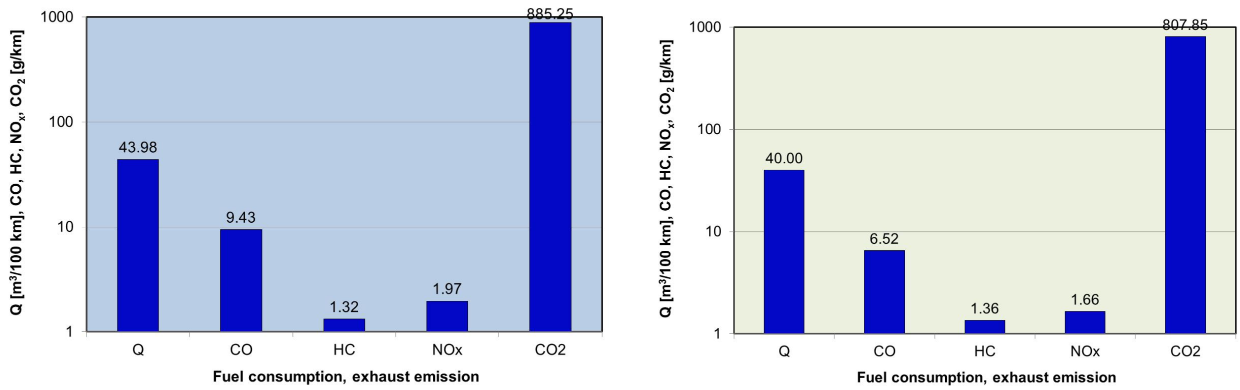


Fig. 11. Results of the road fuel consumption and the road emission of substances obtained during testing

The conducted tests (from the I and II phase), in the real time road traffic, conditions indicate the following conclusions (Fig. 12):

– The road fuel consumption (natural gas): 44 m^3/100 km (I phase) and 40 m^3/100 km (II phase) – reduction by 9%,
– Road emission CO: 9.4 g/km (I phase) and 6.5 g/km (II phase) – reduction by 31%,
– The road emission of HC: 1.32 g/km (I phase) and 1.36 g/km (II phase) – increased by 3%,
– The road emission of the NO_x: 1.97 g/km (I phase) and 1.66 g/km (II phase) – reduced by 16%,
– The road emission of CO_2: 885 g/km (I phase) and 807 g/km (II phase) – reduced by 9%.

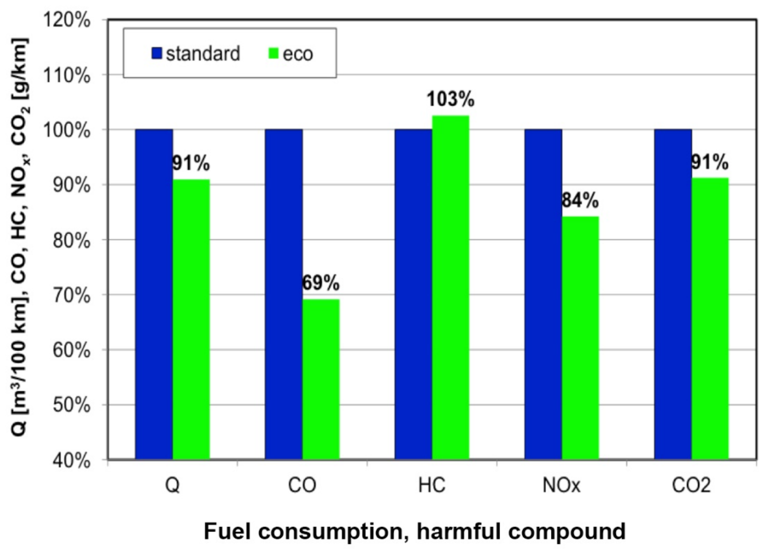


Fig. 12. Percentage changes in fuel consumption and harmful compound, tested buses

5. Conclusions

Biogas is used as an energy source, primarily to produce electricity and heat. Obtained heat is often used in plants and other facilities. In many landfills, there is only a partial utilization of biogas for their own needs. Unused part the complexity of connecting the local energy sources to the electricity networks, it is known that each process of energy conversion is a lossy process, also by the entropy component, which is cumulated at each stage of processing. Supplying the combustion engine driving a generator with biogas, then the flow of the electric current and again supplying an electric engine or another receiver with this current; makes higher losses than directly supplying the engines with biogas as a fuel. Thus, it is believed that the use of biomethane as a direct energy source is more advantageous and should be promoted. On the other hand, the upgrading process is a lossy process also. Promotion of the biomethane as a transport fuel, especially for city busses, will contribute to better environment protection in the cities.

References

[1] Anderson, S., *Integrated regional distribution infrastructure planning*, The case of Stockholm. Final event in Bergen 22 May 2012.
[2] Biernat, K., Gis, W., Grzelak, P., Żółtowski, A., *The study on wider range of biogas production options and experiences*, Motor Transport Institute, Warsaw 2013.
[3] Hallgren, L., *Biogas as fuel – the natural choice for city buses*, Final event in Bergen 22 May 2012.
[4] Hammarlo, L., *With the ambition to contribute to a fossil-fuel independent society*, Final event in Bergen 22 May 2012.
[5] Merkisz, J., Gis, W., Żółtowski, A., *Biogas as vehicle fuel*, PTNSS Congress. Radom, Poland 2011.
[6] Nylund Nils-Olof: *Environmental benefits with biogas buses*, Nordic Biogas Conference Oslo 2010.
[7] Podkówka, W. i in., *Biogaz rolniczy odnawialne źródło energii*, PWRiL, Warszawa 2012.
[8] Wallin, S., *Biogas a key ingredient in a strategy for sustainable fuels*, Final event in Bergen 2012.
[9] www.balticbiogasbus.eu