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KFB

The Swedish Program for Investigations Concerning Biofuels

Föredrag vid "The Sixth International Highway and Urban Pollution Symposium"

May 1998, Ispra/Baveno, Italien

Sören Bucksch, Karl-Erik Egebäck

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Sören Bucksch, KFB
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THE SWEDISH PROGRAM FOR INVESTIGATIONS CONCERNING BIOFUELS

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ABSTRACT

As constituted today, the transport sector is not sustainable in the long term. It is based almost entirely on non-replenishable natural resources which, when combusted, release emissions that can cause serious harm to human beings, animals and the natural environment. Therefore, in order to achieve a sustainable transport system, it is imperative to achieve a means of propulsion, which is based on renewable energy sources in every phase of production and distribution.

The responsibility for developing such a sustainable transport system is an assignment, which must be approached as a common cause, involving both the official agencies of society and the business sector together with international co-operation.

In 1991 the Swedish Government allocated 120 million Swedish crowns to the Swedish Transport and Communications Research Board (KFB) as funds for research, development and demonstration in the field of biofuels to be used in the transportation sector. In order to fulfil this obligation a program was presented and approved and this program for engine alcohols and biogas has been carried out between the summer of 1991 and the end of 1997.

The program has generated a broad spectrum of useful results showing that in general terms there are a number of technical problems connected to the use of biofuels. There is also a need to continue the development of both the fuels and the engines in order to take advantage of all that can be achieved concerning the use of biofuels in the transportation sector.

The presentation at The Sixth International Highway and Urban Pollution Symposium will focus on a brief description of the program carried out and a presentation of the results of the field tests and the emission characterisation.

1. INTRODUCTION

Interest in alternative automotive fuels, and especially renewable fuels, has been increasing during the last decade. In an international perspective the awareness of the foreseen changes of the environment, not least caused by the pollution of so-called greenhouse gases, has been a driving force. In countries such as Sweden, which have no oil production of their own and are very dependent on imported oil for industry, for the heating of buildings and for the transportation of people and goods, there may also be, in the long run, a need to use alternatives to fuels produced from crude oil. Today there is a growing use of renewable fuel, made from wood, for the heating of houses etc.

In order to carry out a study of the possibility of introducing new fuels for the transport sector the Swedish government allocated a fund of 120 million Swedish crowns to the Swedish Transport and Communications Research Board (KFB). Initially the work was concentrated primarily on health and environmental concerns in built-up areas. Pure alcohol fuel was seen as having the greatest potential for the improvement of the air quality. Gradually interest was also focused on the environmental problems, including the greenhouse effect, caused by the increase of CO_2 in

the atmosphere. It was therefore natural to seek solutions that increased the amount of biofuels in the pool of fuels as much as possible. Mixed fuels such as ethanol in both petrol and diesel oil, which can be used in present day engines, became an interesting alternative. Later on the use of biogas, i.e. methane gas from biobased raw material, was also tested and demonstrated.

2. ALTERNATIVE FUELS – ADVANTAGES AND DISADVANTAGES

In order to evaluate the advantages and disadvantages of biofuels a survey was conducted on the initiative of KFB. The fuels included in the evaluation were ethanol, biogas rape methyl esther and dimethyl ether. In short the following disadvantages have been identified for alcohols and gaseous fuels:

For all alternative fuels including biofuels the shortcomings are that;
* at present the cost of the fuels is considerable higher than for petrol and diesel;
* an alternative fuel needs to be separately distributed which adds to the initial costs;
* in order to exploit the advantage of the fuel it is necessary to adapt the engine to the new fuel;
* in order to obtain a sustainable development and use of the fuel a market must be created.

For ethanol or methanol the shortcomings are that;
* a less expensive method for the production of ethanol from hemicellulose-containing is still under development;
* the use of ethanol or methanol in a compression ignition engine needs a special adaptation of the engine (a spark plug or glow plug) or an additive (ignition improver) in the fuel;
* alcohols such as ethanol and methanol are hygroscopic and must therefore be treated in a certain way, when distributed and especially when blended in petrol.

For natural gas and biogas the shortcomings are that-
* taking full advantage of the high emission potential of the gaseous fuels needs a reliable engine with a specially designed fuel control system;
* the use of gaseous fuels needs specially designed fuel tanks, which normally increase the weight of the vehicle;
* usually the use of gaseous fuels in a heavy-duty vehicle needs a conversion of the engine from a compression ignition engine to a spark ignition engine;
* the operation area or distance for a gaseous fuelled vehicle is usually more restricted or shorter than for a petrol or diesel fuelled vehicle.

From the international viewpoint alternative fuels have been subject to many investigations and in the earlier days were used mostly for passenger cars. Later on alternative fuels have been used even for heavy-duty vehicles. At the VIII International Symposium on Alcohol Fuels, an ISAF symposium organised by New Energy and Industrial Technology Organisation (NEDO, 1988) there were more than 1200 presentations of which many were from investigations of the use of alcohols in heavy-duty vehicles. In Sweden many of the studies carried out during the last decade have been directed towards the use of renewable fuels for the transport sector.

The first program, on a larger scale, for the development of ethanol fuelled buses in Sweden started in 1989 when the board of Stockholm Transport decided that 30 new ethanol fuelled buses should be purchased in order to be operated in the city of Stockholm (Egebäck, 1992; Rydén, 1994). This part of the development was financially supported by two of the governmental boards, KFB and NUTEK (Swedish National Board for Industrial and Technical Development). By this program it was demonstrated (Grägg, 1992; Rydén, 1994/95) that the emission performance of the buses was favourable, as can be seen in Figures 1 to 3. By this program it was demonstrated that emission performances of the buses are as can be seen in Figures 1 to 3. Compared with the use of diesel oil the emissions of NO_X were 37 % less when using ethanol.

For the studied buses the particulate emissions were 0.20 g/km without a catalyst and 0.16 g/km with a catalyst when using diesel oil, and 0.12 g/km before catalyst and 0.04 g/km after catalyst when measured according to a transient cycle (Rydén, 1994/95). During a later project, the particulate emissions were measured on two Scania engines (a diesel fuelled DSC 1125 and an ethanol fuelled DSI 11E01) giving 118 mg/kWh and 12 mg/kWh respectively (Westerholm, et al., 1997).

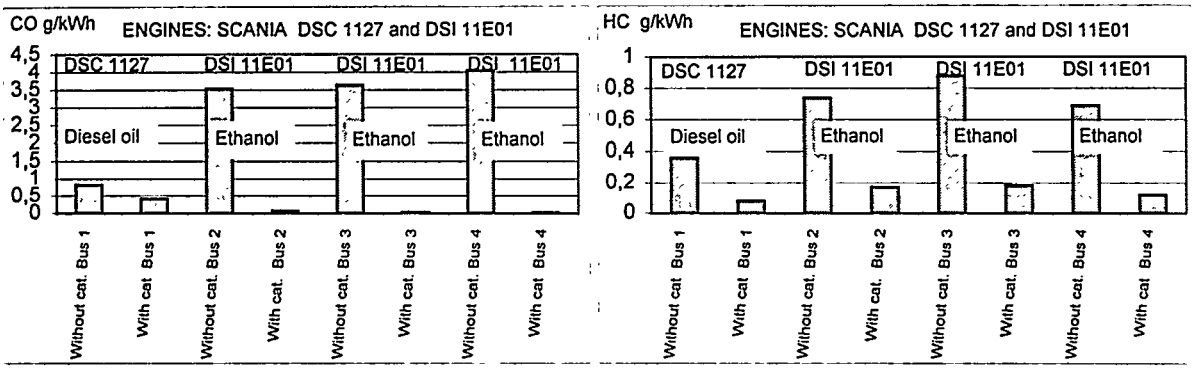

Figure 1. Emissions of CO and HC for buses tested according to the 13 mode cycle.

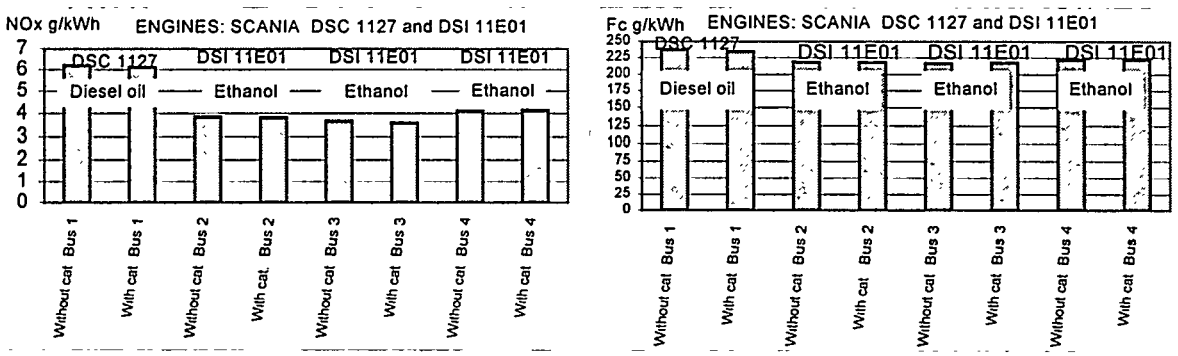

Figure 2. Emission of NO_X and FC for buses tested according to the 13-mode cycle.

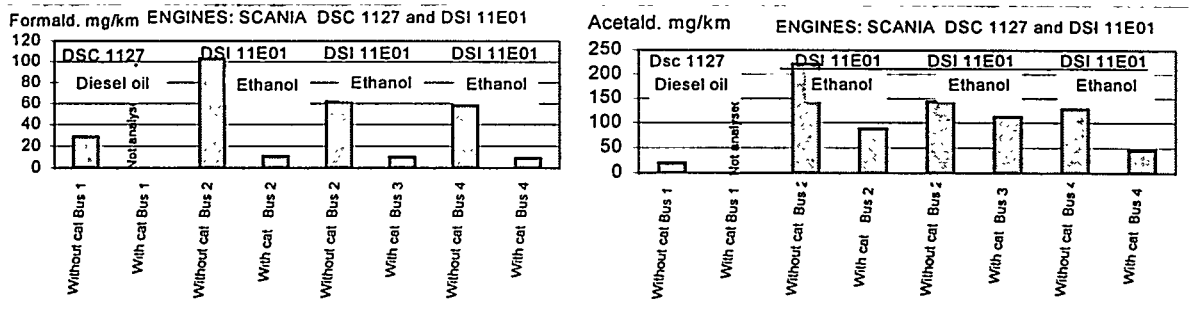

Figure 3. Emission of aldehydes for buses tested according to a transient cycle.

The presentation of the data for CO, HC and NO_x from this investigation is from tests according to this cycle since the 13-mode cycle is still the official test cycle for Europe. Tests carried out according to a transient cycle are presented elsewhere (Rydén, 1994/95). Concerning the emissions of HC (unburned fuel) from ethanol fuelled compression ignition engines an investigation at Luleå University of Technology (Haupt et al., 1997) has shown that the emissions detected as HC by a commonly used FID (Flame Ionisation Detector) contain between 63 and 91 % ethanol by weight. The expression "unburned fuel" should therefore be used instead of hydrocarbons for this group of emissions.

In addition to the advantages in terms of improvements in the regulated emissions, such as CO, HC, NO_X and particles, and in most of the unregulated emissions, the main advantages are that:

Ethanol;

* is a renewable fuel (see Figure 4);
* is simple in structure and will not form as many polluting components as do petrol and diesel oil when combusted;
* can be used in both otto and diesel engines if either the fuel or the engine is adjusted for intended use;
* is easy to handle and does not cause any serious environmental problem if spilled;
* can easily be blended in petrol and also in diesel oil as an emulsion.

Biogas;

* is a renewable fuel;
* can be recovered from sludge, manure and waste (Figure 5). This refuse is in itself a problem causing environmental problems and must therefore be taken care of in a reliable way. One environmentally friendly way to take care of the refuse is to use it as a raw material for the production of methane to be used as a fuel;
* is simple in structure and will not form as many polluting components which cause environmental and health risks as petrol and diesel oil do when combusted (Egebäck and Westerholm, 1997).

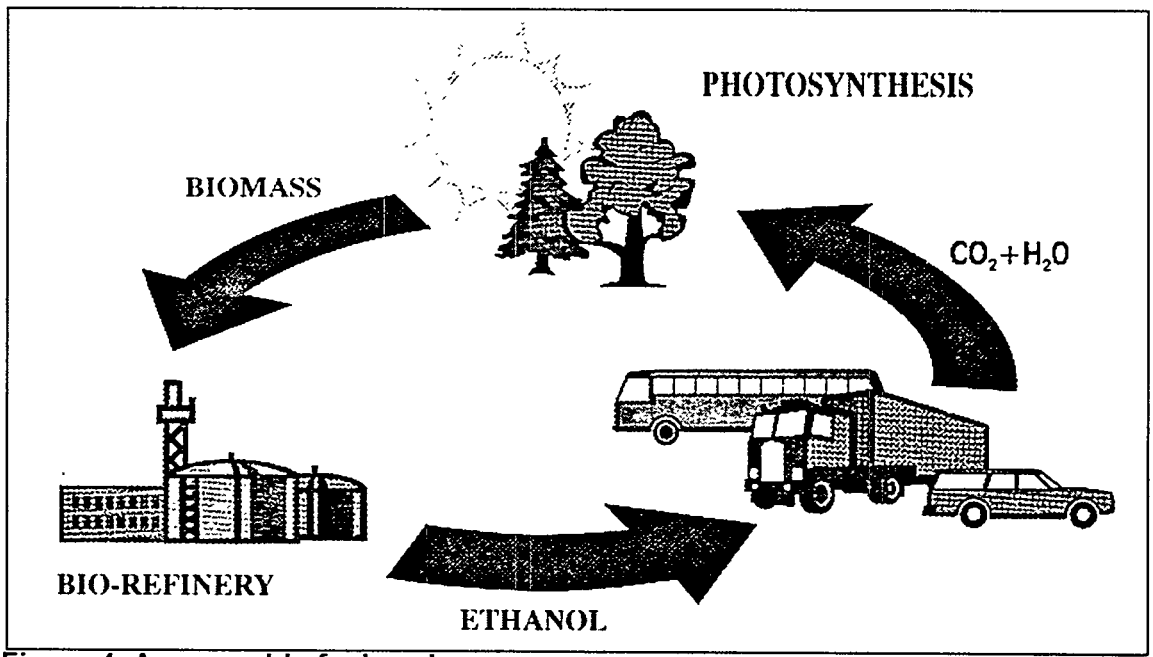

Figure 4. A renewable fuel cycle. Reference: (Rydén and Egebäck, 1997).

The positive results from the characterisation of the emissions from the ethanol-fuelled buses in Stockholm were used as a basis for a new program for the development of the use of biofuels. It must be pointed out that there was no official decision taken by the government as to whether there should be a broader introduction of biofuels in Sweden, but rather the intention of the government was to obtain more experience and facts concerning the use of biofuels.

3. THE SWEDISH BIOFUEL PROGRAM

The Swedish biofuel program, which was carried out under the responsibility of KFB, started in the summer of 1991 and was concluded by the end of 1997. It was financed by a sum of 30 million Swedish crowns per year for a total of four years, i.e. 120 million crowns which were allocated by the state for research, development and demonstration. The conditions for allocating and using the money were that the other co-operating partners would make economic contributions so that the share coming from the state was a maximum of 50%. The program comprised engine alcohols and biogas used as automotive fuels. The objects of the program were:

- to develop, test and evaluate techniques and systems for the use of engine alcohols and biogas,
- to stimulate larger producers and users to take an active part in the development and demonstration projects,
- to increase the knowledge of the long term use of engine alcohols and biogas, their environmental potential and the question of costs,
- to establish whether and under what circumstances engine alcohols and biogas are ready to be introduced in a broader scale.

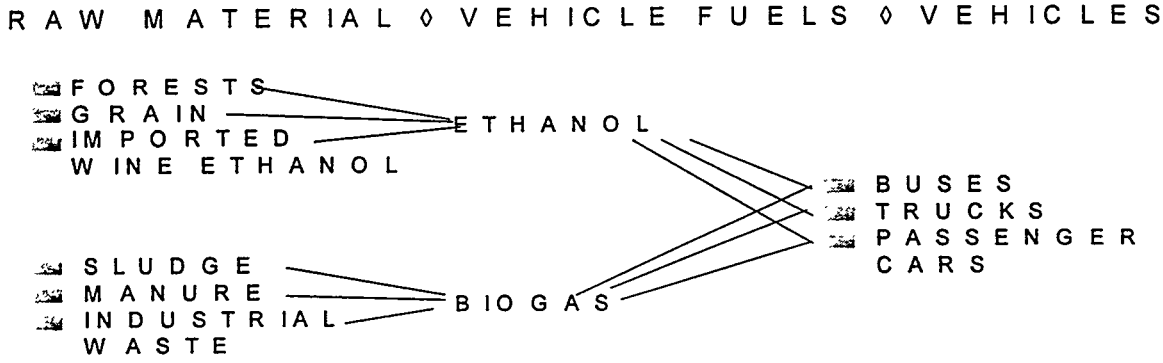

Figure 5. Production and use of ethanol and biogas as automotive fuels.

The KFB biofuel program thus deals with engine alcohols and biogas such as motor vehicle fuels and a diagram of the different alternative use of these fuels is presented in Figure 5. At present there are no suppliers of methanol from biomass and no potential customers who ask for this fuel. Other countries have experience of methanol as a vehicle fuel. KFB has chosen to obtain this knowledge, of running vehicles on methanol, from other countries. Its own efforts have been devoted to ethanol.

As can be seen from Figure 6 the engine and vehicle development trials using pure ethanol were carried out using with various types of ignition improver. Development work on catalysts is being carried out at the Royal Institute of Technology and development work on EGR - exhaust gas recirculation technology for compression ignition engine – has been carried out at Luleå University of Technology. Fleet trials using E95, nearly pure ethanol, in buses have been carried out in the cities of Stockholm and Örnsköldsvik and in the county of Skaraborg. Volvo and Chalmers University of Technology have developed truck engines for use with pure ethanol. Trucks have been tested in fleet trials at various places in Sweden in a project called "SVENOL". Flexible fuel vehicles have been tested in fleet trials spread over the whole country. Distribution facilities (including fuel pumps) have been built up in between 20 and 30 towns all over Sweden for the distribution of pure ethanol, E95 and/or E85.

Trials have also been carried out using a blend of ethanol in diesel with the addition of an emulsifier and there have also been studies of blending techniques.

For biogas, development work using catalysts and fleet trials with buses have taken place in Linköping, Trollhättan and Uppsala. Trials with trucks running on biogas have taken place in Trollhättan. Passenger vehicles run on biogas have been tested especially in Stockholm and to a lesser extent in Trollhättan and Linköping.

Apart from these activities the program comprised many different types of studies and evaluation. International experience was also a useful source of knowledge. A total of 100 documents and reports of various types have been produced.

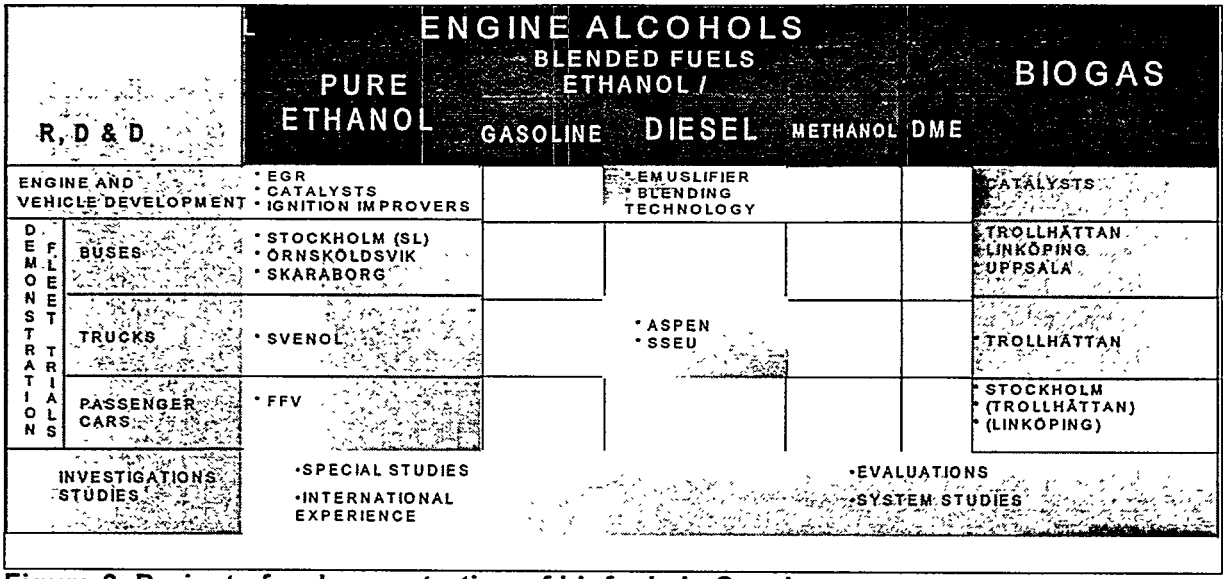

Figure 6. Projects for demonstration of biofuels in Sweden.

A condition for carrying out all the projects has been close co-operation with a number of partners. The funding of the projects amounts to a sum of 120 million Swedish crowns and with the addition of the financial contributions of the partners, the total resources of the program have amounted to 315 million Swedish crowns.

4. METHOLOGY FOR EVALUATION OF THE BIOFUEL PROGRAM

An evaluation of the use of a new fuel is not an easy task because there are many problems and parameters that have to be dealt with. First of all the fuel itself must be studied in order to discover whether it meets the fundamental characteristics for an automotive fuel. The possibility of producing a sufficient amount of the fuel and at an acceptable cost is of great interest. Secondly the use of the fuel must be optimised. Questions should be asked such as in which transport sector is the use of the fuel most efficient, taking into consideration not only the costs but also its environmental potential?

The above-mentioned questions are fundamental because they lead to a need for different activities such as research, investigations and demonstrations. For the actual biofuel program a great part of the activities have been directed to the following. Regarding the development of methods for the production of ethanol, this part of the evaluations, within the field of biofuels, has been under the responsibility of the Swedish National Board for Industrial and Technical Development (NUTEK) and will not be discussed in this paper.

4.1 Research and investigations

The development of engines especially adapted for the use of alternative fuels such as alcohols and natural gas has been carried out at the workshops of many car and engine manufacturers. Some of the best known engine development work was carried out at Detroit Diesel for the conversion of a heavy duty engine to be fuelled with methanol or ethanol (Parry et al., 1993).

As early as 1980 Scania Bus and Truck developed an ethanol fuelled bus engine for the Brazilian market. This engine has been improved in several steps and is now used in the majority of the buses in Stockholm.

In order to further improve the Scania engine KFB supported a project carried out at Luleå Technical University in co-operation with Scania (Egebäck and Pettersson, 1996). A study was carried out of the influence on the emission when changing different parts of the engine such as

the injection pump, the fuel injectors and the turbo or by changing engine parameters such as the injection timing, the compression ratio or the ignition improver of the fuel. All of these alternatives had a positive or negative influence on the emissions, but the most positive alternative studied was the use of EGR (Exhaust Gas Recirculation), by which the NO_X-emissions were reduced by about 50 %, Figure 7 (Tingvall et al, 1997).

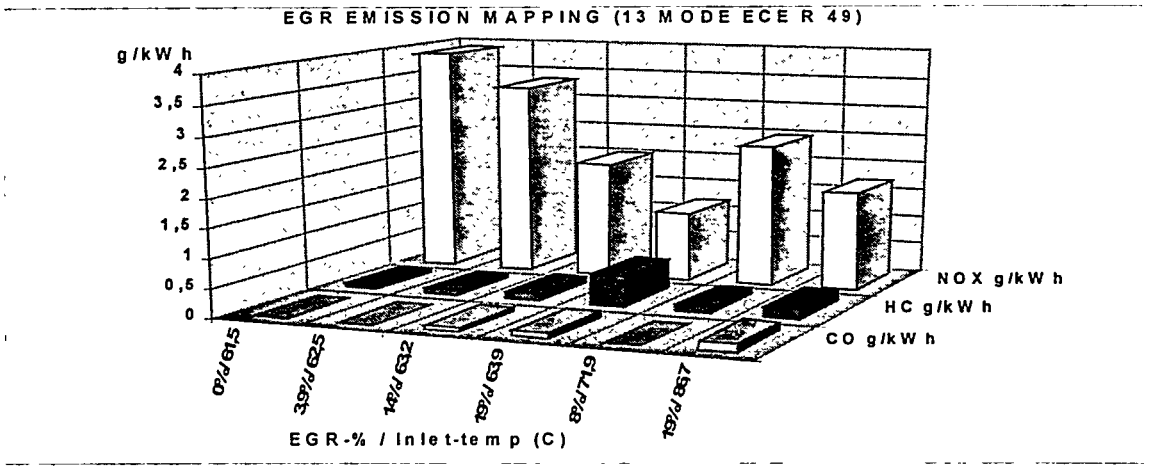

Figure 7. The influence on the NO_X emissions of EGR.

More important engine developmental work was the work carried by Chalmers University of Technology in co-operation with Volvo Truck. This concerned the development of a truck engine (Gjirja and Olsson, 1992) and a 10 litres turbo charged bus engine (Gjirja, 1996). The truck engine is a 7-litre turbo engine which has been tested in 7 trucks used in common truck operations. Figure 8 shows the emission levels of regulated emissions from 5 different Volvo ethanol fuelled trucks. When studying Figure 7 the impression is that there is a great variation in the emissions of CO, HC and particles. It should, however, be taken into account that the levels are so low that the variations may be a result of uncertainties in the sampling and analysis of the test procedure.

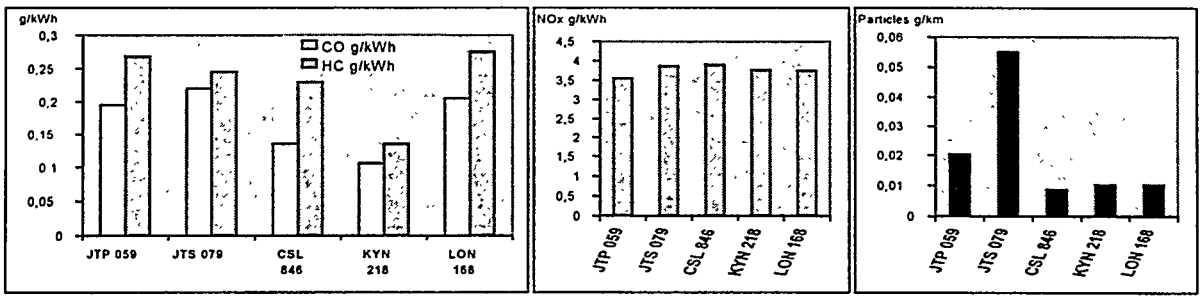

Figure 8. Emissions of regulated emissions from 5 different ethanol fuelled trucks, 13 Mode cycle (g/kWh) and a transient cycle (g/km). Reference: (Egebäck et al., 1997:a).

The bus engine is a 10-litre turbo engine developed for use in citybuses. Some of these Volvo buses are in operation in Stockholm. As in the case of the Scania buses the Volvo trucks and buses are adapted to be fuelled with ethanol treated with an ignition improver.

Despite the low emission levels obtained as a result of the development of engines and catalysts used in buses, some problems related to the catalyst were identified. Acetic acid was formed in the catalyst and proved to be a nuisance to people who were exposed to the exhaust. It was also seen that NO easily oxidise to NO_2 which, under certain meteorological conditions, may cause high levels of NO_2 in the street canyons. The discovery of the above mentioned problems was a valuable lesson in that it showed how important it is to develop the catalyst with respect to the specific fuel used. It was also seen that the catalyst for the methane-fuelled vehicles must be improved. In order to solve the problems a research project on catalyst technology (Pettersson et al, 1997) is in progress at the Royal Institute of Technology (KTH).

4.2 Demonstration and field testing

The conception of a demonstration was to show whether the developmental work that has taken place has led to the expected result. If not, some ideas for changes must be worked out in order to realise the aim of the development work. This was one of the forces behind the different demonstration projects KFB launched during the biofuel program. In all, about 850 vehicles were involved in different trials around the country and all the vehicles were operated in the same way as other commercial vehicles and private cars.

The outcome of these field tests was that;

* the accessibility of the biofuelled vehicles was found to be approximately the same as for vehicles using petroleum fuels since there were no shut-down periods due to problems with the vehicles;
* many stakeholders and actors have been involved in the different projects;
* the knowledge about the use of different automotive fuels, including biofuels, and their influence on the environment has increased among decision takers, traffic holders etc.;
* it has been demonstrated that the use of biofuels decreases the emissions of especially NO_X and particles;
* the cost of the fuel is considerable higher than the cost of fossil fuels;
* the present day use of an ignition improver in ethanol for compression ignition engines increases the fuel costs and therefore some other ignition aid such as spark plugs or glow plugs should be developed. (Studies of the influence on the emissions and also health risks of used ignition improvers have been reported elsewhere (Egebäck and Pettersson, 1996; Westerholm et al., 1994);
* the distribution system for biofuels should be improved;
*biogas is a favourable fuel, in more than one respect, but it is a fuel only for local fleets;
*there is a long way to go before petroleum fuels are replaced by renewable fuels.

4.3 Characterisation of the emissions

In Sweden there is a great concern about the health and environmental problems caused by the traffic even outside city areas. There is also an anxiety among people about the risk of an increase in acidification and about the problems which are foreseen concerning the emission of greenhouse gases. There is always a demand, expressed by the government and those who have to take care of the risk evaluations related to traffic, for a thorough evaluation of all new fuels and new engine technology, and for the characterisation of the emissions of both regulated and non-regulated emissions.

In the case of the biofuel program about 10 % of the fund of 120 million Swedish crowns was allocated for the evaluation of the emission characteristics, i.e. to the program which can be seen in following Table. In addition to the emission tests carried out on vehicles, the research projects at the technical universities comprised a characterisation of the emissions from engines. The projects for research on ethanol fuelled engines at Chalmers University of Technology and Luleå University of Technology, discussed earlier in this paper, included emission measurements presented in the reports (Girja, 1996; Egebäck and Pettersson, 1996). A project, which was also carried out at Luleå University of Technology and then in co-operation with Stockholm University, in order to study the use of a blend of 15 % ethanol in diesel oil, comprised a characterisation of the emissions (Haupt et al., 1997:a; Westerholm et al., 1997).

Table. Tests carried out on vehicles fuelled with ethanol, biogas and blends with ethanol.

Type of vehicles	Number of tests series	Number of vehicles	Number of test accord. to 13 Mode cycle	Number of test accord. to a transient cycle	Fuel
Buses	32	12	72	104 (Bus cycle)	Ethanol 95
Trucks	8	5	16	25 (- " -)	Ethanol 95
Buses	1	1	2	3 (- " -)	Ethanol 95+ diesel
Trucks	10	4	20	42 (- " -)	Ethanol 95+ diesel
Buses	8	5	24	27 (- " -)	Biogas
Trucks	1	1	2	3 (- " -)	Biogas
FFVs	5	6	-	35 (EU/ECE-FTP75)	Ethanol 95
Passeng. cars	1	5	-	15 (- " -)	Biogas
Passeng. cars	1	3	-	18 (FTP 75)	Ethanol 99+ petrol
Sum	69	42	136	272	

As has been shown in Figures and notes in sections 2 and 4.1 the levels of the regulated emissions from buses and trucks fuelled with ethanol are, in general, rather low for particles and even for NO_x compared with diesel fuelled vehicles. NO_x can be further reduced using EGR.

The measurement of emissions from FFV's and other passenger cars has shown that the emission levels from these vehicles are low and that the vehicles fuelled with ethanol and biogas can easily compete with cars fuelled with petrol, as is shown in the following Figure (Fig. 9). The influence of low temperature on biogas is very small.

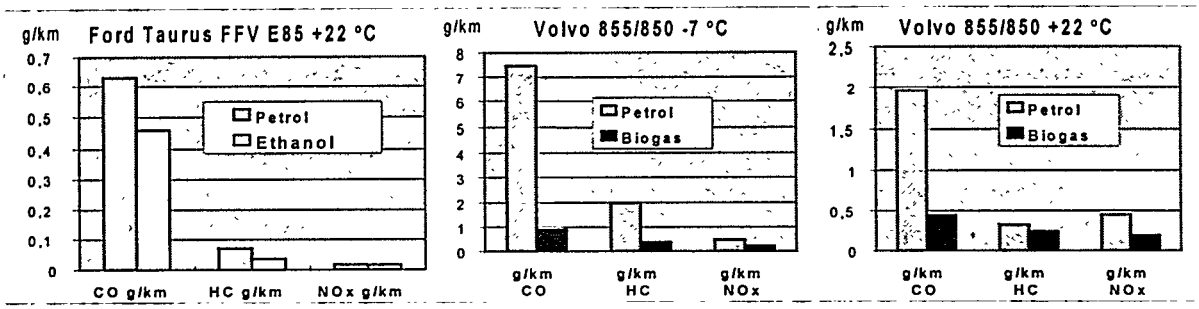

Figure 9. Comparison between the use of petrol and the biofuels ethanol and biogas respectively. Refeference. (The Swedish Motor Vehicle Inspection Co, MTC and Rydén, Egebäck,1997).

4.4 Ranking the different alternative fuels studied

Ranking has taken place (Egebäck and Westerholm, 1997; Egebäck et.al., 1997a) of some of the alternative fuels, taking into account the origin of the fuel (biobased or fossil) and their environmental potential when combusted. The ranking is as follows:

1. **Biogas:** The highest ranked, as biogas is biobased and has a potential for low emissions levels.
2. **Ethanol:** With an environmentally correct method for production and distribution of ethanol, the pollution of CO_2 to the atmosphere may be close to zero. It has a considerably lower emission levels for NOx and particles compared with pure diesel fuel, but there is a problem with the emission of aldehydes.
3. **Methanol:** The same estimation as for ethanol but methanol is aggressive and corrosive.
4. **RME:** This fuel is produced from biomass but the emission potential is not well known.
5. **DME:** No method has been developed for the production of this fuel from biomass, but according to a study carried out by KFB, production is possible. The fuel has a high emission potential.
6. **Natural gas:** Natural gas is not a biofuel, but it has the same emission potential as biogas.
7. **RME in diesel oil:** The RME part can be a biofuel but there are some uncertainties about the emissions produced when the blended fuel is combusted.

In 1997 KFB initiated a project aiming at an evaluation of the potential of different biofuels compared with petrol and diesel oil respectively and the development of emission level up to 2010. One example of the results of the project (Egebäck, et al., 1997b) is presented in Figure 10.

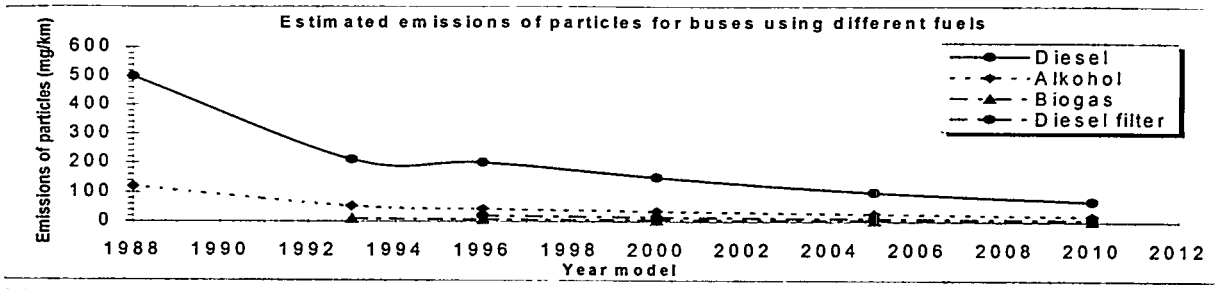

Figure 10. Estimated emission levels and prospected development up to year 2010.

CONCLUSIONS

The use of biofuels has been demonstrated to be an alternative to the use of fossil fuels especially in terms of improvement of the environment (Månsson, 1998). A proper production, distribution and an increasing use of fuels such as bioethanol and biogas will slow down the ongoing increase of the CO_2-emission to the atmosphere and thereby contribute to an alleviation of the serious environmental problems which are expected. The problem today is the higher cost of biofuels compared to petrol and diesel oil. Concerning the blend of ethanol in diesel oil there is a need for further research and additional investigations in order to improve the technique for blending the fuel, especially to improve the stability of the blend. A new emulsifier may have to be developed There is also a need to study the influence, in the long run, on the engine and the engine fuel system of the blended fuel.

REFERENCES

Egebäck, K-E. (1992). Exhaust Emissions from Ethanol fuelled buses, MTC 9056 S. (In Swedish).

Egebäck, K-E. and Pettersson, E. 1996). Research on a Scania 11 litre Ethanol Fueled Bus Engine, TULEA 1996:13 ISSN 0347 - 0081.

Egebäck, K-E and Westerholm, R. (1997 Environmental potential of the alternative fuels; biogas, ethanol, methanol, natural gas, RME,and DME, KFB-Communication 1997:4. (In Swedish).

Egebäck, K-E., Ahlvik, P., Laveskog, A. and Westerholm. R (1997). Emission factors for Vehicles Fuelled with Biofuels (in Swedish) KFB-Communication 1997:22 (In Swedish).

Egebäck, K-E., Ahlvik, P., Laveskog, A. and Westerholm. R (1997). Biofuel. Evaluation of emission measurements and a proposal for development of engine technology, KFB-1998:2. (In Swedish).

Gjirja, S. (1992). Development of an ethanol fueled version of the Volvo TD73 diesel engine, KFB-92-230-742.

Gjirja, S. (1996). Engine Design Optimization for Running on Ethanol with Low Emissions. KFB-communication 1996:10.

Grägg K., (1990) "Lowemitting" buses, diesel catalyst and Volvo particulate filter. MTC 9006 (In Swedish).

Haupt, D., Nordström, F., Hellberg,S. and Uvemo, U-B. (1997 Hydrocarbons from Ethanol Engines. What do we measure with an HFID on an 11-litres Ethanol Fuelled Bus Engine. KFB-Communication 1992:7 (In Swedish).

Haupt, D., Nordström, F., Niva, M., Bergenudd, L. and Hellberg, S, (1997:a). Investigation of regulated and some non-regulated emissions from engines fuelled with mixed fuel, diesel oil and ethanol (English version is available). KFB-Communications 1997:16. ISSN 1401-1271.

Månsson, T. (19989 Clean vehicles with biofuels. A State of the Art Report, KFB-report 1998:18

NEDO (1988). VIII International Symposiium on Alcohol fuels. Nov. 13-16 '88. Tokyo.

Parry, R., Miller, S. and Walker, L. (1993). "Detroit Diesel Corporation Alcohol Engines and Field Experience". Tenth International Symposium on Alcohol Fuels. The Road to Commercialisation. Proceedings: Volume I, 1993.

Pettersson, L, Wahlberg, A.M. and Järås, S.G. (1997). Exhaust Gas Catalysts for Heavy-Duty Vehicles Fuelled by Alcohol or Biogas. KFB-Rapport 1997:11.

Rydén, C. (1994). Field Trials with 32 Ethanol Buses at Stockholm Transport. ISSN 0282-8014. (In Swedish)

Rydén, R. och Egebäck, K-E. (1997). A Field Trial on 53 FFV (Flexibel Fuel Vehicles). KFB-Communicat. 1997:13.

Tingvall, B., Johansson, Ö. Nordström, F., Hellberg, S and Pettersson, E. (1997). EGR on an Ethanol Fuelled Diesel Engine. ISSN 1402-1528 (English version available).

Westerholm, R., Christensen, A., Törnqvist, M., Ehrenberg, L. and Haupt, D. (1997). Chemical and Biological Characterisation of Exhaust Emissions from Ethanol and Ethanol Blended Diesel Fuels in Comparison with Neat Diesel Fuels. KFB-Communications 1997:17. ISSN 1401-1271.