Baltic Biogas Bus

Innovative biogas fuelling system alternatives for buses

Final Report

SL
Local partner

A project to stimulate the use of biogas as fuel for city buses, aiming to reduce environmental impact.

Baltic Sea Region
Programme 2007–2013

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The Baltic Biogas Bus project will prepare for and increase the use of the renewable fuel biogas in public transport in order to reduce environmental impact from traffic and make the Baltic region a better place to live, work and invest in. The Baltic Biogas Bus project is supported by the EU, is part of the Baltic Sea Region programme and includes cities, counties and companies within the Baltic region.

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Appendices:

Summary

This report is part of the Baltic Biogas Bus project. With SL as a reference, the objective of the report has been to describe and compare biogas fuelling system alternatives for buses. The report compares slow and fast fuelling systems for biogas, natural gas and hydrogen fuelling systems and analyses differences between costs, safety, fuelling time and environmental aspects as well as other benefits and disadvantages.

Handling of biogas at the bus depots includes creating an optimal refuelling system in relation to demands and needs. The design of a biogas bus depot and the fuelling system may vary depending on several parameters for example the biogas supply. The biogas supply to the depots in operation today is primarily constituted by a gas pipeline from the gas production unit feeding the depot with CBG/CNG. The biogas may also be delivered to the depot with mobile gas storages on swap bodies.

The typical components of a general refuelling system at a biogas bus depot includes a system for CBG/CNG fuelling that can vary in the detailed design but is conceptually designed after the same model. A fuelling system for CBG/CNG typically comprises:

- gas storage
- compressor unit
- priority panel
- fuelling system (slow system on ramp or fast filling via a dispenser)
- LNG back-up storage for redundancy

Refuelling of biogas is performed outdoors. For slow filling the bus is parked on a ramp location where each bus is connected to an individual fuel hose. Slow filling occurs mainly at night when the main part of the bus fleet is parked. Fast filling from a dispenser takes about 4-7 minutes.

There is a large difference in the operational experiences between the fuels of CBG, LNG and hydrogen. The main experience within Sweden and within SL is based on the great extent use of CBG. Today all of SL's buses run on CBG. As mentioned in Chapter 2, currently (June 2012), there are one LBG fuelling stations built and up and running on trial. The private company Scandinavian Biogas and Fuels International AB has constructed the LBG fuelling station in Uppsala municipality for 2 buses. The filling station is of a pilot size model and the operational experiences are limited. Looking into refuelling buses with hydrogen, the experience is limited to the 3 buses running in Stockholm during the CUTE project. There is today, globally on-going research on hydrogen and fuel cells technology.

The difference in investment costs between fast and slow refuelling is marginal for a 100 bus depot. The cost for a fast filling system is slightly more expensive. The main difference in investment costs is the dispenser for fast filling and refuelling nozzles for slow refuelling.

To conclude and summarise SL's experiences within refuelling of biogas buses, a summary of recommendations is given;

- The main operational experiences is from fuelling systems with CBG/CNG
- The specific conditions at the location of each depot control the choice of fuelling system i.e. slow filling or a fast filling system.
- It is preferably to use a combination of slow fuelling system and a dispenser for best flexibility.
- SL uses both systems today depending mainly on if the buses are parked indoors or outdoors. Fast fuelling alone is only used at indoor depots.
- The operational experiences from Söderhallen show that the try-out period with a higher pressure system led to a change in the system to a lower pressure. Therefore, the experiences gained in early stages shall be collected and used in the future planning of depots.
- Operational experiences show that fast fuelling is creating a more stressful environment for the staff compared to slow filling. At fast fuelling, maintenance staff at the depot fuels the bus and there is a large demand on logistics. The stressful environment has sometimes led to breakage of hoses when being run over by the bus.
- The refuelling system is part of the depot which needs to be planned together with the distribution system and to carefully examine logistics and if there are existing infrastructure that will lower the investment costs.
- Methane slip may occur during the fuelling process and shall be documented. However, the emissions from fuelling could more or less be considered negligible in normal circumstances. Essential measures for reducing methane losses during fuelling of biogas are to ensure proper operation without major fluctuations in the gas pressure and to work with regular controls and gas leakages checks.

Through the activities carried out in the BBB-project, a lot of experience of transnational importance has been gained. This will be communicated to project partners and other stakeholders through different means of communication available to the Baltic Biogas Bus project.

Abbreviations

BBB	Baltic Biogas Bus
BSR	Baltic Sea Region
CBG	Compressed Biogas
CNG	Compressed Natural Gas
LBG	Liquefied Biogas
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
WWTP	Waste water treatment plant

1. Introduction

1.1 Stockholm Public Transport (SL)

Stockholm Public Transport, SL, is 100 % owned by the Stockholm County Council. The Stockholm County Council has set the environmental goals for the transport company, and is the main driving force for expansion of a bus fleet running on renewable fuels in the Stockholm region.

SL manages the public bus transport system in Stockholm and has utilised biogas as vehicle fuel for inner-city buses since 2004. At the end of 2011, SL will have about 230 biogas buses in service and SL has extensive plans to continue the transition from diesel buses to biogas buses.

Today, in December 2011, biogas is considered SL's first hand choice in the company's aim to fulfil its environmental targets of:

1. At least 50 % of the bus traffic within SL will by the end of 2011 be running on renewable fuels,
2. 100 % of the bus traffic within SL will be running on renewable fuels no later than 2025

To meet these goals, a combination of different renewable fuels in the bus fleet is required.

1.2 The Baltic Biogas Bus Project

The Baltic Biogas Bus project prepares for and increases the use of the renewable fuel biogas in public transport sector. The aim is to reduce environmental impact from traffic and make the Baltic Sea region a better place to live, work and invest in.

The Baltic Biogas Bus project is partly funded by the European Regional Development Fund within the Baltic Sea Region programme. Twelve partners from eight Baltic Sea countries are directly involved in the project;

- Storstockholm Lokaltrafik (Stockholm Public Transport), Sweden
- Biogas Öst/ Energikontoret i Mälardalen (Energy Agency Malardalen), Sweden
- Ruter AS (Public Transport Company of greater Oslo), Norway
- HOG Energy, fuel interest organisation for the region around Bergen, Norway
- Hordaland fylkeskommun (Hordalen County Council), Norway
- VTT, Technical Research Centre of Finland
- Tartu city, the second city of Estonia
- Riga city council traffic department, the capital of Latvia
- Kaunas autobusai, the second city of Lithuania

- Motor Transport Institute, MTI, Poland
- ATI erc Education, research and furtherance of cooperations, Germany
- ITC Innovations and Trendcenter, Germany

Extended use of biogas for city buses will lower emissions, improve inner city air quality and strengthen the role of public transport in an efficient strategy to limit the impact from traffic on climate change.

The project generates strategies and policies to introduce biogas as well as analyses necessary measures in biogas production, distribution and bus operations. Activities are executed to facilitate further expansion.

A pan-Baltic network of partners forms a show room to demonstrate a sustainable transport system as a step towards reaching EU's climate goals. The partnership offers an ideal platform for cooperation, exchange and dissemination of knowledge, experience and technology. The partnership makes it possible to obtain a better position to negotiate with infrastructure and bus suppliers and at the same time raise the visibility of biogas buses.

There are good examples of the use of biogas buses in public transport, but wide acceptance and introduction in BSR cities has not taken place yet. Cities are unaware or have incorrect information of the benefits of biogas buses. Furthermore, shifting to biogas buses from fossil fuel buses is complicated and a long-term approach is needed. Biogas can be produced from a range of sources and biogas buses can be ordered from several bus manufacturers. Still the missing link for most cities is an integrated long-term strategy to work towards introduction of biogas buses.

1.2.1 Organisation

The Baltic Biogas Bus project is organized into 6 work packages (WP). The project consists of several parts that together create a platform for increasing the use of biogas as a fuel for buses in cities around the Baltic Sea. You may look upon the project as a jigsaw puzzle where you can identify the whole picture first when all the pieces – or working packages - are laid in correct positions. Close integration between the different parts of the project characterises the progress of the work.

Within the project, focus is on dissemination of the possibilities (WP 2) and providing cities the tools to set up a biogas bus introduction strategy (WP 3) in order to help cities to connect biogas supply (WP 4), distribution (WP 5) and use (WP 6), see Figure 1 below.

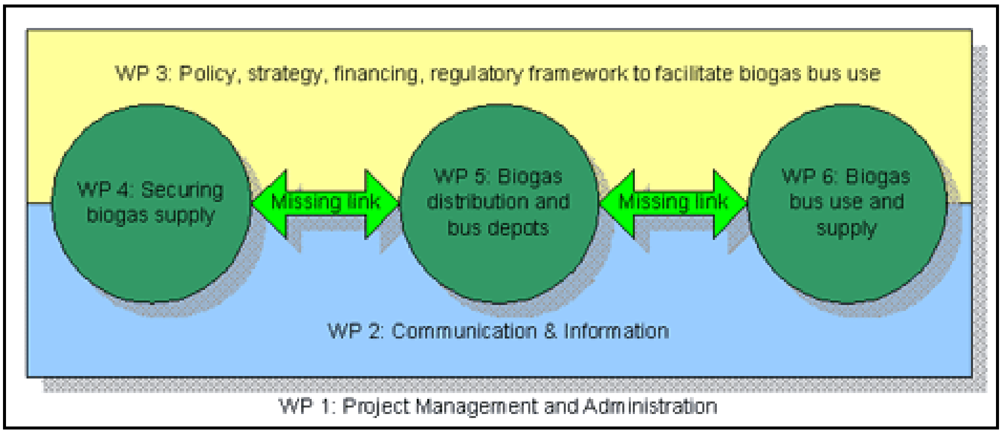

Figure 1. Organisation of the Baltic Biogas Bus project.

1.2.2 WP 5 – Biogas distribution and bus depots

This work package studies technological solutions for distribution of biogas and adaptation of bus depots to biogas, and presents an overview of regional infrastructure planning with focus on distribution and depots.

Work package 5 includes the following:

- Integrated regional distribution planning in Stockholm is presented,
- Alternative fuelling systems are analysed,
- How to design new bus depots and adapt existing depots for biogas is analysed,
- Cost effective options for biogas distribution per trailer is analysed,
- Specification for and logistics of using biogas cartridges system are analysed,
- An overview of the Baltic Sea Region existing and planned biogas infrastructure are presented,
- Feasibility study on a new pilot biogas fuelling station in Rzeszów, Poland is conducted,
- Feasibility study on expanding a fuelling station with biogas supply and adapting the station for biogas buses is conducted in Tartu, Estonia

1.2.3 WP 5.2 – Analyse fuelling system alternatives

Innovative biogas fuelling system alternatives for buses shall be analysed by SL. Operational experience from different biogas, natural gas and hydrogen fuelling systems will be compared for so called slow fuelling (overnight when buses are in the depot) or fast fuelling (within minutes) alternatives. In addition liquid form or gas form fuelling will be compared. The comparisons will take into account impact on costs, safety, fuelling time and environmental aspects and other benefits and disadvantages. The experience about slow and fast fuelling is an important input in design of new biogas bus depots when bus logistics and land area use have to be decided.

1.3 Objective of the report

The report covers comparisons between slow and fast fuelling systems for biogas, natural gas and hydrogen fuelling systems regarding costs, safety, fuelling time and environmental aspects as well as other benefits and disadvantages.

1.4 Methodology and limitations

The information presented in this report is based on:

- SL Action Plan on Biogas and relevant principal documents, existing case studies and conceptual and detailed designs of depots for biogas buses,
- Relevant external reports,
- Contacts and interviews with experts and operational staff within SL and companies connected to SL's activities in the biogas sector. These contacts has proven to be an essential part of this work package and key persons have been able to provide detailed information and on-site knowledge about the bus depots and fuelling systems within Stockholm Public Transport.

The study covers fuelling systems from the point when vehicle fuel (gas or liquefied gas) has entered the bus depot. Production, distribution and delivery of vehicle fuel will be further addressed in other reports within WP 4 and 5.

Production and utilisation of biogas will be further addressed in other reports within WP 4 and WP 6.

1.5 Outline

The structure of this report is as follows; this chapter gives a background to the Baltic Biogas Bus project and describes the objectives of the report and methodology used. Chapter two presents the general process and design of different fuelling systems. Chapter three explains SL's biogas model and presents four of SL's depots and the fuelling system of each depot. In chapter four technical and operational experiences of fuelling systems are described. Chapter five presents a summary of which rules and regulations that govern biogas fuelling systems and the procedure to obtain relevant permissions. In chapter six the main environmental aspects of biogas in a fuelling system are described. Chapter seven presents and concludes the main differences in costs of a slow and fast filling system. Finally, chapter seven concludes the report and gives the reader recommendations from SL's point of view regarding fuelling systems for biogas.

2 Fuelling systems general process and design

Handling of biogas at the bus depots includes creating an optimal refuelling system in relation to demands and needs. The design of a biogas bus depot and the fuelling system may vary depending on several parameters for example the biogas supply. The biogas supply to the depots in operation today is primarily constituted by a gas pipeline from the gas production unit feeding the depot with CBG/CNG. The biogas may also be delivered to the depot with mobile gas storages on swap bodies. The integrated regional distribution planning in Stockholm is presented further in detail in WP 5.1[1]. For details on design and localisation of bus depots for biogas, see further in report WP5.3 Design for new bus depots and adapt existing depots for biogas buses and hybrids[2].

In this chapter descriptions and comparisons of the general process and design for different fuelling systems, i.e. CBG/CNG[3], LBG/LNG[4] and hydrogen gas, are given.

2.1 Fuelling systems with CBG/CNG

The typical components of a general refuelling system at a biogas bus depot includes a system for CBG/CNG fuelling that can vary in the detailed design but is conceptually designed after the same model. A fuelling system for CBG/CNG typically comprises:

- gas storage
- compressor unit
- priority panel
- fuelling system (slow system on ramp or fast filling via a dispenser)
- LNG back-up storage for redundancy

Refuelling of biogas is performed outdoors. For slow filling the bus is parked on a ramp location where each bus is connected to an individual fuel hose. Slow filling occurs mainly at night when the main part of the bus fleet is parked. Fast filling from a dispenser takes about 4-7 minutes.

The different parts of the system are described below.

The schematic pictures in Figure 2 and 3 below, shows a typical bus depots fuelling system for CBG/CNG directly supplied by a pipeline from the biogas production and upgrading plant and respectively supplied from a mobile swap body in Figure 3.

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[1] Sweco, 2012a
[2] Sweco, 2012b
[3] Compressed BioGas/ Compressed NaturalGas
[4] Liquified Biogas/ Liquified NaturalGas

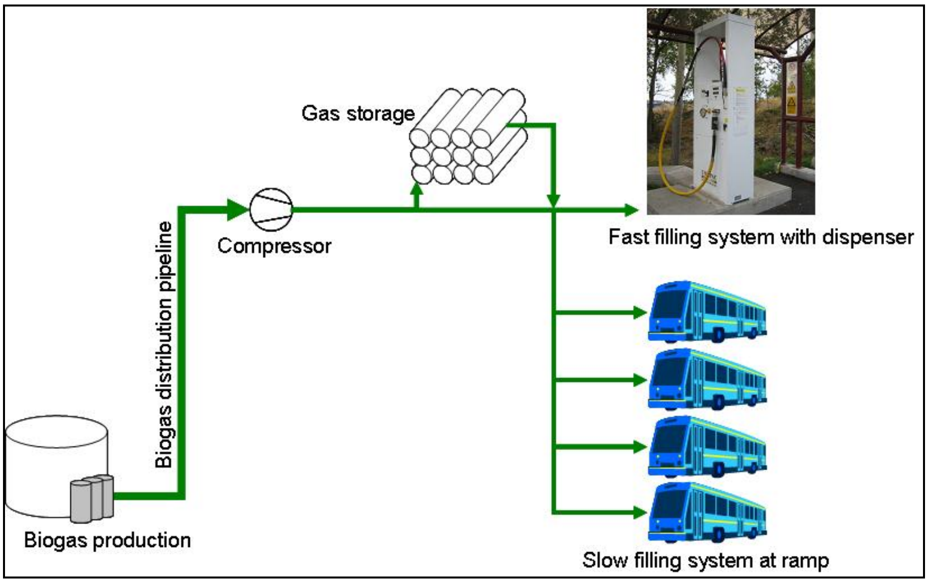


Figure 2. CBG fuelling system directly supplied, by pipeline, with upgraded biogas from a biogas production and upgrading plant.

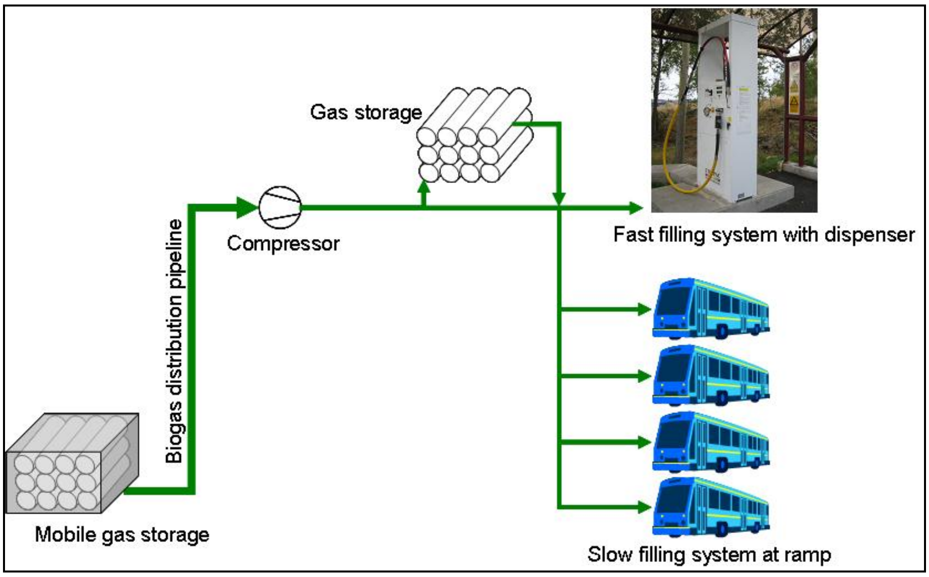


Figure 3. CNG/CBG fuelling system supplied with gas from a mobile swap body.

The biogas fuelling system can either be a part of a newly built depot or build into an existing depot and in both cases the units described below will be needed.

2.1.1 Compressor unit

From the gas supply source, the gas is led to high pressure compressors for increasing gas pressure, usually 200-250 bars. To maintain a constant supply, it is advisable with at least to separate compressor lines. This makes it easier to conduct maintenance and assures redundancy.

Each compressor must have capacity to increase the pressure of the total amount of gas and lead the gas either directly into the vehicle fuel tank or high pressure gas storage.

The compressor units are constantly under surveillance regarding gas pressure, temperature, leakage and fire alarm. If the compressor units are placed in a separate building, the building must fulfil high fire protection standards, high-pressure discharge surfaces and be well ventilated.

The compressors is often placed in a container building including electric and control equipment for slow biogas bus refuelling. In this way, the equipment in the unit can relatively easy be moved. The container building needs a concrete base foundation which demands ground works.

Figure 4. Compressor unit.

2.1.2 Priority panel

From the compressors the gas is further transported to a priority panel or so-called distributor. The priority panel allocates gas flow between the gas storage and the slow filling ramp or filling dispensers.

2.1.3 Gas storage

The gas storage is a stationary storage places at the depot and designed based on the biogas demand and should generally be able to supply the filling station with 24-48 hours of gas consumption.
There are various models for gas storages. In Sweden it is common with horizontal gas bottles stacked on top and next to each other. Geometric volumes vary between 79 – 2 000 litres or more, see examples on different gas storages in the figures below.

Figure 5. Stationary gas storage with horizontal gas bottles at Gubbängen depot.

In Sweden, a temperate climate and long winter months require an outer building or construction for the gas storage. The building needs to fulfil high fire protection standards, high-pressure discharge surfaces and be well ventilated. Geographical placing of the gas storage is also of importance and should be addressed in an early stage of the planning process, due to the safety risks involved. Depending on the placement of the gas storage, it can be shielded with a protective device to avoid risk of coalition with vehicles.

2.1.4 Slow filling system

Slow filling system for biogas means that the bus is refuelled during a longer period of time, often during night time. The fuelling time for a bus is approximately 8-10 hours. The advantages with a slow filling system are mainly due to traffic logistics since most of the buses in a fleet is running during daytime. The bus company's first priority is to maintain the time table for the traffic. This will become easier when the buses are refuelled during the night.

Slow filling is performed directly from a compressor, or a combination of a high pressure gas storage and compressors.

Buses are appropriate vehicles for using the slow filling system. Other possible vehicles may be trucks only running daytime or waste collection trucks.

2.1.4.2 Technical build up of slow filling system

For the slow filling system, the buses are parked adjacent to a ramp connected by a pipeline from the gas storage. Gas nozzles are connected to the pipeline and the driver can easily connect the bus in the evening and the vehicle is refuelled during the night.

Each connection consist of high-pressure hoses with nozzle, break away valve, hanging device and a shutting valve. The filling system must manage a filling pressure of at least 200 bars at 15°C and the ramp is dimensioned to avoid drop in gas pressure.

The gas pipelines in the ramp are protected to avoid risk of coalition and dimensioned to withstand great force from e.g. a hose mistakenly pulled off while connected to the bus or when a “break away valve” breaks.

2.1.5 Fast filling system

2.1.5.1 Fuelling time

For the fast filling systems, the refuelling is completed within 3-7 minutes while the driver is waiting, i.e. similar to conventional fuelling with petroleum or diesel. In comparison, public filling stations for cars and trucks use the fast filling system.

2.1.5.2 Technical build up of fast filling system

When using fast filling system the bus is driven to a dispenser, the engine is turned off and the nozzle is connected to the bus. The filling system consists of single or double hoses, nozzles tailored for different bus types and a break away system. The dispenser is easy to operate and maintain.

Figure 6. Left: Buses on slow filling ramp. Right: Dispenser for fast filling at Gubbängen, Stockholm.

2.2 Fuelling systems with LBG/LNG

Traditionally all biogas in Sweden has been transported and refuelled as CBG or mixed CNG/CBG. The supply of CNG or CBG to filling stations located far from the natural gas grid or a biogas plant is transported by truck in steel bottles on a mobile swap body. The transport model with mobile swap bodies is expensive due to the heavy load of metal i.e. the steel bottles. Biogas can, by cryogenic technique, be upgraded to LBG which results in a 600 times decreased volume. As a consequence, more energy (LBG) can be stored in liquid form then in compressed, and costs for transport and storage, both at the filling station and in the fuel tanks is lower for LBG then for CBG.

Several Swedish private and municipal companies have plans to expand their bus fleets with buses that to run on liquefied biogas. The reasons are primarily to reduce costs for gas distribution and to make refuelling logistic more efficient. Currently (June 2012), there are one LBG fuelling stations built and up and running on trial. The private company Scandinavian Biogas and Fuels International AB has constructed the LBG fuelling station in Uppsala municipality. The filling station is of a pilot size model.

Refuelling systems are often supplied with LNG. LNG filling systems have a storage tank dimensioned in relation to the fuelling demand. The tank is equipped with two pipelines, one for LNG and one for CNG. The pipeline is directly attached to a LNG dispenser while the CNG pipeline is directed to a LNG pump that will increase the LNG pressure up to 250 – 300 bar. A high pressure vaporiser is attached to the LNG pump where the LNG is vaporised. The vaporiser runs on the heat energy in the air and thus need no other energy supply. When the LNG has been vaporised it is odorised and stored in a gas storage before pipeline transport to the CNG dispenser.

At the refuelling station the possibility to refill CNG or LNG is unlimited in term of consumption of either fuel. In other words, the filling station can be used as a pure CNG or LNG filling station or as a combined station. The total consumption of gas can itself affect the gas quality and the storage of LNG at the station which is due to the properties of LNG. LNG is a cryonic liquid which slowly is vaporised in the LNG storage, approximately 0,12 % per day. The effects from the slow spontaneous vaporisation are problematic when the demand of fuel is lower then planned and vaporised LNG is accumulated in the storage tank. Spontaneous vaporisation may lead to:

- Changed composition of the LNG (if the LNG is composed of different gases)
- Venting (losses to atmosphere)
- Variation in fuel density

2.3 Fuelling systems with hydrogen gas

The project CUTE (Clean Urban Transport for Europe) run between 2003-2006 and aimed to operate 27 hydrogen buses in 9 European cities with 3 buses in each city. During the CUTE project in 2004 the activities in Stockholm involved several partner e.g. Stockholm Public Transport (SL), City of Stockholm and the bus operator Busslink. Approximately 59 million SEK was invested in the Stockholm CUTE project. The major part of this investment constituted of the fuel cell buses, 33 MSEK or 11 MSEK per bus, whereas the for the hydrogen refuelling station including production and the modifications on the service garage at the bus depot was 10 MSEK and 4 MSEK[5].

In the Stockholm project the system was based on the CUTE Stockholm hydrogen fuel station, and the Mercedes-Benz Fuel Cell Citaro buses. The station consisted of an electrolyser, compressor, storage vessels of 3690 litres, a dispenser and a

[5] Haraldsson, 2005

booster compressor. Unlike regular fuel stations no fuel, besides electrical power, was transported to the station. The electrolyser produced the fuel on-site[6].

The electrolyser produced hydrogen and oxygen from water and electricity. Oxygen is produced at the anode, and hydrogen at the cathode. A membrane separates the anode from the cathode and prevents the two produced gases from forming an explosive mixture. The electrolyser produced 60 Nm^3 hydrogen per hour at a pressure of 10 bars[5].

The refuelling station had two compressor systems. The first system compressed the gas from the electrolyser, before it was transported into the storage. The fourth compressor was a booster, which compressed the outgoing gas from the storage, when it was needed, as the pressure in the storage could drop.

The storage was divided into three separate sections. It consisted of 18 composite cylinders of 205 litres each and a maximum pressure of 393 bars. The cylinders had an inner aluminium liner and an outer carbon fibre overwrap. The aluminium liner was required in order to prevent the small hydrogen molecules from diffusing through the cylinder walls. The carbon fibre overwrap was required to withstand the high pressure. Hydrogen was transferred into the bus through the dispenser.

An important issue with hydrogen is that there is a risk that the material, e.g. pipes and couplings, will be subject to hydrogen embrittlement. This is avoided by using pipes and couplings made of stainless steel instead of regular carbon steel.

2.3.1 The hydrogen Infrastructure in the Stockholm CUTE project

During the CUTE project in Stockholm hydrogen was produced and stored on-site on the same location as the refuelling station and the bus workshop. The hydrogen was produced from electrolysis of water, using electricity produced by certified green power (hydropower 8 Fuel Cell Bus Demonstration and wind power). The design capacity of the electrolyser, provided by Stuart Energy Systems, is 60 Nm^3 H_2/h with a power consumption of about 4.8 kW.

[6] Niklasson et al., 200X

Figure 7. Hydrogen refuelling station in Stockholm.

3 Stockholm Public Transport biogas bus depots

This chapter explains SL's biogas model and how the company made its way from having no buses running on gas in the beginning of the 2000's, to at, in the end of 2011, having 230 biogas buses on the streets of Stockholm city. The chapter presents four depots and the fuelling system of each depot.

3.1 Biogas strategy and planning for biogas depots

SL has since many years a long-term strategic plan for introducing renewable bio fuels to buses. Today, biogas is considered SL's first hand choice in the company's aim to fulfil its environmental goals, as presented in section 1.3, and has utilised biogas as vehicle fuel for inner-city buses since 2003.

SL states in their Action plan for biogas[7] that the use of biogas buses in the traffic planning shall be where it can do most benefits in terms of lowest emissions and highest environmental performance possible. Therefore, biogas buses were first introduced in the inner city traffic. In later stages, SL has progressed to develop distribution of biogas to the bus depots with suburban traffic.

SL performed several pre-feasibility studies in the 1990's investigating the possibilities of using biogas as vehicle fuel for inner city buses. Availability of large biogas production volumes were identified at the biogas production plant at Henriksdal wastewater treatment plant (WWTP), the largest WWTP in the Stockholm region and located near the central part of the city.

SL signed a contract agreement with Stockholm Water Company[8] in year 2003 for the supply of upgraded biogas from Henriksdal biogas plant. At this time, there was not a market for biogas and therefor it was not possible for SL to perform a procurement process. Henriksdal WWTP did not have any unit for upgrading biogas to vehicle fuel quality, which Stockholm Water Company then decided to invest in. The delivered biogas supported 21 biogas buses for inner city traffic by year 2004. In year 2010 the amount increased to 103 buses. In 2010 the upgrading plant was sold to a private company, Scandinavian Biogas with whom a new contract was signed.

In June 2007, SL signed another contract agreement with Käppala Association[9] for the supply of upgraded biogas produced at the biogas production plant at Käppala WWTP on the island of Lidingö in the Stockholm area. The Käppala Association performed a tendering process which SL won. This made it possible for SL to purchase upgraded biogas from Käppala for distribution and usage in buses at the new bus depot Charlottendal, in Värmdö. However the bus depot in Värmdö has

[7] SL, 2009

[8] The Stockholm Water Company (Stockholm Vatten AB) is 100 % municipally owned and runs the wastewater treatment plants in Stockholm City. The Stockholm Water Company responsibility covers the sewage network and treatment of wastewater from one million people and several industries (the company also own another WWTP).

[9] Käppala Association is owned by eleven municipalities in the Stockholm region, owning and operating Käppala WWTP. The plant receives wastewater from approximately 520 000 inhabitants (2009).

been delayed and some of the biogas has temporarily been delivered to bus depots in Lidingö and Frihamnen.

In May 2009 SL also signed a contract agreement with Stockholm Gas AB[10] for delivery of biogas from a planned biogas plant to be located in Skarpnäck south of Stockholm city. This biogas production shall be based on anaerobic digestion of grains and the start of construction of the plant is scheduled to 2012[11].

Within the framework of these contractual agreements it is estimated that approximately 500 biogas buses will be supplied with upgraded biogas[12].

SL is continuously looking at more alternatives for upgraded biogas supply. Since SL is responsible for approximately 2 000 buses in total, and thus has a large theoretical potential of expanding its biogas bus fleet, the largest limiting factor today is the availability of biogas.

3.2 Bus depots in operation

Four of SLs depots for biogas is presented and described below. Two of the depots, Söderhallen and Lidingö are existing depots that has been converted for biogas as fuel for the buses. Both of the depots also have ethanol buses. The new installations have included construction of biogas system including refuelling equipment for buses. The other two depots, Gubbängen and Charlottendal is new depots of which one of them, Gubbängen is build and recently taken in operation and Charlottendal, is planned to be put in operation in 2016.

3.2.1 Söderhallen, Stockholm city

Söderhallen bus depot was SL's first biogas bus depot and began operating in 2004. The first phase involved a fast filling system for about 50 buses. In 2006 the depot was expanded to about 130 buses. SL prioritises to use biogas buses in the traffic where they can do most good, which means, reducing the environmental impact most. For this reason, the biogas buses were first introduced in the inner city traffic. The strategy was then to develop distribution of biogas into the depots with suburban traffic.

Söderhallen depot is located relative close to Henriksdal WWTP[13] and was the most suitable depot for biogas buses in Stockholm. From Henriksdal WWTP a gas pipeline distributes the upgraded biogas approximately 800 meters to the depot. When Söderhallen was designed as SL's first biogas depot, the first priority was to achieve the same fuelling time for a biogas bus as for a diesel bus. Therefore it was decided that a high pressure system of 350 bar was to be used. Although, the operational experience showed that the higher pressure was not optimal, see further Chapter 4.

[10] Stockholm Gas AB owns Stockholm City's town gas grid and delivers gas to households, real estate owners, restaurants, industries and vehicle fuelling stations.
[11] SL, 2009
[12] SL, 2009
[13] Waste water treatment plant

Discussions between the City of Stockholm and SL have been on-going due to the fact that the depot is located in a valuable exploitation area in the inner city. Therefore, one important parameter in the technical design has been to create a facility that is movable to a new location. Söderhallen bus depot is located in an urban environment close to apartment buildings. This means that the location put great demands on safety, noise and emissions.

When the depot was to be designed there was a limited space for parking and driving space and the buses had therefor to be parked indoors. To perform slow filling of the buses indoors was not a possibility regarding safety aspects. Therefore a fast fuelling system outdoors was the only option at the depot. To meet the safety requirements, the parking hall indoors is equipped with a gas alarm and forced ventilation in three steps. Step 1 is an audible alarm, step 2 is a forced ventilation system and step 3 consists of forced ventilation and the opening of the exit gates. The workshop and wash bay is also equipped with a gas alarm.

The fast filling system consists of four double dispensers for biogas and three for ethanol, placed at 4 separate dispenser areas, see figure 8. A stationary gas storage constitutes of 72 cylinders of 1 900 litres arranged in a three bank system to ensure that the refuelling station have enough capacity for a 24 hour period without gas distribution from Henriksdal WWTP. Three compressors are located in three separate container buildings that also houses the electrical rooms.

A future plan is to move the operation at Söderhallen to the new Fredriksdal biogas bus depot. The depot will be designed for CBG fast filling system outdoors for approximately 120 biogas buses. The new bus depot is estimated to be in service in 2015.

Figure 8. Fast filling dispenser for biogas and ethanol at SL's biogas bus depot Söderhallen.

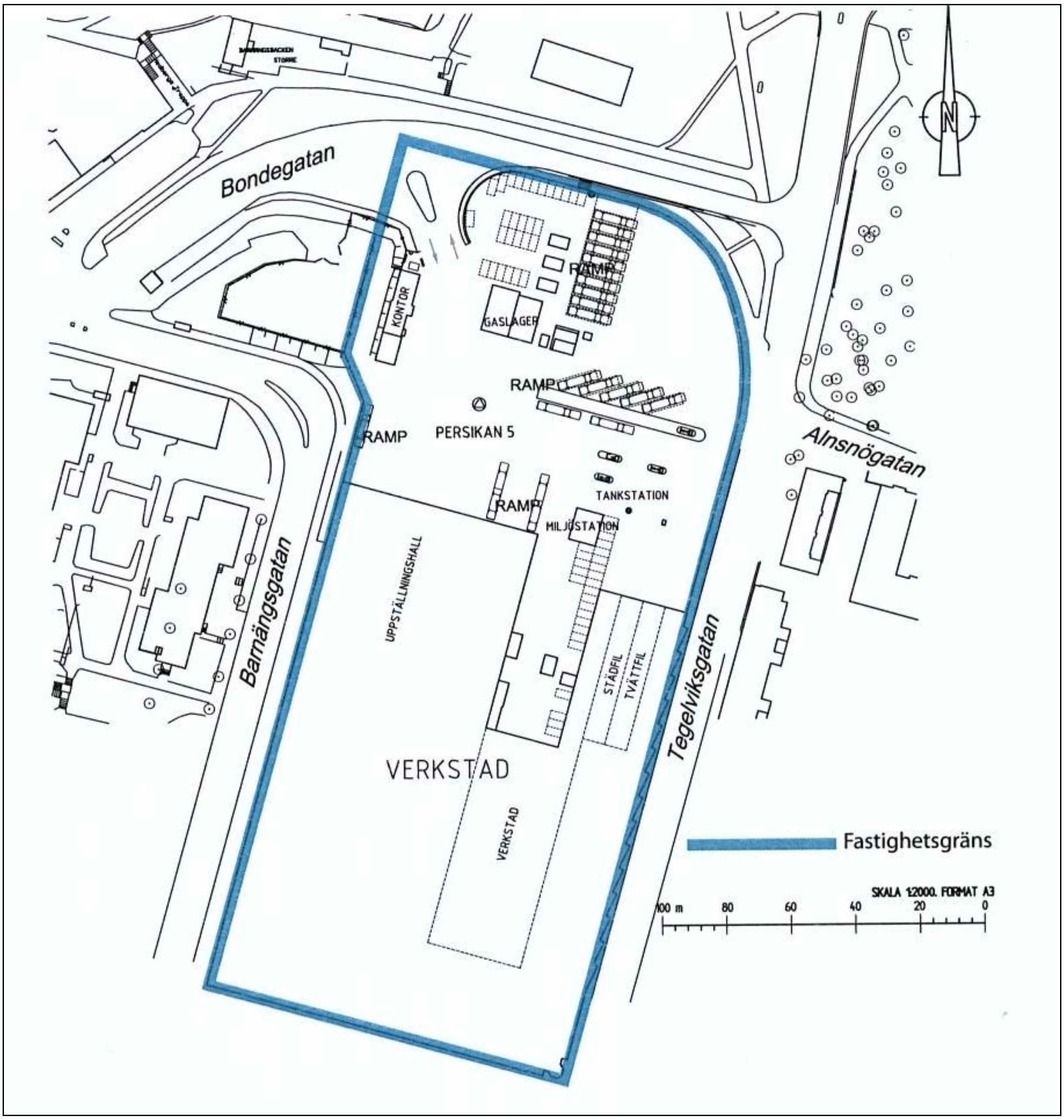


Figure 9. Design of Söderhallen bus depot.

Investment costs

The total investment cost of the biogas refuelling facility at Söderhallen is approximately 48 million SEK. In that cost the following is included; high pressure compressors, gas storage with 72 cylinders, 4 double dispensers for fast fuelling, gas alarm installation, 2 booster compressors, construction costs, costs for regulatory permits and contractor cost. Energy consumption and operation- and maintenance cost is not included. The cost varies depending on the number of buses at the depot, and also, the location and closeness to buildings, roads and other activities. For a bus depot of about 100 buses, the cost for the biogas system is about 10-20% of the total cost of the depot, see further Chapter 7.

3.2.2 Frihamnen biogas bus depot and Lidingö biogas bus depot

Stockholm Public Transport has during 2010 taken two biogas bus depots in operation. The depot in Frihamnen, Stockholm is a new depot while the Lidingö depot is an existing, rebuilt bus depot. The gas is delivered to the refuelling stations through a 4 bar pipeline from Käppala WWTP at Lidingö, an island set outside of Stockholm. Frihamnen is designed for 50 biogas buses while Lidingö is designed for 36 buses. The refuelling systems on the depots is designed and built in the same manner, therefore the description of the system at Lidingö follows.

The refuelling system at Lidingö bus depot is built as a slow-fill fuelling station located on a ramp in open air to make it possible to refuel all buses at the same time during the night. A dispenser for fast fuelling is added to the refuelling station to achieve redundancy and satisfactory fuelling logistics.

To ensure safe operation, the fast filling system is equipped with a hose safety-valve, a pressure transmitter and an emergency shut-down system. The slow filling system is equipped with a hose safety-valve, and a shut-off valve at each refuelling location. The bus ramp is equipped with a shut-off valve and an emergency shut-down system.

A roof was built over the bus ramp to minimize the risk of damage and collision. The distribution gas pipeline was placed in the roof to reduce the risk of being run by. A guardrail protection was built along the main road, Södra Kungsvägen that passes closely along the depot, see the figure below.

Figure 10. Left: Inspection of building with gas storage and electronic equipment. Right: The hose for slow filling is connected to the pipeline for the biogas which is placed in the roof.

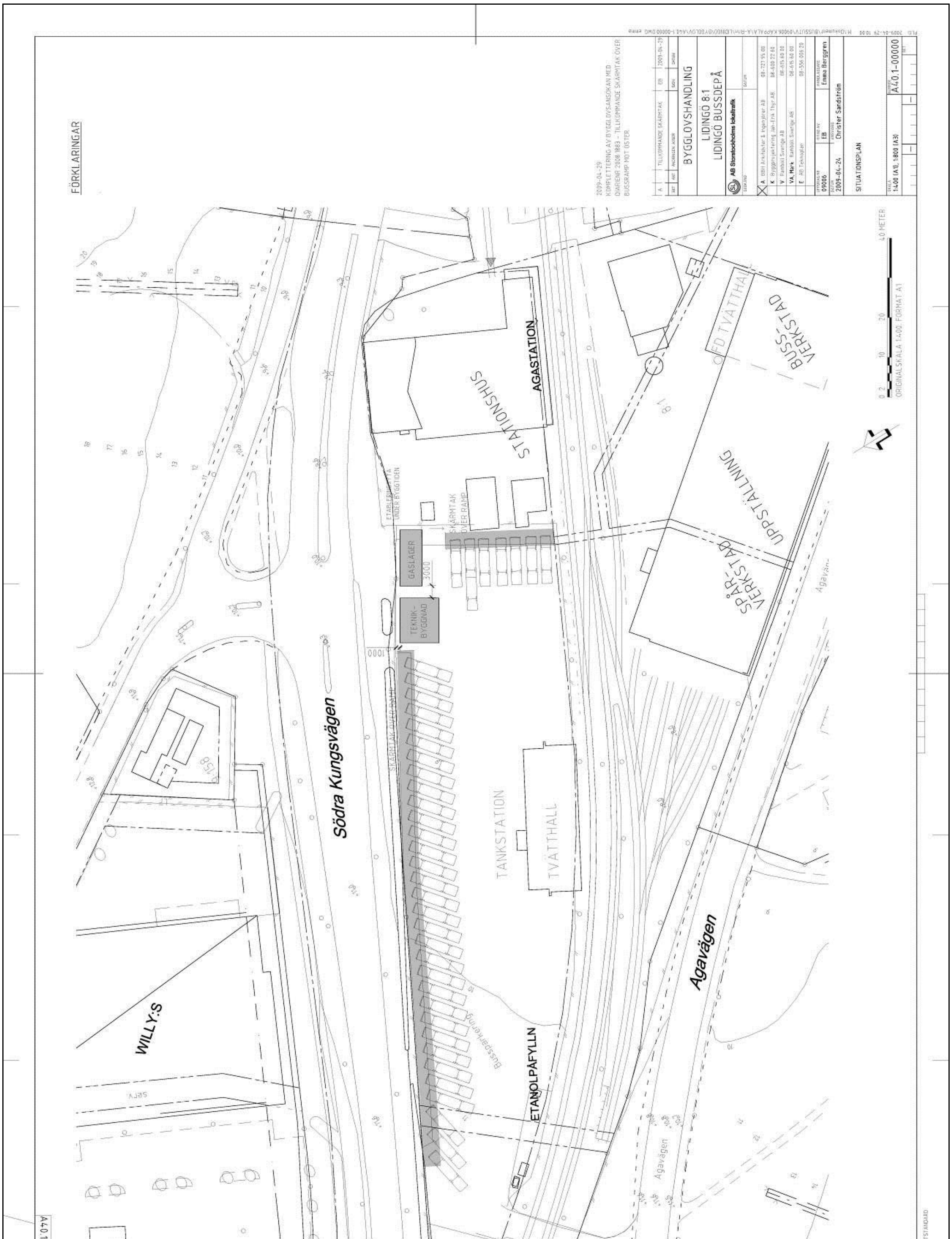


Figure 11. Design of Lidingö bus depot.

Investment costs

The total investment cost of the biogas refuelling facility at the Lidingö depot is approximately 29 million SEK. In that cost the following is included; 2 high pressure compressors, gas storage with 24 cylinders, slow filling system, supplementing existing ramp, 1 double dispensers for fast fuelling, gas alarm installation, 2 booster compressors, construction costs, costs for regulatory permits and contractor cost. A supplementary cost for a guardrail protection was approximately 0,5 MSEK due to safety reasons. Energy consumption and operation- and maintenance cost is not included.

3.2.3 Gubbängen biogas bus depot

SL has constructed a new bus depot of 91 biogas buses in Gubbängen south of Stockholm city, at an area of 30 000 m^2. The depot is a permanent refuelling station for CBG and back-up CNG plus a refuelling station for biodiesel and ethanol. The depot includes a workshop with eight places for repair and maintenance of the buses, two wash bays, heating ramp with a roof and an administrative building for staff including a gym and sauna.

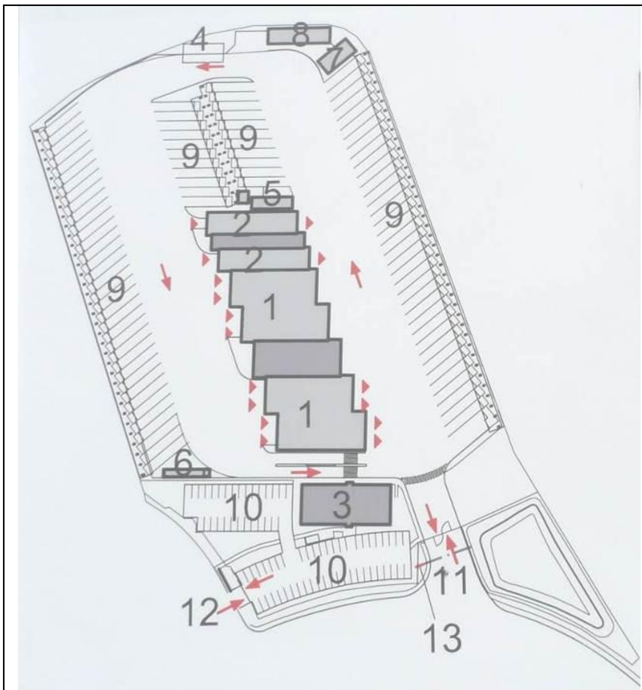
The refuelling station is built as a slow filling station located on a ramp in open air to make it possible to refuel all buses at the same time during a time period of 8-10 hours with a capacity of 1700 Nm^3/h. A double dispenser for fast fuelling is added to achieve redundancy and satisfactory fuelling logistics. To ensure safe operation the fast filling system is equipped with a hose safety-valve, a pressure transmitter and an emergency shut-down system. The slow filling system is equipped with a hose safety-valve and a shut-off valve at each refuelling location. Each bus ramp is equipped with a shut-off valve and an emergency shut-down system. See pictures in Figure 6.

The biogas system consists of stationary gas storage of 24 gas bottles14, each containing approximately 2 m3 geometric volume, so-called water volume, to ensure a total redundancy for a 24 hour period. The main distribution pipeline that feeds the fuelling station operates at 2.7-4.0 bar and three high pressure compressors (one spare) raise the pressure to the required 250 bar needed to refuel the buses. Two booster compressors (one spare) ensure that the gas meets the pressure and temperature requirement before refuelling. The gas will be delivered to the refuelling station through a gas pipeline from the Skarpnäck biogas plant, complimented with back-up gas (LNG) from Himmerfjärden WWTP, with a gas storage capacity of 72 m^3.

[14] Approximately 50m^3 water volume

Figure 12. Compressors and LNG back-up storage at Gubbängen depot.

The new bus depot at Gubbängen was taken in operation in August, 2011.



Design of Gubbängen bus depot.

1. *Workshop*
2. *Washing bay*
3. *Traffic building*
4. *Refuelling of ethanol and biogas*
5. *Storage for hazardous waste*
6. *Storage for tires*
7. *Technical equipment*
8. *Parking with ramp*
9. *Parking for staff*
10. *Entrance and exit buses*
11. *Entrance and exit external vehicles*
12. *Information sign*

Figure 13. Design of Gubbängen bus depot.

Investment costs

The total investment cost of the biogas refuelling facility at the Gubbängen depot is approximately 38 million SEK. In that cost the following is included; 3 high pressure compressors, gas storage with 36 cylinders, slow filling system, supplementing existing ramp, 1 double dispensers for fast fuelling, gas alarm installation, 2 booster compressors, construction costs, costs for regulatory permits and contractor cost. The energy consumption is approximately 1,7 MSEK/year and operation- and maintenance cost is estimated to 0,5 MSEK/year.

3.2.4 Mobile Modular Fuelling station at Björknäs biogas bus depot

Part of this project has been the purchase and installation of a mobile modular fuelling station at one of SLs existing bus depots and it was during this activity decided that the modular fuelling station was to be installed temporarily at the Björknäs depot, east of Stockholm. The objective has been to investigate and identify how mobility will be secured.

The refueling system has been designed so that the input process equipment is built in modules to enhance mobility. For example, the stationary gas storage is equipped with gas bottles with smaller volume than normal, which makes them easier to move.

Process equipment (modules) that can be dismantled and moved to another depot are:

- Booster compressors
- Gas storage (bottles)
- Priority panel
- Dispenser for fast refeuling
- Units for slow filling at the slow filling ramp
- Connections to empty the swap-body containers
- Various gauges, valves, filters etc.

The depot was taken in operation in August, 2011.

Figure 14. Left: Ramp for slow filling at Björknäs. Right: Swap-body containers at Björknäs.

Investment costs

The investment included the construction of a mobile modular fuelling station for biogas buses consisting parking spaces for swap-body containers including connections to empty the containers, a building containing two booster compressors, stationary gas storage and process equipment as well as refueling equipment for slow filling on ramp and a fast filling dispenser.

The total investment is estimated to 36 MSEK. The value of the equipment that can be transferred to another depot is estimated to approximately 15 MSEK. The amount granted by EU is 140 000 Euro, equivalent to approximately 1,4 MSEK.

3.2.5 Charlottendal biogas bus depot

The planned Charlottendal depot is located at Värmdö east of Stockholm and designed for slow filling on ramp outdoors for approximately 147 buses. The depot covers 47 000 m^2 land with workshops, wash bay, biogas system and refuelling ramps. The depot will be equipped with a dispenser for fast filling and LNG facilities. The new bus depot at Charlottendal is estimated to be in service in 2016.

Investment costs

The total investment cost of the biogas refuelling facility at Charlottendal depot is approximately 74 million SEK. In that cost the following is included; 3 high pressure compressors, gas storage with 66 cylinders and LNG back-up system, slow filling system ramp with 137 lots, 1 double dispensers for fast fuelling, gas alarm installation, 3 booster compressors, construction costs, costs for regulatory permits and contractor cost. The energy consumption as well as operation- and maintenance cost is not included.

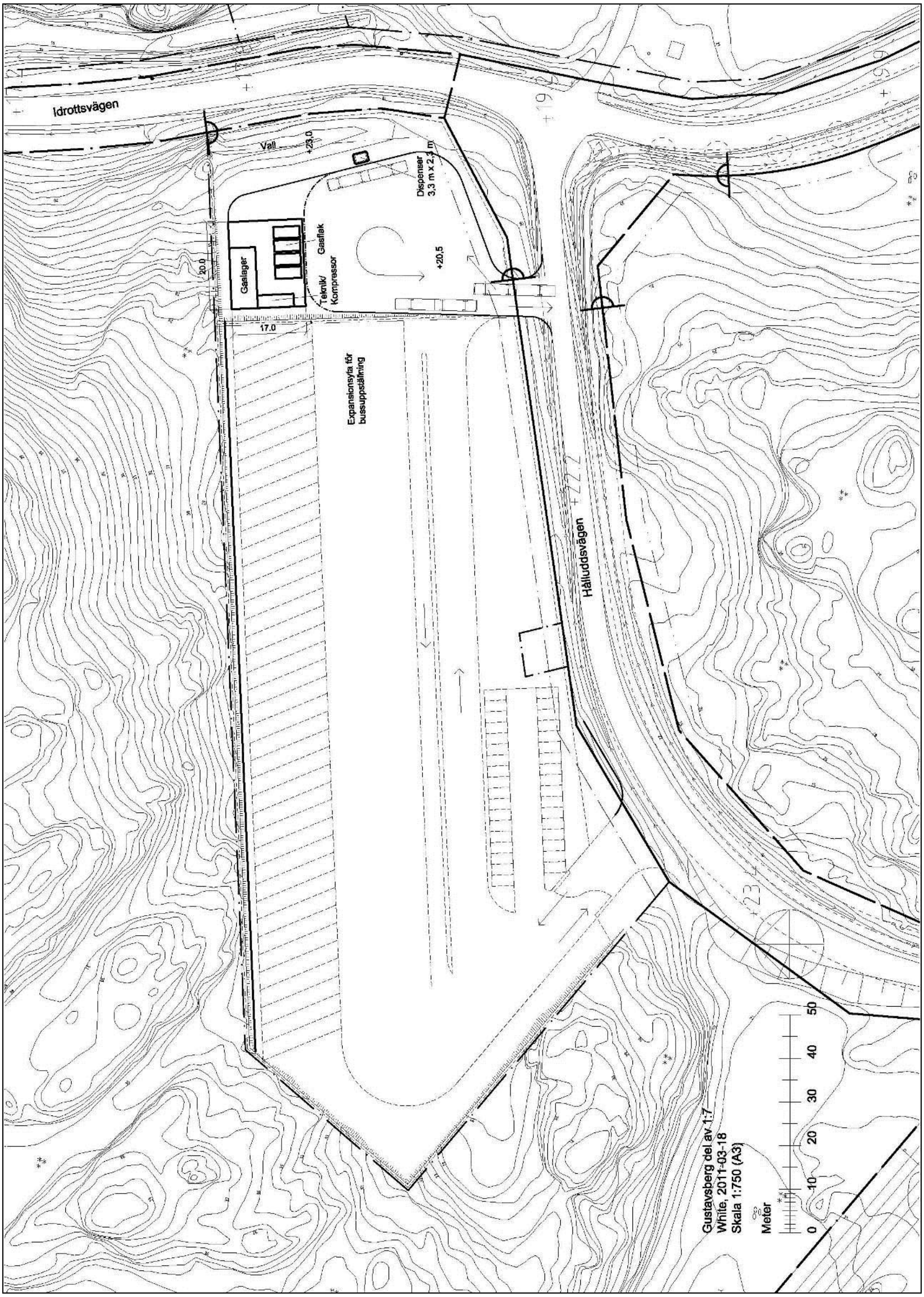


Figure 15. Design of Charlottendal bus depot.

4 Technical and Operational experiences

Technical and operational experinces is mainly gathered from the Söderhallen depot where a fast fuelling system is used. SL has more limited operational experience from slow filling systems since the depot has been in full operation since 2011.

General differences between a slow and fast filling system are:

- The difference in fuelling time between a slow filling system where the buses are refuelled during several hours at night compared to fast fuelling performed within minutes demands different kind of planning and logistics for time tables, staffing etc.
- In a slow filling system the driver connects the hose on the ramp compared to a fast fuelling system which demands maintenance staff that perform the fuelling. This saves costs of staff including costs for logistics and planning.
- A fast filling system is man-operated, which increases the risks for accidents compared to a slow filling system.
- Slow filling is performed outdoors on a ramp while the buses are parked. Buses that uses fast filling may be parked indoors.
- A fast filling system that is in service during daytime demands more coordination in order to minimize traffic congestion at the refuelling pumps.
- Since a slow filling system need to fill buses in sequence the slow filling system has higher demands on when buses are filled so that the system can operate at full capacity.
- The slow filling refuelling system requires sufficient land for the ramp system. The slow filling site must be fenced.
- A slow filling system allows the gas storage capacity to be reduced to a minimum and the capacity requirements for the gas compressors are also minimized.
- Since the demands are more easily forecasted for a slow filling system, the back-up storage can be smaller than that for a fast fuelling system.
- A slow filling ramp can be complement with a fast filling lots on the ramp
- A slow filling system is designed for bus fleet purposes and is not ideally suited to be used by other vehicles while a dispenser easily can be used by for example company vehicles etc.

4.2 Operational experiences

When Söderhallen was designed as SL's first biogas depot, the highest priority was to achieve the same fuelling time for a biogas bus as for a diesel bus. Therefore it was decided that a high pressure system of 350 bar was to be used. The operational experience showed that;

- It was difficult to get valves approved for the high pressure of 350 bar. The standard valves were not approved for this pressure within Europe and the valves had to be ordered from different places around the world.
- The high pressure of 350 bar made the pipeline system in the fuelling station vibrate that in turn caused increased utilisation and wear of the valves in the system.
- The high pressure caused pulsations and movements in the filling equipment which worried the depot staff and made them feel uncomfortable during refuelling.
- Oils used in the refuelling equipment was not adjusted to the high pressure which lead to the oil cracking and flaking in the pipeline system, in valves, filters, gas storage etc.
- There was only a minimal difference in fuelling time between a system of 350 and 250 bar.
- Lower pressure of about 250 bar was found to have lower operation- and maintenance costs compared to a 350 bar system.

The old buses at Söderhallen only have large nozzles for fast filling but have during the recent years been supplemented with small nozzles for slow filling. This is necessary if the bus needs to be moved to a depot with a slow filling system.

At Söderhallen, there are specialised maintenance staff that refuels the buses. The staff at Söderhallen has noticed that the fast filling system is stressful for the depot staff as well as for the drivers and demands planning and logistics. The stressful environment has sometimes led to breakage of hoses when being run over by the bus.

A slow filling system is equipped with less heavy hoses than dispensers for fast filling hoses regarding the working environment.

5 Safety and regulations

This chapter presents a summary of rules and regulations that govern fuelling systems at biogas bus depots and the procedure to obtain relevant permissions. Construction and installation of biogas depots are associated with a number of directives, rules and regulations, mainly concerning safety measures and maintaining a low risk environment for personnel and the general public.

It is recommended that relevant regulations, required permits and necessary contacts with regulating authorities, are investigated and taken into consideration at an early stage of the planning process. Regardless of the specifics of the regulation in the country at hand, acquiring the necessary permits and approvals are most likely a time-consuming task.

5.1 Safety measures

Managing a gas system means working in potentially explosive atmospheres. Safety measures are important and only authorised and educated personnel are allowed to operate with the gas systems.

Of most concern when constructing and operating a gas system is having knowledge and working practices that avoid:

- risks of accidents
- gas leakage
- corrosion
- sources of ignition
- areas where gas can gather

All biogas/natural gas/hydrogen gas bus depots should have one gas safety manager. The gas safety manager is responsible for running the gas system in a safe manner 24 hours a day. Therefore, there shall also be one or two deputy safety managers and it shall always be stated with a special document when the responsibility is shifted to the deputy manager.

5.2 EU-directives, Swedish regulations and standards

The Swedish Gas Association, a trade organisation promoting usage of energy gases in Sweden, is the official agency working with safety, environment and sustainable energy politics for biogas, natural gas and hydrogen gas.

The Swedish Gas Association has in cooperation with the Swedish gas companies and stakeholders, developed guidelines for biogas (CBG) installations in “Biogasanvisningar 2005 (BGA)” and for fuelling stations for methane driven vehicles “Anvisningar för tankstationer 2010 (TSA)”, which today are considered common practice and recommended by Swedish approving authorities.

The Swedish Gas Association has also developed an important norm for biogas distributions “Energigasnormer 2011 (EGN)”. The standard deals with biogas with a maximum operating pressure of 4 bar. Distribution systems that are built, controlled and operated by the standards comply with laws, ordinances and regulations.

EGN 2011 refers to the applicable European Directives and harmonized standards at www.newapproach.org. The EU-directives set the main framework and is usually converted and incorporated into the national laws, as in Sweden. A summary of relevant EU-directives related to gas fuelling systems are listed in Appendix 1. Relevant Swedish laws, regulations and standards are also listed in EGN 2011.

Required permits for approval of a biogas bus depot depend on the amount of gas to be stored and the localisation of the depot. Regarding biogas bus depots the following are required according to Swedish law:

- Permits for handling and management of flammable goods
- Notification according to Swedish environmental law
- Notification and action programme regarding preventative actions of serious chemical accidents
- Building permit

Below is a shorter presentation of the required Swedish permissions. Other countries around the Baltic Sea region most probably have other specific regulations and permits that are required. However, the overall regulation is in co-ordinance with the EU directives and should therefore in every member state in general cover the same aspects and considerations. The EU-directives set the main framework and shall be converted and incorporated into the national laws, as in Sweden.

5.2.1 Permits for handling and management of flammable goods

The authorities, in Sweden the Swedish Civil Contingencies Agency, require that companies handling flammable goods in grid systems such as biogas, apply for a permit under the Act of flammable and explosive products (SFS 1988:868), (SFS 2010:1011).

The application includes a basic description of the installation and its parts, the amount of biogas that is expected to be handled, the name of the person responsible for installation, etc. The application must be submitted to the authority in advance, well before commissioning is allowed. A permit for the operation of the depot is given once the authorities' representative approves the installations at a final inspection.

5.2.2 Notification according to Swedish environmental law

Installations that are expected to handle more than 1 million Nm3 of biogas annually should, in addition to permits for the handling of flammable goods, file a notification with the Environmental Department. The notification includes, for example, a short description of the installation, the location of the installation, waste management plans, chemical handling routines and possible environmental impacts from emissions to air, water and land. This notification must be submitted to the Environmental Department in advance, well before the commissioning of the installation.

5.2.3 Notification and action programme regarding preventative actions of serious chemical accidents

If the proposed facility is expected to store more than 10 tons of methane gas, approximately 14 000 Nm^3, the installation will be subject to regulation SFS 1999:382, regarding the prevention and control of major chemical accidents, and regulation AFS 2005:19, regarding the prevention of serious chemical accidents. A notification shall be filed to the County Administrative Board and the Work Environment Authority. This notification must be filed with the authorities 3 months before the commissioning of the depot. The notification should include a brief description of the installation, name of the person responsible for the installation, description of the site, quantity of dangerous goods that are expected to be handled, factors that can cause serious chemical accidents, etc. A written statement is sent to the installation owner after the authorities have reviewed the notification.

In addition to the notification, a damage prevention plan shall also be written describing how to prevent serious chemical accidents. The damage prevention plan shall include information about the goals and general principles on how to prevent major chemical accidents, information about the installation owner's safety organization and information on how the different risks of serious chemical accidents are managed through routines and instructions.

5.2.4 Building permits

The City Planning Department reviews applications for building permits. Applications should be sent to the City Planning Department in advance so that a permit can be obtained before the planned start of construction. Documents that are usually required for a building permit include a site plan, a drawing showing the main facade, and a general overview to illustrate the project. Any modification in the grade of the lot also needs to be illustrated in the site plan. In addition to obtaining the building permit, the site owner also needs to notify the City Planning Department three weeks before the start of construction.

5.3 Regulations concerning fuelling systems with liquefied gas

LBG/LNG as vehicle fuel is a new field and there are no specific instructions set by authorised agencies/authorities for these kinds of filling stations. The technology is rapidly developing in Sweden and the regulatory system has difficulties managing the same pace.

Where LBG fuelling systems now are in operation, regulations covering biogas, natural gas and LPG have to a large extent been utilised in lack of other more specific rules.

However, this inflicts the approval procedures and constructors, operators and authorities faces challenges as there are differences in the physical properties of LBG/LNG versus the gaseous form and petroleum gas, LPG. Petroleum gas is liquefied through high pressure, whilst methane is liquefied by cooling to -163°C.

5.4 Regulations concerning fuelling systems with hydrogen gas

Hydrogen gas as a vehicle fuel is considered as a relatively new field. In Sweden, where hydrogen gas fuelling systems have been in operation, regulations covering biogas and natural gas have to a large extent been utilised in lack of other more specific rules.

Utilizing biogas and natural gas regulations may, in some cases, inflict on the possibility to optimise the fuelling system, for example regarding physical properties of hydrogen gas versus approved storage volumes or standard of materials used in construction.

An important issue with hydrogen is the material of pipes and couplings. The material may be subject to hydrogen embrittlement. Embrittlement is avoided by using material of stainless steel instead of regular carbon steel. Welding changes the structure of the metal, which increases the risk of hydrogen embrittlement. Therefore the joining of pipes with other components is done with special couplings, called swagelok couplings.

Rules and regulations regarding hydrogen as a vehicular fuel are being worked out in several national and international organisations, e.g. the International Organization for Standardization, and TÜV, an international certification agency based in Germany. According to the Swedish Gas Association no new hydrogen specific regulations have been implemented[15]. According to the association “Vätgas Sverige”[16] hydrogen specific regulations for the European member states are still being worked out[17].

The process for permits in the Stockholm CUTE activity was rather long, 18 months in total. This was mainly due to a lack of established hydrogen regulations in the permit application procedures. Instead, regulations for natural gas were used and adapted to hydrogen. Another complicating factor specific for Stockholm was that

[15] Wasell, 2010
[16] Free translation ”Hydrogen Sweden”
[17] Källström, 2010

the hydrogen production and storage facilities and refuelling station were located on market-attractive land owned by the City of Stockholm and rented by the bus operator. Negotiations with the parties lead to changes of the development plan of that area and a time-limited permit to use the land was granted. With the lessons learned in this particular case, the next time a hydrogen project is to be launched in Sweden, the permit procedure is known and likely to be significantly less costly and time consuming[18].

[18] Haraldsson, 2005

6 Environmental aspects

A major reason for production and utilization of biogas as vehicle fuel is the environmental improvement compared to fossil fuels. Biogas is in an environmental perspective completely carbon neutral when considering the combustion in the vehicle engine. However, the production and utilization processes of biogas may results in methane losses and emissions of other contaminants to air, land and water. In this chapter, the environmental impacts from biogas are presented.

6.1 Composition of biogas

Biogas produced in biogas plants is primarily composed of methane and carbon dioxide with smaller amounts of hydrogen sulphide and ammonia. Trace amounts of hydrogen, nitrogen, saturated or halogenated carbohydrates and oxygen are occasionally present in the biogas. Usually, the gas is saturated with water vapour and may contain dust particles and organic silicon compounds e.g. siloxanes.

6.2 Upgraded biogas quality in Sweden

In 1999 Sweden has developed a national standard (SS 15 54 38) for biogas as vehicle fuel on request of the Swedish vehicle manufacturers as a design basis for fuel- and engine systems. The main parameters of the standard are described in the table below. Motor octane number is a definition of the resistance to knocking of fuels. The Swedish standard is also applied when injecting biogas into the natural gas grid. Additional demands concerning heating value are covered by addition of propane to the gas upgrading National gas standards.

Table 1. Swedish national standard for upgraded biogas (SS 15 54 38).

Parameter	Unit	Type A	Type B
Lower Wobbe index	MJ/Nm3	44,7 – 46,4	43,9 – 47,3
MON (motor octane number)	-	> 130	
Methane	vol-% *	97±1	97±2
Water dew point	°C	t - 5	t – 5
Moister, max	mg/Nm3	32	32
(CO2/O2//N2)	vol-%	4,0	5,0
Oxygen, (max)	vol-%	1,0	1,0
Total sulphur	mg/Nm3	23	23
Ammonia, max	mg/Nm3	20	20

Maximum particle size	µm	1	1

* At 273,15 K and 101,325 kPa

6.3 Emissions of contaminants into air, land or water

Biogas gas may contain contaminants such as halogenated hydrocarbons, higher hydrocarbons and aromatic compounds. Biogas produced from digestion of sewage sludge may also contain siloxanes that may cause severe problems in downstream utilisation. Contaminants that must be removed from biogas are ammonia, dust, particles and siloxanes. However, all technologies used today to produce biogas as a vehicle fuel purify theses contaminants in their processes.

6.3.1 Sulphur gases

Biogas may contain a variety of sulphur compounds, such as sulphides, disulphides and thiols. Oxidized sulphur compounds (sulphate and sulphite) are corrosive in the presence of water. It has to be removed in order to avoid corrosion in compressors, gas storage tanks and engines. The main sulphur compound in biogas is hydrogen sulphide which is reactive with most metals.

6.3.2 Halogenated compounds

Halogenated compounds (e.g. carbon tetrachloride, chlorobenzene, chloroform and trifluoromethane) are often present in for example landfill gas but only occur rarely in biogas from digestion of sewage sludge or organic waste. Halogens are oxidized during the combustion process. The combustion products are corrosive, especially in the presence of water and can cause corrosion in downstream pipes and applications. They can also initiate formation (dioxines and furans) if temperature and time during combustion are favourable.

6.3.3 Ammonia

Ammonia is formed when proteins are degraded and the amount of ammonia in the biogas depends on the substrate composition and pH during the degradation. Ammonia can for example be removed in an absorption process, in an adsorption process or in a condense process.

6.3.4 Siloxanes

Siloxanes are volatile silicones bonded by organic radicals. They occur in gas from digestion of sewage sludge. Siloxanes are converted during combustion to inorganic siliceous deposits in downstream applications. In engine applications the amount of silica has to be reduced to a minimum.

6.4 Methane slip at filling stations

Methane slip is not desirable when biogas is handled since methane is about 20 times stronger greenhouse gas than carbon dioxide. There are a great number of actions that can be taken to minimise and prevent methane emissions from the emission sources identified in the biogas system chain. This is possible through careful consideration of these aspects already in the early phases of conceptual and detailed design, construction and procurement of suppliers of components/facilities, as well as during operation[19].

Methane slip may occur during the fuelling process and shall be documented. The emissions from fuelling could more or less be considered negligible in normal circumstances. It is important to notice the difference between a continuously leakage and an instantaneous slip. Essential measures for reducing methane losses during fuelling of biogas are to ensure proper operation without major fluctuations in the gas pressure and to work with regular controls and gas leakages checks.

Spill of LNG or LBG from LNG/LBG filling stations and back up equipment may occur due to, for example, an accident. In case of a release and leakage the liquified biogas will immediately evaporate to the atmosphere.

For details on methane losses and slip during production and utilization of biogas, see further BBB report “Methane losses in the biogas system”.

[19] Sweco, 2012c

7 Cost analysis

SL run about 2 000 buses in the Stockholm region. In 2020, SL will have a need of approximately 2 300 buses. That figure is equivalent to four new depots where one depot equals about 70 buses. The cost to establish a new bus depot is about 3,5 to 4 million SEK/bus at the depot. The choice of fuel does not affect the price.

For a bus depot of about 100 buses, the cost for the biogas system is approximately 10-20 % of the total investment cost of the depot. Out of the cost for the biogas system, cost for contractor is approximately 30 %.

The difference in investment costs between fast and slow refuelling is marginal for a 100 bus depot. The cost for a fast filling system is slightly more expensive. The main difference in investment costs is the dispenser for fast filling and refuelling nozzles for slow refuelling.

A comparison between investment costs for different biogas systems, including refuelling, per depot and lot is presented below, please note that each depot and what it is containing in detail is described in Chapter 3;

Söderhallen depot	370 000 SEK/lot
Gubbängen depot	415 000 SEK/lot
Lidingö depot	800 000 SEK/lot
Charlottendal depot	540 000 SEK/lot

At the Lidingö depot, which was converted into biogas buses, it was very little area to use and therefore a lot of work was put into the planning and working with permits, risk analysis and contacts with the authorities.
At Charlottendal, there is still some years left before the depot is taken in operation so that figure is still to be finalized.

8 Discussion and recommendations

With SL as a reference, the objective of the report has been to describe and compare biogas fuelling system alternatives for buses. The report compares slow and fast fuelling systems for biogas, natural gas and hydrogen fuelling systems and analyses differences between costs, safety, fuelling time and environmental aspects as well as other benefits and disadvantages.

There is a large difference in the operational experiences between the fuels of CBG, LNG and hydrogen. The main experience within Sweden and within SL is based on the great extent use of CBG. Today all of SL's buses run on CBG. As mentioned in Chapter 2, currently (June 2012), there are one LBG fuelling stations built and up and running on trial. The private company Scandinavian Biogas and Fuels International AB has constructed the LBG fuelling station in Uppsala municipality for 2 buses. The filling station is of a pilot size model and the operational experiences are limited. Looking into refuelling buses with hydrogen, the experience is limited to the 3 buses running in Stockholm during the CUTE project. There is today, globally on-going research on hydrogen and fuel cells technology.

The difference in investment costs between fast and slow refuelling is marginal for a 100 bus depot. The cost for a fast filling system is slightly more expensive. The main difference in investment costs is the dispenser for fast filling and refuelling nozzles for slow refuelling.

To conclude and summarise SL's experiences within refuelling of biogas buses, a summary of recommendations is given;

- The main operational experiences is from fuelling systems with CBG/CNG
- The specific conditions at the location of each depot control the choice of fuelling system i.e. slow filling or a fast filling system.
- It is preferably to use a combination of slow fuelling system and a dispenser for best flexibility.
- SL uses both systems today depending mainly on if the buses are parked indoors or outdoors. Fast fuelling alone is only used at indoor depots.
- The operational experiences from Söderhallen show that the try-out period with a higher pressure system led to a change in the system to a lower pressure. Therefore, the experiences gained in early stages shall be collected and used in the future planning of depots.
- Operational experiences show that fast fuelling is creating a more stressful environment for the staff compared to slow filling. At fast fuelling, maintenance staff at the depot fuels the bus and there is a large demand on logistics. The stressful environment has sometimes led to breakage of hoses when being run over by the bus.

- The refuelling system is part of the depot which needs to be planned together with the distribution system and to carefully examine logistics and if there are existing infrastructure that will lower the investment costs.
- Methane slip may occur during the fuelling process and shall be documented. However, the emissions from fuelling could more or less be considered negligible in normal circumstances. Essential measures for reducing methane losses during fuelling of biogas are to ensure proper operation without major fluctuations in the gas pressure and to work with regular controls and gas leakages checks.

Through the activities carried out in the BBB-project, a lot of experience of transnational importance has been gained. This will be communicated to project partners and other stakeholders through different means of communication available to the Baltic Biogas Bus project.

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Appendix 1

Summary of relevant EU-directives

EU Directive	Encompassing
94/9/EC (ATEX 95 equipment)	The regulations cover electrical and mechanical equipment for usage in explosive atmospheres. Directive 94/9/EC of the European Parliament and the Council of 23 March 1994 on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres, commonly referred to as ATEX ("Atmosphères Explosibles") Products Directive.
97/23/EC (PED Pressure Equipment Directive)	The regulations cover minimum standard requirements for design, manufacture, testing and conformity assessment of pressure equipment and assemblies of pressure equipment. Directive 97/23/EC of the European Parliament and of the council of 29 May 1997 on the approximation of the laws of the Member States concerning pressure equipment
1999/92/EC (ATEX 137 workplace)	The regulations cover minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres. Directive 1999/92/EC of the European Parliament and of the council of 16 December 1999 on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres.
2004/108/EC (EMC Directive)	The regulations cover electromagnetic compatibility of equipment and assure good engineering practice for fixed installations. The EMC Directive limits electromagnetic emissions of equipment in order to ensure that it does not disturb radio and telecommunication or other equipment. The Directive also seeks to ensure that the equipment itself is not disturbed by radio emissions when used as intended. Directive 2004/108/EC of the European Parliament and of the Council, of 15 December 2004, on the approximation of the Laws of Member States relating to electromagnetic compatibility (EMC)
2006/42/EC (Directive on machinery)	The regulations cover machinery, and other mechanical equipment (e.g. lifting accessories, chains and ropes), to ensure minimum safety and health standards, including e.g. ergonomics, control systems, noise, vibrations, etc. Directive 2006/42/EC of the European Parliament and of the council of 17 May 2006 on machinery.
2006/95/EC	The regulations cover electrical equipment designed for use

(Directive of electrical equipment within certain voltage limits)	with a voltage rating of between 50 and 1 000 V for alternating current and between 75 and 1 500 V for direct current (with some exceptions), to ensure good technical safety practices. Directive 2006/95/EC of the European Parliament and of the council of 12 December 2006 on the harmonisation of the laws of Member States relating to electrical equipment designed for use within certain voltage limits. Note that electrical equipment for use in explosive atmospheres is exempted from this directive (Annex II), i.e. only equipment at the filling station not associated with the gas are covered.
1999/36/EC (TPED Transportable Pressure Equipment Directive)	The regulations cover common standards for design, manufacture, testing and certification in all transportable pressure equipment. Council directive 1999/36/EC of 29 April 1999 on transportable pressure equipment