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POTENTIAL OF BIOGAS IN URBAN BUSES

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Satakunnan ammattikorkeakoulu
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Abstract

This Bachelor's thesis was carried out for Pori Environmental Agency with an aim to evaluate whether biomethane as a fuel would be a sustainable solution for public urban buses in Pori municipality. The study was conducted to overview the core aspects of potential biogas bus fleet implementation in city of Pori, considering basic infrastructural requirements, fuel source availability for biomethane production and the fuel demand of the fleet. Environmental aspects were considered by means of potential carbon emission cuts in case of replacing diesel fuel by biomethane.

CONTENTS

Terms and definitions

NG	Natural gas
LNG	Liquefied natural gas
CNG	Compressed natural gas
LBG	Liquefied biogas
CBG	Compressed biogas
AD	Anaerobic digestion
GHG	Greenhouse gases
EEA	European Environmental Agency
ACAEA	European Association of Car Manufacturers
CO_2	Carbon dioxide
CO	Carbon monoxide
HC	Hydrocarbons
NOx	Nitrogen oxides
IPCC	Intergovernmental Panel on Climate Change
VTT	Technical Research Centre of Finland
BOD	Biological Oxygen Demand
VS	Volatile solids
SS	Suspended solids

INTRODUCTION

Energy security and environmental matters have nowadays caused a greater importance to research alternative fuels and sustainable transportation systems. The EU Renewable Energy Directive demands 20% share of its total energy demand to come from renewable energy sources by 2020 and cut the greenhouse gas emissions by 20% from 1990 levels. In 2016, the road transport accounted for 17% of total carbon dioxide emissions in Europe. However, a forecast projects an increase of mobility demand of 2.6 times the current level by 2050. Also changing consumer habits such as reduced commitment to ownership and interest of constantly staying online favor the use of public transportation (ACEA, 2016).

There are several ways how transportation could be improved: smart transportation systems, alternative fuels, stimulated public transportation, efficient engines, design of cars, electric vehicles. Alternative fuels like biodiesel, biomethane, ethanol, hydrogen and electricity stored in batteries or fuel cells have already increased the importance due to depleting oil resources and stricter emission standards.

1.1 Motivation of the study and objectives

The study was conducted for Satahima – Towards a carbon neutral Satakunta – project, carried out by Pori Environmental Agency to develop and promote carbon neutral activities and services in Satakunta region. The project was launched 1.1.2015 and it ends 31.12.2017. Satahima project has been funded by European Regional Development Fund and Satakuntaliitto.

The use of biogas fuel in urban buses has been seen as a perfect solution to cut the emissions and improve the air quality in city environment, and support the local infrastructure and energy security. Sewage sludge and biowaste can be considered as an ‘always present’ resource for biogas production that does not conflict the land use for the food production unlike some other types of biomass. This kind of utilization would reduce the amount of landfills and prevent there occurring methane and carbon dioxide emissions from entering the atmosphere.

The focus of this study was to estimate the potential demand of biomethane fuel equivalent to supply the energy need of local bus fleet in Pori. The available biogas resources (sewage sludge and biowaste) were reviewed to estimate the biomethane production rates and evaluate if they would meet the demand of fuel equivalent for the local bus fleet. Based on obtained results, it was possible to compute the potential carbon reductions in scenario if CBG buses substituted the current diesel buses of the Pori fleet.

Chapter 2 consists of general overview of biogas characteristics, biomethane fuel applications and required infrastructural storage requirements. The study will mainly refer to current situation of the public transportation, potential biogas production and infrastructural requirements for biogas based fuel utilization in the city of Pori.

1.2 Reviewing previous research

The study is supported by a combination of data obtained from different sources. However, some values had to be based on theoretical assumptions. Data on local bus fleet and buses in Chapter 3 was provided by Porin Linjat Oy, the biomethane production estimation in Chapter 4 was based on report compiled by Pöyry Oy. Theoretical assumptions on the average fuel consumption are based on data provided by city of Vaasa which has introduced 12 CNG fueled buses in the city fleet.

Site visit to the city of Vaasa was organized to acquire information on the new CNG buses and familiarize with the biogas infrastructure. It was said that 12 buses can substitute 280 000 liters of fossil diesel fuel every year and the carbon emissions are on the same level as the fully electric vehicles where electricity would come from the wind power. The capacity of Stormossen, the local biogas producer in Vaasa, utilized regional household waste and sludge waste from Vaasan Vesi, could supply 12 city buses and for about 1 000 passenger cars, *(Hällilä 2017).*

Figure 1. *CNG bus in city of Vaasa at the slow filling station. Photo by the author.*

1.3 Use of buses in Europe

Table 1 presents the data of bus uses in Europe (EU-15). While Finland has been increasing the number of buses (+2.2% from 2009 to 2014), in EU-15 countries in total the use of buses has decreased rapidly by 17.4%. The use of bus by country can be affected by many factors – population density, price of the passenger car fuel, price, reliability and comfort of the bus service, price of other public transportation services (trains, trams, metro, etc.) Furthermore, table 1 does not present data as the number of buses in use per population neither as a share of total transportation vehicles, so the increase of bus use can be simply explained by population growth of area. For example, Italy in 2014 had around 8 times more buses in use than there were in Finland, but also the population was 12 times bigger.

However, alternative fuel vehicles took up 1.8% of the total bus fleet. The figure was higher for the city buses – 20% of those were using alternative fuels (ANFAC 2015).

Table 1. *Number of buses in use in EU-15 (ANFAC 2015)*

	2009	2010	2011	2012	2013	2014	% growth 13/14
AUSTRIA	9.599	9.648	9.602	9.546	9.579	9.585	0,1%
BELGIUM	16.005	16.112	15.958	15.796	15.775	16.028	1,6%
DENMARK	9.205	9.195	9.093	8.812	8.646	8.769	1,4%
FINLAND	11.488	11.610	11.782	12.012	12.183	12.446	2,2%
FRANCE	85.000	86.000	86.000	87.000	88.000		
GERMANY	76.433	76.463	75.988	76.023	76.794	77.501	0,9%
GREAT BRITAIN	85.934	87.524	87.604	86.860	85.782	85.557	-0,3%
GREECE	28.255	28.726	28.851	29.403	29.835	26.691	-10,5%
IRELAND							
ITALY	98.724	99.895	100.438	99.537	98.551	97.914	-0,6%
NETHERLANDS	11.667	12.000	11.000	11.000	10.000	10.102	1,0%
PORTUGAL	15.500	15.600	15.500	15.100	14.800	14.500	-2,0%
SPAIN	62.663	62.445	62.358	61.127	59.892	59.799	-0,2%
SWEDEN	13.407	13.873	13.947	14.203	13.986	13.992	0,0%
EU-15	**523.880**	**529.091**	**528.121**	**526.419**	**523.823**	**432.884**	**-17,4%**

1.4 Use of fuels

According to the European Automobile Manufacturer's Association, the number of passenger cars in Finland has increased by 0.8% from 2009 to 2014, which is below the European average of 1% growth. However, most of the passenger cars are fueled on gasoline or diesel, leaving only 0.2% for alternative fuel vehicles (ANFAC 2015).

Finland has set goals to achieve 4.6% of road vehicles registered from 2012 to 2020 to methane fueled (Lampinen, 2012).

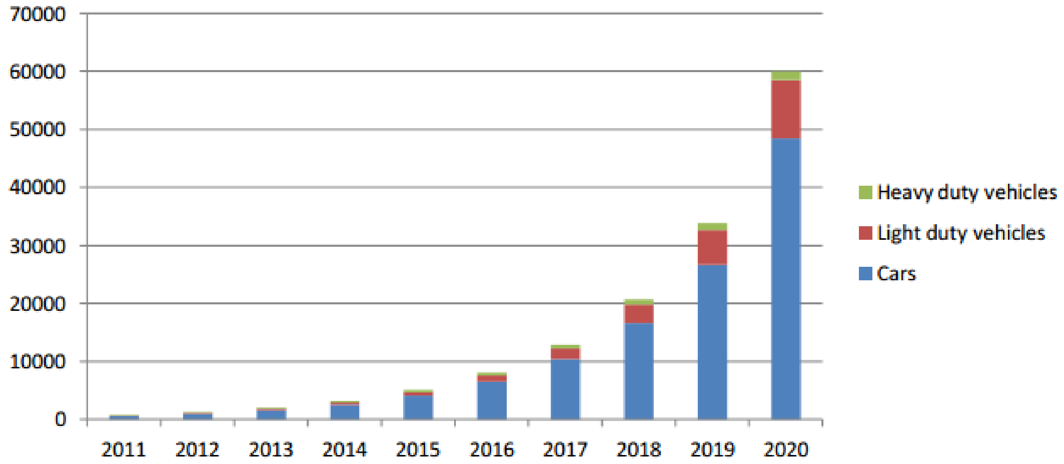

Figure 2. *Targets for road methane development in Finland until 2020, (Lampinen 2012).*

2 BIOGAS AS A FUEL

2.1 General

Biogas can be used to produce heat, utilized in fuel cells or as a vehicle fuel, or injected into natural gas grid. Each application requires gas treatment from impurities and possible other procedures, see figure 3. Regardless of financial feasibility, there are several obvious reasons for biogas production: it decreases dependency on fossil fuels, reduced emissions and landfills and improves local infrastructure, creates more jobs etc.

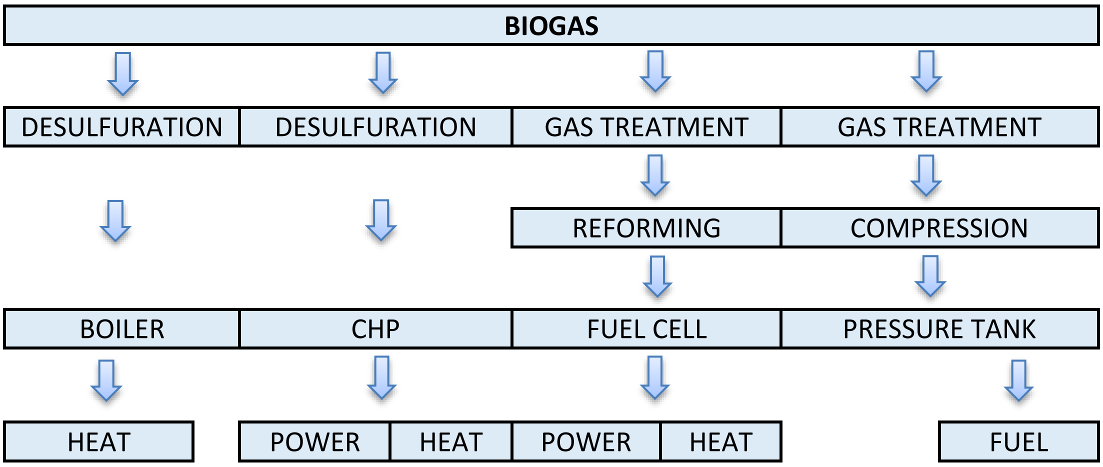

Figure 3. *Different biogas processing methods and applications*

2.2 Production of biogas

Biogas is a result of anaerobic digestion of organic material, which can originate from plants or animals, sewage, landfills. Biogas should contain 50-80 % of methane, the other share is taken by mixture of carbon dioxide (CO_2), H_2, H_2O, NH_3, H_2S, O_2, etc. The chemical composition and physical characteristics of biogas depends highly on the raw material origin and treatment process. Table 2 shows the difference of biogas chemical composition based on the raw material origin. The physical characteristics of biogas are based on its composition (table 3). Raw biogas from household waste produces 50% less energy by combustion compared to equal volume of natural gas.

Table 2. *The chemical composition of biogas based on source (Website of Naskeo Environment 2009)*

Components	Household waste	Wastewater treatment plants sludge	Agricultural wastes	Waste of agrifood industry
CH4 % vol	50-60	60-75	60-75	68
CO2 % vol	38-34	33-19	33-19	26
N2 % vol	5-0	1-0	1-0	-
O2 % vol	1-0	< 0,5	< 0,5	-
H2O % vol	6 (à 40 ° C)	6 (à 40 ° C)	6 (à 40 ° C)	6 (à 40 ° C)
Total % vol	100	100	100	100
H2S mg/m3	100 - 900	1000 - 4000	3000 – 10 000	400
NH3 mg/m3	-	-	50 - 100	-
Aromatic mg/m3	0 - 200	-	-	-
Organochlorinated or organofluorated mg/m3	100-800	-	-	

Table 3. *Physical characteristics of biogas and natural gas (Website of Naskeo Environment 2009)*

Types of gas	Biogas 1 Household waste	Biogas 2 Agrifood industry	Natural gas
Composition	60% CH4 33 % CO2 1% N2 0% O2 6% H2O	68% CH4 26 % CO2 1% N2 0% O2 5 % H2O	97,0% CH4 2,2% C2 0,3% C3 0,1% C4+ 0,4% N2
PCS kWh/m3	6,6	7,5	11,3
PCI kWh/m3	6,0	6,8	10,3
Density	0,93	0,85	0,57
Mass (kg/m3)	1,21	1,11	0,73
Indiex of Wobbe	6,9	8,1	14,9

(PCI - lower heating value, PCS – higher heating value)

2.3 Bio methane as a vehicle fuel

Biogas was first adopted for vehicle fuel use in Germany in the 1930's. There has been three main key development waves since: the Second World War, the 1970's oil crisis, and the present day quest for sustainability. "One of the alternatives offering complete crude oil in all forms of transport needs, is methane. Although it receives much less media attention than hydrogen and electric cars, it is the only alternative fuel, which has already proved that crude oil dependency can be broken," *(Lampinen 2013).*

Biogas by definition is a mixture of several gases obtained by anaerobic digestion of organic material. However, the chemical composition is based on the type of feedstock *(table 3).* The chemical and physical properties of natural gas and biomethane fuel are the same, the only difference is the fuel source origin, since natural gas is considered fossil but biomethane renewable.

The useful part of the energy of biogas is the calorific value of its methane content. The other components of biogas rather absorb than create energy in combustion process.

The complete combustion reaction of methane:

$$CH_4+2O_2 = CO_2 + 2H_2O.$$

Vehicle manufacturers state that vehicles can use either compressed natural gas or liquefied natural gas. Biomethane has a low volumetric calorific value so it has to be compressed or liquefied to be stored in vehicles, otherwise the vehicles would not receive the necessary energy content. The technical conditions for gas storing are discussed in Chapter 2.4.

2.4 Infrastructural requirements

A reliable infrastructure is required in order to support the transition to biogas fueled vehicles. A stable supply of fuel as well as accessible filling stations are needed to support the transition to biomethane from diesel or gasoline. Currently (2017), there are 25 public biogas filling stations in Finland, located mostly in the southern part of the country (figure 4) and they are operated by 8 different operators. Fossil methane is also available in 21 of these biogas filling stations, and in 3 other stations. Most of the biomethane available at the filling stations originates from domestic biowaste.

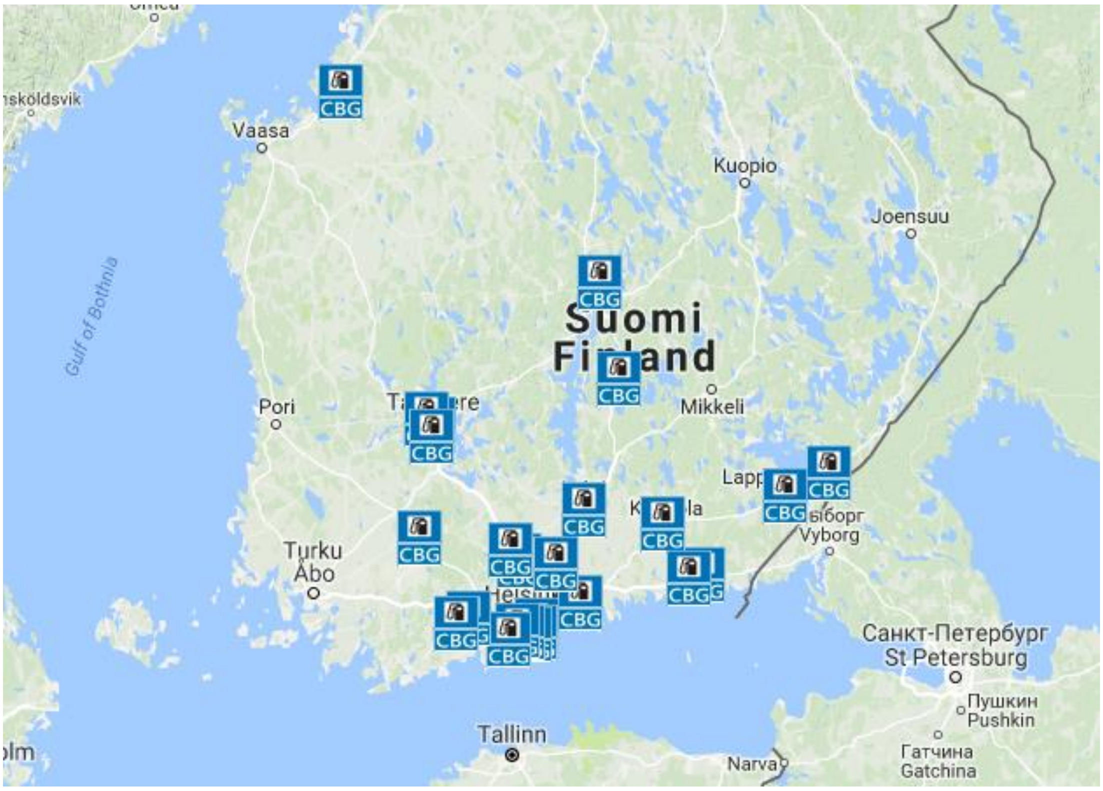

Figure 4. *Map of existing CBG100 filling stations in Finland (Website of CBG100 2017)*

2.4.1 CNG station

Buses are usually fueled with CNG at *time - fill* stations during night time. Low pressure CNG is delivered to on site compressor, where gas is compressed to 200 to 250 bar pressure and directly filled to vehicle tanks. In difference to *fast - fill* stations, vehicles are generally filled with gas from high pressure storage vessels (see figure 5). The purpose of buffer tank in figure 5 is to keep the compressor from turning off and on unnecessarily which would lead to wasting electricity and causing damage to the compressor. The size of the compressor depends on the demand of the compressed gas supply. The filling time of the vehicles can take from minutes to hours, depending on the compressor size, amount of vehicles and the amount of buffer storage *(Website of Alternative Fuels Data Center 2017).*

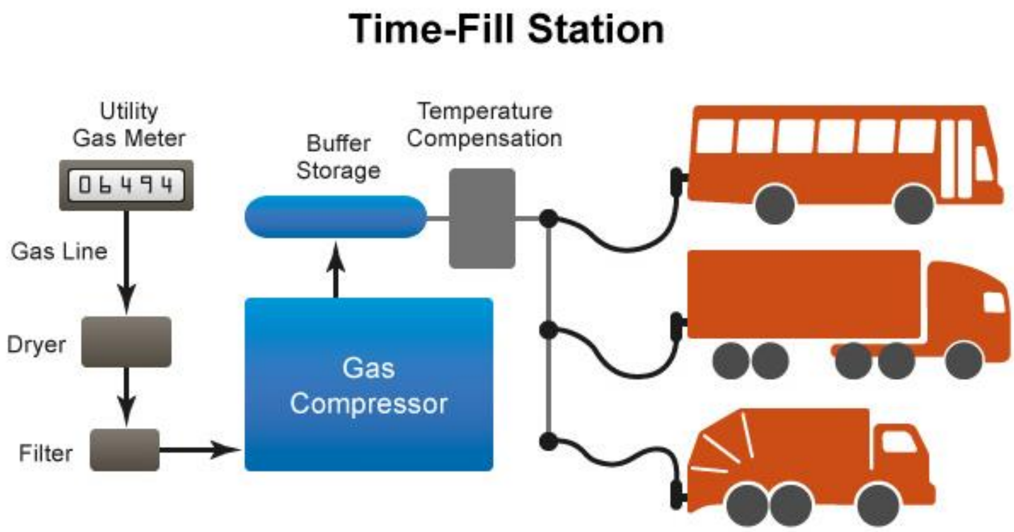

Figure 5. *Example of a time-fill CNG station configuration (Website of Alternative Fuels Data Center 2017)*

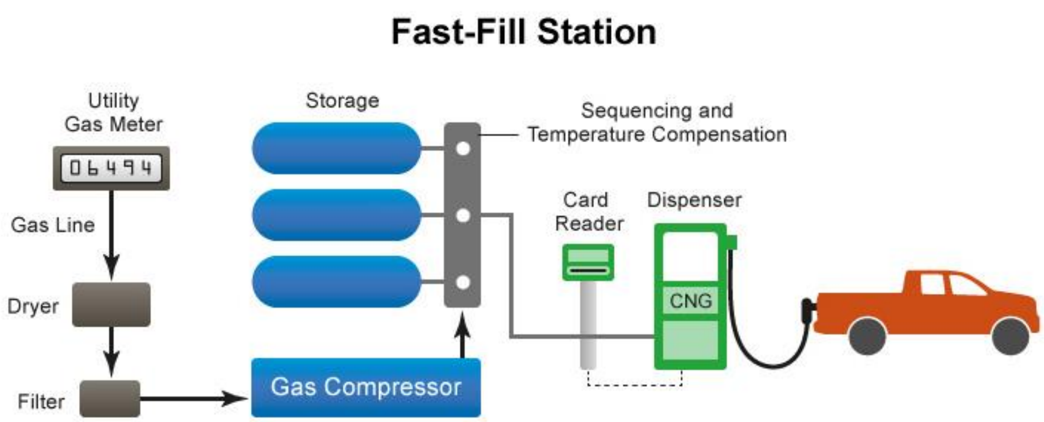

Figure 6. *Example of a fast fill CNG station configuration (Website of Alternative Fuels Data Centre 2017)*

Figure 7. *CNG bus left for filling at station in city of Vaasa. Photo by the author.*

2.4.2 LNG station

LNG is natural gas stored as a super-cooled liquid typically between -120 °C and -170 °C. LNG has a high energy density comparable to other forms of methane, making it more suitable for heavy duty vehicles, extending the travel range and reducing refueling frequency. However, it is very energy intensive to store the natural gas at the required temperature. LNG has become more popular in the US, Japan, the UK and some countries in Europe for heavy duty applications. However, LNG has not been seen currently as a practical option for many developing countries. *(Website of Alternative Fuels 2017)*

LNG filling stations (figure 8) are structured similarly to diesel and gasoline filling stations as the fuel is delivered in a liquid state. The dispenser delivers fuel to the vehicle tank at a pressure of 2…8 bar. Stations can be mobile, containerized or permanent with a greater storage capacity.

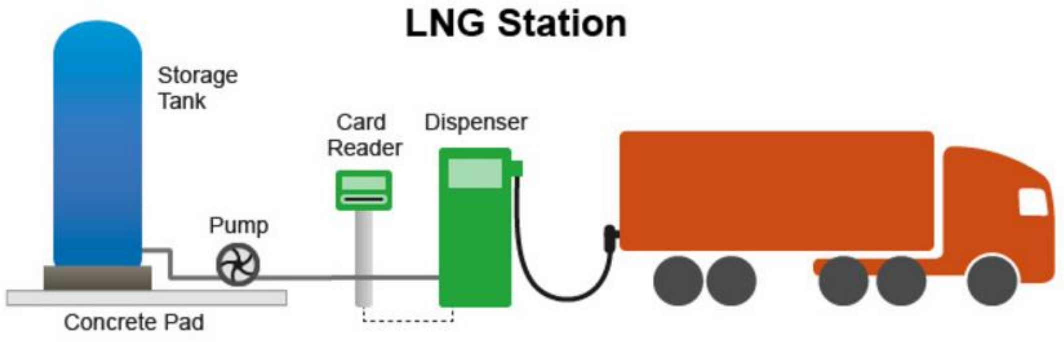

Figure 8. *Example of a fast fill LNG station configuration (Website of Alternative Fuels Data Center 2017)*

3 PUBLIC BUS SERVICE IN PORI

3.1 General

The local bus service in Pori is divided in 40 bus lanes covering the city with additional routes to nearby towns. The service is operated by Porin Linjat Oy which holds ownership of 90% of the city lanes. The service of Porin Linjat is used by approximately 4 500 customers on a daily basis. There are 50 buses serving the daily routes and the total length of the bus lanes is around 800 km. Buses are fueled by diesel and annually consuming 992 147 liters of fuel. The average consumption of a bus is 33.02 liters per 100 kilometers. The total annual mileage of the buses is around 3 004 232 kilometers and around 2 440 000 bus lane kilometers. Most of the buses are Scania brand, but there are a few Volvo, Man and Iveco buses (*Valtanen 2017).*

Figure 9. *Buses of Porin Linjat at maintenance. Photo by the author.*

3.2 Bus emission standards

The emission regulation standards for heavy duty vehicles started in 1988. However, the “Euro” track started in 1992 strengthening the standards to be implemented in the next few years *(Website of Transport Policy)*. Most of the buses in city comply with Euro III, IV and V emission standards (figure 10) which regulates the amount of CO, NOx, PM and HC in the exhaust gas. The CO_2 exhaust emissions of vehicles are not regulated. More detailed information about the buses can be seen in appendix 1.

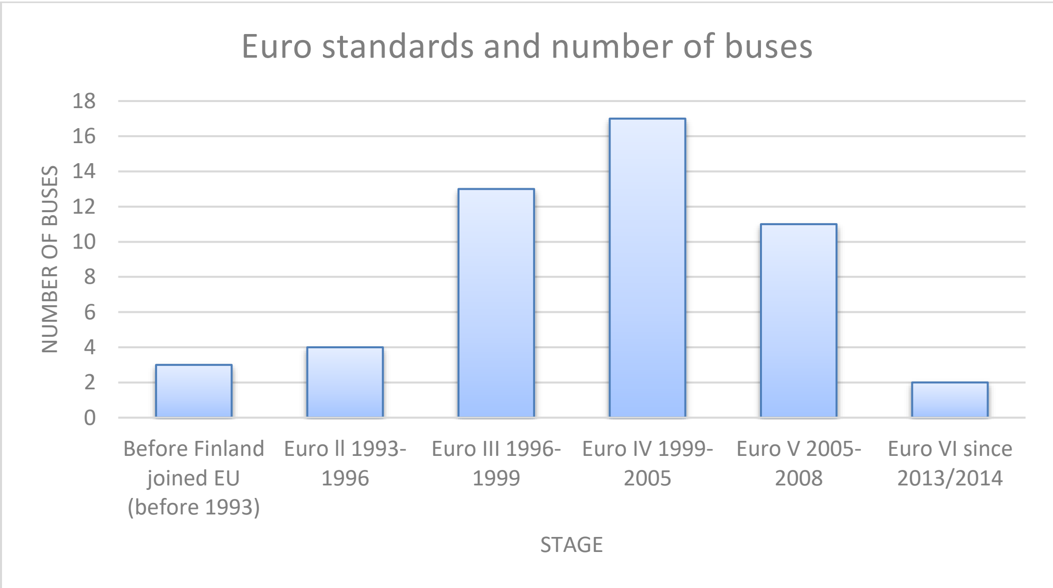

Figure 10. *Porin Linjat vehicles and corresponding Euro emission class based on bus registration year*

3.3 Theoretical fuel consumption

The actual fuel consumption and the emissions of the buses are affected by the characteristics of the journey (traffic and road conditions, number of stops) as well as the driving style, bus occupancy and technical conditions of the bus (Nylund 2007). The other important consideration here is the difference between the engine technology of diesel and CNG buses. By comparing the spark ignition engine (gas fuel) to compression ignition engine (diesel fuel) it has been found that diesel engines are substantially more efficient (Harvey 2010).

The method used for theoretical value of potential CNG consumption in Pori is based on the ratio of the performance of CNG buses in Vaasa and average diesel fuel consumption in Pori. Most of the data was obtained from Porin Linjat and Vaasa. Corresponding calculation and data explanation are found on appendix 2 and appendix 3. The average diesel consumption of Porin Linjat buses was recalculated neglecting vehicles that do not possess the typical characteristics of an urban passenger bus.

The theoretical value of CNG consumption is computed by following equation:

CNG (P) = CNG (V) x Diesel (P) / Diesel (V), where

CNG (P) = Theoretical CNG consumption in the city of Pori (kg/100km);
CNG (V) = Average CNG consumption in the city of Vaasa (kg/100km);
Diesel (P) = Average diesel fuel consumption in the city of Pori (kg/100);
Diesel (V) = Calculated value of diesel fuel consumption in the city of Vaasa (kg/100km).

3.4 Results on fuel consumption

Based on obtained data and assumptions, the computation results (see appendix 3) show that the theoretical value of diesel equivalent for CNG bus in city of Pori would be approximately 38.2 kg of fuel per 100 km which would be by 35% more than current average diesel consumption based on fuel mass. The total CNG demand for the whole bus fleet would add up to 114 764 745 kg annually. However, other test studies on fuel consumption conducted by VTT suggest that CNG buses consume on average 30% more energy than diesel buses (Nylund, Erkkilä, Clark & Rideout 2005).

3.5 Carbon dioxide accounting methodology

The most extensive studies and calculations of the regulated traffic exhaust emissions (NOx, CO, PM, HC, SO_2, CH_4) in Finland are assessed by LIPASTO calculation system, which is developed by VTT. The results of software calculation are presented in unit of grams of emissions per kilometer per passenger *(Website of VTT 2009).*

In this study, the carbon dioxide emission calculations are based on the tier 1 methodology of IPCC 2006 Guidelines for National Greenhouse Gas Inventories which enables to evaluate carbon dioxide emissions based on the amount of fuel consumed. The aim was to compute the current carbon dioxide emissions of the bus fleet and compare the results to an equivalent bus fleet operated by CNG or CBG. In this case, the number of passengers is not relevant as the use of fuel would not affect the passenger amounts.

The mass of carbon dioxide emissions is computed by following equation:

Emission amount (CO_2) = Fuel x SE x 44/12 x oxidizing factor, where

Emission amount CO_2 = t CO_2 emissions (t);
Fuel = amount of fuel used (TJ);
SE = Special emissions of carbon (t C/TJ);
44/12=molar mass ratio of carbon dioxide and carbon.

3.6 Factors considered and assumptions

The calorific value of diesel and CNG fuel and special emissions of carbon in table 4 were obtained from VTT. The other values, such as annual mileage and number of buses, are provided by Porin Linjat. The annual mileage is considered as distance travelled of lane kilometers plus the rest of the distance when bus is in operation but not on duty. The theoretical fuel consumption of CNG is explained in Chapter 3.4 and calculated in appendix 3. Emissions resulted from bio methane fuel combustion are assumed as 0 as the source of its production is renewable, even though in real life those are almost identical to carbon emissions resulted from natural gas combustion.

3.7 Results on CO_2 emissions

Table 4 presents the carbon dioxide emissions based on tier 1 methodology and assumptions explained in Chapters 3.5 and 3.6. Based on all assumptions, the results tell that if biomethane was substituted for diesel fuel, there would be around 2 672 tonnes of savings for CO_2 annually for total fleet, however natural gas equivalent would increase the CO_2 emissions by 470 tonnes.

Other studies where tested CNG consumption was 39 kg/100 km and 34 kg/100 km (41 l/100 km) of diesel, suggest that natural gas equivalent of urban bus fleet with similar annual mileage as Pori fleet would save around 100 tonnes of carbon dioxide emissions annually and 3 774 tonnes if biomethane was used (Tonissoo 2012).

Table 4. *CO_2 emissions computation of diesel, CNG, CBG fueled buses*

	Calorific value	Carbon emission	Oxidation factor	Fuel consumption		Carbon emissions		1 bus	All buses
	MJ/kg	gC/MJ		l/100 km	Kg/km	g/CO_2/kg	g/km	t/yr	t/yr
Diesel	43	20.2	0.99	33.43	0.28	3 148	889	53.43	2 672
Natural gas	49.1	15.3	1		0.38	2 750	1 046	62.82	3 141
Bio methane	49.1	15.3	1		0.38	0	0	0	0
				Annual CO_2 cuts if NG is used (t/yr):					**-470**
				Annual CO_2 cuts if biomethane is used (t/yr):					**2 672**

4 BIOGAS SOURCES IN PORI

4.1 Source availability

A research conducted in 2012 by Pöyry Finland Oy found that heat production from biogas is not economic, because it would exceed the need of district heating network, and additional capacity would not be required. Also bio methane production was found not viable because of no existing gas - powered vehicle fleet. However, it was mentioned that if the use of LNG increases in the region, biogas production should be reconsidered. In autumn 2016, Finland's first LNG terminal was constructed in port of Tahkoluoto, Pori. The facility is promoting the use of LNG for ships, contributing to the security of gas supply in Finland *(Website of Hydrocarbons-technology).* New LNG terminal would also support the transition of bio methane fuel utilization, meaning that the produced biogas could be injected in LNG grid as well as the new LNG source would serve as a back-up fuel in case if the demand for biomethane exceeds production rates.

4.2 Raw materials for biogas production

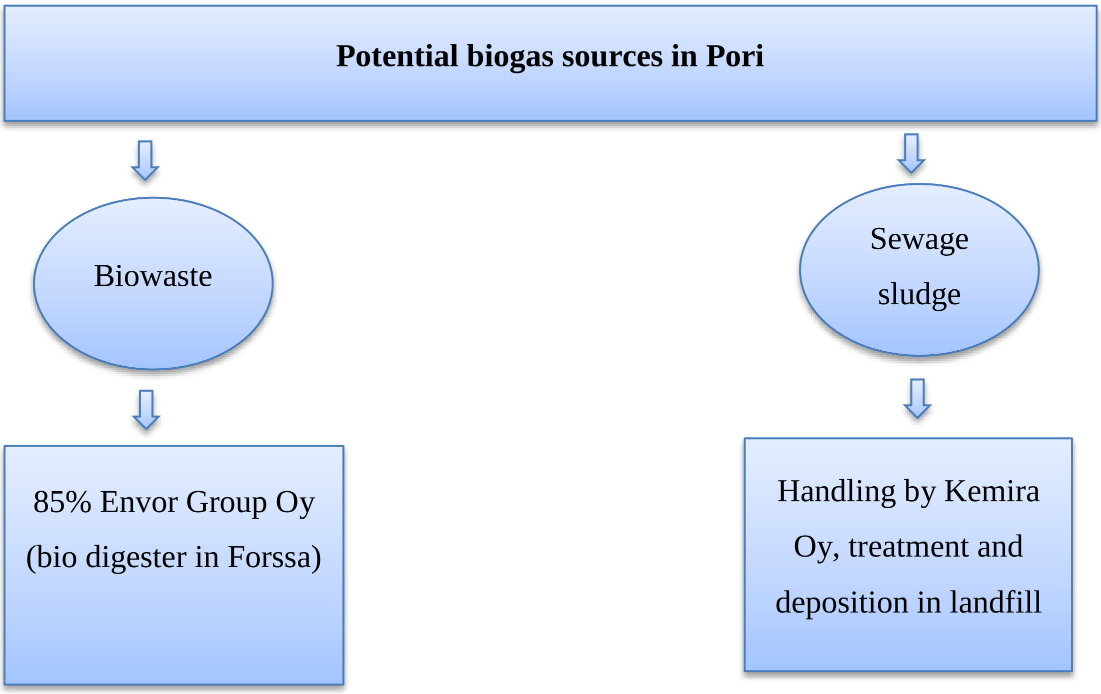

Figure 11. *Biowaste and sewage sludge handling in city of Pori*

Figure 11 presents current (2017) handling of biowaste and sewage sludge from Pori. Sludge from waste water is one of the potential raw material sources in city of Pori for biogas production. The biogas produced from sewage sludge typically contains 60 to 75% of methane gas. The waste water treatment is operated by Porin Vesi and the sludge treatment is handled by Kemira Oy before it is finally disposed into the landfill. In 2012, Pöyry Finland Oy assessed a scenario of biogas production from sludge after termination of the current contract. The daily flow rate of waste water, dried sludge, suspended solids and biological oxygen demand from 2011 to 2012 are shown in figure 12.

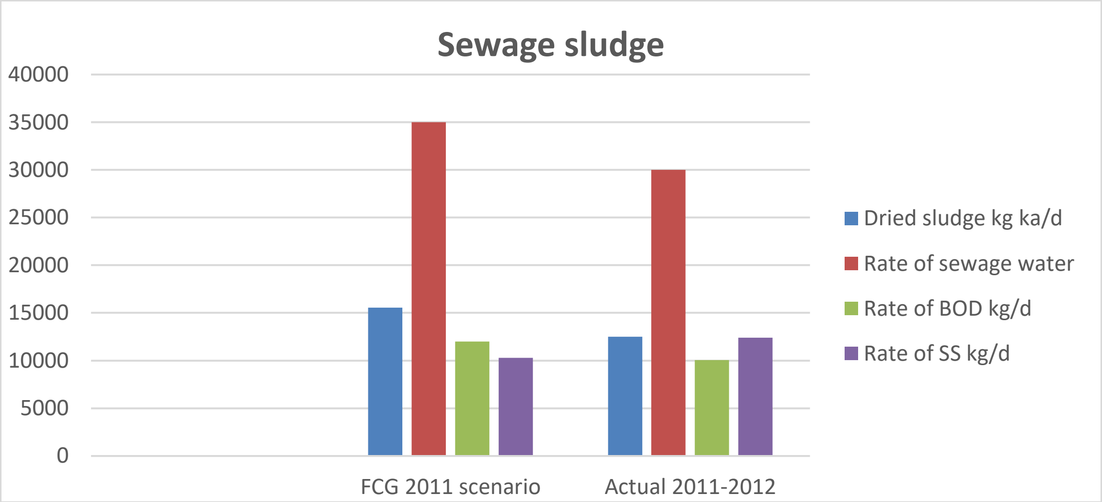

Figure 12. *FCG's (consulting company) predicted sludge production in 2011 versus the actual rate of return sludge 2010-2011 (Pöyry, 2012)*

The other available source for biogas production in Pori is biowaste. Around 85% of biowaste produced in Pori is transported to a bio digester in Forssa, which is operated by waste company called Envor Group Oy. The amount of biowaste from city of Pori has increased from 2006 till 2011 from 25 000 to 35 000 tonnes (see figure 13). Both biowaste and sewage sludge are reliable sources for biogas production.

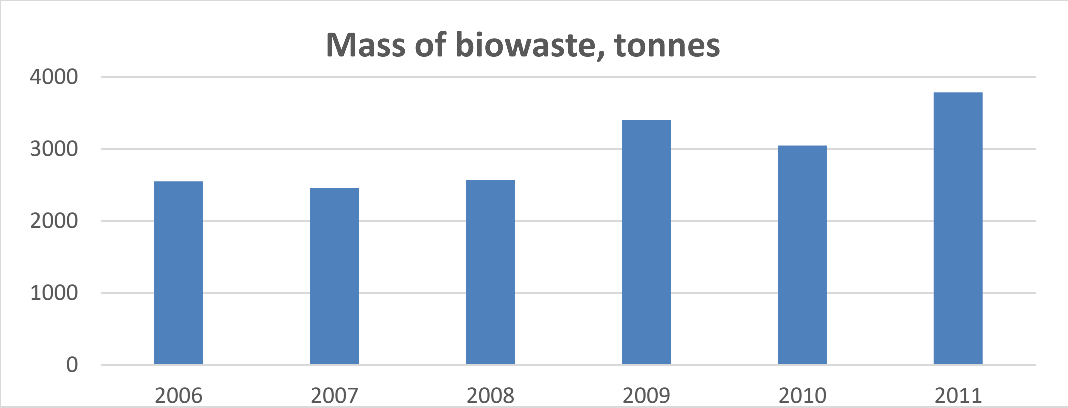

Figure 13. *Amount of biowaste 2006 – 2011 (Pöyry, 2012)*

4.3 Method of biogas production estimation

The purpose of the potential biomethane production calculations was to evaluate if the produced amount of biomethane could supply the demand for CBG fleet in city of Pori. The computations of production are based on data of a previous study, presented in table 5 and table 6. The theoretical demand of CBG equivalent for the bus fleet is discussed in Chapter 3.4 and calculations are found in appendix 3.

Table 5. *Dimensioning of biogas production from sewage sludge (Pöyry 2012)*

BIOGAS PRODUCTION FROM SLUDGE	
Required reactor capacity, m^3	7 400
Number of reactors	2
Capacity of one reactor, m^3	3 700
Detention time, d	21
Organic load, kg VS/ m^3 d	
Summer	2.33
Winter	2.27
Specific gas yield, l CH_4 / kg VS_{in}	300
Gas production rate, m^3/ h (CH_4 65%)	270
Gas energy output, kW	1 750

VS – Volatile solids

Table 6. *Dimensioning of biogas production from sewage sludge and biowaste (Pöyry 2012)*

BIOGAS PRODUCTION FROM SLUDGE AND BIOWASTE	
Required reactor capacity, m^3	8 200
Number of reactors	2
Capacity of one reactor, m^3	4 100
Detention time, d	21
Organic load, kg VS/ m^3 d	
Summer	2.50
Winter	2.43
Specific gas yield, l CH_4 / kg VS_{in}, sludge	300
Specific gas yield, l CH_4 / kg VS_{in}*, biowaste	430
Gas production rate, m^3/ h (CH_4 65%)	330
Gas energy output, kW	2 150

VS – Volatile solids

4.4 Results

Table 7 presents a theoretical estimate of the biomethane production from waste water sludge and biowaste and the number of CNG buses that could be supplied with fuel. The estimated production of biomethane from sewage sludge and biowaste would supply the need of 59 buses, which is more than there are currently operating on daily service. Estimated biomethane production from sewage sludge alone could fuel 48 CNG buses which is almost the whole fleet. According to data presented in tables 5 and 6 the methane content of the produced biogas is 65% regardless if it is produced only from sewage sludge or from sewage sludge and biowaste.

Table 7. *Potential of CH_4 production in city of Pori and number of CNG buses*

Nr.	Material	Generation of gas	Generation of gas	Amount of CH_4	Amount of CH_4	Nr of buses
		m^3/h	m^3/d	m^3/d	kg/d	
1	Sludge and bio-waste	330	7 920	5 148	3 707	59
2	Sludge	270	6 480	4 212	3 033	48

The number of buses was computed by following equation:

Nr of buses = Amount of CH_4 (kg/d) / CH_4 consumption (kg/d/bus), CH_4 consumption – see appendix 3.

1. *Nr of buses =(3 706.56 kg/d) / (62.55 kg/d/bus) = 59 buses*
2. *Nr of buses = (3 032.64 kg/d) / (62.55 kg/d/bus) = 48 buses*

Table 8 describes the number of buses that could be supplied with biomethane produced from sludge and biowaste and the corresponding annual carbon dioxide cuts. Biomethane produced from sludge could fuel up 48 buses and cut 2 565 tonnes of carbon dioxide emissions annually. However, fuel produced from biowaste could fuel up 11 buses saving only 587 tonnes of carbon dioxide emissions on annual basis.

Table 8 *Potential of biomethane production in city of Pori and CO_2 cuts*

Nr	Material	Generation of gas	Generation of gas	Amount of CH_4	Amount of CH_4	Nr of buses	CO_2 cuts (t/a)
		m^3/h	m^3/d	m^3/d	kg/d		
1	Sludge and biowaste	330	7 920	5 148	3 707	59	3 152
2	Sludge	270	6 480	4 212	3 033	48	2 565

5 CONCLUSIONS

Generally, biomethane as a renewable vehicle fuel has a potential to reduce the fossil fuel dependency and improve the local air quality. Therefore it can be considered as a sustainable alternative to diesel fuel. In order to carry out transition to biomethane fuel in bus fleet, investment in infrastructural development is required. Apart from local biogas production and upgrading plant, filling stations would have to be installed as well as new buses would have to be purchased or leased. As for any investment, the fuel transition would have to be financially feasible.

It was interesting to find out that the theoretical CNG consumption appeared to be about 35% higher than the average diesel equivalent based on fuel mass. This is so even though the calorific value of CNG is higher. This might indicate the efficiency differences between the gas and diesel engines. However, the calculated CNG consumption is theoretical. Exact consumption values can be obtained by performing real-life testing of CNG buses in the actual routes where buses are daily operating. Naturally the fuel consumption is also affected by the characteristics by the road conditions, traffic and driving style. However, the fuel consumption would be important to consider when assessing the financial feasibility.

The results in chapter 4.4 show that there would be enough raw material for biomethane production to supply the fuel demand of the bus fleet in Pori. The total capacity of biomethane production could supply fuel for 59 buses, which is more than required. However, the biowaste from the city of Pori is already used for biogas production but not locally.

The data of sewage sludge from waste water treatment and biowaste amounts are from 2012 and those values may have changed by now (2017). It is assumed that there has not been any dramatic change in waste water and biowaste production rates in past years, but in order to obtain more precise results, calculations should be based on updated values.

It was estimated that the use of biomethane equivalent for entire bus fleet could reduce CO_2 emissions by 2 672 tonnes annually. However, the carbon calculation results are based on fuel combustion reactions. Even though it is assumed that biofuels are carbon neutral, in real life the carbon dioxide emissions from biomethane and natural gas combustion would be almost identical. Based on theoretical assumptions in this study, equivalent amount of combusted diesel fuel for same travel distance would result to less emissions than those from natural gas or biomethane.

It would be worth to study further the carbon footprint from biomethane production, transportation and storing to create more comprehensive understanding of the total environmental impact. Also it would be interesting to evaluate the emissions resulted by decomposition process of deposited sludge and biowaste in landfills.

REFERENCES

ANFAC 2015: Vehicles in Use (2009-2014). Referred: 10.03.2017. http://www.acea.be/statistics/tag/category/anfac-vehicles-in-use-report

European Automobile Manufacturers Association 2016, "Manifesto for Clean, Smart and Smart Mobility", http://www.acea.be/publications/article/manifesto-for-clean-safe-and-smart-mobility

Hällilä P., 2017. Presentation on biogas buses in city of Vaasa. 30.03.2017.

Harvey, D. D. L., 2010 Energy and the New Reality 1, Energy Efficiency and the demand for Energy Services. London: Earthscan. Page 264.

Lampinen A., 2012. Roadmap to renewable methane economy. Page 18-19. https://www.globalmethane.org/documents/finland_roadmap_renewable_methane_economy.pdf

Lampinen A., 2013. Development of biogas technology systems for transport. Page 5. http://www.ths.fi/Lampinen_TW-3-2013.pdf

Nylund, N., Erkkilä, K., Clark N. & Rideout G., 2005. Buss Emission Evaluation: 2002-2004 Summary Report. Page 34. http://www.vtt.fi/inf/pdf/tiedotteet/2007/T2396.pdf

Pöyry Finland Oy, 2012 "Porin Vesi. Luotsinmäen keskuspuhdistamon lietteenkäsittelyn ja energiakysymysten esiselvitys". Page 42- 44, 54, 60.

Tonissoo T, 2012. "Feasibility study on the introduction and use of biogas buses in the Tartu City". Page 54. http://www.balticbiogasbus.eu/

Valtanen J., Data of Porin Linjat fleet. Sent: 04.04.2017. Referred 04.04.2017

Website of Alternative Fuels Data Center 2017. Referred 01.05.2017. http://www.afdc.energy.gov

Website of Alternative fuels, http://www.afsglobal.com/faq/gas-comparisons.html 2017. Referred 01.02.2017.

Website of CBG100. http://www.cbg100.net/in-english/map-of-filling-stations/. Referred 10.10.2017

Website of Hydrocarbons-technology. http://www.hydrocarbons-technology.com. Referred: 25.01.2017.

Website of Naskeo Environment 2009. http://www.biogas-renewable-energy.info/biogas_composition.html. Referred 24.01.2017.

Website of VTT 2009. http://lipasto.vtt.fi/. Referred 27.03.2017.

APPENDIX 1

LINJA-AUTOLIIKENTEEN AUTOKALUSTOLUETTELO 1.1.2017

Liikenteenharjoittajan nimi: **PORIN LINJAT OY**

Kotikunta/LAL:n osasto: Pori/Lounais-Suomi

Luvanvaraiseen liikenteeseen rekisteröityjen linja-autojen lukumäärä ilman vara-autoja: **50** kpl

* vara-autojen lukumäärä (ajosuorite alle 10 000 km linja-auto): **2** kpl

	Alusta			Kori		Matkustajatilat		Auton varustus						Auton käyttö				
Nro	Merkki	Rekisterinro	Vm	Merkki	Vm	Istuma	Seisoma	100	WC	Video	Puh.	ML	VV	Tilaus	Pika	Paik	Vakio	Vara
1	Scania	XEY-629	2008	Lahti Scala	2008	46	30					1	1			1		
2	Scania	JHK-502	2008	Lahti Scala	2008	46	30					1	1			1		
3	Scania	BPM-852	2004	Vest Center	2004	40	35					1	1			1		
4	Scania	OUN-396	2014	OMNI 320LE	2014	48	31					1	1			1		
5	Scania	OUN-397	2014	OMNI 320LE	2014	48	31					1	1			1		
6	Scania	CLI-966	2006	VestCenterH	2006	41	30					1	1			1		
7	Scania	KBF-587	2005	Lahti Scala	2005	46	32					1	1			1		
8	Scania	KBF-588	2005	Lahti Scala	2005	46	32					1	1			1		
9	Volvo	OFI-469	1993	Wiima K202	1993	46	22										1	
10	Volvo	OFI-468	1993	Wiima K202	1993	46	22										1	
11	MAN	KLF-376	2005	Lion's City	2005	41	39					1	1			1		
12	Scania	HTF-612	2005	Lahti Scala	2005	46	32					1	1			1		
13	Volvo	JFA-813	2002	8700 LE	2002	46	24					1	1			1		
14	Scania	FHP-314	2006	Lahti Scala	2006	46	32					1	1			1		
15	Scania	FJV-947	2000	Omnilink	2000	38	25					1	1			1		
16	Scania	FJV-956	2000	Omnilink	2000	38	25					1	1			1		
17	Scania	JHK-617	2008	Lahti Scala	2008	46	32					1	1			1		
18	Scania	EMK-922	2005	Vest Center	2005	40	37					1	1			1		
19	Scania	OVK-672	2006	VestCenterH	2006	41	25					1	1			1		
20	Scania	FHP-320	2006	Lahti Scala	2006	46	32					1	1			1		
21																		
22	Scania	SLU-292	2015	OMNI 320LE	2015	48	31					1	1			1		
23																		
24	Scania	UZJ-175	2008	Vest CenterH	2008	41	28					1	1			1		
25	Scania	BPM-854	2004	Vest Center	2004	40	35					1	1			1		
26	MAN	BUF-512	2004	SU 313	2004	44	0	1		1							1	
27	Scania	JIJ-273	2012	Lahti Scala	2012	50	29					1	1			1		
28	Scania	EKY-728	2010	Lahti Scala	2010	46	37					1	1			1		
29	Scania	EKY-719	2010	Lahti Scala	2010	46	37					1	1			1		
30	Scania	NHV-348	2011	Lahti Scala	2011	46	37					1	1			1		
31	Scania	NHV-347	2011	Lahti Scala	2011	46	37					1	1			1		
32	Scania	YIU-332	2008	Lahti Scala	2008	44	33					1	1			1		
33	Scania	LYY-464	2009	Lahti Scala	2009	46	37					1	1			1		
34	Setra	BZK-614	1998	Setra	1998	44	26					1				1		
35																		
36	Scania	LYY-466	2009	Lahti Scala	2009	46	37					1	1			1		
37	Scania	YIU-337	2007	Lahti Scala	2007	41	31					1	1			1		
38	Scania	YIC-268	2004	Vest Center	2004	40	35					1	1			1		
39	Scania	EMK-920	2005	Vest Center	2005	40	37					1	1			1		
40	Scania	GMK-930	2016	InterLink	2016	49+1		1	1	1				1				
41	Scania	UZJ-185	2007	VestCenterH	2007	41	27					1	1			1		
42	Scania	SLU-270	2007	VestContrast	2007	51	4										1	
43	Scania	YIC-271	2004	Vest Center	2004	40	35					1	1			1		
44	Scania	YFG-676	2004	Lahti Scala	2004	46	32					1	1			1		
45	Scania	KBF-470	2004	Lahti Scala	2004	46	32					1	1			1		
46	Scania	YIC-269	2004	Vest Center	2004	40	35					1	1			1		
47	Scania	YIU-347	2003	Lahti Scala	2003	46	35					1	1			1		
48	Scania	YIC-272	2004	Vest Center	2004	40	35					1	1			1		
49	Scania	EJO-449	1988	Ajokki	1988	38	35									1		
50	Scania	EMK-921	2005	Vest Center	2005	40	37					1	1			1		
51	Iveco	XAY-351	2008	Marco Polo	2008	21	0	1		1				1				
52	Volvo	IRF-717	2002	8700 LE	2002	40	26					1	1			1		
53	Scania	JCS-51	2006	Lahti Falcon	2006	52	0	1	1	1				1				
54	Scania	NBR-967	1997	Carrus Class	1997	48	0	1	1	1				1				
55	Scania	HXG-755	2007	Eagle	2007	48	0	1	1	1				1				
56	Volkswage	RNZ-558	2005	Transporter	2005	9	0											
	Yhteensä					**2235**	**1438**	**6**	**4**	**6**	**0**	**42**	**41**	**5**	**0**	**43**	**4**	**0**

Rasterilla merkityt autot uudelleen koritettuja. **52**

Auto 56; Volkswagen Transporter, (henkilöauto omassa käytössä) on kuljettajien tuurinvaihtoauto

APPENDIX 2

Performance of the CNG buses in city of Vaasa and estimation diesel fuel equivalent.

Given data:		
Average CNG consumption per 100 km	**41**	**kg**
Number of CNG buses	**12**	
Estimated substitution of diesel fuel	**280 000**	**l**
Estimated annual CNG consumption	**320 000**	**kg**
Used values:		
Specific weight of natural gas	**0.72**	**kg/m^3**
Specific weight of diesel fuel	**0.845**	**kg/l**
Calculated values:		
Consumption of diesel fuel		
280 000 l x 0.845 kg/l	**236 600**	**kg**
Total fleet annual mileage		
320 000 kg CNG x 100 km /41 kg$_{CNG}$	**780 487.8**	**km**
Annual mileage per one bus		
780 487.8 km / 12 buses	**65 040.65**	**km**
Diesel consumption per 100 km		
236 600 kg $_{Diesel}$/ 780 487.8 km x 100 km	**30.31**	**kg**
Diesel consumption per 100km		
280 000 l $_{Diesel}$ / 780 487.8 km x 100 km	**35.88**	**l**

APPENDIX 3

Average diesel consumption per 100 km for Porin Linjat Buses

Given data:		
Total annual mileage of buses:	3 004 282	km
Average annual mileage of a bus:	60 084.64	km
Average daily mileage of a bus:	165	km
Buses in service on daily basis:	50	
Total annual diesel consumption:	992 147	l
Average consumption per bus per 100km	33.02	l

New theoretical average diesel consumption per 100 km excluding vehicle 51 and 56 since they do not possess characteristics of a typical city bus.

	Annual mileage [km]	**Annual diesel consump-tion [l]**
All 51 buses	3004282	992147
Bus 51	41911	6285
Bus 56	19037	1997
Excl. 51, 56	2943334	983865
New average consumption [l/100 km]:		**33.43**

Theoretical average bus CNG consumption in city of Pori per 100 km:

CNG (P) = CNG (V) x Diesel (P) / Diesel (V);
CNG (P) = 41 kg x 33.43 l / 35.88 l
CNG (P) = 38.20 kg

Theoretical annual demand of CNG fuel for Porin Linjat buses:

$$CNG_{(annual)} = 38.20\ kg / 100\ km \times 3\ 004\ 282\ km = 114\ 764\ 744.6\ kg$$
$$CNG_{(daily/bus)} = 38.20\ kg \times 164\ km / 100\ km = 62\ kg$$