Gas as Vehicle Fuel in the Nordic Region

Ongoing Field Tests involving Natural Gas, Biogas and Propane

Anne Marit Hansen
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0. Introduction

Over the past two years, the interest in running vehicles on natural gas in the Nordic Region has increased. The reason for this is increasing environmental awareness of the transport authorities, motorists and authorities.

An example of this is the ban by the Gothenburg local authorities in Sweden on the purchase of new diesel buses in Gothenburg after January 1st 1992. Another example is the tax benefit of driving on gas, particularly in Finland and Sweden.

One of the most important milestones in developments is the signals from the engine manufacturers that they are able to supply engines optimally suited to run totally on natural gas. Some engine makers can already supply buses optimized for gas operation; others will be able to do so within the immediate future.

In order to develop this market, experience data from field tests with gas are essential. Above all, it is these data which give other prospective customers a usable knowledge of the gas's potential as a vehicle fuel.

Efforts here in the Nordic area have primarily been concentrated on heavy-duty diesel-driven vehicles, as this is where the conversion to an alternative fuel offers the greatest environmental benefit. The heavy duty vehicle market is also easier to enter because it is subject to control from state, municipal and county-municipal authorities to a larger extent than the private vehicle market.

A joint Nordic gas bus project is in progress financed by the transport authorities, gas industry, engine industry and the Nordic authorities. In its initial phase from 1988 to 1990, the project concentrated on engine development; the result demonstrates the methane gas bus's potential for very low emissions. In the second phase of the project, 1991-1993, activities will concentrate on standardization, safety, the market and technical specifications. The project has been an important catalyst in the development of the vehicle gas market in the Nordic area, partly because major transport authorities have been in charge of the project.

This paper is intended to provide a brief outline of the tests which have been initiated using natural gas, propane and biogas as a vehicle fuel. The paper will also give an overview of future tests for which specific plans have been made.

Additional information can be had from NGC.
List of Contents

1. Sweden
   1.1 General
   1.2 Natural gas operation of buses in Malmö
   1.3 Natural gas buses in Gothenburg
   1.4 Passenger cars on natural gas in Varberg
   1.5 Biogas buses in Linköping
   1.6 LPG buses in Sundsvall

2. Norway
   2.1 Natural gas bus in Trondheim
   2.2 LPG buses in Oslo
   2.3 Natural gas bus in North Rogaland

3. Denmark
   3.1 Odense City Transport, LPG operation of buses
   3.2 The Skibby coaches
   3.3 The domestic filling project

4. Finland
   4.1 Development of the Valmet gas engine at VTT
   4.2 Demonstration of LPG operations on a lorry
   4.3 Demonstration of an LPG bus in Espoo
1. Sweden

1.1 General
Sweden has been highly active within the field of alternative fuels for heavy vehicles seen from a Nordic point of view. Sweden has major vehicle production and tradition therefore dictates that alternative fuels should be an area of interest for Sweden. In addition to a number of projects involving natural gas, propane and biogas-driven vehicles, Storstockholms Lokaltrafik (The Greater Stockholm Local Transport Authority) has a large fleet test in progress with 32 ethanol gas-driven buses.

1.2 Natural gas operation of buses in Malmö
Malmö Local Transport (ML) currently has three natural gas buses in operation. The aim of the project is to try out ABB’s lightweight composite tanks and infrastructure in respect of bus tanking and servicing. The project started in 1989 and is scheduled to run until the turn of the year 1992/1993.

Buses
- Scania CR 112 (1984) with a Scania DN 1101 diesel engine converted to natural gas operation by TNO in Holland. The engine output is 143 kW.
- Scania CR 113 (1988) with a Caterpillar 3306 natural gas engine. The engine has an output of 164 kW and is fitted with an IMPCO automatic control system.
- Ontario II natural gas bus (regular service bus).

Natural gas tanks
The buses are equipped with ABB's new-design lightweight tanks. Each tank weighs 37 kg when empty. The tanks are made of carbon fibre/epoxy glass composite, optimized for high strength and minimal weight. These tanks enable the original number of passengers without exceeding the axle load limits.

Each bus is fitted with 8, 9 or 10 tanks, depending on the size of the bus. Each tank has a volume of 70 litres, giving a total tank volume of 560, 630 and 700 litres, respectively. With a fuel pressure of 250 bar, the respective gas volumes are 150, 160 and 175 Nm³. One Nm³ is equivalent to approx. 1 litre of diesel. The buses have therefore been put into service on routes which match their cruising range.

Filling installations
The filling installation was supplied by the Italian manufacturer Nuovo Pingone, Florence. The filling pressure is 250 bar. The filling capacity is about 800 Nm³/hour.
Operating experience to date
The field test with ABB's fibre composite tanks has now been completed and the results are good, with no regard to the tanks' performance. ABB is continuing work on specification and standards for its composite tanks. Any future mass production is dependent on a new ISO standard and sufficient interest on the part of customers. As far as ML's buses are concerned, these operate on ordinary service routes with no operating disruptions. During the operating period to date, the buses have proved to be highly reliable and their drivers are most pleased with the performance of the buses.

Further activities
ML has concluded that, as an alternative fuel, CNG makes for clean collective transport and a sound economy. The transport authority will therefore convert a further 10 city buses and 6 regional traffic buses to natural gas.

1.3 Natural gas buses in Gothenburg
The background for the natural gas project at Gothenburg Trams is the municipal authority's decision that no more diesel buses are to be purchased after January 1st 1993. Gothenburg Trams are in charge of investments in and operation of the buses, while the Gothenburg Energy Authority is responsible for investing in and operating filling installations. The plan is to acquire 100 natural gas buses before 1996. That will mean that 40% of the bus fleet is running on natural gas.

Buses
In 1991, Gothenburg Trams converted one of their Scania DS 11 diesel buses (1986) to natural gas in collaboration with Marintek in Trondheim. The engine was converted from diesel to an otta lean-burn engine. The bus is equipped with steel tanks and has a cruising range of 260 km.

In addition, Gothenburg Trams have ordered 20 natural gas buses from Volvo. Two buses were delivered on March 10th 1992 and the remaining 18 will be delivered in February 1993. The first two buses are standard vehicles with steel cylinders. The next 18 will probably be low-floored buses. The new buses will possibly be fitted with fibre composite tanks, depending on how standardization of this type of tank progresses (see point 1.2).

The tank volume has been specified to 1,200 litres at 200 bar pressure. This will give the buses a cruising range of 350 to 400 km, i.e. the same as for a standard diesel bus.

Filling installation
The Gothenburg Energy Authority (EIG) has built a "mobile" CNG station in a container. The CNG station is based on the parallel linkage of 4 Fuel Maker domestic filling installations. The station is dimensioned to fill one bus and has
been in operation for about 6 months.

EIG is in the process of setting up a larger permanent filling installation for the next 20 Volvo buses. The plant compressors are being supplied by Reawell Kompressorer. The supplier has a service organization in Sweden. EIG has concluded a 2-year service and training contract with the company. The delivery pressure from the filling installation will be 250 bar. The filling installation is dimensioned to fill all 20 buses simultaneously for a maximum of 5 hours. Capacity is 770 m³/hour.

Economy
The added investment for the first 20 buses from Volvo is an estimated SEK 345,000/bus, all in (including filling facilities). The added investment for the next 60 is an estimated SEK 212,000/bus, making an additional cost of approx. 15% in relation to a new diesel bus. There are clear signals that the added costs will be covered by public funds.

The investment cost for the permanent filling installation is an estimated SEK 3m.

The price of fuel (CNG) will be fixed on the alternative principle, i.e. calculated on the basis of the price of diesel.

Environment
The reason for Gothenburg Trams’ intensive commitment to natural gas buses is the requirement for more environmentally acceptable bus operations. There is therefore a stipulation on the part of the transport authority that these bus engines must be optimized for 100% natural gas operation and very clean combustion.

The guaranteed emission values for the converted bus are:

<table>
<thead>
<tr>
<th>GUARANTEED EMISSION VALUES g/kwh</th>
<th>NOₓ</th>
<th>CO</th>
<th>THC</th>
<th>Part.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scania DS 11 converted at Marintek</td>
<td>3.1</td>
<td>0.1</td>
<td>2.2</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

THC = Total hydrocarbons, i.e. including methane
Measurement method: ECE R49 (European 13 Mode)

The specification for the new buses to be supplied by Volvo is:
VOLVO NATURAL GAS BUS SPECIFICATION  g/kwh  NO,  CO  HC

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>0.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Measurement method: ECE R49 (European 13 Mode)

Provisional measurements have shown that the emission from the first two buses is below the specified emission values.

1.4  Passenger cars on natural gas in Varberg

Vattenfall, in cooperation with private interest in Varberg, have converted a Volvo 740, 1988 model, to natural gas operation. A domestic filling installation of the Fuel Maker type has been set up in the customer’s garage.

The project includes collation of experience data on the vehicle’s reliability and performance when run on gas. Emission measurements will also be performed on the car. The project will also gather experience data on Fuel Maker, which is a relatively new product. A report on the project will be published in September 1992.

The project has been financed by the following interested parties:
* Vattenfall Energi AB, in charge
* Swedegas AB
* Malmö Energi
* Sydgas AB
* Göteborg Energi
* The Swedish Board for Technical Development (STU)

1.5  Biogas buses in Linköping

The transport authority in Linköping, LITA, will convert 6 Scania buses to methane gas operations. The methane gas is produced from the local sewage purification plant and the gas to be used as fuel will have a methane content of 95%. The buses will be put into operation during the first half of 1992.

The background for the project is the desire for environmentally friendly bus operations. Moreover, the transport authority wishes to gear itself to gas operations in connection with a future link-up to the Swedish gas network.

The aim of the project is to collect experience on gas operation of city buses and to undertake emission measurements. The buses are being converted to run on gas by Sylinderservice and Marintek in Trondheim. The test period has been defined as 70,000 km.
The following emission limits have been outlined for the gas buses:

<table>
<thead>
<tr>
<th>NO(_x) g/kWh</th>
<th>CO g/kWh</th>
<th>THC g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>0.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

THC = Total hydrocarbons, i.e. including methane
Measurement method: ECE R49 (European 13 Mode)

The emission requirements are to be followed up with measurements of emissions from the buses as per ECE R49, supplemented by several metering points in order to form a better picture of the actual emissions.

1.6 LPG buses in Sundsvall

The background for the bus project in Sundsvall is that the city suffers from traffic pollution. The local authorities therefore have a vested interest in evaluating whether gas-driven buses are an option for reducing emissions. The city's prime objective is first and foremost a reduction in NO\(_x\) (NO\(_2\)).

The aim of the LPG bus project is to assess whether commitment to LPG operation of city buses can contribute to emission reductions.

Since mid-1991, Sundsvall Trafik (The Sundsvall Transport Authority) has had an LPG bus in operation. The bus is a converted Volvo diesel bus from 1983 and has previously been run on LPG in Stockholm. The Volvo engine has additionally been optimized for gas operations at Marintek in Trondheim. The engine is a lean-burn engine with an oxidizing catalytic converter. The bus's fuel consumption is equivalent to diesel operations.

Marintek has specified the following emission values for the buses:

<table>
<thead>
<tr>
<th>LPG buses in Sundsvall</th>
<th>NO(_x) g/kwh</th>
<th>CO g/kWh</th>
<th>THC g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus no. 1: Volvo 1983</td>
<td>3.7</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Bus no. 2: Volvo 1991</td>
<td>2.5</td>
<td>0.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

THC = Total hydrocarbons, i.e. including methane
Measurement method: ECE R49 (European 13 Mode)

Sundsvall Trafik put an additional LPG bus into service in April 1992. The engine is a converted Volvo, 1991 model, lean-burn engine with oxidizing catalytic converter.
The following exhaust gas results were reported for the two LPG buses as at April 12th 1992:

Emission values:

<table>
<thead>
<tr>
<th>LPG buses in Sundsvall</th>
<th>NOx g/kwh</th>
<th>CO g/kWh</th>
<th>THC g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus no. 1: Volvo 1983</td>
<td>3.7</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Bus no. 2: Volvo 1991</td>
<td>2.1</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

THC = Total hydrocarbons, i.e. including methane
Measurement method: ECE R49 (European 13 Mode)

Sundsvall Trafik has defined a test period up to 1993. Experience data will be collected from operations and maintenance. In addition, emission measurements will be performed on both engines in accordance with ECE R49.
2. Norway

2.1 Natural gas bus in Trondheim
Since 1988, Trondheim has had a natural-gas-powered bus on its service network. The bus is a converted Scania DS 11, refitted by Marintek. During its operational period of more than 2 years, the bus has shown that the low emission values can also be achieved during normal bus operation. The noise level has been reduced by 10 DbA, representing a fifty-percent cut in relation to diesel operation. Operations have also shown that natural gas as a fuel offers operating reliability comparable with diesel operation. The transport authority's technical staff and drivers are extremely pleased with the natural gas bus.

The bus is fitted with 11 steel tanks. The tank volume is 145 Nm$^3$ and the bus consumes 5.5 Nm$^3$/10 km, providing a cruising range of 250 km.

Emission values:

<table>
<thead>
<tr>
<th>GUARANTEED EMISSION VALUES g/kwh</th>
<th>NOx</th>
<th>CO</th>
<th>THC</th>
<th>Part.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scania DS 11 converted at Marintek</td>
<td>3.1</td>
<td>0.1</td>
<td>2.2</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Optimized engine, laboratory test</td>
<td>2.0</td>
<td>1</td>
<td>0.1</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

THC = Total hydrocarbons, i.e. including methane
Measurement method: ECE R49 (European 13 Mode)

Additional activities in Trondheim
In 1992, the Trondheim Transport Authority and Marintek will start a project in which 6 buses will be converted to natural gas operations, 4 of the buses being powered by CNG and 2 by LNG.

The Norwegian Ministry of Transport and Communications will finance the project. NGC will co-finance the development of new LNG engineering in the project.

2.2 LPG buses in Oslo
Oslo Sporveier (Oslo Trams) have 4 LPG buses in operation on their service network. These are equipped with MAN engines and were put in operation in April 1991. The buses have driven an average of 40,000 km/year, which constitutes only 60% of normal operations for a city bus. This is due to operating problems during the start-up phase of the buses. These problems are particularly caused by the control system and problems with the catalytic converter. Moreover, motor defects have also been identified in connection with engine breakdowns.
Despite these initial setbacks, the bus company is satisfied with the buses' performance, discharge and noise. Fuel consumption is approx. 9.2 l/10 km.

2.3 Natural gas bus in North Rogaland
Haugaland Billag wishes to hire Trondheim Transport Authority’s natural gas bus, as described in point 2.1, in 1992.

It is planned to construct a natural gas filling installation at Statoil’s onshore installation at Kårstø, where the gas is accessible at 210 bar. The filling installation will be dimensioned to be able to fill the bus’s tanks in 15 minutes. The purpose of the project is to evaluate natural gas operations both with regard to emissions during operations, operating economy and noise.

Haugaland Billag will be using the results to assess the purchase of new gas buses. In connection with this project, a market strategy will be formulated in order to get more companies in the area to convert their vehicles to natural gas.
3. Denmark

3.1 Odense City Transport, LPG (propane) operation of buses

The reason for the project in Odense is the current surplus of LPG on the Danish market.

Projects have been financed by:
* The Danish National Agency of Environmental Protection
* BP Gas A/S
* Statoil A/S
* DAB Silkeborg
* Man Last & Bus A/S
* Odense City Transport
* The Technological Institute of Denmark (DTI)

Objective

The aim of the project is to demonstrate and document that a gas-powered bus is fully competitive with a diesel-powered bus in terms of operations and maintenance. A further objective is to document emission and noise reduction in connection with the conversion from diesel to LPG.

The environmental goals is represented through the following desired reductions:

<table>
<thead>
<tr>
<th>NO\textsubscript{x}:</th>
<th>min. 50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO, HC:</td>
<td>40-60%</td>
</tr>
<tr>
<td>SO\textsubscript{2} and part.:</td>
<td>90%</td>
</tr>
<tr>
<td>Noise:</td>
<td>40%</td>
</tr>
</tbody>
</table>

Status and results

The first LPG bus was put into regular service in June 1990 and has now clocked up more than 70,000 km on LPG. Bus number two was put into service in February 1991. Both the buses are fitted with an MAN engine on the lambda=1 principle, with a gas control system from Deltec Fuel and a three-way catalytic converter. There have been a number of initial problems with the buses as emissions have proved to be far higher than anticipated. The catalytic converter has therefore been rebuilt and the gas control system refined in association with MAN and Deltec Fuel.

Emission measurements following optimization, reported by DTI:

<table>
<thead>
<tr>
<th>NO\textsubscript{x} g/kWh</th>
<th>CO g/kWh</th>
<th>HC g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.63</td>
<td>0.01</td>
</tr>
</tbody>
</table>
Measurement method: ECE R49 (European 13 Mode)
Noise measurements both inside and outside the bus have shown that the desired noise reductions are perfectly attainable.

Operational reliability and performance have also been reported as being competitive compared to the diesel bus. Fuel consumption, calculated per unit of energy, increased by approximately 10% owing to the lower efficiency of the gas engine.

Additional activities
A report on the project will be given at the end of 1992. A decision will then be taken as to whether Odense City Transport will continue with LPG operations.

3.2 The Skibby coaches
In 1991, the Skibby Rejser Coach Travel Company, in cooperation with DTI (The Technological Institute of Denmark) and DAB Silkeborg, converted three diesel buses to LPG operations. The engine design is lambda=1, with a three-way catalytic converter.

The following emission measurements were reported by DTI:

<table>
<thead>
<tr>
<th></th>
<th>NOx g/kwh</th>
<th>CO g/kWh</th>
<th>HC g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skibby (Iveco)</td>
<td>1.26</td>
<td>1.11</td>
<td>0.04</td>
</tr>
<tr>
<td>Skibby (Leyland)</td>
<td>2.41</td>
<td>0.6</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Measurement method: ECE R49 (European 13 Mode)

3.3 The domestic filling project
Dansk Naturgas A/S, together with the regional gas companies and the Danish Gas Technology Centre, has concluded a joint-venture project on the installation of 10 domestic filling stations and the conversion of 10 cars to natural gas operation.

The motivation behind the project is to try out Fuel Maker's domestic filling installation. It will focus on the consumption of resources by providing the gas companies with domestic filling pumps in their own area.

In the context of the project, a market strategy will be prepared for natural gas for the passenger car market.
4. Finland

The projects described have been jointly conducted by the Finnish State Research Institute, VTT and Neste OY.

4.1 Development of the Valmet gas engine at VTT

In 1977-1989, development work was carried out on a Valmet 3-cylinder gas engine at VTT. The engine is a Valmet 312 engine with a rated electrical output of 30 kW. The engine was converted into a spark ignited engine and equipped with a lambda control system and a three-way catalytic convertor. The test period was set to 1,000 hours. Tests have been run using both propane and methane.

The results of the emission tests, both for propane and methane, in accordance with the European testing cycle, are:

<table>
<thead>
<tr>
<th>CO g/kWh</th>
<th>HC g/kWh</th>
<th>NOₓ g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Measurement method: ECE R49 (European 13 Mode)

The results reflect what is actually achievable under ideal conditions in the laboratory. The CO₂ emission was somewhat higher from propane than methane. Emission tests were undertaken at many operating points and it transpires that the NOₓ emissions increase at low loads.

In the course of the engine's 1,000-hour testing period, no special problems were recorded. Neither spark plugs nor engine oil were changed.

4.2 Demonstration of LPG operations on a lorry

Experience from development work on a Valmet 312 was transferred to a Valmet 612 (6-cylinder), 7.4 litre, installed in a Sisu SL 170 lorry. The engine was fitted with an IMPCO control system for lambda control and a three-way catalytic convertor from Kemira. The lorry was fitted with four 60-litre LPG tanks. The lorry had been in operation since the spring of 1990 and had been tested both in ordinary operations and in the laboratory.

Average fuel consumption increased by approx. 20% in relation to the diesel model. Drivers reported that they found the engine very flexible and easy to drive. The lorry has been tested for emissions in a chassis dynamometer at VTT.
Results from the emission measurements:

<table>
<thead>
<tr>
<th>CO g/kWh</th>
<th>HC g/kWh</th>
<th>NO\textsubscript{x} g/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>0.7</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Measurement method: ECE R49 (European 13 Mode)

As shown, emissions are not as low as the laboratory engine, but are still very low compared to diesel - about 85% lower for NO\textsubscript{x}.

The work on the Valmet 612 engine will continue; a major assignment will involve test operations with other fuel control systems.

4.3 Demonstration of an LPG bus in Espoo
The town of Espoo outside Helsinki has had an LPG bus in operation since April 1991. The bus is fitted with an MAN 12-litre engine and has a maximum output of 177 kW. The bus is equipped with 6 propane tanks with a total volume of 650 litres, providing a cruising range of 700 km. The bus is part of a comprehensive measuring programme at VTT, which will last 2-3 years.

The bus's lambda control and catalytic convertor are checked every week. Emission measurements are carried out every 2-3 months. The emission measurements are conducted according to a modified ECE R49 and ECE 15, which is a transient measurement cycle for lightweight vehicles. So far, the emission measurements have shown that NO\textsubscript{x} varies a good deal at various loads, but is very low compared to diesel operations; HC and CO have also turned out to be very low. The objective is to put 5-10 buses into service in the Helsinki area during the next two years.
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- Naturgas i industrin
- Forskning och utveckling inom naturgasanvändning
- Naturgas och miljö
- Industriella tørringsprocesser
- Forskning och utveckling inom naturgasanvändelse
- Naturgasanvändning inom kraftvärme-sektorn
- Fuel Cell Workshop I 1989
- Reburning Workshop 1990
- Fuel Cell Workshop II 1991
- Nordisk FUD-Workshop "Naturgasanvändelse"

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- Erfarenheter från finska gasturbinanläggningar
- Erfaringer med danske och andre europäiske naturgasdrevne gasmotoranläg
- Små gasturbiners tekniska nivå och utvecklingsriktningar
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- Utredning av små gasturbin- och motorkraftverksanläggningar
- Motorer och kraftvärmeaggregat för naturgasdrift
- Cheng Cycle - Et nyt kraftvarmesystem
- Drift- och underhållskostnader vid gasturbinanläggningar i Mellaneuropa
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- Industriell gasanvändning i Norden - En branschanalys. Bind 2: Massa- och pappersindustri
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