Sustainable logistics through methane gas vehicles
- test in commercial operations 2000 to 2005
Executive summary

In brief this project has organisationally been a success that should be copied as the commitment from the participating consortium members has been very good. With regard to the aims, success has been more variable. From an industrial point of view, functionality, technically and economically it has not been enough successful. From a working conditions and environmental perspective it has been more successful. Somewhat more in detail, the results were as described in summary below:

Better
Function Technique Economy
Worse
Work Environment

Performance summary

The industrial effort aimed at establishing a new technique (automatic adaptation due to gas quality) promoted by the purchase of vehicles from the consortium and thereby enable new markets. The technique has been developed but the demand for these types of vehicles has been low and at present neither Scania nor Volvo manufactures these vehicles.

Functionality meant that the vehicle should be totally compatible to the other existing vehicles in the fleets of the operators. This has not fully been achieved although the majority of the users are satisfied.

The economical performances for these vehicles are substantial more expensive than similar diesel vehicles. At the moment it would be impossible to carry out haulage operation in a cost neutral way with these vehicles without subsidies and owner support.

The environmental demands that originally were established for the project were tough for the gas vehicles, but over the years has conventional diesel technology improved with regard to environmental performance. Biogas is however a renewable fuel and the emissions for these vehicles are very low. The vehicles in the project have not fully fulfilled the environmental performance demands due to uncertain function in the catalytic converters. This malfunction is probably due to incomplete burning processes in the engines which leads to leakage of unburned methane and other hydro carbons which oxides in the catalytic converter at a very high temperature which in effect ruins the catalytic converter.

The techniques itself has been reasonable good even if the skills in the work shops has been substantial lower than skills in diesel techniques. Therefore has standstills been longer than for a similar diesel vehicle.
Working conditions in and around the gas vehicle are seen as much better than for similar diesel vehicle.

In order to introduce new technology it takes time especially when complex technical systems shall interact. Production and distribution of gas, development and production of vehicles and transport logistics operation are all complex technical systems itself and this project has strived to develop them all with regard to distribution vehicles. The main experiences from the project have thus been the need for humbleness regarding change in technology, attitudes and behaviours.
Table of content

1. Background .......................................................................................................................... 5
   1.1 Driving forces alternative fuels ....................................................................................... 7
       1.1.1 Market demand ........................................................................................................ 8
       1.1.2 Authorities demand and regulations ........................................................................... 12
   1.2 Objectives of pilots, why heavy duty vehicles ................................................................. 13
2. Aim of the project ................................................................................................................ 14
3. Method and organisation ...................................................................................................... 14
   3.1 Organisation ..................................................................................................................... 16
   3.2 Benchmark with traditional technology ......................................................................... 16
   3.2.1 Benchmark with traditional technology ....................................................................... 17
4. Delimitations ......................................................................................................................... 18
5. Methane gas .......................................................................................................................... 19
   5.2 Natural gas ....................................................................................................................... 19
   5.2 Bio gas ............................................................................................................................. 19
   5.3 Gas prices ......................................................................................................................... 20
   5.4 Distribution and filling ..................................................................................................... 20
6. The vehicles .......................................................................................................................... 21
   6.1 Volvo ............................................................................................................................... 21
   6.2 Scania ............................................................................................................................... 22
   7.3 Mercedes - Benz ............................................................................................................... 22
7. Results and discussions ........................................................................................................ 23
   7.2 Results and discussions regarding economy and environment ....................................... 24
       7.2.1 Discussion on economical aspects ............................................................................. 24
       7.2.2 Discussion on environmental aspects ......................................................................... 28
1. Background

Environmental awareness has fluctuated over time in various cycles\(^1\), but with a gradual increase of general acceptance in society of how environmental resources are one delimitating factor in societal development. In these cycles of environmental awareness the public opinion, and as a consequence the industrial sectors has been affected by strong environmental opinion. The underlying factor for this change has often been some major environmental catastrophes taking place.

The general growing environmental awareness that started in the early 1960’s has been more evident in some countries and industrial sectors than others. In Sweden the environmental focus has been very clear and in particular for some industrial sectors. The pulp and paper sector was for example much affected by customer environmental demands as well as legislative demands.

Over the years a more European uniform environmental agenda has developed in the environmental field. Furthermore is the environmental market demands and environmental legislation today embracing more or less all industrial sectors that have a negative impact on the environment.

A sector that early came in to focus was the transport sector due to its environmental impact on health, nature and climate. Still the transport sector in one of the most debated sector with regard to environmental concern as no major shift in reduced environmental impact can be seen. Much of the improvements due to new cleaner techniques are offset by a steady increase in the traffic flows. Furthermore is the average fuel consumption not shifting downwards due to larger privet cars.

\(^1\) The first cycle came about in the early 60’s very much initiated by Rachel Carson, and her book Silent spring. This new environmental focus culminated in the first UN conference on environment in Stockholm 1972. The second cycle of environmental awareness culminated in the UN conference 1992 in Rio de Janeiro. A third and short cycle of stronger environmental awareness came about in the late 1990’s. A common speculation on driving forces for a forth wave of stronger environmental concern is if several dramatic weather changes comes about due to the green house effect. This would probably increase the demand for renewable fuels.
Transport logistics is taking an increasing part of operation in trade and industry as the general trend is centralisation, outsourcing and globalisation which are strong drivers for change i.e. more transport logistics of the added value.

![Figure 1. Increase of transport work within EU15](image)

**Figure 1. Increase of transport work within EU15**

Large scale production and trade flows reduces the average energy use in the fixed facilities meanwhile the average energy use increases in transport logistics as that is a precondition for this change towards large scale operation.

![Figure 2. Change in EU25 CO2 emissions](image)

**Figure 2. According to a study within the EU it is predicted that the transport sector's share of all emissions of carbon dioxide will increase most to year 2010.**
Transport sector has an influence on almost all of the well known environmental problems we face today and it is therefore of utmost importance to develop new solutions that can take us in to the future. This is even more urgent today than ten years ago, considering the increasing dependence on transportation in the modern society.

Within the goods transport sector environmental demands came about in the early 90’s in some countries and today one can see environmental work being carried out throughout Europe and all continents in this sector. Moreover is the legislation catching up due to the EU enlargement i.e. a more uniform environmental legislation as well as national initiatives on road pricing based on the principle of polluter pays principle etc.

In this context new technical solution has been searched for in Sweden and elsewhere. One could argue that technical fixes are much wanted in order to solve problems with the systems as whole but they may well prove insufficient due to the magnitude of how transport logistics has developed over the last ten years and before. Alternative fuels will not at present demands last for replacing today’s needs of fossil fuels.

1.1 Driving forces alternative fuels

Before going in to each technical solution it is important to dwell somewhat on the underlying reasons for why a shift for new techniques are sought for and what type of implications these reasons may lead to in terms of concrete driving forces in society. The main driving forces identified are:

- Shortage of oil supply due to ending sources as well as unstable conditions where oil can be extracted. The peak of oil production is today estimated to 2010 to 2020. The unstable conditions in Iraq and in other oil producing areas are furthermore a potential risk for shortage in oil supply.
- Climate change has today gained general scientifically as well as political acceptance. If this green house effect speeds up with unpredictable effects on the weather, urgency for change will increase dramatically.
- Negative impact on the nature in terms of acidification, over fertilisation, and small and large scale leakage of oil in the nature.
- Negative impact on health due to particulates and hydrocarbons released from combustion engines.

In general we can see how new techniques within the internal combustion solutions step by step is improving on the aspects that negatively affects nature and human beings. This is done by improved combustion as well as after treatment of fumes. Within the diesel engine the efficiency is also relative high today, being approximately 45 % from input of fuels to momentum on the axis.

Never the less, climate change and future lack of crude oil is the big problematic areas to deal with when using fossil oil. In response to this challenge, market as well as regulatory initiatives is gradually shouldering this need for change.
1.1.1 Market demand

Market demand seems to be a relative weak driver for more fundamental change with regard to reduced negative environmental impact. Few companies and private people are in fact willing to pay more or give up present standards of living for a better environment. Minor changes in behaviour have been seen in purchase pattern among private persons of some commodities (typically those that does not have a major impact on the total economic budget) as well as an increase in sorting and recycling.

Among companies the awareness and real environmental work is today often fairly advanced and based on a certification according to ISO 14001 or an EMAS registration. The focus of the environmental work is resource saving i.e. cost savings rather than investing in new cost driving techniques.

Studies on how the transport buyer includes environmental concerns show differences between countries. In general an increasing number of professional transport buyers claim that they consider environment when choosing transport supplier. One could always suspect the results that this reflects their lip service rather than true commitment for change. Independently on that suspicion there are today many buyers and sellers that include environmental actions in the commercial agreement.

In order to describe how the industry in general includes various criteria’s for transport logistics in general and specifically environment some major representatives for the transport logistic sector ranked different criteria’s for buying transport logistic services\(^\text{1}\). The result is a combination of pure buyer’s idea and how the sellers perceive demands from the buyers of transport logistic services.

![Figure 3. Customers demands in logistic services](image-url)

\[^1\text{The result is a combination of pure buyer’s idea and how the sellers perceive demands from the buyers of transport logistic services.}\]
In order to further dwell on the issue if environment is included and considered in the transport solutions a specific question on that topic was asked in the same study.

Do you consider environment in today’s transport solutions?

![Figure 4. The relative share of how providers and buyers of transport logistic services mean that they include environment when choosing transport solutions.](image)

The strongest market driver for improved environmental performance in companies is probably still deliberate certification in accordance with ISO 14001. Very often an ISO 14001 certification is a mandatory demand from buyers as it is simple to follow up and proves some sort of environmental commitment. The environmental improvement implication of a certificate for transport logistics companies is often two folded as a certification it self constitute a commitment for improvements within the transport company. If not fulfilling the continuous improvement condition the company risks to lose their certificate. Secondly, the ISO 14001 constitutes that the holder of a certificate must handle their significant environmental aspects, including controlling their suppliers environmental performance. Very often the transport supplying company thereby comes into double focus of environmental control.

In theory the ISO 14001 system should lead to continuous improved environmental performance. The drawback of the system however, is that the magnitude of the improvements is not defined. Moreover is the starting point not fixed i.e. different companies can start from very different levels and still comply with the standard.
Eco labelling is another market way forward in order to achieve environmental improvements. Within transport services only the Swedish “Bra Miljöval” (good environmental choice) is available at present. The conditions for freight transport are very tough and at the moment only rail services as well as alternative fuelled vehicles with a high utilisation degree fulfil the demands.

### Maximum levels on energy and emissions

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy Type</th>
<th>Emissions of NOx+ SOx</th>
<th>Emissions of NMHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>General demands</td>
<td>0.10 kWh</td>
<td>0.25 g per tonnekm</td>
<td>0.01 g per tonnekm</td>
</tr>
<tr>
<td>Distribution</td>
<td>0.60 kWh</td>
<td>0.75 g per tonnekm</td>
<td>0.03 g per tonnekm</td>
</tr>
<tr>
<td>Light goods</td>
<td>0.6 kWh</td>
<td>4.0 g per vehicle km</td>
<td>0.4 g per vehicle km</td>
</tr>
</tbody>
</table>

Distribution: Includes transport that at a minimum of 75 percentage of its length is carried out in highly populated areas.
Light goods: Includes shipments with a total weight of maximum 1 tonne.
General demands: Includes all other transport services.

*Present criteria’s for “Bra Miljöval” from The Swedish Society for Nature Conservation in brief*

An additional area being tested is deliberate agreements between authorities and companies. Mostly these agreements include an upside of no regulation if companies adapt and a downside of new legislation implemented if the companies does not fulfil their part. At the moment it is still unclear weather this will work or not. A fairly advanced project in this field is presently being carried out by the Swedish environmental protection agency and a number of companies. The project related to transport is called “Future trade” and aims at substantial improvements within the time frame of 2025, but with concrete part objectives.
In summary we have seen a huge increase in the number of companies becoming certified in accordance with ISO 14001. The number of transport companies fulfilling the criteria’s within “Bra Miljöval” is fewer as well as the number of purchasers asking for these types of services and performance. There are at the moment, however also several transport companies offering various additional services in order to reduce the environmental impact from transport logistic services.

*Figure 5. Difference within ISO 14001 and compared with eco labelling. In the ISO example three organisations could be certified and complying to continuous improvements but from different levels, where as an eco label demands a specified level to be met.*
1.1.2 Authorities demand and regulations

As international agreements such as the Kyoto protocol is ratified there is a need to tackle the increase in transport work i.e. increase of fossil energy use and hence emissions of carbon dioxide from the sector. The aim is to reduce the contribution of green house gases from the transport sector. Moreover is negative impact on nature and health a burden on the transport sector. Policy makers have in reality three optional choices for changing the course with regard to improving environmental performance:

1. Absolute and preventive legislation
2. Demand control such as traffic control e.g. road tolls, km fees, quotations of numbers of passing etc.
3. Encouraging the implementation of new techniques by subsidies and taxes

Absolute and preventive legislation for transport are based on different part of the regulations. In Sweden a new structure of environmental legislation was introduced 1999. Furthermore 15 national environmental targets were introduced the same year. In effect of this structural change different maximum levels on immissions are put into action such as the rate of particulates in the air in cities. If these levels are not met the local politicians needs and have the obligation to implement restrictions in order to meet these demands.

Environmental standards of vehicles are another important driver for improvements. Within the EU, heavy duty vehicles must adapt to various Euro classes (see 5.3).

With regard to demand control the most well known initiatives are road pricing in Switzerland and since January 1 also in Germany. Other countries are likely to follow this solution. Austria has in many years used a quotation on the number Lorries from different countries being allowed for a certain period. Austria has given all countries a fixed number of Eco points that then are distributed to hauliers enabling them to pass Austria. The better environmental standard of the vehicle the fewer points are consumed.

When it comes to technical improvements with regard to fuels and vehicles many pilot tests have been made on different types of vehicles, often sponsored by different authorities. Large scale incentives for new solutions are presently being implemented. The most important example is the EU directive on Bio fuels, Directive 2003/30/EG. The directive is compulsory and includes an indication of an objective level for replacing fossil fuels with bio fuels by 2 % in 2005 and 5, 75 % by 2010. At present the Swedish implements this Directive. A new proposed way to reach these is to introduce “Green certificates” that corresponds to the amount of renewable fuels being sold from a fuel distribution company and that must be bought by the fuel distribution company.
1.2 Objectives of pilots, why heavy duty vehicles

In the early 1990’s the environmental performance of heavy duty vehicles in commercial operation was fairly poor. This was due to older engines as well as another quality of the diesel fuel until the beginning of the 1990’s, with regard to sulphur content. In 1991 a new classification system for diesel was introduced including environmental classes 1 to 3 and since 1996 diesel fuel according to environmental class 1 is the dominating quality on the market in Sweden. It has a maximum content of sulphur of 10 ppm, but in practice the content is around 3 ppm.

The content of sulphur has previously been regulated as described below:
- 1 October 1977 max 0.5 weight % S
- 1 October 1980 max 0.5 weight % S
- 1 October 1987 max 0.2 weight % S as annual average value

Former fuel quality and performance of heavy duty vehicles engines increased the incentives for new solutions. Therefore it was very adequate to strive for improvements within these vehicles. The most relevant diesel vehicles to swap with new alternative fuelled vehicles were, and still are within urban areas due to the higher population density and also that supplying vehicles with alternative fuel is only a realistic option in captive fleets. Another strong reason is the lower range of some of the alternative fuels as it is not as good as traditional diesel or not available everywhere. Last but not least is the fact that vehicles used in local distribution last longer than vehicles in long haul. Therefore the oldest fleet of Lorries has traditionally been located in urban areas where most people live and work. Thus city distribution is the best place for pilot tests. In order to offset the negative fact that cities holds the oldest vehicles Sweden introduced environmental zones in the three largest cities regulating the maximum age of these vehicles.

<table>
<thead>
<tr>
<th>Mode of transport</th>
<th>Life length (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lorry</td>
<td>8-15</td>
</tr>
<tr>
<td>Train</td>
<td>approximately 40</td>
</tr>
<tr>
<td>Aviation</td>
<td>20-30</td>
</tr>
<tr>
<td>Ship</td>
<td>approximately 40</td>
</tr>
</tbody>
</table>

Average length of operations
2. Aim of the project

This paper aims at describing result from tests carried out of methane gas driven distribution vehicles in active commercial operations throughout Sweden over the years 2000 to 2005.

The aims of the project were to:
- Introduce the closed-loop technology in combination with latest after treatment of fumes technology and thereby fulfil the emission levels of the EEV, Environmentally friendly Enhanced Vehicles.
- Use pure local biogas sources or in combination with natural gas and thereby achieve lower CO2-emissions.
- Testing the automatic adaptation technology for enabling various gas qualities.
- Forming a consortium of large transport logistics operators in order to purchase two types of distribution vehicles delivered by the large vehicle suppliers and thereby open up a market for heavy duty gas vehicles.
- Testing the vehicles in commercial operation over a period of three years.

3. Method and organisation

In order to enable access to alternative driven heavy duty distribution vehicles a consortium of several logistics players and vehicle manufacturers were formed. In this group of companies many different needs and skills were gathered. As the logistics players are large vehicle buyers the potential vehicle market motivated the manufacturers to join and develop this consortium.

A number of municipalities in Sweden are producing or plan to start up biogas production and distribution as stand-alone solutions and/or combined with existing natural gas distribution and dispensers. Therefore the need to enable vehicles adapting to different gas quality was identified. Vehicles carrying out transport services between different biogas production plants should also be able to drive on all types of gas. Furthermore the different quality of natural gas from different gas fields motivated inclusion of an automatic adaptation.

In south and western Sweden natural gas is presently distributed by pipeline. In addition there are plans to further develop this pipeline northbound to the middle of Sweden. In all regions with access to natural gas and biogas production the distribution could be carried out in common pipes. As a consequence of an increase in blended distribution of biogas and natural gas there is a need for vehicles adapting to various gas qualities.
The process of the project was to:

1. Develop vehicle criteria’s and demands as briefly described below:
   - Two sizes of vehicles 18-19 and 24-26 tonnes total weight
   - Automatic adaptation between biogas and natural gas
   - Emission levels:
     - CO < 3, 0 g/kWh
     - NMHC < 0, 4 g/kWh
     - CH4 < 0, 65 g/kWh
     - NOx < 2, 0 g/kWh
     - PM < 0.02 g/kWh
   - Vehicles fulfilling emission demands in tree years or 100 000 km
   - Range 300 km
   - Loading capacity not affected by gas tanks
   - Engine effects 220 and 250 braking horse power
   - Cooling equipment must be possible to adapt
   - Service agreement mutual to agreements offered to common diesel vehicle
   - If standstill a replacement vehicle should be offered
   - Similar life length as for similar diesel vehicle
   - Conditions for rebuild the vehicle for diesel fuel if access < 90 %
   - Guarantees, service and spare parts after the project time
   - Fuel efficiency should be strived for
   - Insurance cost must not increase
   - Noise levels compared to similar diesel vehicle shall be stated

2. Procure and purchase.
   Procure and purchase of the vehicles was mutually done. The commercial agreement and conditions between vehicle suppliers and buyers were however bilateral and not transparent for the consortium as a whole.

3. Use the vehicles in commercial operation
   The vehicles are in operation in Halmstad, Helsingborg, Gothenburg, and Stockholm.

4. Evaluate in accordance with evaluation model and parameters briefly described below.
   Functionality (range, filling-up, Strength and reliability)
   Economy (Total cost, Cost per km, Cost of capital)
   Environment (Energy, emissions and market attention)
   Technology (Stand-stills, Service, repairs)
   Working conditions (Noise, vibrations, fumes, function in operation)

The methodology for putting this paper together is to go through available evaluation reports and interview responsible persons for the pilots.

This paper aims at describing this specific test of methane gas in commercial operation for large distribution vehicles in Sweden with its advantages and drawbacks.
3.1 Organisation

The projects were named “Biobil” aiming at testing heavy duty vehicles in commercial operation driven on a variable gas quality i.e. automatic adaptation to different methane levels enabling optimal combustion at all time, driving on natural gas, biogas or different combinations. By introducing automatic adaptation the aim was also to open up a larger market for gas vehicles. The project is unique as it embraces a broad spectrum of participants as Arla foods, Axfood, Coop, DHL, ICA, Sweden Post, Schenker and Servera. Moreover were Scania and Volvo participants. Late in the project a Mercedes – Benz vehicle was also included in the test.
3.2 Benchmark with traditional technology

When starting out with new alternative fuels both health aspects and climate/resource aspects were relevant reasons for a change. As the standards for new heavy duty vehicles has evolved over the years the health aspects has somewhat decreased. Furthermore has retrofitting of after treatment of fumes been introduced including catalytic converters and particulate filters/traps.

<table>
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<tr>
<th>Name</th>
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<th>Euro 0</th>
<th>Euro 1</th>
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<th>Euro 3</th>
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<td>2,1</td>
<td>1,5</td>
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</tr>
</tbody>
</table>

In the coming examples of alternative solutions we have mainly compared them with a Euro III.

² Environmentally enhanced vehicles
4. Delimitations

This paper is based on a relatively small sample of vehicles and tests and should therefore not be interpreted as general results for all gas vehicles.

Figure 6. There are broad spectra of various future fuels. Which ones that will become the future alternatives.
5. Methane gas

Project Biobil aimed primarily to run Lorries on methane gas from biomass i.e. biogas, but also in combination with fossil based methane gas. The project is furthermore based on the ability to handle a variable gas quality.

5.2 Natural gas

Natural gas contains 85 – 95 % of methane, CH$_4$. Methane is lighter than air. Other fractions in natural gas are the hydrocarbons, nitrogen and carbon dioxide.

Natural gas can be compressed and named as Compressed Natural gas, CNG or at low temperature (-162 ºC) as a fluid named as Liquefied Natural Gas, LNG.

Natural gas is a fossil fuel with variable quality due its origin. Natural gas is only available in southern and western Sweden.

Combustion of natural gas is done in an Otto process with a lower efficiency than the diesel principle. The combustion is however a “lean-burn” process which reduces the loss of efficiency.

Natural gas is distributed in pipelines to southern and western Sweden.

5.2 Bio gas

Biogas contains to 60 – 70 % of methane, CH$_4$. Biogas comes from biomass and the process includes purification from carbon dioxide and other fractions. According to Swedish standards the biogas for vehicle fuels must contain 97 ±1 % methane. The specification of gas quality is named SS 155438

Within the EU biogas is used as a denominating name but in English literature, SNG (synthetic natural gas) is used for gas coming from metanization.

According to “Introduktion av förnyelsebara fordonsbränslen” today’s production capacity of biogas in Sweden is 0,085 TWh which is expected to grow to 0,38 TWh during 2005. This is however only 0,5 % of the total energy use f petrol and diesel for the transport sector as a whole.

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3 SOU 2004:133
5.3 Gas prices

The price for natural gas is corresponds to the diesel price hence the natural gas price follows the development of the diesel price. This means that an increase of the diesel price not necessarily improves the competitiveness for methane gas. One litre of diesel is approximately equal to one normal cubic meter (ncbm) where the energy content is somewhat higher. The energy content is:

– 1 litre Mk1 diesel equals 0.88 ncbm natural gas measured as the energy content
– 1 litre Mk1 diesel equals 1.01 ncbm biogas measured as the energy content

The natural gas has approximately 13 % higher energy content per m$^3$ compared to biogas. One can expect the total biogas consumption (m$^3$) to be approximately 10 - 15 % higher compared to driving on natural gas. This could be an argument for cheaper biogas per m$^3$ compared to natural gas. Another reason is that biogas is renewable and therefore should have an additional incentive.

The price for biogas is depending on the geographical localisation, but is often in parity with natural gas or the price of petrol. The price also depends on who is the distributor that provides the gas.

In the project the average price is estimated to SEK 6.50 excluding VAT.

5.4 Distribution and filling

Biogas is to an increasing extent being distributed in the natural gas pipe lines where possible. This takes place in Gothenburg, Eslöv/Laholm and is being planned for in Malmö and Falkenberg. Even in Stockholm this may be possible by using the former distribution network for city gas. A condition is that natural gas is shipped to some port on the east coast. If his solution is introduced some gas stations can provided with natural gas and biogas through the former city gas distribution network.

Filling up the vehicles took initially a relatively long time but this has improved during the project. The problem was due to low pressure filling stations. The problem is today eliminated.
6. The vehicles

The participating companies and vehicles are listed in the table below. In the early phase of the project two vehicle manufacturers participated in the project through their vehicles, but later one vehicle from Mercedes Benz was added in the project.

<table>
<thead>
<tr>
<th>Company</th>
<th>Owner</th>
<th>Reg. Nr.</th>
<th>Producer</th>
<th>Gas</th>
<th>Localisation</th>
<th>Contact</th>
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<tbody>
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<td>Åsa Ericsson</td>
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<tr>
<td>Servera</td>
<td>Servera</td>
<td>SRY 082</td>
<td>Scania P114</td>
<td>Bio</td>
<td>Stockholm</td>
<td>Bengt Sandell</td>
</tr>
</tbody>
</table>

Figure 5. Vehicle summary. Bio = Biogas; Blend = Distribution of biogas bended in the natural gas pipelines dominated by natural gas

6.1 Volvo

Engine name: G6B
Euro class: Euro 4
Engine: 6 cylinders gas engine with turbo and intercooler.
   Effect: 205 hk (150 kW)
After treatment: Oxidation catalytic converter.
Fuel tanks: four composite tanks, in total 500 dm3 mounted on the frame.
Fill up: Fill up can be carried out slowly over night at low pressure or equally fast as equal diesel vehicle, but under high pressure.
Adaptation: Works in accordance with the closed loop technology i.e. sensing the gas quality and automatically adapts combustion and optimize performance.
Others:
   Volvo has produced Lorries for mane gas operation sine the early 90’s. In 1998 the first FL 6 for methane gas was introduced. In total, including approximately 45 FL 10 Volvo has produced approximately 200 Lorries with methane gas. Production ended in 2004.

Volvo vehicles in the project
   Arla: Volvo FL 6
   Posten: Volvo FL 6
   Schenker: Volvo FL 6 (fuel tanks placed behind the driver cabin)
6.2 Scania

Engine name: OSC11 G03
Euro class: Euro 4
Engine: 6 cylinders Otto engine with 11,0 litres volume. The combustion is "lean burn" i.e. exceed of air.
Max effect 191 kW (260 hk) at 2000 rpm
1000 Nm at 1150 rpm
After treatment: Oxidation catalytic converter. Noise level is under 78 dB(A) at noise certification.
Fuels tanks: the vehicle is equipped four standing fuel tanks behind the driver cabin with a total volume of 560 litres (the customer solves the tank issue themselves).
Adaptation: Two of the vehicles in the project were rebuilt for closed loop and lambda regulation, enabling automatic adaptation of gas/air mix for different gas quality. The regulation has had some problems during the project.
Others: Production of the engine ended during January 2005, due to few orders. In total approximately 85 vehicles have been built since 2000.

Scania vehicles in the project
Axfood: Scania P 114
Coop: Scania P 114
DHL (GB Framåt): Scania P 114
DHL (VGT): Scania P 114
ICA: Scania P 114
Servera: Scania P 114

7.3 Mercedes - Benz

Engine name: OM 906 LAG
Euro class: EEV
Engine: 6 cylinders gas engine
Effect 279 hk (205 kW) at 2200 v/min.
Torch 1000 NM at 1400 v/min.
After treatment: Oxidation catalytic converter.
Fuel tanks: two fuel tanks in steel (2*300 litres shared in 8 containers mounted on the vehicle frame.
Fill up: can be carried out slowly over night at low pressure or equally fast as equal diesel vehicle, but under high pressure.
Adaptation: Automatic adaptation in accordance with gas quality.
Others: Low driver cabin with a conventional door or a bus door on the rights side of the vehicle.

Mercedes-Benz vehicle in the project
DHL (Harplinge): MB Econic
7. Results and discussions

In brief the project has organisationally been a success that should be copied as the commitment from the participating consortium members has been very good. With regard to the aims, success has been more variable. From an industrial point of view, functionality, technically and economically it has not been enough successful. From a working conditions and environmental perspective it has been more successful. Somewhat more in detail, the results were:

The industrial perspective aimed at establishing a new technique (automatic adaptation) that should be promoted by the large consortiums purchase of vehicles that then would open up for new markets. The technique has been developed but the demand for these types of vehicles has been low and at present neither Scania nor Volvo manufactures these vehicles.

Functionality meant that the vehicle should be totally compatible to the other existing vehicles in the fleets of the operators. This has not fully been achieved although the majority of the users are satisfied.

The economical performances for these vehicles are substantial worse than in similar diesel vehicles. At the moment it would be impossible to carry out haulage operation in a cost neutral way with these vehicles without subsidies and owner support.

The environmental demands that originally were established for the project were tough for the gas vehicles, but over the years has conventional diesel technology improved with regard to environmental performance. Biogas is however a renewable fuel and the emissions for these vehicles are very low. The vehicles in the project have not fully fulfilled the environmental performance demands due to uncertain function in the catalytic converter. This malfunction is probably due to incomplete burning processes in the engines which leads to leakage of unburned methane and other hydro carbons which oxides in the catalytic converter at very high temperature which in effect ruins the catalytic converter.

The techniques itself has been reasonable good even if the skills in the work shops has been substantial lower than skills in diesel techniques. Therefore has standstills been longer than for a similar diesel vehicle. Working conditions in and around the gas vehicle are seen as much better than for similar diesel vehicle.

![Figure 7. Performance summary](image-url)
7.2 Results and discussions regarding economy and environment

7.2.1 Discussion on economical aspects

The weakest spot in the test is the economical outcome. It is therefore important and interesting to dwell deeper into this aspect as it is a prerequisite for successful introduction of alternative fuels in large scale.

Our assessment of the results of the project showed the following results:

<table>
<thead>
<tr>
<th></th>
<th>Additional relative cost</th>
<th>Total additional cost during test (kSEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital</td>
<td>220/260 kSEK per vehicle</td>
<td>2 480 000</td>
</tr>
<tr>
<td>Fuel</td>
<td>13 SEK/10 km</td>
<td>548 918</td>
</tr>
<tr>
<td>Service/maintenance</td>
<td>5 SEK/10 km</td>
<td>211 035</td>
</tr>
<tr>
<td>Stand still</td>
<td>1500 / occasion</td>
<td>82 500</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>3 322 453</td>
</tr>
</tbody>
</table>

Given the fact that the test fleet was not economical viable we raised the question of how these vehicles could reach break even with a similar traditional diesel vehicle. The possible variable components to moderate on were:

- Fuel price
- Fuel consumption
- Capital costs

Different cost variables were available from the tests. Furthermore we based the calculation on the assumption that a conventional distribution vehicle has an annual range of approximately 4-50000 km. Hence we arrived at the following costs.

- Diesel fuel VAT excluded SEK 8 per litre
- Gas price VAT excluded SEK 6.50 SEK per ncbm
- Diesel consumption 3 litre per 10 km
- Gas consumption 5 ncbm per 10 km

Additional costs per 10 km
- Purchase (capital) SEK 5 per 10 km
- Service/maintenance SEK 5 per 10 km
- Stand still SEK 2 per 10 km
- Fuel (2 ncbm x SEK 6:50) SEK 13 per 10 km
Reaching economic break even

Alternative 1. Increase of diesel price

By increasing the diesel price with approximately SEK 8 per litre i.e. in total approximately SEK 16 (VAT excluded) per litre a methane gas and a diesel driven distribution vehicle has equal costs in total

Alternative 2. Decrease of methane gas price

By reducing the methane gas price with approximately SEK 4 per ncbm i.e. in total approximately SEK 2.5 per ncbm, a methane gas and a diesel driven distribution vehicle has equal costs in total

Reducing extra costs by driving behaviour

Consumption of gas is apart from the capital cost a large part of the additional costs in the project. In the project a significant vacation of gas consumption has been identified. The reason may be cargo weight, driving behaviour, traffic situation etc. The energy content difference between biogas and natural gas is also an explaining factor as can be seen in figure below.

![Gas consumption graph](image)

*Figure 8. Fuel consumption (ncbm/10 km), blue bars (dark) is biogas driven vehicles and yellow (light) bars are blended gas (often natural gas) driven vehicles.*
Discussion on the fuel consumption:
Gas engines works in accordance with the Otto principle and the diesel engine works in accordance with diesel principle.

The Otto principle is based on blending fuel and air which is ignited in the combustion room. The temperature must not lead to self ignition. The compression in an Otto engine is normally 9:1 - 12:1 which is half of the pressure in a diesel engine. Hence is the Otto engine more silent than a diesel engine. The effect from the engine is controlled by the injected fuel/air blend. This is part of the efficiency losses in the Otto engine. The lower compression also leads to a lower efficiency compared to the diesel engine.

The diesel principle is based on highly compressed air which leads to a high temperature in the combustion room. Thereafter is fuel injected and self ignites by his compression heat. The high temperature is being achieved by a compression of, 16, 5:1 - 18:1 the compression pressure in a modern’s diesel engine can at maximum are approximately 150-180 bars. The engine effect is only controlled by the injected fuel amount which leads to lower efficiency losses compared to an Otto engine.

In total this leads by definition to a higher energy use in the Otto engine compared to a diesel engine.

Figure 9. The difference in consumption of gas per hour (m$^3$/h) compare to diesel per hour at different effects.

The diagram shows an approximation of how the fuel consumption varies at different effects measured as gas (m$^3$/h) compared to diesel (dm$^3$/h) at different effects (≈ gas pedal) at 1200 r/min. It is obvious that the reduction of injected fuel/air in the Otto engine leads to higher fuel consumption and that this difference increases at lower effects. It’s also obvious that a biogas vehicle consumes more compared to a natural gas vehicle at a given effect.
Figure 10. A normal operational situation. Fuel consumption at 1200 r/min at different load.

Diagram 10 illustrates a normal driving pattern at constant gas pedal pressure (50 %) on a straight road. Assume an average speed of 50 km/h. Diesel consumption is at approximately 16 dm$^3$/h i.e. 3.2 dm$^3$/10 km, which is a reasonable number for a distribution vehicle. For a similar biogas vehicle the same figure is 21 m$^3$/h or 4.2 m$^3$/10 km. In order to reach the same consumption as the diesel engine one has to reduce the gas pedal pressure, hence the effect to 30 %. Average speed will decrease somewhat. It is important to drive less aggressive in a methane gas driven vehicle. In an aggressive driving pattern the fuel consumption will increase significantly more than in a similar diesel engine under the same conditions. The driver’s behaviour is of huge importance when driving gas vehicles.

As a rule of thumb one can say that 1 litre of diesel contains equal energy as 1 m$^3$ of natural gas. (Heat value for MK1 diesel is 34.4 MJ/dm$^3$, for natural gas 39.2 MJ/m$^3$ and biogas 34.7 MJ/m$^3$).

All together this explains the difference between the differences in fuel consumption between diesel, natural gas and biogas vehicles.

**Reducing capital costs by large scale production**

Overall has these vehicles been manufactured in a small scale. In total has Scania and Volvo produced approximately 230 vehicles of this type. Both have stopped their production. Mercedes Benz is still producing their vehicles but it is unknown how many vehicles they have built so far. An informed guess would say that production cost would be reduced dramatically in a large scale production. It is however most likely that the fuel tank and catalytic converter would remain more expensive to produce as they need to be more advanced than in regular diesel vehicles.
7.2.2 Discussion on environmental aspects

Based on average figures for the test fleet of methane gas vehicles compared with a diesel driven similar distribution vehicle the result shows that the methane alternative is better on the regulated emissions. Among the vehicles there were however individual vehicles that were weaker than similar EEV diesel vehicles on specific emission fractions.

Furthermore is the question of hydrocarbon emissions arguable. When eliminating the methane emissions from the total sum oh hydrocarbons the total hydrocarbon emissions are zero or even lower due to weak measuring techniques etc. Assuming that the emissions of hydrocarbons are zero one has to decide if the emitted methane should be seen as an added net in the atmosphere or only part of the natural emissions of methane from nature. In a natural gas vehicle this should most probably be seen as an added net of emissions. In a biogas vehicle it should most probably be seen as a zero net of emissions.

Coming to the issue of green house effect and the potential for these vehicles the question must be divided between natural gas fuelled vehicles and biogas fuelled vehicles.

Natural gas vehicle and green house effect

Natural gas is a fossil fuel but the content of carbon is lower than in diesel.

In general these vehicles have a lower efficiency as it is based on the Otto principle than the alternative diesel engine. Furthermore is the energy content is lower in the methane alternatives than in diesel.

The net green house gains when driving on natural gas in these distribution vehicles is approximately zero.
Bio gas vehicle and green house effect

Bio gas is a renewable fuel i.e. the net emissions of green house gases should be approximately zero.

In general these vehicles have a lower efficiency as it is based on the Otto principle than the alternative diesel engine. Furthermore is the energy content is lower in the methane alternatives than in diesel.

The question is how much fossil carbon dioxide is needed in order to produce the biogas fuel. Life cycle assessment shows that there is a net green house gain. Depending on where the gas is produced the results varies.
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