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CLEAN VEHICLES WITH BIOFUEL

A State of the Art Report

Tommy Månsson

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FOREWORD

KFB's biofuel programme has been in progress, in its present form, for some six years. Development work on vehicles and engines has being carried out at universities and in industry under the aegis of the programme, as well as system demonstrations for municipalities, public transport companies and other vehicle users. Overall, the programme has involved a hundred or more scientists and researchers along with numerous individuals at our partners. The hundreds of ethanol- and biofuel-engined vehicles which have been involved in the programme have covered more than ten million kilometres on Sweden's roads. All in all, this has resulted in the accumulation of an immense range of competence on the part of the players in the industry.

The results of the various activities in the programme suggest that the technology required for the use of ethanol and biogas as fuels, functions satisfactorily and that biofuels possess considerable potential as a means of improving health and environment. However, much remains to be done when it comes to the further development of engines and vehicles, which is natural since the technology is still at the beginning of a development process, when compared with established petrol and diesel engines and vehicles.

The purpose of this report is to provide an overall analysis and assessment of the use of biofuel in the Swedish transport sector. The report is based on the information and experiences that have been accumulated within the KFB biofuel programme and which are documented in numerous special reports which have been published separately as part of KFB's series of reports and releases.

The report has been produced within KFB's biofuel programme by Tommy Månsson. I would like to thank him, as well as Sören Bucksch, who has served as programme manager for the biofuel programme. I would also like to express my gratitude to Professor Karl-Erik Egebäck, who has devoted a great deal of energy to evaluating and scientific control, and to all project managers, representatives of our co-financiers, local municipalities, road haulage companies, the automotive and petroleum industries, government authorities, universities, the Swedish Ethanol Development Foundation, and all the other individuals and organisations who have devoted their time and energy over the past six years to the patient and systematic development and testing of new types of vehicle and fuel.

Urban Karlström
Director-general, KFB

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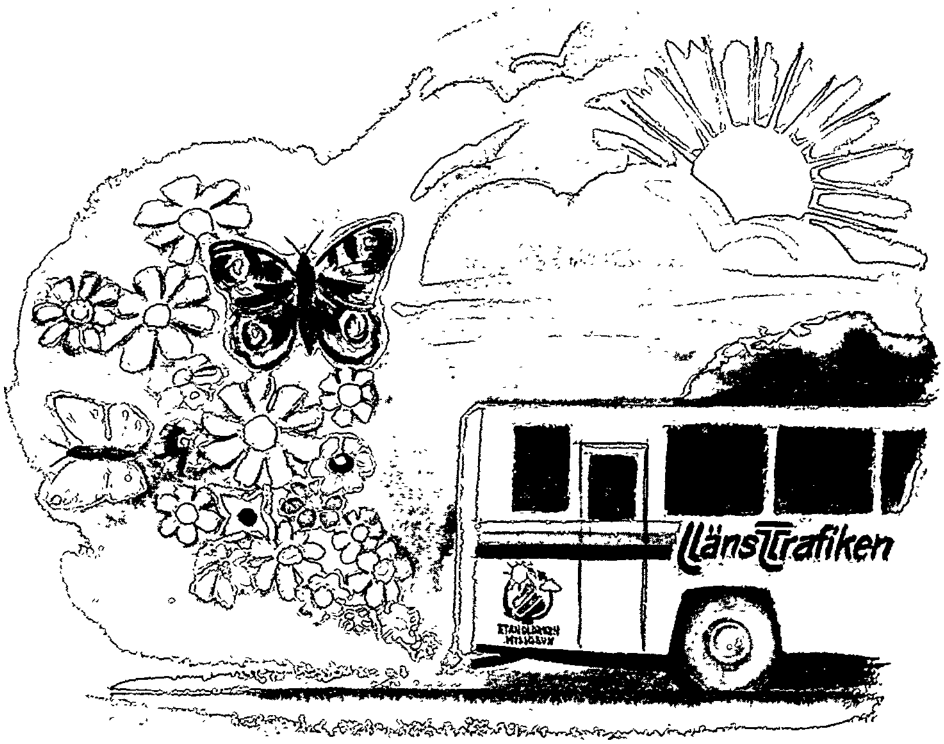
Clean vehicles with biofuel – a state of the art report

SUMMARY

□ The transport systems we have today are not sustainable in the long term. In order to bring about sustainable development in the transport sector, new solutions are required which overcome environmental threats as well as satisfying the needs which create today's mobility. This will demand new technical solutions as well as changes in the attitudes and behaviour of all players who influence the transport sector. These players include us as consumers and travellers, as well as buyers and users of vehicles, the automotive and petroleum industries, the forestry and farming industries, and all the new industries that a new sustainable transport system could give rise to.



□ To bring about sustainable development it is not enough merely to improve the efficiency of existing transport systems. What is needed is to develop fuel systems which are based on renewable sources of energy at all stages of production and distribution. In Sweden, ethanol and biogas are the alternatives which appear, in both the short and the medium-to-long term to be the most suitable alternatives to petroleum and diesel fuel. These fuels have therefore tended to dominate KFB's biofuel programme. This programme have involved more than one hundred buses, a hundred or so passenger cars, mainly flexible fuel vehicles (known as FFV) and some fifty or more trucks, which were driven more than ten million kilometres on these fuels. A hundred or so extensive emission tests have been carried out on some of these vehicles within the programme, as have extensive development activities at universities and in industry.

□ The programme has helped to provide more facts for players in the industry on how ethanol and biogas could become the fuels of tomorrow. Most progress has been made in connection with ethanol buses, for which techniques have been specifically developed. In the case of trucks and vans operating in urban areas, developments have not advanced so far. In principle, however, as there is no great difference between an ethanol engine for a city bus and one for a truck, the prospects for developing better ethanol-engined trucks are considered to be favourable. In the case of biogas, the experiences gained from operating buses, trucks and passenger cars suggest that this fuel is currently the most environmentally friendly. However, further development of engines and vehicles is required for both ethanol and biogas, if their environmental advantages are to be utilised to the full, and if the new techniques are to be placed on a sound financial footing. A central area when it comes to ethanol-engined vehicles is to develop engines which do not require the addition of ignition-improvers.

□ The admixture of ethanol in petrol and diesel fuel is one way of introducing a biofuel into existing vehicles. KFB's programme has demonstrated that admixtures of 15 per cent ethanol into diesel can, with the aid of an emulsifying, function as a high quality fuel, which displays better environmental characteristics than the best grade of diesel fuel currently available, without any deterioration in running characteristics. Before the method is applied on a large scale, however, long term testing of vehicles and fuels is required, as well as the development of a rational, large-scale method for mixing ethanol with an emulsifying agent into the diesel fuel. As far as the admixture of ethanol into petrol is concerned, things are easier, and international experience in this field suggests that admixtures of up to 20 per cent ethanol by volume in petrol are perfectly possible in modern passenger cars.

□ The introduction of flexible fuel vehicles, known as FFVs, marks the start of the creation of a nationwide distribution network for ethanol. This has enabled the FFV project to show the way for resolving the chicken-or-the-egg dilemma. However, in order to bring about greater use of biofuel it will be necessary for the state to take active responsibility for stimulating the process of change.

□ The key role of the state should include, for example, a clear and definite adjustment in taxes and charges on fuels so that at the consumer level fuel prices reflect their effects on health and the environment. As we are concerned with substantial, long-term investments by the new players who will be involved in building up a new market for biofuels, it is essential that the means of control adopted by the state are both consistent and sustainable.

□ The lessons learnt from KFB's biofuel programme show that the introduction on to the market of a new fuel such as ethanol needs to be preceded by practical demonstrations to a wide range of different users around the country. Such system demonstrations create development environments which can serve as test platforms based in different principles, where several generations of vehicle developments can be tested under practical operating conditions. This type of continuity in the test conditions will also facilitate an independent and objective evaluation process.

□ The transition from fossil fuels to biofuels would be a long-term process, and if it is to succeed it is essential that it begins now. This means that facilities for the production of biofuel need to be built at numerous locations around the country, that funds be invested in buses, trucks and cars which can use the new fuel, and that these investments are made parallel to each other. This requires determination on the part of the state, as well as municipalities and the business sector, to invest in new technical solutions. Consequently, an extensive commitment is required on the part of all players in the transport sector. If all these conditions are satisfied, this could create the model that is needed to enable us to set in motion the process of transition to a sustainable transport system.

Introduction

- *Sustainable mobility*
- *What do we mean by alternative fuels?*
- *KFB's biofuel programme*

Chapter 1

INTRODUCTION

Sustainable development in the transport sector involves a development process which satisfies the existing need for access to goods and services, without jeopardising the ability of future generations to enjoy a good life. However, today's transport systems are not sustainable. The fundamental aspect of the transport sector is mobility, and it is this constantly increasing mobility that creates environmental problems. In order to achieve sustainable development in the transport sector what are needed therefore are new transport solutions that not only overcome environmental threats but also satisfy the needs that give rise to mobility – sustainable mobility. Sustainable mobility will require new technical solutions as well as changes in attitudes and behaviour. This report discusses how the use of engine alcohols and biogas can create the conditions needed to develop transport systems in such a way as to make them more sustainable.

Sustainable mobility

In all ages mobility has been a characteristic of mankind. Mobility has enabled people to extend their territory, it has enabled ideas and information, as well as goods and services, to move freely around the world. Greater mobility of goods and services is also one of the ideas behind the vision of a single European market. In all ages, politicians have also promoted greater mobility by subsidising roads and other types of infrastructure which facilitate it.
But we are beginning to see that this mobility exacts its toll in the form of congested cities, smog, acidification, holes in the ozone layer and climatic changes.

Transportation, especially road transport, is one of the major forces powering these changes; it is also a sector whose negative contribution to the environment is growing rapidly, seen in global terms. The reason is that the energy sources used by the transport sector are almost 100 per cent based on fossil fuels. Such a trend is not sustainable!

Globally, the number of vehicles is currently increasing very rapidly. From the present level of around half a billion vehicles, the number of vehicles on the world's roads is expected to rise by around 4-5 per cent a year between now and 2010 (**Figure 1.1**). A very large proportion of this growth will take place in countries which are on the threshold of industrialisation. China, for example, expects its vehicle fleet to triple in size during the coming decade. But Europe also expects dramatic growth from the current level of just under 200 million to some 270 million vehicles in 2010. This may be compared with North America, where the number of vehicles is also expected to rise, but rather more slowly than on other continents.

Even if we in Sweden are now beginning to see a debate emerging on the need to obtain access to fuel-efficient cars, there is a long way to go before all the vehicles in the world only consume a few centilitres per kilometre. And the fact remains that this mobility is still based on a non-renewable resource. Many people are deeply concerned about this, and oil companies are also beginning to realise that in the long run we must start to use alternative energy sources to a totally different extent than at present. In a forecast published by Shell (Shell, 1996), it is estimated, for example, that by 2060, some 60 per cent of the world's total energy consumption will need to be based on renewable energy sources, such as solar energy, bioenergy, and new sources of energy of which we are not yet even aware. The reason for this is that oil is expected to be in short supply in the near future. The UN's panel of experts on the climate (Intergovernmental Panel on Climate Change, or IPCC) has reached a similar conclusion (**Figure 1.2**).

In order to bring about sustainable mobility it is not enough merely to improve the efficiency of existing transport systems. What is needed is to develop fuel systems in which all stages of production and distribution are based on renewable sources of energy. To enable these new transport systems to become sustainable in the long term a further precondition is that at no stage (from cradle to grave) do they have an adverse effect on health and the environment.

It takes a long time to develop long-term solutions. In order to avoid expensive mistakes, it is essential to work towards long-term goals and to examine a number of different alternatives alongside each other.

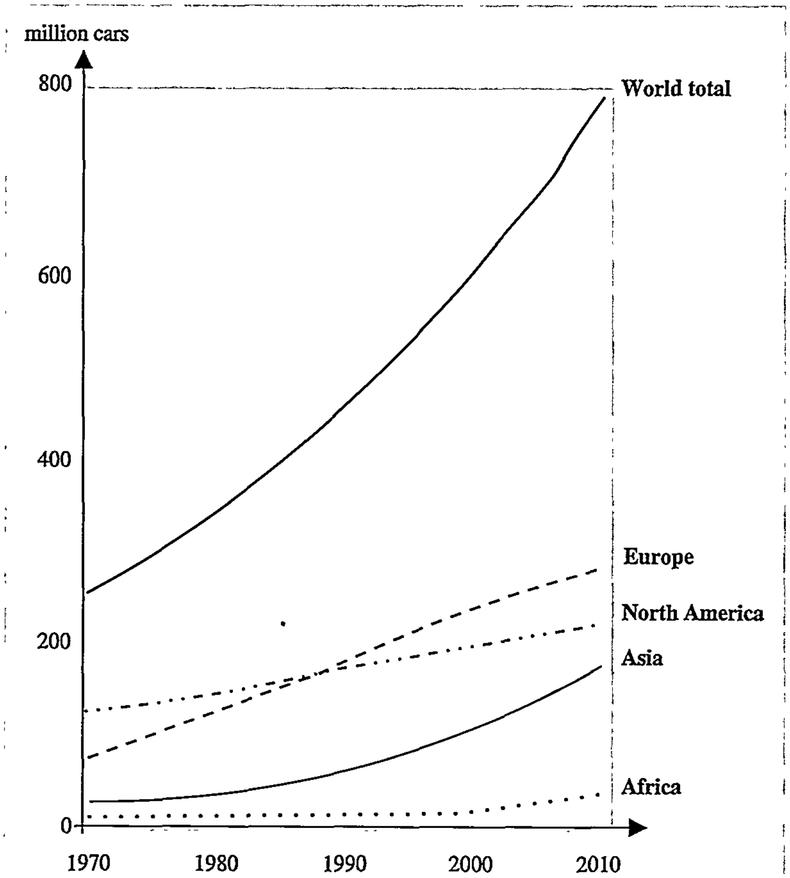


Figure 1.1. Changes in number of passenger cars worldwide, 1970-2010 (Månsson, 1996)

What do we mean by alternative fuels ?

Today's transport sector is more or less 100 per cent dependent on two fossil fuels: petrol and diesel. All conceivable fuels which could replace these may thus be defined as alternative fuels (both renewable and fossil). However, their interest as alternatives is dependent on their being superior in environmental terms, and that they have the technical and financial possibility to become widely available within a reasonable future. In Sweden, therefore, the concept of alternative fuel normally includes those fuels which are based on renewable resources. This report is mainly concerned with the alternative fuels that were included in KFB's fuel programme, i.e., mainly ethanol and biogas.

There are a number of alternative

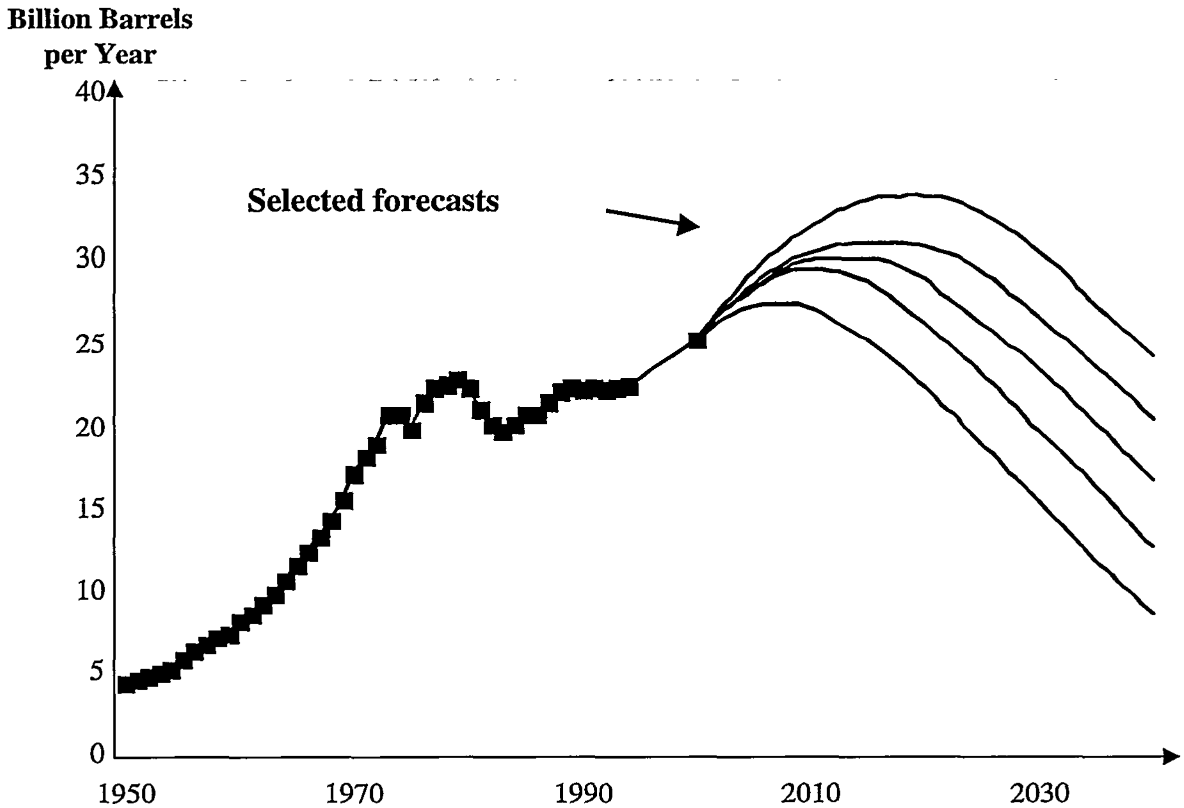


Figure 1.2. The world's total oil reserves are depleting sharply due to the rapid growth in motoring and as the number of new oil discoveries falls. Oil consumption could therefore reach a peak within the next ten years. (IPCC, 1997).

fuels whose characteristics differ in terms of environmental friendliness, availability and so on.

Table 1.1 presents an overall description of which alternatives might be of interest in the future. They can be classified into alternatives based on *fossil* or *renewable* raw materials, or on the basis of *small-scale* ("niche"[1]) use and *large-scale*[2] *use*. It should be noted that Table 1.1 primarily presents an assessment of the technical conditions for use in the future. The financial consequences and environmental effects, as well as the effects in such areas as emergency energy planning, of the large-scale introduction of the various alternatives have not been explored in detail. By short term we mean ten years, by medium to long term we mean 10-20 years, and by long term longer than 20 years.

The table shows that the number of alternatives which could be of interest in the future, and which are based on renewable sources of energy, is quite small. It is mainly bioalcohols which could be used. Eventually, also biogas could perhaps be used on a large scale if grass crops are used as raw materials. In the short term, however, it may be expected that most biofuels will be used on a more limited scale as "niche" fuels. The question of whether a fuel will remain a "niche" fuel or will come into a more widespread use is, in the final analysis, a question of what financial conditions are provided.

[1] niche means a level of 0-10% use of an alternative fuel.
[2] large-scale can mean use of more than 10% based on the total pool of fuel for road traffic.

KFB's biofuel programme

Tests and demonstrations of alternative fuels have been going on in Sweden for a long time and on the basis of different approaches. During the Second World War, for instance, the use of producer gas and bentyl petrol were both tested, and in connection with the oil crises in the seventies extensive trials were carried out on mixtures of methanol and petrol (M15).

These early projects originated from Sweden's considerable dependence on oil. Arguments based on vulnerability and emergency planning, apart from environmental considerations, provided the grounds for this development work. During the 1980s and

Alternative	Alternatives that can satisfy 0-10% criterion for niche use	Alternatives that can satisfy10% criterion for large scale use		
		Short term	Medium term	Long term
Fossil raw materials				
Reformulated petrol		X	X	
Reformulated diesel		X	X	
Natural gas				X
Methanol from natural gas			X	X
DME from natural gas			X	X
Blend of diesel and vegetable oil esters	X			
Renewable raw materials				
Methanol from cellulose				X
Methanol from sugar- and starchcontaining plants	X			
Ethanol from cellulose				X
Ethanol from sugar- and starchcontaining plants	X			
Vegetable oils	X			
Esters from vegetable oils	X			
Biogas	X			X
DME from cellulose				X
Hydrogen from renewable sources				X
Electricity from renewable sources				X

Table 1.1. Potential use in Sweden of a variety of fuels and conversion techniques (KFB, SIKA, NUTEK, 1996)

1990s the justification for this type of development work has increasingly been the need to bring about environmental improvements in the transport sector. In recent years, the greenhouse effect has come to play a role of growing importance.

The Swedish Transport & Communications Research Board (KFB) has primary responsibility for developing and testing engine alcohols and biogas on a large scale. KFB's biofuel programme has been going on since 1991, but it is based on knowledge and experience gains from earlier demonstration projects. This report summarises the information obtained and the aggregate experience acquired during the course of the programme.

KFB's directive in the biofuel area was defined in the 1991 Energy Policy Bill (Bill 1990/91:88). The bill as adopted by Parliament stated inter alia:

The use of engine alcohols as vehicle fuel offers advantages in environmental and emergency planning terms. It is desirable to stimulate the development of techniques and equipment for alternative fuels and to carry out trials and tests with vehicles in built-up areas in order to gain experience of the handling and use of alternative fuels.

The objects of KFB's biofuel programme were the following:

- *to* develop, test and evaluate equipment and systems for the use of engine alcohols
- *to* encourage major producers and users to play an active role in development and demonstration projects
- *to* increase knowledge concerning the long-term

usefulness, environmental potential, and costs associated with engine alcohols, and
- *to* clarify if and under what conditions engine alcohols would be ready for introduction in a large scale.

The programme has been concerned with developing and carrying out practical trials of ethanol and biogas as fuels for vehicles, and by making a variety of studies, with creating a library of information concerning alternative fuels which could become available in the near future.

Ever since it began, the programme focused primarily on stimulating the development and demonstration of vehicles and engines that would run on *pure alcohol*, i.e., would use pure or almost pure alcohol (E95/E85)[3]. The reason for this ranking of priorities was the potential alcohol offered to improve health and the environment in urban areas, as well as emergency planning considerations. As time passed, the interest in *fuel blends* (15% ethanol in diesel) for existing engines has shifted into prominence as this could be an alternative during a transitional period pending the introduction of pure alcohol fuels on a full scale. In 1993 a further alternative fuel was taken up, namely *biogas*. During the final phase of the programme, some studies of *dimethyl ether (DME)* as a fuel have also been carried out.

The focus of the programme has been placed on field testing of vehicles by various players in different parts of the country. The demonstration activities were mainly concerned with heavy vehicles, such as buses and trucks, although they also included the development and testing of passenger cars. Vehicles for pure ethanol running and blended fuels (ethanol +diesel) as well as biogas have been tested. Moreover, complementary development work on engines and vehicles has been carried out in key areas. The programme also included investigations and studies of other fuels such as methanol and DME, and evaluations and system studies (**Figure 1.4**). However, responsibility for the development of new fuel production methods, rested on a different authority, namely NUTEK.

KFB's six-year biofuel programme received government funding of 120 million kronor to support research, development and demonstration projects in different parts of the country. The total resource budget was expanded to 315 million kronor by contributions from other interests in view of the demand for joint funding of the project.

Figure 1.5 shows the use of the funds during the different phases of the project in the following areas: ethanol, biogas, and blends (ethanol + diesel).

Evaluations have been a recurrent feature of KFB's biofuel programme. In the spring of 1994 an independent assessment was made (S. Faugert, 1994) to determine how the focus of the programme on the industries and players concerned could be sharpened. As the assessment shows, it is general questions relating to society

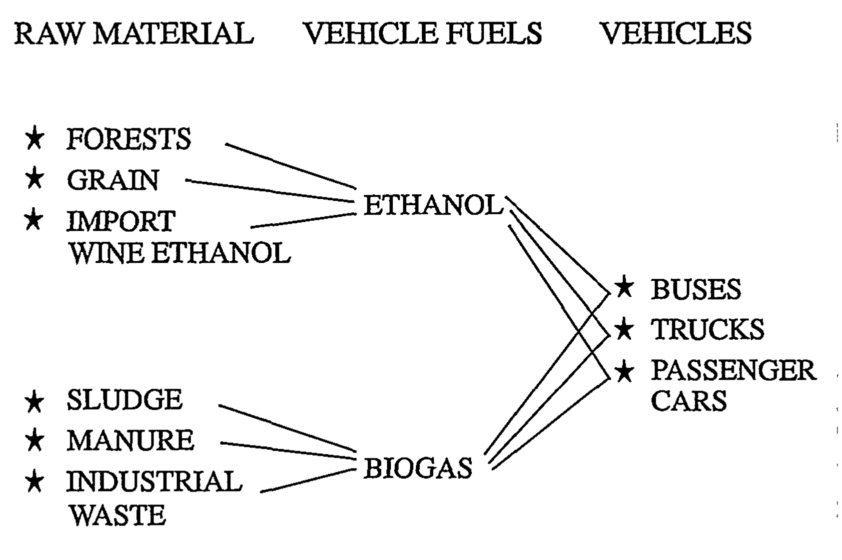


Figure 1.3. Schematic description of which combinations of raw materials, fuels and vehicle types were included in KFB's biofuel programme. The raw material (grain) for ethanol can be obtained from forests or farms (grain). Sweden also imports surplus ethanol made from wine from Southern Europe. Ethanol has been used as a fuel in fleet trial of buses, trucks and passenger cars. The raw material for biogas can be sewage sludge, manure or industrial waste (slaughterhouse waste).

[3] E95 and E85 stand for ethanol fuels with ethanol contents of 95% and 85% respectively. The rest of the fuel consists of water, denaturing agent, and an ignition improver.

VEHICLE FUEL / R, D & D		ENGINE ALCOHOLS				DME	BIOGAS
		PURE ETHANOL	BLENDED FUELS ETHANOL / GASOLINE	BLENDED FUELS ETHANOL / DIESEL	METHANOL		
ENGINE AND VEHICLE DEVELOPMENT		* EGR * CATALYSTS * IGNITION IMPROVERS		* EMUSLIFIER * BLENDING TECHNOLOGY			* CATALYSTS
DEMONSTRATIONS FIELD TESTS	BUSES	* STOCKHOLM (SL) * ÖRNSKÖLDSVIK * SKARABORG					* TROLLHÄTTAN * LINKÖPING * UPPSALA
	TRUCKS	* SVENOL		* ASPEN * SSEU			* TROLLHÄTTAN
	PASSENGER CARS	* FFV					* STOCKHOLM * (TROLLHÄTTAN) * (LINKÖPING)
INVESTIGATIONS STUDIES		* SPECIAL STUDIES * INTERNATIONAL EXPERIENCE				* EVALUATIONS * SYSTEM STUDIES	

***Figure 1.4.** Description of structure and content of KFB's biofuel programme.*

that cause most uncertainty among current players. What they would like to see is a sort of national consensus regarding the long-term use of biofuels.

A further assessment was made in 1995 at the request of the National Audit Board (J. Hedman, 1996). This assessment noted that KFB's programme has served to establish a user network with key players in the field (**Figure 1.6**). One of the most important effects of the programme, therefore, is that expertise in the biofuel field has been diffused in society.

As the result of these evaluations, KFB carried out a system study (T. Sterner, 1997) with the object of arriving at financial evaluations and assessments of the potential for the production and use of alternative fuels. In the final phase of this work, KFB was also engaged by the government to draw up proposals together with SIKA and NUTEK (KFB, SIKA, NUTEK, 1996) for strategic assessments of the general economic effects of alternative introduction strategies. These projects are based on the experience and assessments of the environmental and health potential, for example, of alternative fuels and vehicle combinations which could be reached on the basis of KFB's system demonstrations.

An assessment (known as a peer-review) involving foreign experts (E. Arnold et al, 1997) was carried out during the final phase of the programme with the object of obtaining an independent quality scrutiny of KFB's biofuel programme. This review noted that the research project has generally been of good quality and that the programme as a whole has achieved its four goals, namely:

- *to* create a bank of knowledge that will provide the pre-conditions for assessing to what extent and in what way biofuels can be introduced on a large scale.
- *to* increase information concerning the long-term development potential of biofuels and their effects on the environment and the economy, etc.
- *to* persuade vehicle manufacturers and users to become actively involved in development and demonstration projects.
- *to* develop, test and evaluate a variety of key technologies and system solutions under practical operating conditions.

Looking ahead, the review recommends that KFB be enabled to maintain and develop the bank of information on biofuels that is beginning to be built up. Tomorrow's fuel market will probably include numerous alternatives to petrol and diesel. This creates a need for several complex, strategic choices for the players in the transport sector, which in turn will require access to a broad and independent bank of information. The importance of system studies is referred in this context as well as the need for concrete development activities in certain key areas, such as the development of ethanol-driven bus and truck engines which do not require the addition of ignition improvers.

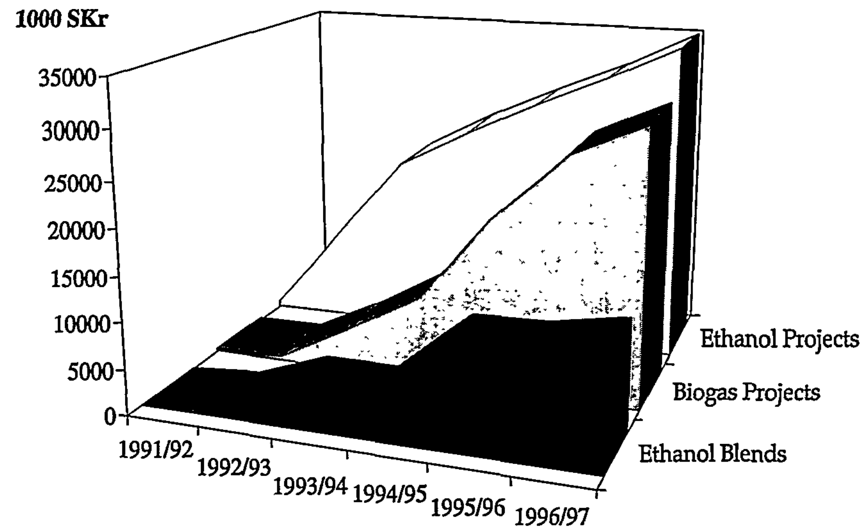


Figure 1.5. Breakdown of KFB's budget for ethanol, biogas and blended fuels containing ethanol and diesel.

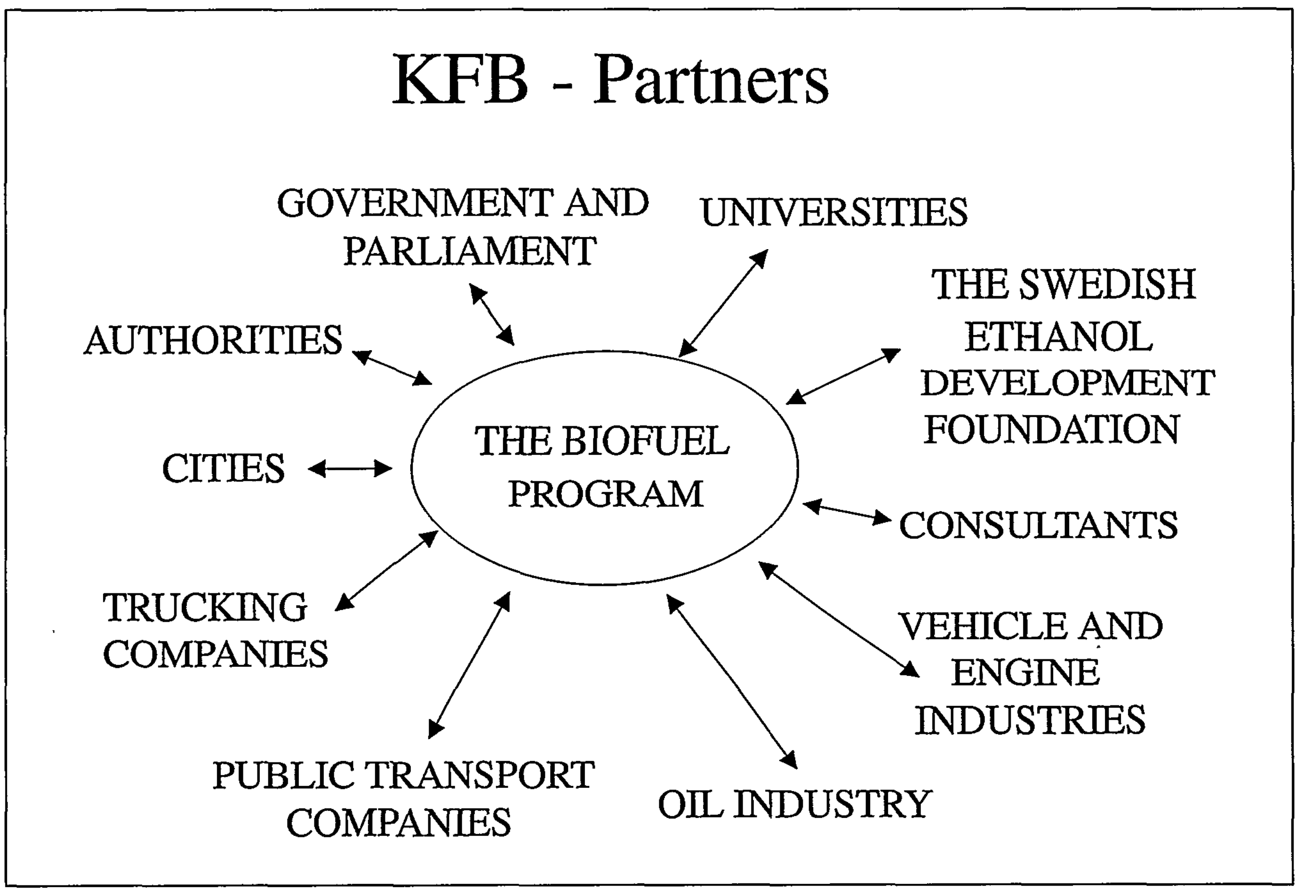


Figure 1.6. KFB's biofuel programme has created a user network that will make it easier to diffuse facts about biofuel throughout society.

Vehicles, fuels and the environment

- *What are environmental goals?*
- *Vehicle exhaust emissions*
- *The greenhouse effect*
- *A life cycle perspective*
- *Conclusions*

Chapter 2

VEHICLES, FUELS AND THE ENVIRONMENT

The transport sector is not sustainable in the long term as it is almost totally based on depleting natural resources which cause serious harm to people and the environment when combusted. The largest and most serious threats are long-term effects on the climate that are expected to arise as a result of increasing emissions of carbon dioxide and the threat to human health as a result of air pollution and noise in urban areas.

What are environmental goals?

The Environmentally Sustainable Transport System project, EST (in Swedish the MaTs-project), a joint project involving eleven government authorities and trade organisations, has demonstrated that the players in the transport sector share a common conviction that transport in the future must be arranged in an environmentally, economically and socially sustainable way. The final report from this project (Swedish Environmental Protection Agency, 1996a) presents a common platform for how such an adjustment can be made. The principle behind this work is a long-term environmental goal for the transport sector defined on the basis of current information about what people and nature can tolerate. The threats to the environment that are considered to be most difficult to overcome in the long-term perspective are:

- Effect on climate of carbon dioxide emissions
- Human health hazards due to air pollution and noise
- Effect of infrastructure on natural landscape and biodiversity

One conclusion of the EST-project is that the process of developing an environmentally adapted transport system must be driven across several fronts and by numerous different parties. Further technical development of vehicles and fuels will be an essential and important aspect of this process. However, this will not be sufficient partly for reasons of cost and partly because not all environmental threats can be dealt with by measures of this type. In order to bring about real environmental adjustment many small

Areas for protection	13 environmental threats	Parameters	Sector
Health	• Greenhouse gases	CO_2	Traffic
Biodiversity	• Depletion of the ozone layer	NO_x	Industry
Natural resources	• Acidification of water and soil	VOC	Energy
Natural and cultural landscapes	• Photochemical oxidants and ground-level ozone	NO_2	Agriculture
	• Urban air pollution and noise (local problems)	Particles	etc
	• Eutrophication of water and nitrogen saturation of soil	Noise	
	• Effects of metals	Physical encroachment	
	• Effects of persistent organic pollutants	etc	
	• Introduction and spread of alien organisms		
	• Inappropriate use of land and water resources in production and supply		
	• Exploitation of land and water for housing, industry and infrastructure		
	• Pressures on areas of special conservation interests		
	• Non-cyclic material flows, wastes and environmentally hazardous residues		

Environmental quality goals ⟶ Operative goals

Figure 2.1. A model for defining operative environmental goals for the transport sector (Swedish Environmental Protection Agency, 1996a)

changes are needed which, individually or together, can lead to improvements. A strategy for accomplishing this will include the following

- More stringent environmental rules for emissions from vehicles
- Differentiated taxation of vehicles and fuels in order to stimulate environmentally friendly alternatives
- Information and training to stimulate all players to act in an environmentally friendly way
- Active Agenda 21 work at local level
- Support for research, development and demonstration (FUD) within strategic systems and technical fields.

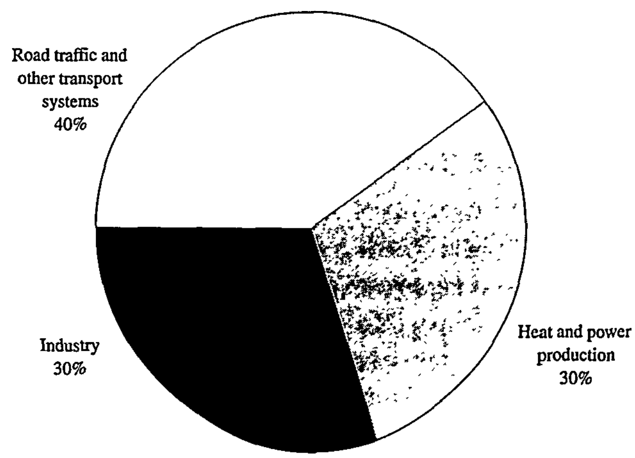


Figure 2.2. Carbon dioxide emissions in Sweden by source (Pilo C, 1996c)

Vehicle emissions

Despite extensive technical development and the introduction of catalytic cleaning and similar equipment, car exhaust emissions are still the most serious

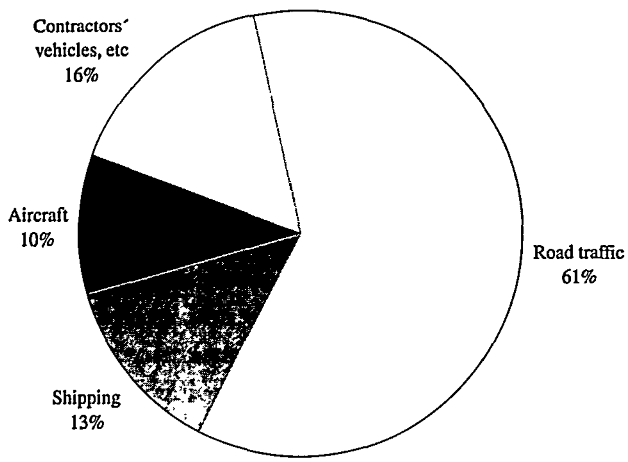


Figure 2.3. Carbon dioxide emissions from Swedish transport sector by type of traffic (Pilo C, 1996c)

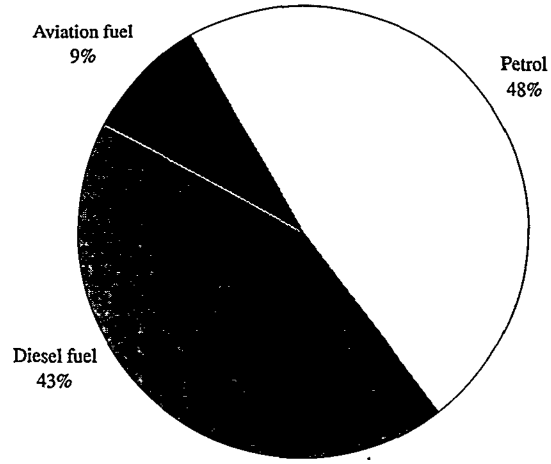


Figure 2.4. Carbon dioxide emissions from Swedish transport sector by type of fuel (Pilo C, 1996c).

type of pollution in urban areas. They harm our health and the environment. As vehicles are also almost exclusively run on fossil fuels, road traffic makes a very significant contribution to the quantity of greenhouse gases in the atmosphere. Eventually, this could have dramatic effects on the very survival of the planet.

The world's total oil resources also have a limit. With an unchanged rate of global recovery, the now known reserves of extractable oil would last about 45 years. Even on the most extreme assumptions, these reserves won't last for another hundred years. The transport sector in Sweden currently accounts for some twenty per cent of the country's total energy consumption. However, as this sector is entirely based on fossil oil, its contribution to our national carbon dioxide ratio is approximately forty per cent (**Figure 2.2**). The long-term goal (according to EST) is to reduce emissions of carbon dioxide from the transport sector by sixty per cent by 2050. A large proportion of this reduction is expected to be made in the field of road traffic as this accounts for the greater part of the emissions (**Figure 2.3**), and it is considered that there is more potential in this sector than in other types of transport to replace fossil fuels with renewable fuels.

Emissions of nitrogen oxides, NO_x, are another serious environmental problem caused by road traffic. Nitrogen oxides play a part in acidification of ground water and over-fertilisation of lakes, seas and water courses. Nitrogen oxides also cause health problems in our urban areas. Parliament stated as a target that nitrogen oxide emissions in Sweden should be reduced by thirty per cent by 1995 from the level of 1980. However, it turned out not to be possible to achieve this target, due to developments in the transport sector.

As traffic is responsible for the bulk of society's

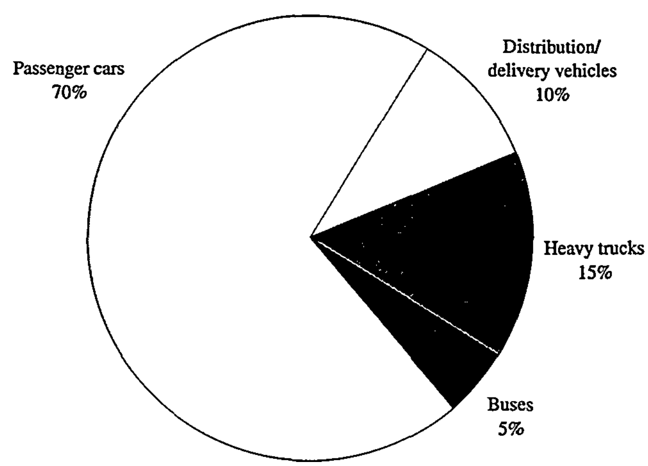


Figure 2.5. Carbon dioxide emissions from Swedish transport sector by type of vehicle (Pilo C, 1996c).

emissions of nitrogen oxides, far-reaching measures are needed in this sector to reduce the impact below critical threshold values established on the basis of what nature can tolerate. The introduction of catalytic cleaning has resulted in significant reductions in emissions of nitrogen oxides from vehicles, but these improvements have been more than offset by increased transportation, higher speeds, heavier vehicles and such factors. In order to reduce NO_X emissions to a level that nature can tolerate in the long term, they would have to be reduced by between 75 and 90 per cent.

Six hazardous substances in vehicle exhaust fumes

Nitrogen oxides **NO_x**	Contributes to euthropication and acidification of soil and water. Health hazards. Catalysts and cleaner fuel will reduce these emissions.
Hydrocarbons, Carbon monoxide HC, CO	Consist of uncombusted residues of fuel and lubricants. Exhaust fumes contain thousands of different hydrocarbons. Contribute to the formation of ground level ozone. Have adverse effects on health. Catalysts and cleaner fuels will reduce these emissions.
Particles	Hydrocarbons, soot, water and (if the fuel is a fossil fuel) sulphur. Have adverse effects on health and cause contamination. Can be carcinogenous and affect genetic characteristisc. Cleaner fuel, improved engines and cleaning devices will reduce these emissions.
Sulphur oxides **SO_x**	Found in fossil fuels, such as diesel. Contribute to acidification, corrosion and health problems. Cleaner diesel fuel has halved these emissions since 1980 in Sweden.
Carbon dioxide **CO_2**	Formed whenever organic materials are combusted. Contribute to the greenhouse effect and the associated risk of climatic effects. Cannot be removed by cleaning. Use of biobased fuels, such as ethanol and biogas, generates no net addition of carbon dioxide as it is a closed cycle (provided that biofuel is used in all stages of production and distribution).

***Figure 2.6.** Six hazardous substances in vehicle exhaust fumes.*

Diesel fumes are the largest individual source of emissions of cancerogenous air pollution in urban areas and are estimated alone to account for some 350 cases of cancer per year. Emissions of nitrogen oxides are also suspected of having genotoxic effects. Emissions of benzene from filling stations, as well as during cold starting and acceleration of otto engines also make a contribution.

Allergies are increasing, especially among children. There are grounds for suspecting that the air pollution caused by traffic contributes to this. There are also suspicions that the incidence of cardiovascular complaints is partly due to the growing urban air pollution due to traffic.

Car exhaust emissions also contain a large number of unregulated chemical substances about which our knowledge is very incomplete. We

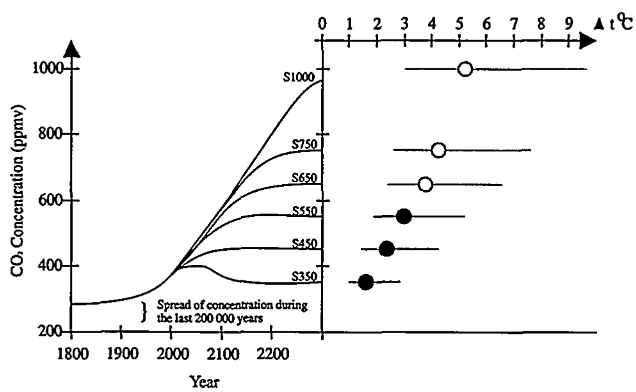


***Figure 2.7.** The atmospheric concentration of carbon dioxide will increase dramatically if today's trends of using energy continue and if we continue basing our energy and transport systems on fossil fuels. IPCC has made calculations based on a variety of assumptions, of the growth in the use of energy and equivalent emissions of greenhouse gases. The scenarios presented (S350-S1000) show that the average global temperature could rise by 1.5 to 4.5 °C if the concentration of CO_2 were to double (Swedish Environmental Protection Agency, 1996).*

do, however, know that aldehydes, aromatic compounds, gaseous olefines, polyaromatic hydrocarbons (PAH) and nitro-PAH can be found in exhaust fumes from petrol-engined and diesel-engined vehicles (Pilo C, 1996c)

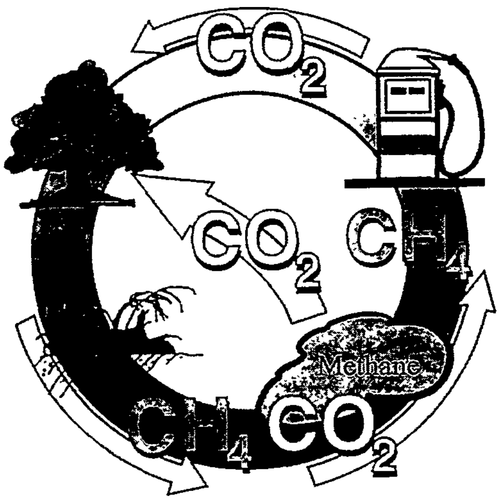
The greenhouse effect

We are slowly making the planet hotter. The carbon dioxide content of the earth's atmosphere is increasing dramatically year by year as a result of the continued dependence of many countries on fossil fuels. The threat associated with coming climatic changes is one of the most serious environmental hazards that mankind has so far faced.

For the first time ever, the world's leading experts on the climate now agree that people actually do influence the climate. In 1995, the UN panel of experts on the climate, IPCC, reported facts which indicate that the temperature increase which has occurred during the past century is, at least in part, due to emissions of greenhouses gases, mainly carbon diox-

Green plants absorb carbon dioxide from the air

Methane is used as a vehicle fuel and carbon dioxide is released into the air, where it is absorbed by the green plants.



Green plant decay and emit methane and carbon dioxide

The carbon dioxide in biogas is separated from methane and recycled into the atmosphere

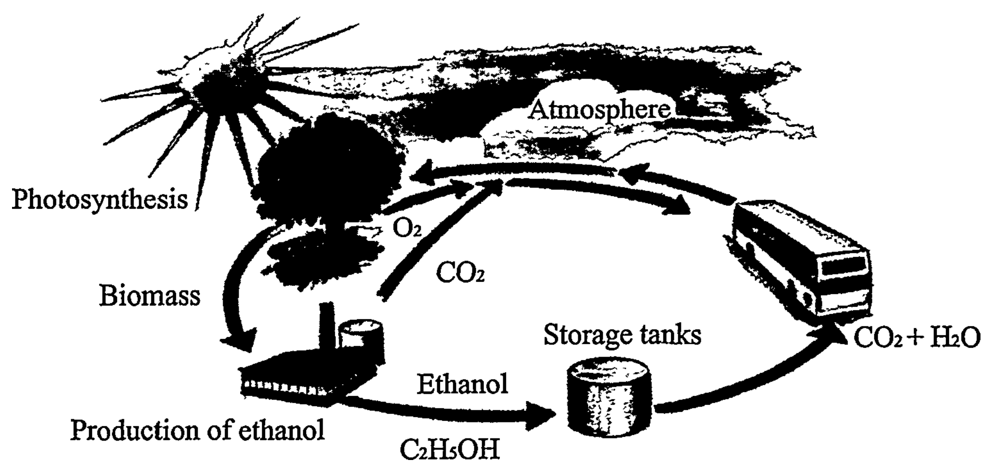


Figure 2.8. When a biobased fuel, such as ethanol or biogas, is combusted, the carbon dioxide remains in a closed ecocycle – the amount of carbon dioxide released during combustion equals the amount plants absorb for growth. The total quantity of carbon dioxide does not increase (provided that biobased fuel is used at all stages of production and distribution).

ide and methane, caused by people's actions. Scientists are not yet certain about *how* sensitive the climatic system is to changes in the composition of the atmosphere but there is widespread agreement that the planet *will* heat up significantly if our present way of using fossil sources of energy is allowed to continue.

The combustion of coal, oil and natural gas releases carbon dioxide, which is the main source of the greenhouse effect. There are no cleaning methods which can remove these emissions. The only solutions are to improve combustion efficiency, reduce the volume of transport activity, and gradually replace fossil sources of energy with renewable ones such as sun, bioenergy, wind and water. In its report, IPCC demonstrated that it is possible to improve the efficiency of energy use by ten to thirty per cent at little or negligible cost. However, IPCC's report also shows that in the longer term more than improvements in energy efficiency will be required to prevent climatic change. New types of energy based on renewable sources must in the future come to dominate the world's energy supply.

At the 1992 UN conference on the environment and development in Rio de Janeiro, Sweden and other countries signed a convention on the climate that was intended to stabilise the CO_2 emissions of the industrialised countries at their 1990 level by 2000. Eventually, however, this will mean that the concentration of CO_2 in the atmosphere will continue to increase. The UN General Assembly also noted at its extraordinary session in June 1997 (Department of Environment, 1997) that carbon dioxide emissions are still rising, despite the adoption of the convention, and even though scientific evidence from IPCC has eliminated much uncertainty and indicated more definitely than ever the serious risks associated with global climatic change. International activities to tighten and redefine international climatic goals are therefore continuing. The UN's climate conference in Kyoto, held in December 1997, was a first step to persuade individual countries to make binding commitments to reduce emissions.

If global per capita emissions of carbon dioxide are to be uniformly distributed it will be necessary for an industrial country such as Sweden to reduce its emissions by 50-80 per cent. As transport accounts for some forty per cent of Sweden's carbon dioxide emissions, eventually equally large emission reductions would in principle be required in that sector as in other sectors. In an analysis by type of traffic, the EST-project, for example, has assumed (Swedish Environmental Protection Agency, 1996a) that the greatest potential to bring about these reductions in a cost-effective way lies in road traffic. A long-term goal has therefore been established of reducing emissions of carbon dioxide by seventy five per cent by 2050 (**Table 2.1**).

Base year 1990	2005	2020	2050
Road traffic	-10%	-20%	-75%
Aviation	+30%	0%	-20%
Rail	0%	-20%	-20%
Shipping	0%	-10%	-20%
Total	-5%	-15%	-60%

***Table 2.1.** Proposal for national goals for reductions in CO_2 emissions from 1990 level (Swedish Environmental Protection Agency, 1996a)*

Life cycle perspective

Life cycle assessments (LCA) of fuel have been made by several parties, all of whom recognised a need to analyse their own products from their own point of view, possibly to improve the environmental reputation of the product or as a marketing measure. The consequence is that numerous reports have been published containing analyses of more or less the same problem which lead to different results. Most often these divergent results are due to differences in the definition of life cycle, in other words, at what point between cradle and grave a decision made to start and stop the analysis. A further problem is caused by the different bases used for selecting data, and what generalisation have been made from these data. However, analyses of the environmental impact of fuels cannot be regarded as complete if account is not taken of their total life cycle.

Two major life cycle assessments have been made within KFB's biofuel programme:

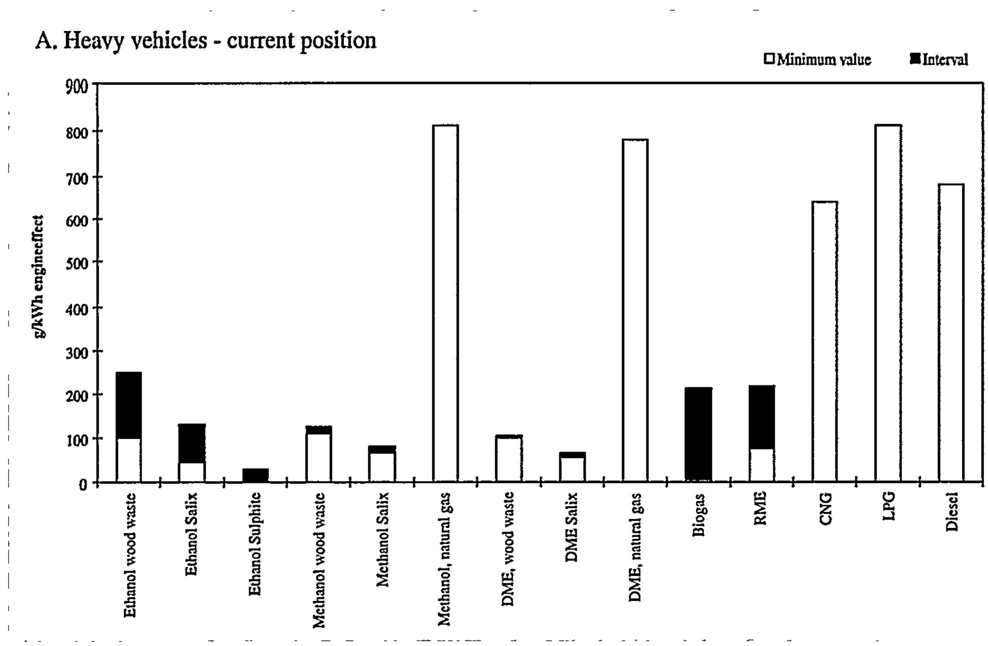


Figure 2.9. Composition of life cycle fossil CO_2 emissions from heavy vehicles (Blinge M et al, 1997).

the first is a study made in the beginning of the programme, Ecotraffic (1992). The second came at the end, Blinge (1997). As the second of these is the most relevant and has been updated with relevant and comparable data, this chapter is based primarily on this latter report.

Blinge (1997) presents results from a LCA of the following vehicle fuels: ethanol, methanol, biogas, rapeseed methyl ester (RME), di-methyl ether (DME), compressed natural gas (CNG), motor gas/propane (LPG), petrol, diesel and blends of ethers (MTBE and ETBE) with petrol.

Seen from a life cycle perspective, eighty to ninety percent of the emissions of acidifying and excessively fertilising substances are caused by the process of combusting the fuel. This is true, in principle, of all fuels, both fossil fuels and biobased ones. The same applies to emissions of carbon dioxide from fossil fuels. In case of emissions of carbon dioxide from biofuels, on the other hand, the entire life cycle is important.

Emissions of fossil CO_2 from a biobased fuel are approximately 10-15 per cent of the emissions from a fossil fuel. The fuels should therefore mainly be compared with the respective groups, i.e. fossil fuels with fossil fuels and biofuels with biofuels.

In case of biofuels, relatively similar CO_2 emissions are obtained for all of the fuels in the study. However, there is a tendency for the cultivation and production of rapeseed for RME production and of lucerne for biogas production to give rise to higher CO_2 emissions than the cultivation of energy forest (salix) for the production of ethanol, methanol or

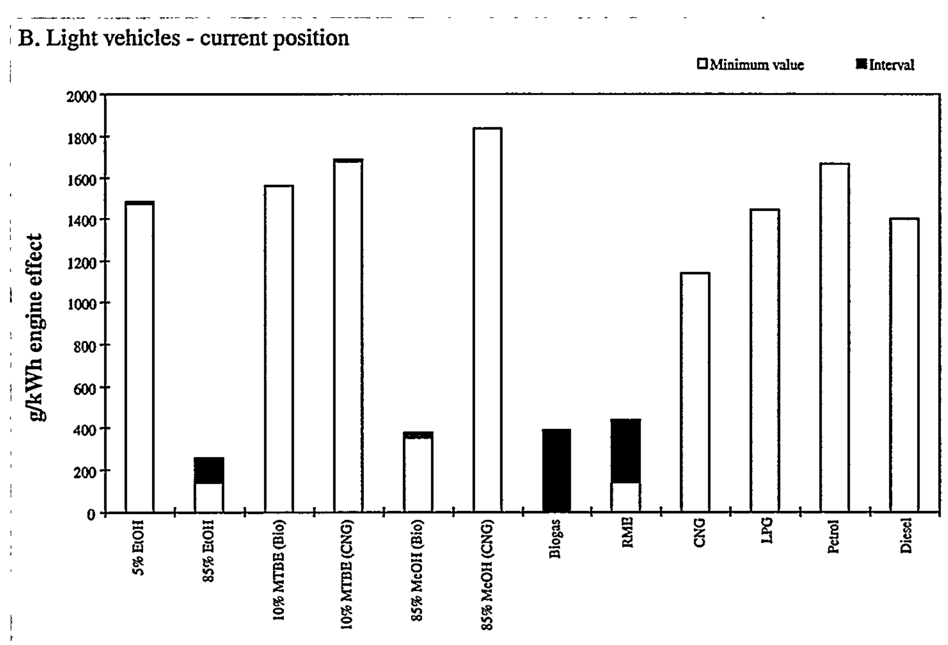


Figure 2.10. Composition of life cycle fossil CO_2 emissions from light vehicles (Blinge M et al, 1997).

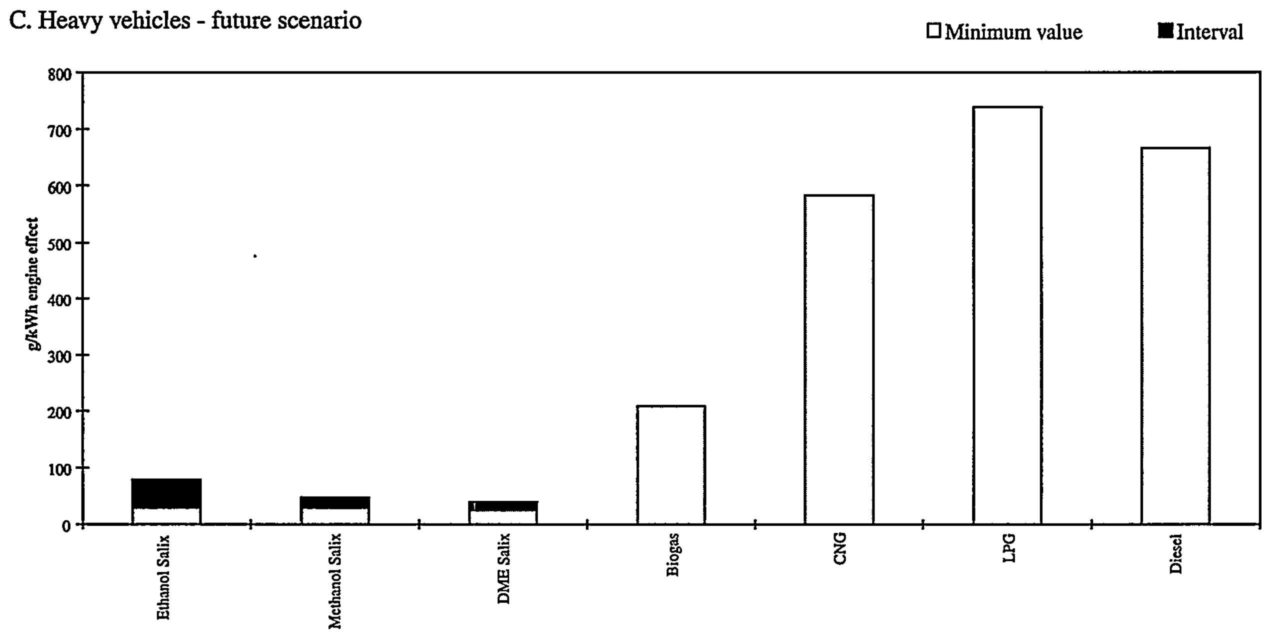


Figure 2.11. Composition of life cycle fossil CO_2 emissions from heavy vehicles – future scenario (Blinge M et al. 1997).

DME. The difference in emissions between the production of ethanol and methanol/DME, is too small, given the currently available facts, for any definite conclusions to be drawn from a life cycle perspective. Biogas produced from organic waste cause by far the lowest emissions, but it should be noted that CO_2 emissions vary widely, depending on whether the raw material is cultivated or whether it is a waste product.

The results of the life cycle assessment are presented by means of a number of figures which show fossil CO_2 emissions for both heavy and light vehicles, and for alternative choices of fuel, see **Figures 2.9** and **2.10**. The result of the assessment applies at the technical level that can be expected to make its commercial breakthrough in about ten years' time.

The report also examines a future scenario for selecting fuels for heavy vehicles – ethanol, methanol and DME from salix, biogas, CNG, LPG and diesel (see **Figure 2.11**). It should, however, be noted that this scenario is very uncertain and should therefore be interpreted more as a possible indication of the way in which fuels could be improved in environmental terms if environmental production methods are introduced, and what, in such a case, would be the results in relation to other methods in the future. Despite these uncertainties, however, this LCA shows that the use of biofuel has the potential to halve CO_2 emissions compared with the currently best available technology.

To sum up, Blinge (1997) shows that the differences in emissions into air from different fuels are smaller than in previous LCA studies might suggest. However, the analysis also shows quite clearly that CO_2 emissions can be reduced by at least a factor of five in relation to the level of emissions that would be generated by the continued use of fossil fuels in our vehicles.

It is possible to reduce CO_2 emissions slightly by replacing petrol and diesel by other fossil fuels, such as natural gas (LPG, CNG) or natural gas based fuels (MTBE, DME, methanol), but the effect would be no more than about 10-15 per cent. If fuel blends of 5-10 per cent alcohol or ETBE with petrol are used, the reduction in fossil CO_2 emissions would be less than if CNG were used. The conclusion, therefore, is that if CO_2 emissions from the transport sector are to be radically rapidly reduced it is necessary to change over to using biobased fuels.

Conclusions

- Today's transport systems are not sustainable in the long term. A global situation with constant growth in motoring and thus higher global emissions of carbon dioxide will make radical changes in the transport sector in general and in road traffic in particular essential.

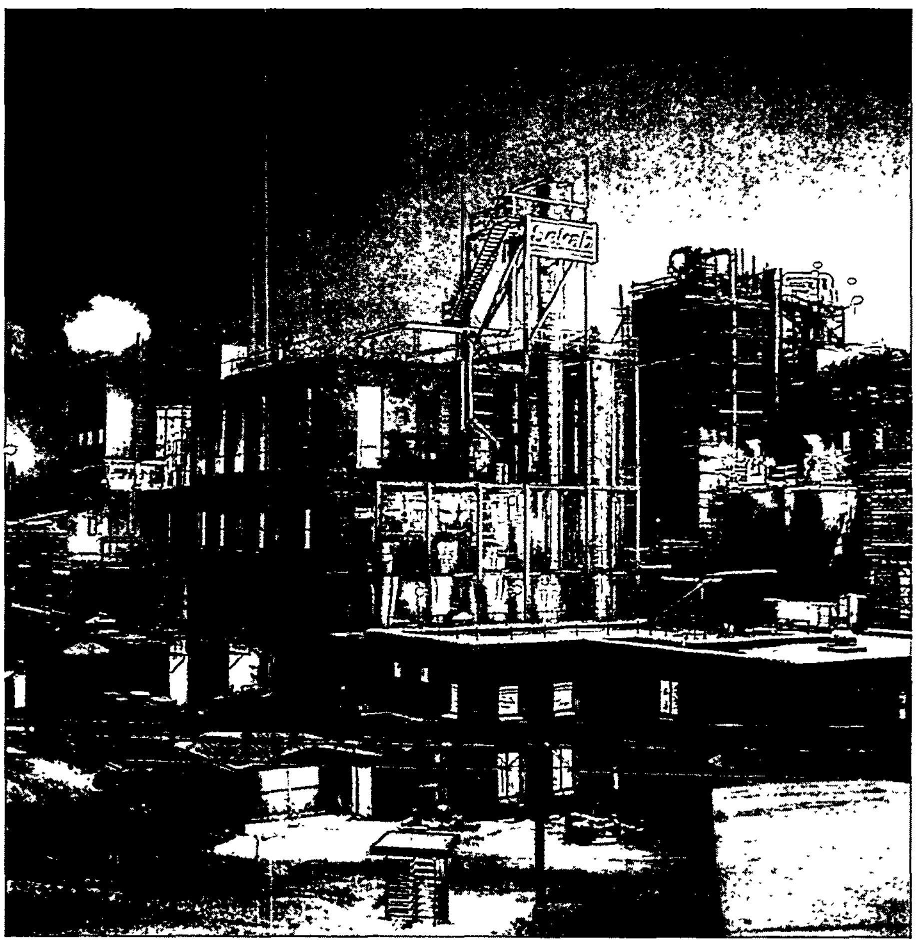
- The first step to reduce emissions of greenhousegases from road traffic is to reduce fuel consumption and improve the efficiency of the transport system. However, this is not enough. New fuels from non-fossil sources will eventually have to be introduced on a large scale.

- The transition to a society which generate fewer emissions of greenhouse gases into the atmosphere is a global issue requiring internationally coordinated action. However, Sweden, as a rich industrial nation, has a responsibility to take the lead in this process of adjustment. Moreover, we, like everyone else,must act in accordance with the principle of "the polluter pays".

- Life cycle assessments which take account of all the effects of the entire chain from production and use should be made as a means of evaluating of alternative fuel-vehicle combinations. LCA that have already been carried out show that a change from fossil fuels to biofuels could reduce CO_2 emissions by a factor of five, provided that a high proportion of renewable energy is used at all stages in the process.

Engine alcohols

- *Fuel characteristics*
- *Admixture of alcohol in petrol and diesel*
- *Use of alcohols in pure form*
- *Ethanol or methanol*
- *Production*
- *Biofuel potential*
- *Financial considerations*
- *Conclusions*



Chapter 3

ENGINE ALCOHOLS

By engine alcohols in this report we mean methanol and ethanol produced from biological raw materials. As far as Sweden is concerned, however, it is above all ethanol which is of interest. Both alcohols can be used as pure fuel in both otto engines and diesel engines or blended into petrol or diesel fuel. At present, ethanol is mainly produced from agricultural products but in future the intention is that Swedish ethanol production should largely be based on forest raw materials.

Fuel characteristics

The use of alcohols as vehicle fuels is not a new practice. It was in fact done in the earliest years of motoring. Alcohols had been used on and off throughout the entire history of motoring. Most often, alcohols have been seen as alternatives to conventional fuel in times of uncertainty, such as war or economic depression. The safeguarding of supplies was most often the factor determining the use of alcohol. This argument has now tended to slip into the background in favour of the environmental potential the use of biobased engine alcohols provides.

When it comes to the characteristics of alcohols as vehicle fuels, they have both advantages and disadvantages. Whether the positive or negative characteristics predominate depends to some extent on what type of engine (otto or diesel) is used. Generally, it may be stated that alcohols often provide advantages if they are used in otto engines, whereas in diesel engines there are physical obstacles making the use of alcohol difficult.

The specific characteristic of alcohols which makes them suitable as a fuel for otto engines is their high *octane count*. The octane count is a measure of the ability of the fuel not to self-ignite at high pressures and temperatures. Ignition of the fuel-air mixture should take place under controlled conditions and be caused by a spark. If the fuel self-ignites before the spark has flashed a phenomenon occurs which is popularly known as "knocking". Apart from the noise, knocking can seriously damage the engine.

In practice a high octane count means that the engine's compression ratio can be raised. In physical terms, this means that a higher compression ratio

Fuel characteristic	Unit	Ethanol	Petrol	Diesel
Boiling point	°C	78.3-78.5	27-225	188-340
Density	kg / litre	0.792	0.72-0.78	0.81-0.88
RVP, steam pressure	kPa	15-17	50-100	0.1-0.15
Steam formation heat.	kJ / kg	842-930	330-400	225-600
Self-ignition temp.	°C	365-425		204-260
Flame point	%	3.3-19	1.0-8.0	0.6-5.5
Stochiometric ratio	kg / kg	8.97-9	14.5-14.7	14.6-14
Adiabatic flame point	°C	1930	1977	2054
Upper thermal value	kJ / kg	29.70	47.00	45.60
Upper thermal value	kJ / litre	23.40-23.60	34.80-35.20	38.66-38.80
Lower thermal value	kJ / kg	26.80-27.00	42.00-44.00	42.80-45.30
Lower thermal value	kJ / litre	21.10-21.20	30.40-33.20	35.90-36.60
Cetane count		8		40-60

Table 3.1. Comparison of critical characteristics of ethanol, petrol and diesel as engine fuels (Olsson L-O, 1996).

produces a higher theoretical efficiency. In other words, the engine uses less fuel.

In the case of diesel engines, the fuel requires other characteristics. These are directly opposite to those required by a fuel for otto engines. A diesel fuel should self-ignite easily. In fact, the better a fuel self-ignites the better it is as a diesel fuel. The reason for this is the method used to ignite fuel-air mixtures in a diesel engine. The fuel is injected into the engine's cylinder when the piston is around its upper turning point. At that point the pressure and temperature in the cylinder are then high. It is then desirable for the fuel to ignite as fast as possible when injected into the cylinder.

The measure of a fuel's ability to self-ignite is known as its *cetane count*. The higher the cetane count the more easily the fuel self-ignites. Normally, diesel fuel has a cetane count of at least 47 for modern European diesel engines, whereas ethanol and methanol have cetane counts of around 8 and 5 respectively. In order to improve the cetane count of ethanol, an additive known as an *ignition improver* is added. However, the cost of such additives is currently very high (around one krona per litre).

As far as worker protection is concerned, ethanol represents less of a hazard than diesel and petrol. Ethanol has a low toxicity and is relatively harmless in moderate doses. Ethanol is soluble in water and natural bacteria exist which can break down ethanol into carbon dioxide and water. On account of the risk of misuse and confusion with beverage spirit, the addition of a denaturing agent is a statutory requirement (the addition of odorous substances that also have a taste).

Methanol, on the other hand, unlike ethanol is highly toxic and is therefore subject to special rules regulating its use. Even very small doses (< 15 ml) can cause blindness or death. Given the toxicity of methanol and its solubility in water, spills and leaks can cause serious problems.

In terms of fire risk, ethanol and methanol, like petrol, are classified in Fire Class 1, whereas diesel is classified in Fire class 3 (class 3 means there is less risk of fire than class 1). This makes demand on the equipment used to store and handle engine alcohols. Tank facilities, storage sites and other equipment have to be classified with regard to the risk of explosion. Alcohols have low ignition temperatures and burn with a flame which is not readily visible to the naked eye. On the other hand, as an ethanol fire is relatively easily quenched, ethanol cannot be placed on the same footing as petrol, even though it belongs to the same fire class.

According to a review of the laws, ordinances and rules regulating the handling and use of engine alcohols made at the beginning of KFB's biofuel programme, it emerge that these appear to be adequate (Brandberg Å, Johansson A, 1992). Certain application ordinances may, however, need to be complemented as engine alcohols come into more widespread use.

Blending of alcohols with petrol and diesel

The blending of small amounts of alcohols or ethers is a method which could be used to quickly introduce alcohols on a large scale. The use of ethers involves few or no changes to the basic petrol. Storage and distribution are affected to some extent. The problem is the availability of olefines at refineries, which limits the total potential.

Blends containing small quantities of pure alcohols require them to be water free, which makes greater demands in terms of storage and distribution than today. The basic petrol also has to be reformulated to prevent the steam pressure from rising to too high a level.

Several oxygenates (alcohols and ethers) are already available on the market as components for blending into petrol. One reason for blending is that oxygenates raise the octane count. According to the Swedish Environmental Protection Agency's proposal for environmental classification of petrol an upper limit of 2 per cent by weight is set for the oxygen content of petrol, which would allow ethanol blends of up to 5.5 per cent by volume or 13 per cent in the form of ETBE, of which some 40 per cent of the ETBE consists of ethanol. The proposal to limit the oxygen content was explained by the need to ensure that old cars can still be used and by the observation in the USA that nitrogen oxide emissions can increase when the content of oxygenates rises above some 2 per cent.

Companies in the industry have from time to time discussed whether low blends of ethanol and petrol could be a first step on the way to introducing a blended fuel by raising the percentage blended from 5 per cent to, say, 10 or 20 per cent (in Brazil the blend is 22%). The Swedish oil company OK has recently opened filling stations in Göteborg and Örnsköldsvik which supply 10 per cent blends of ethanol and petrol. The Örnsköldsvik filling station is a further innovation in that it has Sweden's first automatic pump for low ethanol-petrol blends. The method used is to store the ethanol and petrol in separate tanks and then mix them direct in the pump upon delivery. Normally, these components would otherwise be mixed directly in an underground tank.

One factor limiting the blending of ethanol and petrol (to around 10-20%) has been the hesitation of vehicle manufacturers over providing guarantees for such running. However, a change is in the way as modern vehicles have greater fuel flexibility, and many car manufacturers are now prepared to provide guarantees for ethanol blends of 15-20 per cent. This was demonstrated by means of the unique tendering for 500 cars for the County Council and six municipalities in Värmland, where Saab, Opel, Volvo and Renault each guaranteed that their cars would run on a 15 per cent ethanol blend (in Renault's case 20%).

When it comes to blends of ethanol and diesel, these substances cannot normally be blended into a stable product. However, the addition of an *emulsifying agent* enables a stable and homogeneous emulsion to be obtained. In the tests with this type of mixed fuel carried out as part of KFB's programme of biofuel tests (described in Chapter 7), it turned out that a 15 per cent blend of ethanol and diesel performs quite satisfactorily.

Use of alcohols in pure form

If passenger cars (otto engines) are to run on pure alcohol it is essential, in Sweden's climate, that the ethanol content of the original fuel is at least 99 per cent, i.e., almost water free. This 99 per cent alcohol can then be blended with hydrocarbons or petrol as a means of facilitating ignition when starting at low temperatures. In principle, one can consider two different types of vehicle: firstly flexible fuel vehicles or FFVs, and secondly vehicles which are dedicated to use of a specific fuel, such as ethanol or methanol. The use of FFV vehicles is one way of facilitating the introduction of ethanol combustion in Sweden. Thanks to their fuel flexibility, these vehicles can also be used in situations without ready access to ethanol. Consequently, there would be no need for the immediate expansion of a nation-wide distribution system for this new fuel. OK already supplies E85, an ethanol fuel, at 20 or more locations in the country (see Chapter 7). This is the fuel that is recommended for the Ford Taurus FFV. These cars can however, be driven using a higher ethanol content.

In the case of heavy vehicles (which use diesel engines), commercially tested techniques are already available which allow them to be run on ethanol. However, this technique requires the use of an ignition improver, which involves high fuel costs and inconvenience in operational terms as well as certain problems with regard to health and the environment. Sparking plugs and glow plugs are alternatives to ignition-improvers in the fuel. In Japan sparking plugs are being used with converted diesel engines running on methanol with some success.

Ethanol or methanol?

Ethanol and methanol are two different engine fuels that can be manufactured from biomass. Each fuel has its advantages and its shortcomings. With current methods, it would appear that methanol can be produced at a slightly lower cost than ethanol, whilst the environmental profile of ethanol, seen overall, is slightly better than that of methanol.

In the wake of the oil crises in the 1970s, methanol programmes were started in the USA, Japan, and New Zealand, as well as in Sweden. The Swedish methanol programme covered a total of one thousand vehicles with a variety of levels of admixture, from 5 per cent to 100 per cent (M5, M23, M100). Modified pumps were also installed in some towns for filling tanks. Towards of end the 1970s, however, most parties involved withdrew from the programme and the trials were concluded in the 1980s (Egebäck, Walsh, Westerholm, 1997).

The USA methanol programme has also declined in extent during the 1990s. The number of filling stations for methanol, as well as the number of vehicles running on methanol, is still relatively high but the total volume of methanol sales is falling rapidly. A case in point is MTA, the Los Angeles bus company. Their fleet of around 300 buses has been converted from methanol to ethanol in recent years owing to the occurrence serious engine problems and difficulties in obtaining methanol at reasonable prices. Similar developments have taken place in Canada and New Zealand. However, Japan's methanol programme, which is based on the use of natural gas as a raw material, is still going on. There is also some interest in methanol in China and South Africa, as these countries see great potential from producing methanol from domestic natural resources, although this would involve vast environmental problems.

There are many reasons why ethanol is increasingly emerging as the best engine alcohol. One of the most serious drawbacks of methanol is that it is hazardous, to both people and the environment, as a material. Methanol is highly corrosive which leads to higher costs for the materials in pipelines, filling equipment and so on. Methanol is also highly toxic, can cause blindness, or at worst death, and, in the event of exposure to the skin, blood poisoning. If methanol leaks into water, i.e., through ground water leakage, it can have devastating consequences. Methanol's current cost advantages are also expected to disappear eventually as new more efficient methods are developed for producing ethanol.

Production

Engine alcohols can in principle be produced by two different techniques – fermentation or gasification. The predominant method is fermentation of biomass followed by distillation, for which a variety of different technical concepts have been developed. The gasification technique has so far mainly been tested for producing methanol from fossil raw materials, but development work is in progress on developing techniques for the gasification of biofuel.

Both fossil materials and a variety of bio raw materials can be used to produce engine alcohols, either methanol or ethanol. For biobased production of engine alcohols, the following raw materials are of most interest:

- *Sugar-containing agricultural products, such as sugar beet and sugar cane.* The technique for fermentation of sugar is well known and the process design is simple. The cultivation of sugar-containing agricultural products is too expensive for the production of ethanol at latitudes such as Sweden's but it is attractive in countries with a

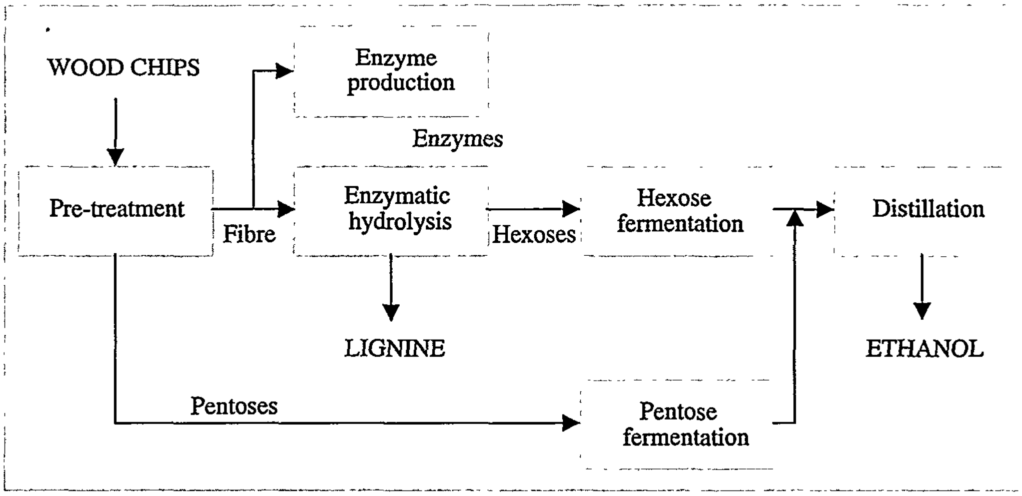


Figure 3.1. Schematic description of ethanol production from lignocellulose based on enzymatic hydrolysis (Zacchi G 1996).

sub-tropical climate. In Brazil, the sugar in the sugar cane is used to produce ethanol for fuel purposes. On the other hand, waste products from the sugar cane (bagasse) are not at present used to manufacture ethanol and are burnt instead.

- *Starch-containing raw materials, such as potatoes and grain.* This process is slightly more complex as a starch has to be hydrolysed into sugar before fermentation. The technique is well established and all beverage spirits in Sweden are manufactured from starch. These agricultural products are also too expensive, i.e., generate too low a return if used to produce ethanol for fuel purposes.
- *Pulp and hemicellulose-containing raw materials, such as straw, softwood and hardwood, waste paper and municipal refuse (pulp and hemicellulose fractions).* These raw materials are less expensive but on the other hand the process is more complex, as the material is solid and the pulp is protected by hemicellulose and lignin. Moreover, the hydrolysation of cellulose is a more difficult process than the hydrolysation of starch.

In Sweden ethanol at present is only manufactured via the fermentation of starch-containing materials (grain, potatoes, etc.). However, development work is being carried out in Sweden and abroad (mainly in the USA) with the aim of finding effective production methods involving enzymatic hydrolysis (**Figure 3.1**) which can also use cellulose-containing materials that are currently regarded as waste, such as harvest residues from forestry, byproducts from the wood, pulp and paper industries, building waste, municipal waste, straw, etc. Fuel forests could also be considered.

In theory, all cellulose and hemicellulose can be converted into sugar, which can then be gasified into ethanol. This method produces 480 litres and 580 litres of ethanol from one tonne of softwood and hardwood respectively, which represents 55 per cent and 65 per cent respectively of the energy content of the wood. The lignin can be obtained as a solid fuel and the theoretical yield amounts to a further 20-25 per cent of the energy content of the wood. (**Figure 3.2**)

When ethanol is produced from cellulose-containing raw materials, the aim, apart from the conventional hexose fermentation, is also to be able to ferment pentosene xylose. As traditional methods of fermentation using baker's yeast (*Saccharomyces*) do not work in the case of pentoses, intensive development work is in progress all over the world to solve this problem. One method could be to convert the yeast. This could be described as genetical engineering design with the object making possible the direct fermentation of xylose.

An important part of the research, which, in Sweden, is mainly carried on at the University of Lund, involves attempting to find methods which produce a high yield and fewer by-products than fermentation. Valuable development work is also in progress in the process industries on new methods, such as drying by the molecular-membrane technique, extraction and various combinations of

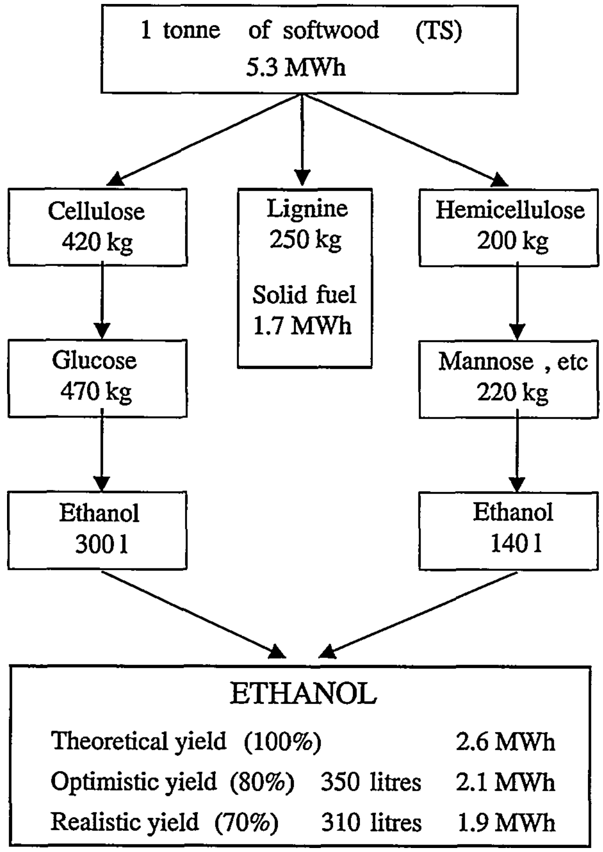


Figure 3.2. Theoretical ethanol yield (Zacchi 1996).

distillation, all with the object of lowering production costs.

Large-scale production of ethanol in the future will probably be based on construction of a number of biorefineries. Such biorefineries would be based on a production mix of different products, such as ethanol, thermal energy (district heating), electricity, pellets and possibly also other chemical products.

Potential as a biofuel

The annual forest harvest in Sweden corresponds to some 150 TWh per year, of which around one half is used as energy, mainly in the forest industry. However, there is unutilised potential energy in the form of branches, roots, bark and other felling waste (known as GROT from the Swedish abbreviation) which is not at present utilised by the industry.
B Johansson (1996) estimates that this resource correspond to some 60 TWh per year. Another source of potential biofuel of the same order of size as GROT, is fuel forests, which can be cultivated on abandoned farm land. Other major potential sources of biofuel are industrial by-products (waste) from the wood and timber industry (some 50 TWh per year). By making use of these possible sources, it is estimated

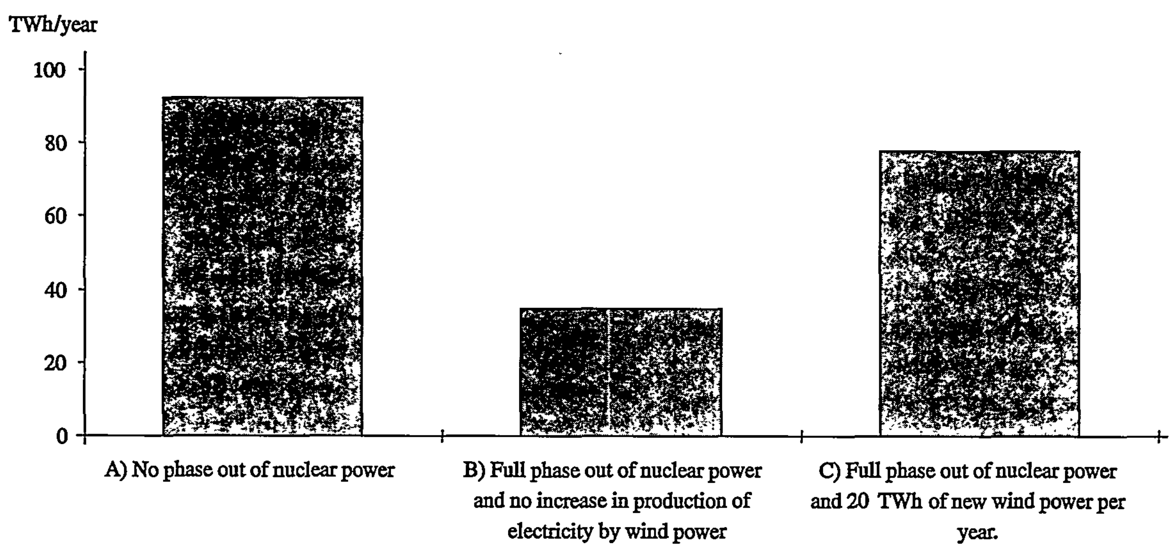


Figure 3.3. Quantity of biofuel that may be expected to be used for fuel production on three different assumptions: A) No phasing out of nuclear power, B) Full phasing out of nuclear power and no increase in production of electricity by wind power, C) Full phasing out of all nuclear power and introduction of new wind power of 20 TWh/year. All three cases assume that currently available energy-efficient equipment is used (Johansson B. 1996).

that the use of biofuels could be raised by approximately 125 TWh compared with the 1994 level. Such quantities would be sufficient to cover existing fuel requirements (some 70 TWh/year) as well as the estimated fuel requirements for 2015.

These estimates of the future potential for biofuels are, however, especially uncertain, as the supply of biofuel for energy purposes is determined by many different factors, such as the demand for agricultural and forest products, productivity improvements in agriculture on account of new seeds and plants and new methods of cultivation, changes in the prices of competing types of energy, possible effects of environmental changes on the growth of the biomass, and possible conflicts between higher biomass recovery and other environmental goals, such as biological diversity.

In terms of cost efficiency, it is, up to a given level, generally more advantageous to use biofuel for power and heating than for transportation. However, Johansson B. (1996) shows (**Figure 3.3**) that even if biofuel would primarily be used for the production of electricity and thermal energy, ample supplies would still be left to produce engine alcohols. How large this fuel potential might be is rather uncertain and would depend on several factors related to energy policy. Johansson's scenarios are therefore based on a variety of assumptions regarding the phasing out of nuclear power and the effect of improvements in energy efficiency in various sectors.

Financial considerations

In the short term perspective, tried and tested commercial techniques are available for manufacturing ethanol from either molasses or grain. The ability to stimulate any significant production of ethanol in Sweden would depend primarily upon the ability to engage in such activities on a competitive basis in relation to ethanol prices on global markets. Ethanol can be manufactured from molasses in tropical countries at a cost of 3-3.50 kronor per litre. There are large surpluses of molasses, although most of it comes from countries such as Indonesia, China, India and Pakistan, which are far away from Sweden.

Sweden has approximately 300,000 hectares of no longer cultivated land for which farmers receive financial aid, mainly from the EU. The cost of producing ethanol domestically from grain is in the region 3.50-4.50 kronor per litre, depending on raw

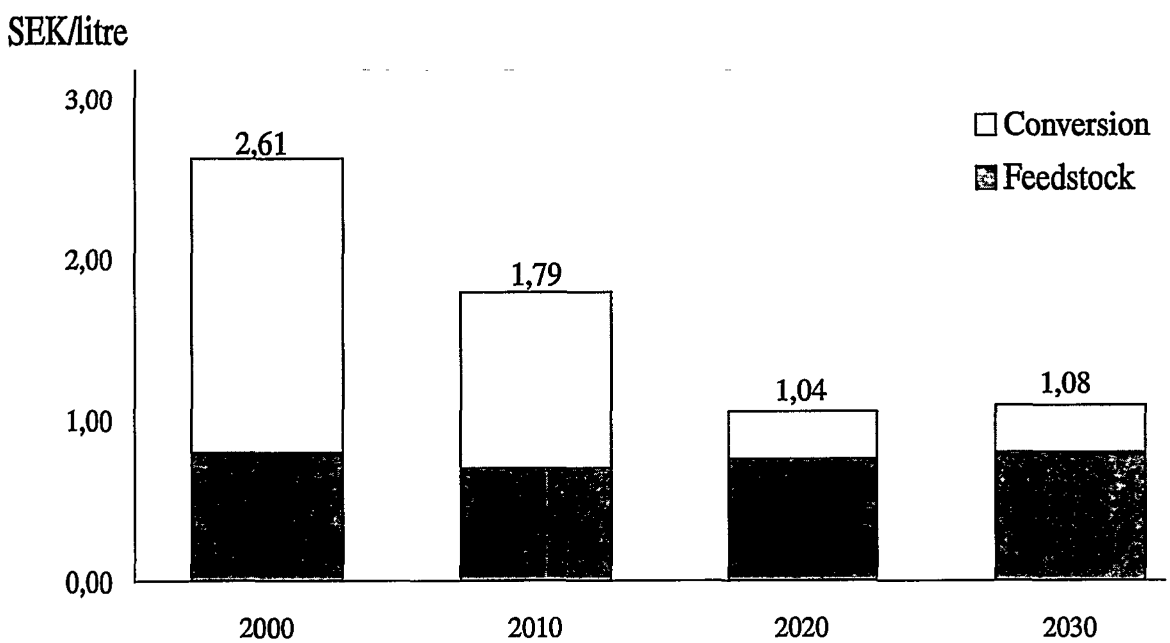


Figure 3.4 Development targets in the USA for the cost of producing ethanol (Pilo C, 1997).

material prices, the price of by-products and, to a lesser extent, operating and capital costs.

In total it is estimated that some 1,500,000 m^3 of ethanol could be produced at a cost of around 4 kronor per litre (KFB, NUTEK, SIKA, 1997).

In order to make widespread use of ethanol possible, a further requirement, in the long term, is the production of ethanol from wood. The construction of a pilot plant for the production of ethanol based on cellulose-containing raw materials is currently under discussion, but it is uncertain if and when such a plant could be brought into operation. Bringing down the cost of wood-based ethanol, at least to a level which corresponds to the cost of grain-based ethanol, would be a commercial necessity. R&D activities in Sweden and abroad are therefore focused on increasing the ethanol yield, improving production efficiency, and lowering production costs by means of enzyme techniques and the like.

At the NREL research laboratory in Colorado, USA, for example, a new method of ethanol production has been developed that is based on enzymatic fermentation (Pilo C, 1997). If the results of the development work are as good as has been foreseen, this will represent an economic breakthrough (1.20 kronor per litre by 2000) (**Figure 3.4**). As relative production costs decline, the critical factor as to whether such facilities are economically worthwhile will increasingly become the cost of raw materials.

Perhaps the most serious obstacle to introducing ethanol on a large scale is related to questions having to do with commercial risk management. If a company is to commit itself to such a heavy investment it needs to be able to evaluate both the risk and the potential return. The current high cost level for biofuel, by comparison with the prices of petrol and diesel, therefore represents a serious obstacle. If access to stable sources of raw materials, and finding markets for the fuel and by-products at reasonable prices, and not least the risks associated with the cost structure can suddenly be altered by political decisions, this type of project will often be regarded as a high risk venture.

The consumer price of ethanol as a fuel will in the final analysis largely be determined by the cost of the alternatives, i.e., petrol and diesel. Their prices are determined partly by the global market price of crude oil, and partly by national taxes and excise duties, which, for a variety of reasons (fiscal, energy security, emergency planning, environmental, etc.) are determined by political decisions.

Conclusions

- Engine alcohols produced from biomass can be used as vehicle fuel in pure form and in the form of blends with petrol or diesel. Ethanol appears to be the best alternative among the engine alcohols. In contrast to ethanol, methanol is highly toxic and corrosive and consequently it makes very heavy demands at all stages of handling. Methanol can at present be produced at a lower cost than ethanol but as new more efficient processes are developed for manufacturing ethanol this cost advantage is eventually expected to decrease.

- Tested techniques and raw materials are already commercially available for the use of ethanol in low blends (5%) in all petrol in Sweden by 2002. This ethanol production, corresponding to some 320,000 m^3 per year, can be based on grain from abandoned farm land for which farmers receive special financial aid from the EU. Imports may also be possible during an initial phase.

- In the longer term promising techniques and adequate potential for raw materials (forests) are available to permit the use of ethanol on a large scale and for the use of biofuel to produce power and thermal energy. Any limits as to how high this volume could possibly be depend mainly on the ability to produce ethanol at competitive prices.

- In many cases, energy losses are considerable when bio raw materials are converted into vehicle fuels. Use of the raw material direct in a power station is normally more efficient. However, the best way of using the bio raw material is in combined facilities (biorefineries) which produce electricity, thermal energy, pellets, fuel and possibly by-products.

Biogas

- *What is biogas?*
- *Production*
- *Quality specification*
- *Filling and distribution*
- *Supply*
- *Financial considerations*
- *Conclusions*

Chapter 4

BIOGAS

Biogas is one of the least environmentally hazardous biofuels that is currently practical and financially possible to use. To date, biogas has mainly been used in stationary facilities but it is now in use as a fuel in vehicles here and there around the country.

What is biogas?

Biogas is the name given to the mixture of gases formed when bacteria break down carbon-containing organic materials in an oxygen-free environment. The gas contains a combustible gas, methane (CH_4), carbon dioxide (CO_2) and water (H_2O) as well as small quantities of other components.

Biogas is spontaneously produced in nature and the process continues in low-oxygen environments where organic materials are available, such as in marshy ground, at the bottom of lakes and in the stomachs of ruminants.

Biogas has in the past mainly been extracted from sludge from sewage plants – known as sewage gas. Biogas from dumping sites is normally known as deposit gas. After the carbon dioxide has been separated and the methane content amounts to at least 95 per cent we refer to it as biomethane. Biomethane is the substance that could be used as a fuel in vehicles.

Production

Several different technical solutions are available for recovering biogas from organic by-products, effluent and cultivated biomass. A common feature of all these techniques is that they use an airtight tank to create an environment similar to that existing when biogas forms spontaneously in nature. The tank is normally called a biogas reactor, a fermenter or a sludge chamber. In the case of refuse tips the necessary airproof environment is created by the tip itself.

A biogas system for vehicle fuel must be designed

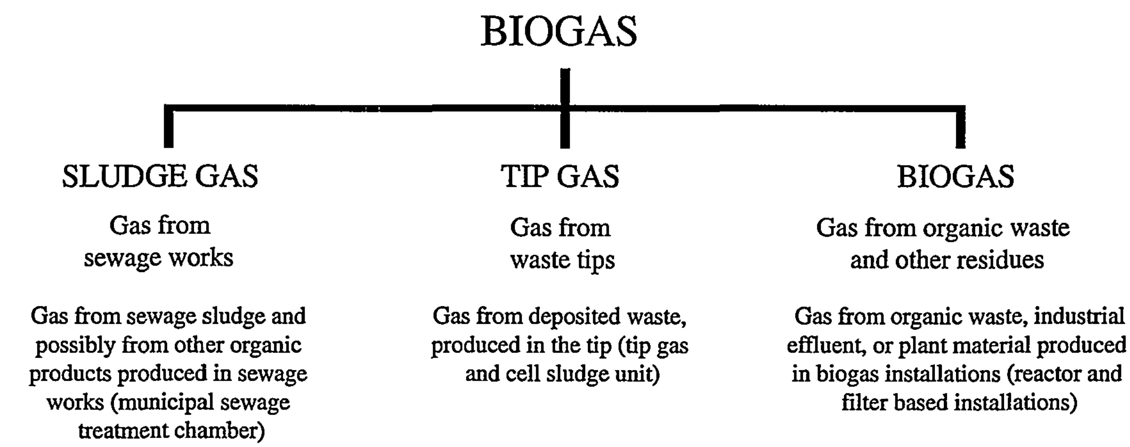


Figure 4.1. *The concept of biogas as a collective term (Maltesson, 1997).*

in a way that takes into account the fact that the biogas is produced continuously, that the quantities of gas are relatively small, that it can only be stored to a limited extent and that filling vehicle tanks is not done continuously. **Figure 4.2** illustrates the main aspects of the layout of a biogas facility.

At the moment of production, the biogas consists of methane and carbon dioxide. The proportions depend on the chemical combination of the sludge used. The gas is then saturated with steam in the reactor, and at that time other substances, such as hydrogen sulphide, hydrogen, volatile organic compounds and carbon compounds, nitrogen and oxygen may all be formed.

Often the system has a gas valve fitted to maintain a constant pressure on the low pressure side. Gas which cannot be used is flared off (burnt). Before the gas is used as a vehicle fuel it must be purified by separating solid particles, carbon dioxide, steam and other corrosive components. The object is to achieve as high a methane content as possible and to minimise the content of other substances. The biogas treated in this way is then pumped to a filling station, where it is compressed to a pressure of up to 200-250 bars.

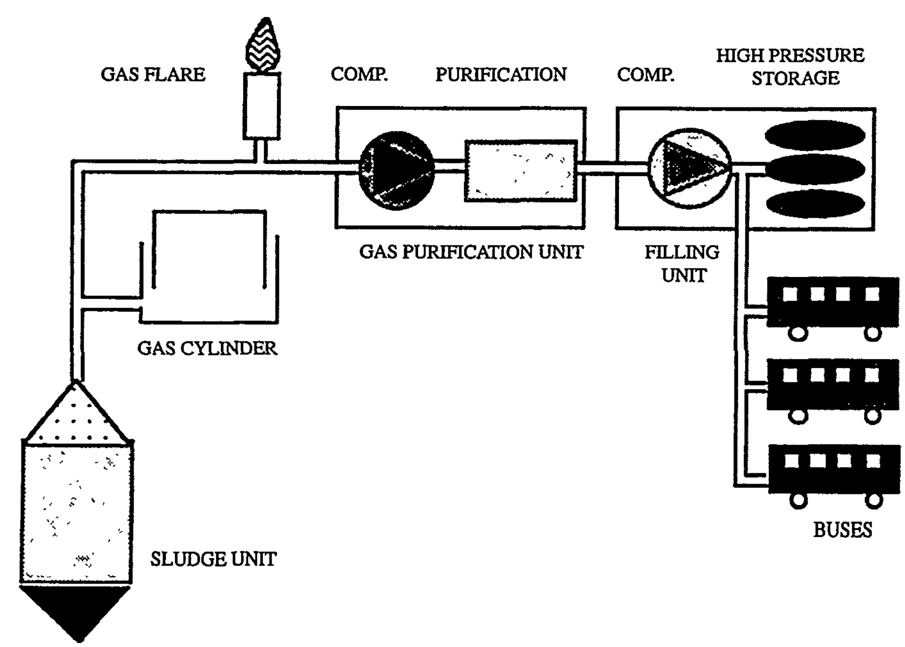


Figure 4.2. *Biogas from production to consumption (Maltesson, 1997).*

Characteristic	Unit	Requirement		Test method
		Biogas Type A	Biogas Type B	
Wobbe index $_{lower}$, min	MJ/Nm^3	45.5	44.7	ASTM D 3588
Wobbe index$_{lower}$, max	MJ/Nm^3	48.2	48.2	ASTM D 3588
Methane count, min		80	80	ASTM D 2613
Pressurising water dew point at maximum storage pressure, °C below lower monthly mean daily temperature	°C	5	5	ASTM D 1142
Water content, max	mg/Nm^3	32	32	ASTM D 1142
CO_2, max	vol. %	3.0	4.0	ASTM D 1945
Oxygen, max	vol. %	1.0	1.0	ASTM D 1945
CO_2+O_2+N, max	vol. %	3.0	4.0	ASTM D 1945
Hydrogen, max	vol. %	0.5	0.5	ASTM D 2650
Hydrogen sulphide, max	mg/Nm^3	23	23	ASTM D 4084
Methanol	vol. %	0	0	-
Particles or other solid substances	µm	5	5	-

Table 4.1. Demands made on biogas as a vehicle fuel (Maltesson, 1997).

Quality specification

When KFB's biogas programme was begun there were no standards for the composition of purified gas. Information concerning the composition of the biogas also varied widely, depending on the source and sometimes even from the same source. This will become a problem as it is not known how the crude gas should be handled. At the same time, it makes it difficult to adapt and evaluate systems for gas processing.

A project was started with the object of establishing quality requirements for biogas for use in running vehicles. This project, which was co-ordinated by the Swedish Gas Engineering Centre, highlighted the various factors which can influence the specification. The work had the support of vehicle manufacturers, biogas producers and others in the industry. This study was summarised by Maltesson (1997).

The quality specification has been adapted to make it possible, in terms of materials engineering, also to use filling and vehicle equipment developed for natural gas running with biogas. An underlying and crucial difference between the two gases is that biogas contains a larger quantity of carbon dioxide which under unfavourable conditions could involve a risk of corrosion.

Requirements have been worked out for safeguarding the engine's operating characteristics, emissions and durability, regardless of whether the engine involves the feedback and control of the oxygen content of the exhaust fumes with the aid of a lambda sond. Quality requirements are therefore divided into two groups: biogas type A, and biogas type B, where type A refers to the quality of gas intended for engines with lambda regulation, and type B is for engines without lambda regulation.

The specification establishes that the methane content shall lie between 96 and 100 per cent (**Table 4.1**).

The specification can be used as a general basis for drawing up agreements between the various parties involved in a biogas project. However, it cannot be regarded as a generally approved nation-wide standard since further development work is needed to upgrade the specification to that level.

Work in the future should be focused, on the basis of the biogas specification, on adapting both the upgrading equipment and the vehicle to each other in order to arrive at the best solution for the running of vehicles on biogas in terms of technical quality, and financial and environmental considerations.

Filling and distribution

Car tanks should be filled with biogas in an entirely closed system. This can be ensured according to either two principles – high-speed filling and slow filling.

In the case of *high-speed filling* the gas is compressed into a high-pressure storage facility consisting of a number of gas tanks. The tanks are filled until the pressure 50-100 bars above the pressure in the vehicle' tank, which often results in pressures of 250-300 bars in the high-pressure storage facility. High-speed filling takes place in roughly the same way as filling a tank with petrol or diesel. A bus tank can be filled in 10-15 minutes, and a car in 3-4 minutes.

In the case of *slow filling*, the compressor compresses the gas directly in the vehicle's gas tanks, where it raises the pressure to the operating pressure after a few hours. This technique is suitable for a company with a large fleet of vehicles which are on the road in the day and which are lined up in a filling unit at night.

When it comes to distributing gas from the production plant to filling stations, the most common way is to use pipelines, but mobile gas stores can also be used. In Stockholm biogas is distributed by

Biogas raw material			**Potential (GWh)**	**Available part of potential (GWh)**	**Recoverable part of potential (GWh)**
Municipal	- sewage sludge		1,000	800	640
	- domestic refuse		2,800	2,240	1,800
		Sub-total	*3,800*	*3,040*	*2,440*
Industry	- effluent, food industry		550	440	350
	- food waste		800	200	160
	- waste water, forest industry		1,300	900	728
	- forest industry sludge		750	525	420
		Sub-total	*3,400*	*2,065*	*1,650*
Agriculture	- manure		6,000	3,000	2,400
	- crops grown for biogas (0.5 million ha)		10,000	*	*
		Sub-total	*16,000*	*3,000*	*2,400*
TOTAL			**23,000**	**8,105**	**6,490**

* The potential from crops grown to produce biogas is considered to be less available on account of the relatively high production costs.

Table 4.2. Estimated annual biogas production in Sweden for selected degrees of raw material utilisation (Brolin L, 1995).

a biogas-driven gas distribution van to the various biogas filling stations which have been installed around town.

Supply

Biogas is currently being produced at over 200 installations in Sweden, which supply a total of some 1.5 TWh of energy. The bulk of the biogas is at present being used as thermal energy and the gas is only used as a fuel for vehicles at a small number of facilities (7 sites).

In principle, it is considered that most of Sweden's 55 towns with populations of more than 20,000 could produce sufficient biogas for a local vehicle fleet. Refuse and sludge generated in the community are normally enough to supply city buses and a number of other vehicles, such as refuse trucks, taxis, etc, with biogas. If manure, crops and other industrial organic waste from the food industry, say, are also used, many more of the municipal vehicles could be run on biogas.

The total biogas potential in Sweden has been estimated at more than 20 TWh (**Table 4.2**). However, it is estimated that at present only some 6-8 TWh per year of this potential could be made available for practical and financial reasons (Lindberg A, 1997). This estimate is based on an inventory of the country's biogas facilities. How large a proportion of this potential would be used in the transport sector would depend on such factors as the future competitive position of biogas for heating and as a vehicle fuel respectively.

At present it is sludge from our sewage and drainage systems that is used to generate most of the biogas produced in sludge chambers at local sewage works. The main potential lies in using the organic materials we all help to produce, i.e., all domestic and industrial refuse that is capable of rotting, as well as sewage sludge that is still not processed in this way.

If in addition to this crop sequences were introduced on surplus farm lands, which would benefit the soil, it will be possible to produce large quantities of silage that would be suitable for converting into biogas.

Research has been going on for several years at the Swedish Institute of Agricultural Engineering (JTI) into the use of grass crops for biogas production. It has been shown in a variety of system studies (Dalemo et al, 1993; Sundberg et al, 1997) that farmers and the environment would benefit from cultivation of grass crops if they were then harvested and processed together with other organic waste. This type of processing would produce biogas that could be used for heating, electricity production and as a vehicle fuel as well as organic residues that could be used as fertiliser. In the long term, if the system were developed on a major scale, the large volume of organic residues in the system would be enough to replace all imports of nitrogen fertilisers. On the given assumptions and price relationships, the studies also show that it is most profitable to use biogas as a vehicle fuel. The next most profitable would be for the production of thermal energy while the direct production of heat would produce the lowest return.

Financial considerations

The biogas concept includes installations for the production and processing of the gas, as well as distribution and filling systems. In order to assess the overall financial aspects of the whole system assessments need to be made of the following factors:

- raw material costs
- additional costs for vehicles
- size of facilities
- capacity utilisation
- interest rates
- price of gas
- distribution area (distances) and local conditions
- taxes

The cost of raw materials and to a certain extent also of producing biogas produced at a mixed sludge installation is often regarded as zero as the gas is produced as a by-product from the sludge stabilisation process. Apart from sludge, various types of organic waste, such as slaughterhouse waste, waste from the food industry, manure from farms and restaurant waste, are also used at several of the facilities which have been installed for production of biogas for fuel (Linköping, Trollhättan and Uppsala). It is typical of these types of installation that the raw material cost for the biogas produced depends very much on the price for the alternative use of the waste products in question, and the disposal costs, and the alternative income from the sale of process residues.

The cost of distributing biogas is determined entirely by local conditions. The location of the production facilities in relation to the filling stations, i.e., the length of the pipeline will, however, be a crucial factor affecting distribution costs. This explains the high price in Trollhättan, for example, where it turned out to be necessary to build an expensive distribution pipeline from the sewage works under the River Göta to the city centre where the bus filling stations were located.

	Individual gas-engined vehicles Additional cost today, SKr 1,000	Numerous gas-engined vehicles. Additional cost today, SKr 1,000	Additional cost for future series production SKr 1,000
Buses	500	350	100
Trucks	500	200	75

Table 4.3. Additional investment for gas-engined vehicles compared with vehicles running on diesel (Brolin L et al, 1995).

One factor which influences the overall financial aspects of the biogas system is vehicle costs. Gas-driven vehicles are more expensive than the corresponding diesel-engined vehicles. This is due to gas-driven vehicles not being manufactured in long series, that they are still under development, and that they have more expensive fuel tanks.

Table 4.3 shows the additional investment for gas-driven vehicles compared with vehicles using diesel.

The financial aspects of running vehicles on biogas may be summarised as follows:

- At present biogas cannot compete with diesel as a fuel since the additional investments required in production and distribution facilities and vehicles are too high.
- In the future with moderate additional investments in vehicles but with otherwise unchanged

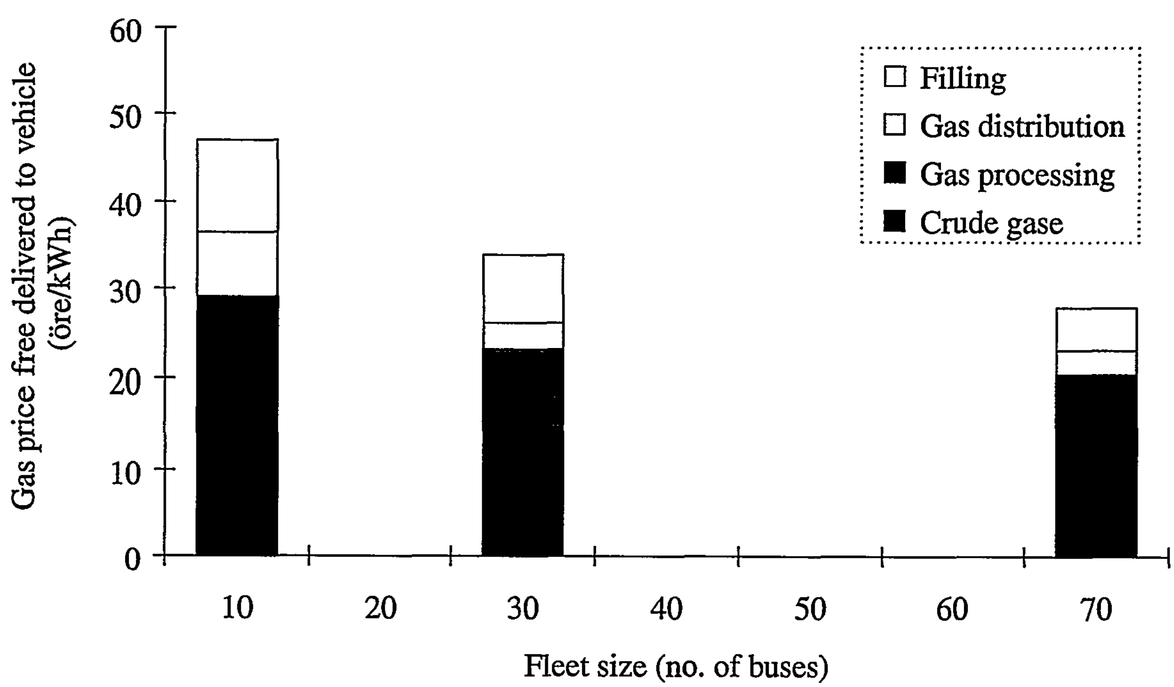


Figure 4.3. Price of gas delivered to vehicle fleets of varying size. 6% real interest (Brolin L. et al, 1995).

conditions it could be possible to make it worthwhile to run fleets of more than 20 heavy vehicles on biogas. The price paid to the crude gas producer might then be 10-20 öre per kWh. This is a low price, but probably adequate if the gas is produced at a sewage treatment plant, say.

- Biogas production from grass crops is at present not profitable, but it could become so in the future.

An estimate of the total price of biogas for a local vehicle fleet of varying sizes is shown in **Figure 4.3**.

Conclusions

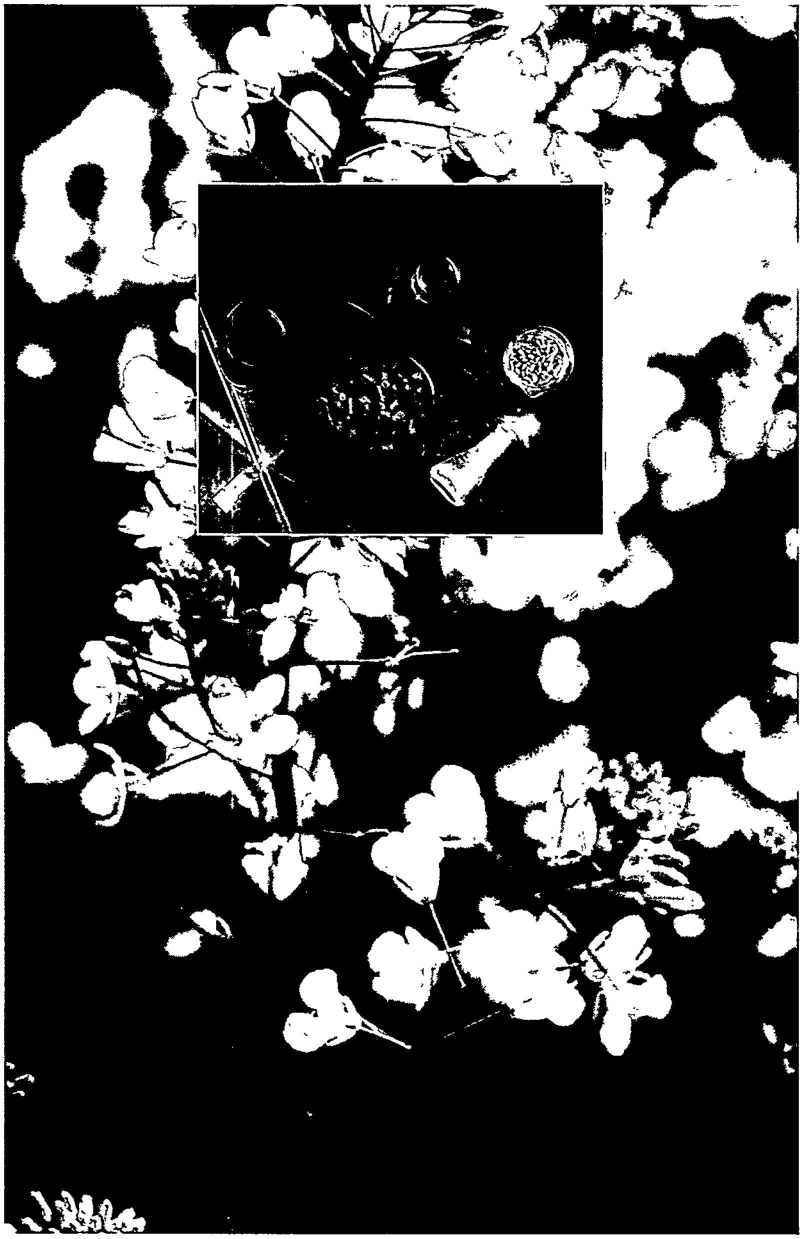
- Even though the biogas project within KFB's biofuel program has not been in progress very long it nevertheless demonstrates considerable development potential. Interest around the country in starting similar projects is extensive. In terms of emissions, biogas offers clear environmental advantages over other fuels and in the long run will be in a position to demonstrate an acceptable cost profile.

- The bulk of the biogas at present produced comes from sewage treatment plants. However the main potential lies in using the community's production of organic materials, such as all domestic and industrial organic waste, and the sewage sludge that is not currently processed. In the long term, it would also be possible to use various crops for biogas production. Grass which is introduced into a cropping sequence on surplus farm land would enable farmers to manage without artificial fertiliser as well as producing large quantities of organic materials (silage) for the production of biogas as a vehicle fuel.

- At present, it is difficult for biogas to compete with diesel fuel on account of the excessive cost of additional investments in production and distribution facilities and vehicles. However, as the cost of the new technique falls as a result of rationalisation and longer series production and as the environmental benefits are increasingly reflected in the price, biogas will eventually be able to compete with petrol and diesel. A trend towards environmentally adapted farming which would involve the cultivation of more grass crops could also help to further such a development.

Other alternative fuels

- Dimethyl ether, DME
- Vegetable oils
- Conclusions



Chapter 5

OTHER ALTERNATIVE BIOFUELS

DME and RME are examples of fuels which in their pure form or as blends with diesel, could become alternatives to fossil-based types of energy. These vehicles fuels have not been included in KFB-funded fleet trials, only being covered in certain introductory studies.

Dimethyl ether, DME

Dimethyl ether, DME, is an ether which could be suitable as a diesel engine fuel on account of its low degree of self-ignition (235°C). DME is a gas that burns without producing soot and which, if it is to be used as a fuel, has to be handled under pressure in broadly the same way as LPG. At present, DME is mainly used as a propellant in sprays (an environmentally friendlier alternative to CFCs and propane) and as a chemical raw material. DME is produced via synthesis gas and can thus be produced from any raw material, including biomass by a process of gasification. At present, however, all DME is produced from natural gas, naphtha, heavy oil residues or coal, whereas the technique for basing production on biomass is still at the development stage.

The current output of DME is very modest, approximately 150,000 tonnes per year. The method used is based on the dehydration (chemical separation of water) of methanol produced in an earlier stage in the process. In the event of large-scale production for use as of a fuel, the production method would probably be direct dehydration in a synthesis gas reactor. One of the leading companies in the development and testing of DME is a Danish company Haldor Topsoe A/S, which has developed a method that is based primarily on the use of natural gas as a raw material. However, this technique could in the longer term be served as a basis for using biomass.

Compared with methanol production, a DME synthesis process would be slightly more efficient in terms of energy due to the higher flow of synthesis gas through the reactor and the lower pressure. So far, however, only natural gas based facilities have

	DME	Propane	Diesel fuel, MK1	Methanol
Chemical composition: % C	52.1	81.7	~ 86	49.9
Chemical composition: % H	13.1	18.3	~14	12.6
Chemical composition: % O	34.7	0	0	34.7
Molecular weight	46.068	44.094		32.042
Density (l), 20°C, kg/m^3	668	501	810 – 820	795
Density (g), 20°C, 1 bar kg/m^3	1.92	1.88		1.35
Gas density in relation to air = 1 (15°C)	1.59	1.55	3 – 4	1.11
Steam pressure, 20°C, bar	5.1	8.3		0.12
RVP (37,8°C), bar	8	13.5	0.0007	0.32
Steam pressure, 60°C, bar	14	20.8		0.77
Boiling point (1 bar), °C	-24.9	-42.1	180 – 300	65
Freezing point °C	-139	-190	-9 – -45	-94
Steam formation heat at boiling point, MJ/kg	0.41	0.43	0.25	1.17
Thermal value (HHV), MJ/kg	31.8	50.3		22.65
Thermal value (HHV), MJ/litre	21.2	25.6		18.0
Thermal value (LHV), MJ/kg	28.8	46.4	43.2	19.9
Thermal value (LHV), MJ/litre	19.2	23.5	35.2	15.8
CO_2 formation, g/MJ (LHV)	67	64.6	72	68.9
Self-ignition temp., °C	235	460	~ 250	470
Flammability limit in air, vol %	3.4 – 17	2.1 – 9.5	0.6 – 6.5	6.7 – 36
Flame point, °C	-41	-100	>50	11
Solubility in water, 1 bar (20°C), mass %	5.7	0.39		∞
Solubility of water in, 4.8 bar, 20°C, mass %	5.5			∞
Cetane count	>55	– ––	~ 50	~ 5
Octane count (RON)	70	112	– ––	120

Table 5.1 Specification data for DME , propane, diesel fuel and methanol (Brandberg et al, 1997).

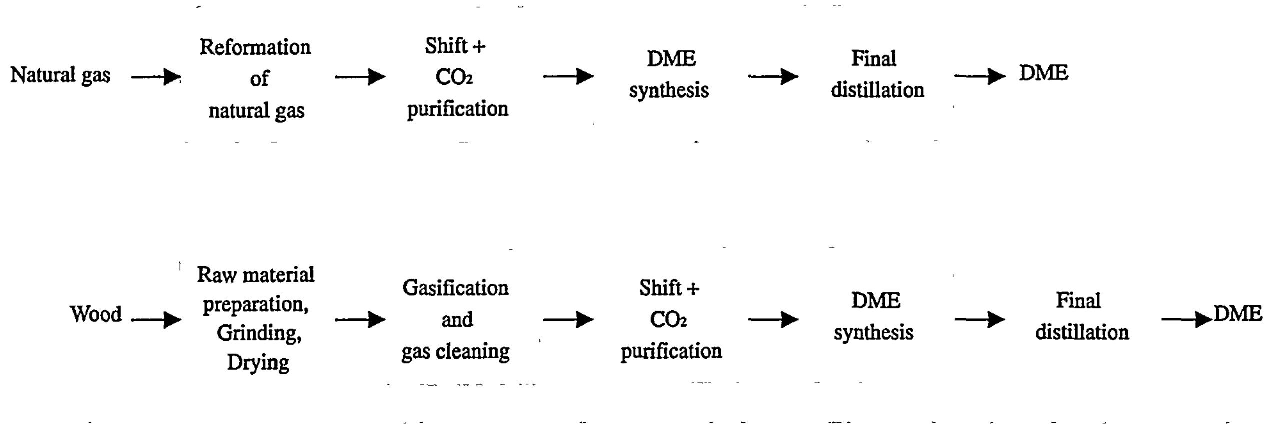


Figure 5.1. DME can be produced from natural gas or wood (Brandberg et al, 1997).

been studied in detail. However, if biomass is used as a raw material, the synthesis and processing stages are identical to those required for natural gas. A biomass-based DME installation would, however, become significantly more expensive owing to the need for a gasification stage together with the associated oxygen production and gas processing. An installation based on a solid raw material would be about twice as expensive to build as one based on natural gas, and would also involve significantly higher fixed operating overheads (i.e. more personnel and maintenance).

The production costs at a DME installation are dominated by the cost of raw material and capital. A rough comparison between natural gas-DME and bio-DME suggests that raw material and capital costs would both double, that operating and maintenance costs would be some 75 per cent higher, and that the efficiency would be some 10-15 per cent lower if a change-over was made from natural gas to biomass. According to estimates made for a possible DME plant in Växjö (Elam N, 1997), DME produced from biomass would be twice as expensive as DME produced from natural gas (**Table 5.2**). However, as the process technique and equipment have not yet been developed this type of estimate is rather uncertain.

As DME requires pressure vessels and an entirely new distribution system, the total financial aspects would be influenced quite significantly by higher distribution costs. According to Brandberg et al (1997) this would involve an additional cost equi-

SKr per tonne	**Natural gas à 5 öre/kWh**	**Biomass à 10 öre/kWh**
Raw materials	523	1,360
Capital	424	742
Operating costs	95	143
Total, SKr per tonne of methanol	**1,042**	**2,245**

Table 5.2. A rough comparison of the cost of producing DME from natural gas and from biomass (Elam N, 1997).

valent to some 40 öre per litre of DME as compared with diesel.

One of the reasons why Volvo and other engine manufacturers are interested in DME is the high performance and emission profile of the fuel. DME has a high cetane number (55-60 compared with 40-55 for diesel) which means short ignition times and for that reason cleaner combustion. In the USA, DME is used as an additive with methanol in order to reduce the ignition time. Unlike methanol, DME does not corrode metals and no special materials are required for the fuel system. However, certain plastics disintegrate after being exposed to DME for some time. It is therefore important that sealing materials are chosen with some care.

One condition upon which DME could become a sustainable alternative fuel are that the fuel is produced from biomass. As yet there are no such production facilities anywhere in the world and the development conditions for the fuel are currently rather uncertain. As far as Sweden is concerned, DME will therefore not become a viable alternative in the long term, if then.

Vegetable oils

Vegetable oils, mainly rapeseed methyl ester (RME) is another biobased fuel which has made a relatively strong impact in recent years. However, this fuel was not included in KFB's programme.

Vehicles fuels can be produced from a number of different vegetable oils, of which rapeseed oil is the one used in Sweden. The production process involves pressing the oil out of the plants and then refining it to purify it. The oil is then allowed to react with methanol to form RME. As the viscosity, density and cetane number of RME are broadly the same as that of diesel, RME can be used in diesel engines either in its pure form or blended into the diesel. In France, for example, a decision has been made to blend 5 per cent RME in all diesel fuels (see Chapter 8).

The current level of RME use and domestic production in Sweden is in the region of 10,000 m^3 per year. The current breakdown, of use in diesel-engined vehicles, is 1,000 m^3 RME blended into paraffin, 2,000 m^3 into 2 per cent low blends, and 7,000 m^3 in the form of 100 per cent pure RME. The rule in Sweden limiting blends to 2 per cent is due to the fact that a higher admixture in the grade of diesel used in Sweden (MK1) would produce an illegally high final boiling point (>285°C).

One advantage of RME is that it can be produced at relatively low cost, and the process can be carried out in small installations. Vegetable oils can be produced on the basis of a variety of different bio raw materials and then used as a fuel in diesel engines. In Sweden rapeseed oil is the vegetable oil that has been subject to most testing. These oils can be used in their crude form, but this gives them very poor fuel characteristics. They are therefore used instead as a base for the production of esters such as rapeseed methyl ester, RME.

Experiences from the use of RME are mixed. Among the positive points, naturally, is that RME is a renewable biobased fuel which reduces carbon dioxide emissions into air. However, it also has its drawbacks. Some tests show higher emissions of mainly nitrogen oxides. There are also problems with cold-starting of vehicles, the product is not stable with long storage, and so on.

A definite limitation as far as Sweden is concerned is that the country has a limited potential to cultivate vegetable oil plants. EU has stipulated that the maximum permissible Swedish oil plant acreage is 120,000 hectares, which corresponds to 250,000-300,000 tonnes of rapeseed, i.e., a nominal amount of 80,000-100,000 m^3 of rapeseed oil, or the same quantity of RME. In Sweden, the greater part of this is used in the food industry and only marginal volumes could become available for technical use.

As a fuel, therefore, RME is largely dependent on the EU's common agricultural policy. A general assessment within the EU is that 5-10 per cent of Sweden's agricultural land should be regarded as "set aside" with all the grants that involves, and available for production of RME equivalent to some 5,000-10,000 m^3 per year. More optimistic estimates indicate a potential of some 20,000 m^3 per year, while higher volumes could give rise to competition against use in the food industry.

A large-scale RME installation with an annual capacity of 20,000 m^3 would require investments of some 5-10 million kronor, while a small "farmyard plant" would only require a capital input of some 500,000 kronor.

Technically, it is possible to produce 70,000 m^3 of RME, the technique is simple and the necessary investments are not unreasonable. There are also a number of possible producers. In view of the RME cost structure, the limitations on production acreage, the market situation. and the associated financial considerations, it must, however, be acknowledged that serious difficulties would arise should volumes increase. Moreover, there will be competition over the use of rapeseed oil for alternative purposes. KFB, NUTEK, SIKA (1997) have therefore arrived at the view that a production volume of some 35,000 m^3 of RME, corresponding to approximately 1 per cent of the diesel fuel used, could be a reasonable potential for the future.

Conclusions

- The technique for producing DME from bio raw materials is in a very early stage of development and no installation has yet been built anywhere in the world. The economic conditions for such a plant would at present appear very doubtful. Biobased DME can therefore not become an alternative fuel on any significant scale, except in the longer term, and then only possibly.

- As far as RME is concerned the view is that its use as a fuel will in future be limited, very much due to the limited availability of raw materials, as well as competition for the use of rapeseed oil for various purposes. A consumption volume in Sweden, based on domestic production, in excess of 1 per cent of diesel fuel, does not appear likely.

Development of engines and vehicles

- *Engine development*
- *Development of catalysts and other cleaning systems*
- *Technique for light vehicles*
- *Technique for heavy vehicles*
- *Conclusions*

Chapter 6

DEVELOPMENT OF ENGINES AND VEHICLES

The force driving the development of new types of engines and vehicles is the increasingly rigorous demands being made with regard to health and the environment. New technologies can help us to reach more of our existing and future environmental goals. Some of these goals can be achieved by improving the efficiency and generally upgrading existing petrol-engined and diesel-engined vehicles, but the potential to satisfy stringent requirements on the basis of existing technology is very limited. New engines and vehicles based on biofuel, in the form of pure alcohols, biogas or as blended fuels therefore need to be developed and introduced on the market.

Engine development

There are two predominating types of combustion engine: the otto engine and the diesel engine. All vehicle manufacturers use these engines as their overwhelmingly predominant propulsion technique. Huge investments have therefore been made in these engine types, in terms of both capital and expertise, and the bulk of the development resources are invested in them. Such development work as has been carried out on the powering of engines with biofuel have also largely been concerned with how to adapt conventional otto and diesel engines for use of these new fuels. The problem associated with this approach is that the environmental potential provided by the use of cleaner fuels has not been fully exploited in these engines.

Otto engine

The otto engine has considerable potential to consume less fuel if it is optimised to run on alcohol. It is primarily the ability to raise its compression ratio that would improve the otto engine's efficiency. As diesel engines operate on a slightly different principle from otto engine, the potential for improvement with alcohols is not so much in their case.
It must, however, be emphasised that diesel engines are at present far more efficienct than otto engines specially at low loads. Even if the otto engine were optimised for ethanol, it would still not be as efficient as a diesel engine at low loads. **Figure 6.1** show how the efficiency of the two types of engine varies depending on the compression ratio.

One conclusion that can be drawn from figure 6.1 is that it is theoretically possible to improve the efficiency of an alcohol-optimised otto engine by 25 per cent. It should, however, be pointed out that this figure has been arrived at on theoretical grounds and that it should be seen as reflecting the potential of the fuel. Under practical operating conditions, which include an entire running cycle on both highways and in urban traffic, the difference would be less.

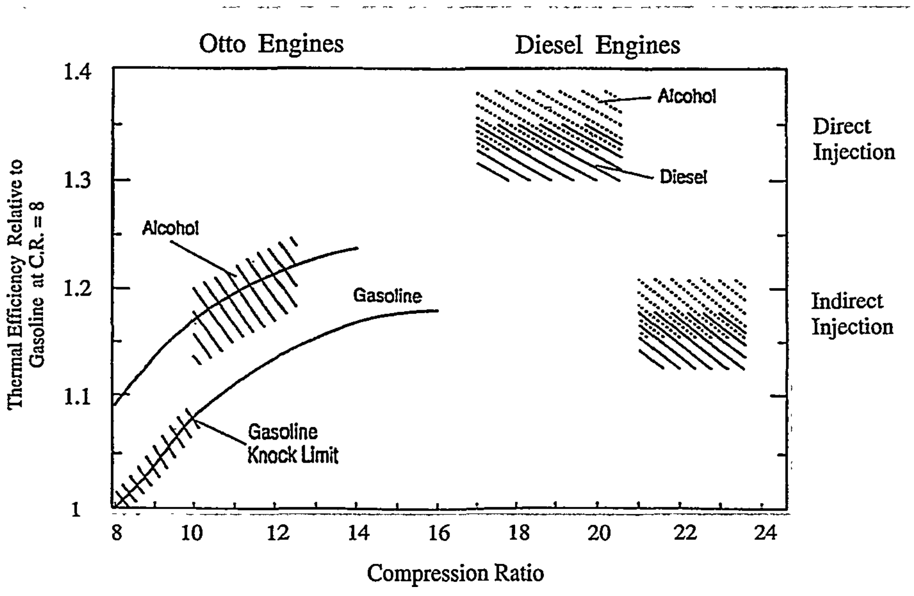


***Figure 6.1.** Efficiency as a function of compression ratio for an otto engine and a diesel engine with direct and indirect injection respectively (Olsson L-O, 1996).*

It is also possible to see from figure 6.1 that diesel engines with direct-injection have relatively higher efficiency. Diesel engines with indirect injection (with a swirl-air combustion chamber and precombuston chamber) have levels of efficiency which are comparable to an alcohol-driven otto engine. The figure also shows that the conversion of an otto engine from petrol to alcohol would produce greater efficiency gains than converting a diesel engine to run on alcohol instead of diesel fuel. One conclusion therefore is that no significant improvements in efficiency can be expected from blending ethanol with diesel fuel.

As far as the ability to improve the emission profile is concerned, there are, in the case of the otto engine, at present two basic problems to be solved, regardless of whether the engine runs on petrol or ethanol:

- fuel-air preparation
- the catalyst does not ignite directly when the engine is started

The problem with fuel-air preparation is most serious in connection with cold starting. More fuel than corresponds to the theoretical engine requirement has to be introduced to get the engine to start and run during the first minutes after it has started. This naturally causes a higher level of CO and hydrocarbon emissions when starting. One way of improving the fuel-air preparation would be to gasify the fuel prior to or during the preparation process.

Another serious problem is that the fuel-air mixture ends up in all the small cracks and crannies in the combustion chamber and so does not get combusted. The only method currently known for dealing with these problems is direct injection of the fuel into the cylinder.

As the otto engine normally causes high emissions, the catalyst must be particularly efficient if emission values are to be kept down. This problem is well known – the catalyst needs a minute or two to reach a sufficiently high temperature and ignite. As emissions are also very high during start up, the proportion of emissions at this phase is often more than 80 per cent of total emissions for an entire running cycle. Newly-developed catalysts have significantly improved performance characteristics than the normal three-way catalyst although some technical problems still remain to be solved. Above all, costs have to be lowered.

Alcohol-powered otto engines suffer for the most part from the same problems as a petrol driven ones and can also benefit from the technique being developed for these. This will lead to the relative advantages of alcohol over petrol in terms of emissions could actually increase in some cases.

With well-functioning fuel-air preparation alcohol-driven engines generally cause lower emissions of CO and hydrocarbons than petrol engines. This is due to the physical and chemical characteristics of the alcohols which lead to faster and more stable combustion than petrol. However, fuel-air preparation in connection with cold starting is more difficult with alcohol, mainly on account of the high gasification temperature and the higher initial boiling point. This can lead to higher CO emissions in connection with cold starting. By the same token, it also means that any improvements in fuel-air preparation will have a greater impact on alcohol engines than on petrol engines.

When it comes to NO_x emissions, these are generally lower with alcohol than with petrol, mainly on account of the lower combustion temperature. A reduction of some 30 per cent is normally the rule. Otto engines running on alcohol have a further advantageous effect, namely that the effects of EGR[1] are significantly greater than in the case of petrol. If this potential is utilised to the full, NO_x emissions can be lower than with petrol by a factor of 2-4. Judging from emission tests carried out on a number of FFV vehicles which were included in KFB's fleet trials (see Chapter 7) this potential to reduce NO_x emissions has not been utilised. As a result of the lower exhaust gas temperature with alcohols the catalyst could be mounted closer to the engine, which would lead to faster heating and further reductions in emissions.

Diesel engines

The alcohol engines for heavy vehicles are as a rule of the diesel engine type, the main reason being their high efficiency. Low fuel consumption is by tradition of great importance in the case of heavy vehicles.

High NO_x emissions are one of the most serious problems associated with diesel engines. When ethanol is used as a fuel these emissions are normally some 30 per cent lower than with diesel fuel. If advanced technology such as EGR is used, nitrogen oxide emissions can be reduced even further.

The other major environmental problem associated with diesel engines is the high particulates content. However, the diesel engine can also be improved in this respect by the use of ethanol due to the unique ability of alcohols generally not to form soot in connection with combustion.

As a fuel consisting of pure ethanol has a very low cetane number (measure of its ability to ignite) and is therefore most suitable for otto engines, additives need to be used to improve the ignition performance of diesel engines. The additive that was used during the early phases of KFB's biofuel programme – known as *Avocet* – was based on nitrated polyethylene glycol. This nitrate ester is an irritant, toxic and produces an acidic pH figure. Other nitrate esters that have been tested cause the same problems. This require separate lubrication of the engine, and they are corrosive and therefore create technical problems. Since the production of Avocet has been discontinued, the ethanol vehicle fleet in Sweden now runs on another additive, named *Beraid*. This additive is a pure polyethylene glycol and is not toxic.

However, even these more recent types of additive have also turned out in some cases to cause problems with deposits and other technical problems that have not yet been fully overcome. The overriding problem, however, is that the use of additives significantly raise the price of the fuel. As there appears to be little scope to produce ignition improvers at significantly lower cost, other alternatives will need to be developed. Successful trials have been made abroad with sparking plugs and glow-plugs in combination with alcohol engines of the diesel type.

Gas engines

Gas-driven vehicles are not new. There are more than one million such gas vehicles around the world running on natural gas. The engines that use natural gas and biogas are also otto engines. A major advantage of gas engines is precisely that the fuel is gaseous. This results in lower emissions as the fuel-air preparation is far better than in the case of petrol, for instance.

In the case of heavy vehicles, we are most concerned with converted diesel engines with lean combustion, known as lean-burn engines (**Figure 6.2**), although KFB's programme also includes a biogas bus (the MAN bus in Uppsala) that uses stochiometric[2] combustion. However, stochiometric fuel-air mixtures usually lead to higher fuel consumption, although no reliable assessments have been made of how large the difference is between the two types of engine. Generally, however it may be commented that an engine with stochiometric combustion and a

[1]) Exhaust Gas Recirculation EGR is a method that is widely used with otto engines, but that has not yet been used to anything like the same extent with diesel engines.

[2]) Stochiometric combustion involves the quantity of oxygen being entirely adapted to the quantity of fuel. Stochiometric combustion with a three-way catalyst is used in modern, petrol-engined vehicles.

three-way catalyst produces lower emissions than a lean-burn engine.

Methane gas has a relatively high octane number (130 for pure methane), which makes it possible to combine a high compression ratio with high efficiency. However, gas engines have a lower compression than diesel engines.

A gas engine that has been developed to use a given type of fuel can be adapted relatively easily to run on gas with other specifications. Other engine parameters can be altered with various types of regulation equipment. Consequently, it is not necessary to develop special engines for biogas as existing engines can be used for other gaseous fuels, such as natural gas. Modifying a natural gas engine to run on biogas is primarily a matter of adapting the flow of the fuel to the composition of the biogas. A reduction of 10 per cent in the methane content would cause a reduction of 0.5-2.0 per cent in the engine power. Often, however, this can be offset by increasing the charging pressure.

A comparison between gas-driven otto engines and diesel engines show that the gas engine has:

- lower efficiency, i.e., higher energy consumption (approximately 20%)
- often a lower torque at higher rpm
- higher torque at lower rpm
- lower peak engine power
- lower noise levels on account of the lower compression
- lower exhaust emissions

New engine technology

When it comes to engine concepts of the future it is difficult to foresee with any certainty which technique will be used. As a rule it is rarely a matter of one single measure that will be used, it is rather a combination of several measures. This means that the number of possible combinations could be quite large. This diversity of possible future propulsion techniques may be illustrated by means of an example.

A hybrid vehicle consists of an energy store (e.g. a battery or a inertia wheel), a combustion engine (e.g. otto, diesel, Stirling or gas turbine) and an electricity generator (e.g. DC, AC, reluctance generator). The engine in this hybrid vehicle can use a number of different fuels, such as ethanol, methanol, biogas, natural gas, DME, hydrogen). Each combination will produce different emissions and have different cost profiles.

A technique for which many people have great hopes is the fuel cell. Most of the development work is being done in the USA and Japan. So far, mainly vehicle concepts based on the storage of hydrogen in tanks on the vehicle have been presented. However, concepts have also been developed that are based on the vehicle filling a liquid fuel – petrol or engine alcohol – in the normal way. A vehicle of this type has a transformer – a reformer – which converts the liquid fuel into hydrogen which then powers a fuel cell (**Figure 6.3**). This method has many advantages by far the most important being the fact there is no need to build a new infrastructure for producing and distributing hydrogen.

Another promising new engine concept that has been tested in the USA is the Stirling engine. The

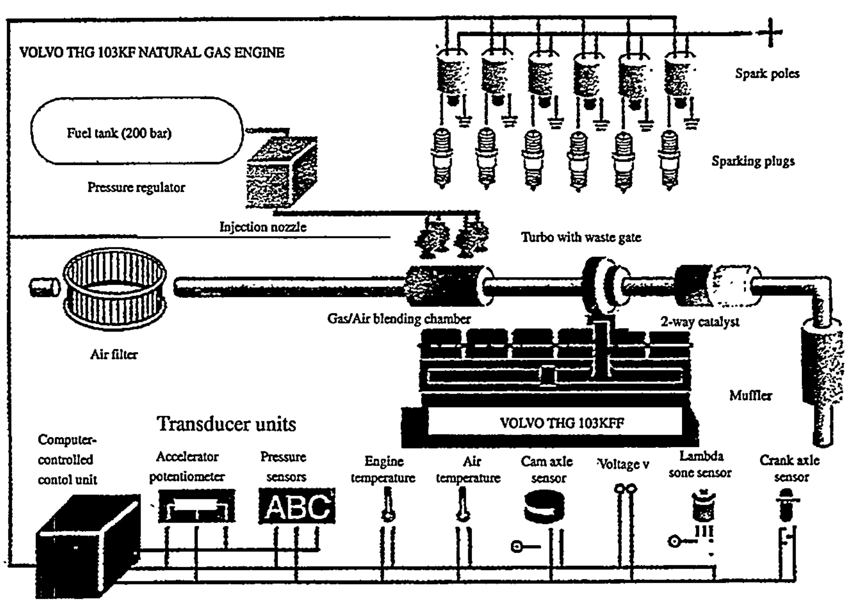


Figure 6.2 *Gas engine system, according to Volvo (Brolin et al, 1995).*

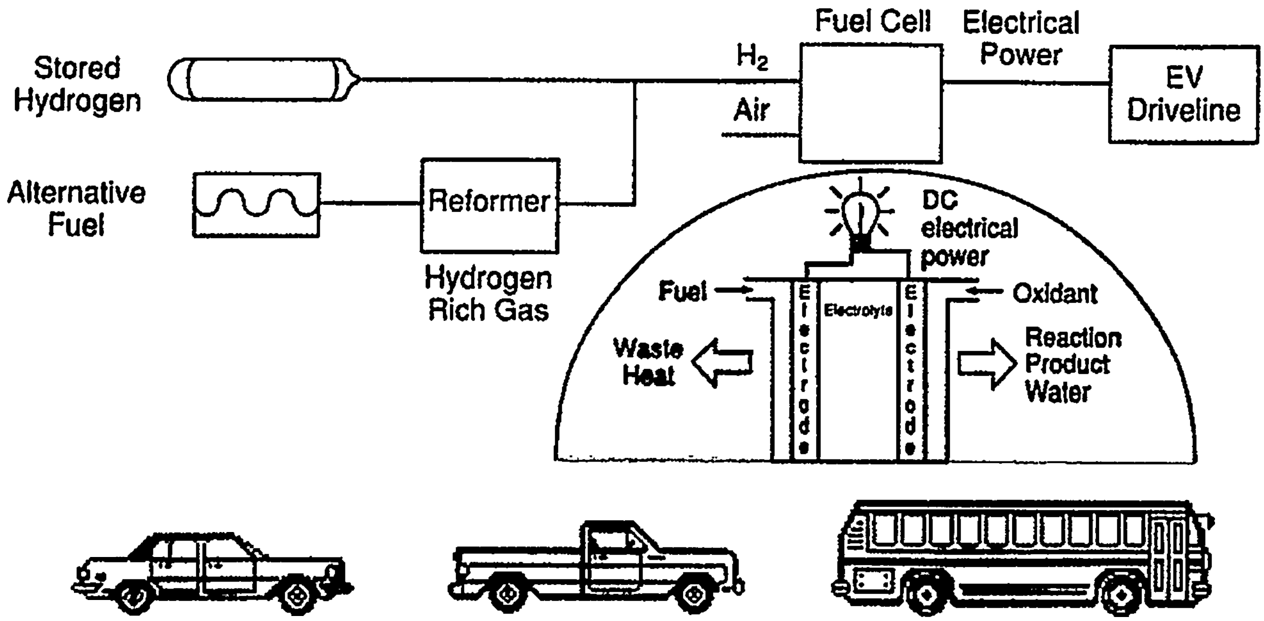


Figure 6.3. Vehicles with fuel cells can either be run on hydrogen, which is stored on the vehicle, ethanol or another fuel which is converted on the vehicle into hydrogen using a reformer. The hydrogen then powers the fuel cell, which generates electricity for the electric motor which drives the vehicle. Emissions from this type of vehicle are surplus heat and water (Bucksch, Månsson, 1996).

Stirling engine is able to run on a variety of different fuels and produces low emission levels. In early trials it was difficult for the Stirling engine to be competitive on account of the high production costs and difficulties in controlling its size and weight. However, this engine concept has been further developed and is now included in the American automotive industry's efforts to develop a range of alternative vehicle concepts.

An engine concept with more immediate potential involves developing a direct-injection otto engine. At best this could make it worthwhile in the longer term to use otto engines with direct injection for heavy vehicles.

Development of catalysts and other cleaning techniques

Technical developments are proceeding very rapidly at international level in the catalyst field, and further progress can be expected in the near future. Emissions of uncombusted fuel residues and contaminants which are formed during combustion in the engine can be reduced dramatically if an oxidising catalyst is used.

Of the contaminants formed in an ethanol engine, it is mainly emissions of aldehydes that need to be controlled. Unlike a diesel engine, which runs on diesel fuel which produces emissions containing sooty particles, it is technically much simpler to use the catalyst technique with ethanol-driven vehicles.

Extensive work has been carried out within KFB's biofuel programme on the development and customisation of exhaust catalysts for ethanol-driven heavy vehicles in city traffic. The lessons learned from the introductory activities are that it is relatively easy to limit formaldehyde emissions with the aid of catalysts, whereas acetaldehyde can be formed out of ethanol in the catalysts. Moreover, a catalyst with a powerful oxidising function may convert ethanol and acetaldehyde into acetic acid, which will lead to problems associated with the typical exhaust odour on the streets where the vehicles are used. A further problem with powerful oxidising catalysts is that a large proportion of the nitrogen oxides will be oxidised into nitrogen dioxide (NO_2) in the catalyst.

New catalyst concepts

Manufacturers of catalysts for heavy vehicles are currently concentrating largely on conventional fossil fuels, for the most part different grades of diesel, and the specific problems associated with these fuels. Some interest is also being devoted to catalysts for natural gas engines, the results of which can also be applied to biogas, whilst research into catalysts for ethanol-driven vehicles is more or less negligible. Within the framework of KFB's biofuel programme extensive development work has therefore been carried out at KTH with the object of developing new catalyst concepts based on the need for ethanol-related purification. This research has resulted in new types of catalyst being designed involving combinations of different precious metals (Pettersson L et al, 1997).

Measurements of emissions have been carried out at the Luleå University of Technology on diesel engines converted for ethanol running, with and without the various types of catalyst developed at KTH. Comparative studies of a powerful oxidising catalyst and a catalyst with a moderate oxidising function show that the powerful oxidising catalyst (catalyst 1) has the capability to limit emissions of hydrocarbons and carbon monoxide very effectively, whilst emissions of nitrogen dioxide are doubled (**Figure 6.4**). In the case of the catalyst with moderate oxidising effects (catalyst 2) the effect on emissions of hydrocarbons and carbon monoxide was consequently slightly less whilst, on the other hand, emissions of nitrogen dioxide did not increase.

Tests for aldehydes, ethanol and acetic acid showed that emissions of formaldehyde were only insignificantly higher in the case of catalyst 2 than catalyst 1, while the difference was wider in the case of emissions of acetaldehyde and, to some extent, of ethanol. On the other hand, more or less no detectable quantities of acetic acid were formed in catalyst 2, while the tests showed that this was definitely the case with catalyst 1.

Apart from the technical development work, introductory life cycle assessments have also been carried out, along with estimates of life cycle costs for the new types of catalyst developed at KTH, as well as ageing trials at Svensk Emissionsteknik.

EGR

Another purification method studied within KFB's programmes is the method for recirculating exhaust fumes known as EGR or Exhaust Gas Recirculation. This method appears capable of creating further environmental potential for biofuel.

EGR involves a small quantity of exhaust gas being recirculated into the combustion chamber together with new fuel and the replacement of surplus air in the fuel-air mixture by CO_2-rich exhaust gas. Carbon dioxide absorbs heat and lowers the temperature in combustion, which in turn reduces nitrogen oxide formation. One of the reasons is that EGR reduces the formation of nitrogen oxides (NO_X) by lowering the flame temperature when the fuel mixture is combusted in the engine. This effect has been used with petrol engines for a long time, whereas the application of EGR for conventional diesel engines has not made a breakthrough, mainly on account of the dramatic increase in the soot content associated with the use of EGR. In the case of ethanol-driven engines with compression ignition (converted diesel engines), however, soot is not formed in connection with combustion since ethanol does not contain sulphur and has a simple molecular structure. In design terms, it is therefore easier to use EGR with an ethanol engine with compression combustion than with a conventional diesel engine.

Trials carried out at the Luleå University of Technology (Tingvall et al, 1997) demonstrate that it is possible to reduce nitrogen oxide emissions from an ethanol-driven engine by means of EGR control. Measurements show a reduction in NO_X of between 60-70 per cent, measured as an average value during a test cycle. This can be achieved while retaining levels of hydrocarbon and CO emissions in combination with conventional cleaning systems (oxygen catalysts). The measurements show that the engine effect and fuel consumption are not affected to any significant extent in the EGR conditions used for the test (**Figure 6.5**).

A system for automatic EGR control has also been developed and tested at the Luleå University of Technology. The system consists of a structure of valves, coolers, automatic control equipments and the EGR system. The results of running engines with automatic EGR control show that it is possible to reduce NO_X emissions by almost 40 per cent with only a limited effect on hydrocarbons and CO.

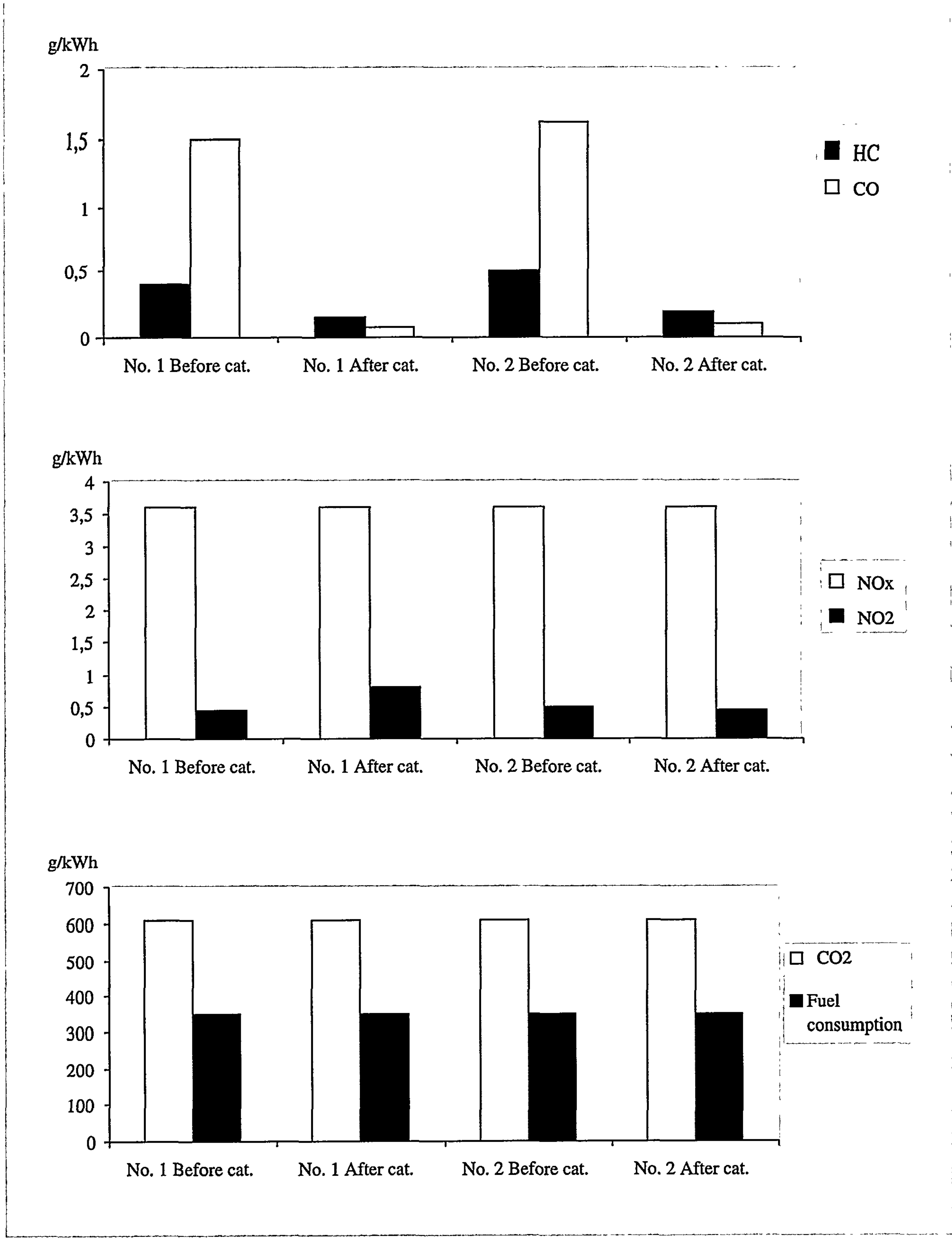


***Figure 6.4** Results of measurements of emissions from diesel engines converted to run on ethanol, with and without various catalysts. No. 1 catalyst is a powerful oxidising catalyst while No. 2 catalyst is a moderately oxidising one (Månsson T. 1995).*

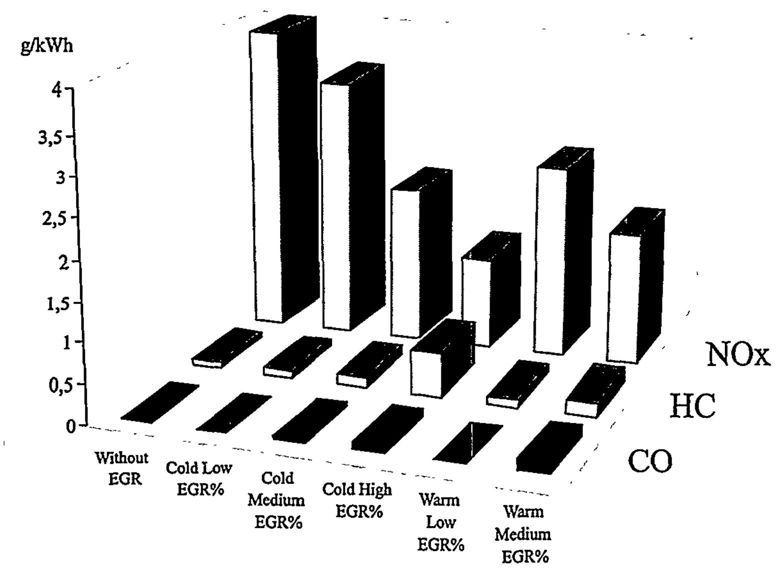


Figure 6.5. Measurements of emissions from ethanol-driven diesel engines with a range of EGR conditions. The figure shows the weighted total values for NO_x HC and CO from a 13-mode cycle for various EGR proportions and EGR temperatures (Tingvall et al, 1997).

Technique for light vehicles

Ethanol

The use of low blends of alcohols or ethers is a method which could be applied to introduce alcohols on a large scale quickly. Manufacturers of most passenger cars nowadays guarantee that their cars can run on an alcohol mixture of approximately 5 per cent without modification. Modern cars of today with catalysts can probably run on alcohol blends of up to 20 per cent, without any material or running problems, or unacceptable increases in NO_x emissions, arising. We know from Brazil, where all passenger cars run on blends of at least 22 per cent alcohol, that this is possible, although we have no documented experience from Swedish conditions.

A likely development of the fuel market, both in Sweden and abroad, is that we can expect a very long transitional period during which numerous different fuels will be available on the market. The traditional petrol market will also include a very extensive range of different grades and blends. In the USA, for example, there are already a thousand different grades of fuel. In the future, therefore, vehicle manufacturers must increasingly design their vehicles so that they can run on more than one fuel. This can be achieved in two ways, either by means of fuel flexibility, i.e. the vehicle has only one fuel tank and the engine adapts automatically to the type of fuel (FFV), or the vehicle has two fuel systems and the driver switches manually between them (dual fuel). There are already vehicles which are built according to one or the other of these principles.

Use of flexible fuel vehicles (FFV) would make it possible to gradually build up an infrastructure including filling stations in pace with the growth in vehicle fleet and without limiting the range of the vehicles. Drivers will find that driving an FFV is not unlike using an ordinary car. The FFV technique, which involves a fuel sensor and a powerful computer, can automatically adapt the car's fuel system to any blend between ethanol and petrol. At present, there is only one model of car of this type in series production anywhere in the world – the Ford Taurus FFV. However, most major manufacturers, including Volvo and Saab, have access to the technology and have been involved in trials of test cars in California (**Figure 6.6**).

The Swedish Ethanol Development Foundation, SSEU, has began to introduce FFV cars onto the Swedish market on a trial basis with support from KFB. Consequently, some 300 FFV cars are now running on the country's roads and filling stations for ethanol are under construction (see Chapter 7).

Thanks to their flexibility and relatively small number of problems, FFV cars are a natural component in an introduction strategy. Consequently, FFV cars may come to dominate the market for alcohol-driven light vehicles for some time to come. Even though the most modern engines now available generate low emissions some problems still remain to be solved, however. Emission levels in connection with cold starting are still high, and starting the engine at really low temperatures is not yet a problem-free exercise. Fuel-air preparation is in this respect far and a way the predominant problem. Although new solutions with considerable potential are available, they have not yet been finally developed. It would also be worthwhile to interest Swedish vehicle manufacturers of light vehicles to develop and launch FFVs on the market.

Facts about the car

Ford Taurus FFV Sedan GL. FFV technique. Certified environmental class 1 for use with petrol or ethanol. 85% recoverable. V6 engine 3.0-litre 154 bhp (146 bhp 100% petrol)

Automatic gearbox	Satisfies 1997 crash requirements in the USA
Double airbags	Electrically heated outdoor rear-view mirrors
Micro airfilter	Electrically heater driver's seat
Engine heater, comfort extractor	ABS brakes
Air condition	Electrically-powered driver's seat
3-year guarantee	Central locking system
Speed controller	Double electric mirrors
New car guarantee 1 yr/30,000 km	Electrically operated windows

The Ford Taurus FFV is the first passenger car to be approved as a GOOD CHOICE FOR THE ENVIRONMENT by the Swedish Society for the Conservation of Nature.

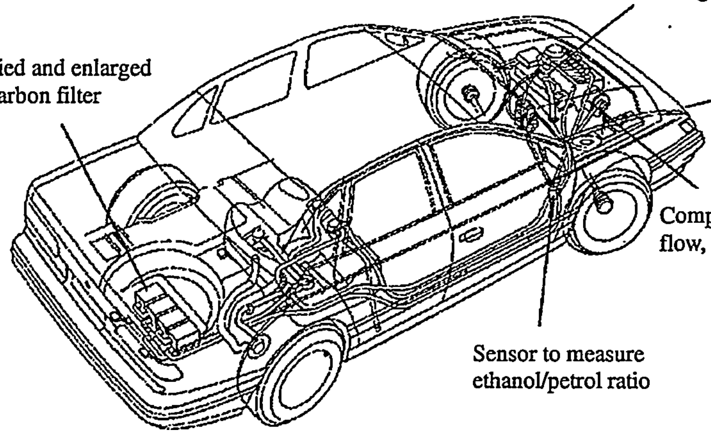


***Figure 6.6** The Ford Taurus FFV can run on petrol as well as on ethanol.*

As far as fuel flexible vehicles are concerned the situation today is such that the tendency is to optimise the engine for the poorest fuel, which means that the potential an alcohol fuel offers in otto engines is not utilised to the full. To take full advantage of the environmental potential of an alcohol fuel what is needed, therefore, is an engine that is optimised for a specific fuel.

Figure 6.7 shows possible changes in fuel consumption in the future that would result from harnessing the potential that modern conventional engine technology and the further potential provided by the use of a purer biofuel offer.

In recent years another promising line of development has emerged, namely the direct-injection otto engine. This type of engine, often known as GDI (Gasoline Direct Injection), is at present only available commercially for use with petrol, but it can probably be modified fairly simply to run of alcohol. The great advantage it has over the conventional petrol engine is the dramatic reduction in fuel consumption (specially at low loads, i.e. in city traffic). However, there are at present some problems associated with emissions, mainly of NO_x and hydrocarbons, with the further possibility of some particulate emissions. A direct-injection alcohol en-

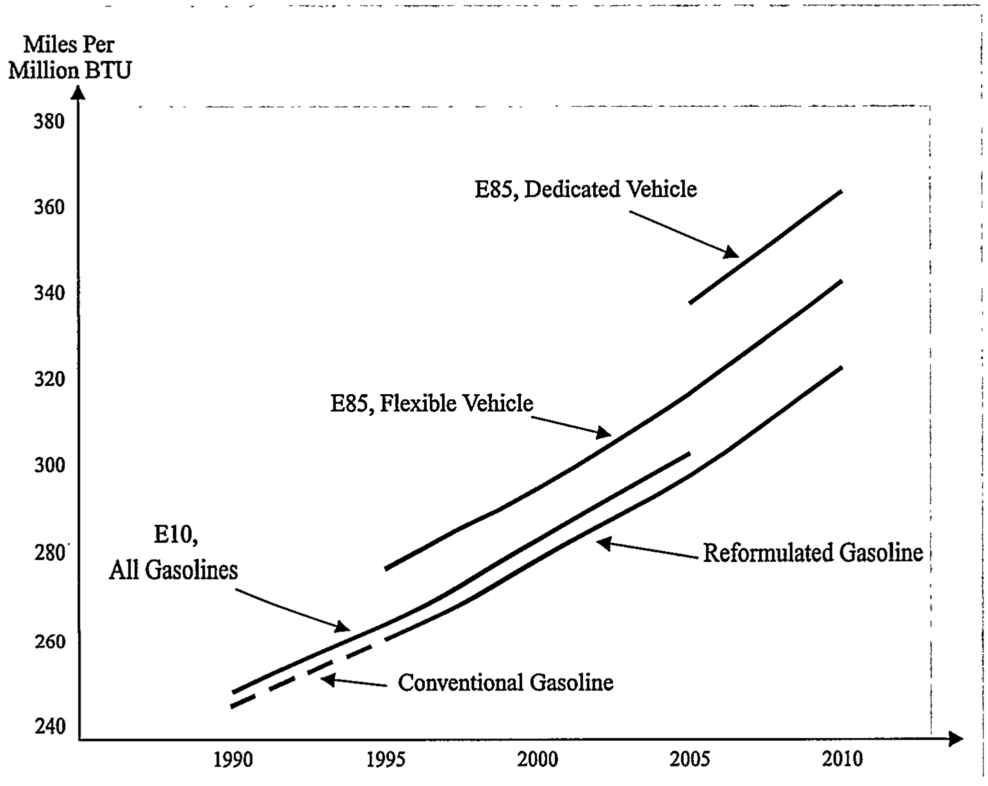


Figure 6.7 The difference between fuel consumption per equivalent energy unit for conventional petrol-engined vehicles, FFV and vehicle optimised to run on ethanol. By E10 is meant a fuel blend with 10 per cent ethanol in petrol and by E85 is meant all ethanol fuels with 85 per cent ethanol (the rest is water and denaturing agent) (Olsson L-O. 1996).

gine (by analogy the ADI) would offer several advantages over the corresponding petrol-engine model. For example, NO_x emissions could be reduced by half, while the formation of soot is broadly eliminated. NO_x emissions are low, provided that a catalyst for ethanol can be developed that produce the same reduction in NO_x as the GDI engine. The direct injection of the fuel would probably dramatically reduce or eliminate the problem of emissions in connection with cold starting as well as the difficulty in starting the engine. However, the ADI engine might have some problems in terms of fuel flexibility (if FFV is required) on account of the intricate conditions prevailing during the injection sequence and where a compromise between two fuels inevitably involves a poorer solution than two systems, each of which is optimised for one fuel. For both the conventional otto engine and the ADI model there is still nevertheless ample scope to achieve considerable environmental improvements by further developing EGR.

A further possibility for using alcohol in light vehicles, as with heavy vehicles, is to use the diesel engine principle. This approach has the greatest potential in terms of low fuel consumption, but it would be hard to develop as a FFV model. Nor are the problems associated with emissions as easy to overcome as with a conventional otto engine, but the problems to be tackled are not unlike those with the ADI model. Another problem is the high cylinder pressure, which would make it necessary to start from a basic engine that has been developed to run on diesel fuel.

In view of the above advantages and disadvantages of the respective combustion systems, the top priority for the short and medium terms (5-15 years) should be the further development of the conventional otto engine and an ADI version of this. In the longer term, a diesel version might also be of interest but in view of the difficulty developing an FFV model of this would involve, this perhaps would not arise until the infrastructure had been put in place.

Biogas

At present, the use of biogas with light vehicles, is exclusively in connection with vehicles with otto engines, supplemented with some control equipment and a gas tank. This provides flexibility with regard to the fuel, i.e. it is possible to use either petrol or biogas.

A significant advantage compared with petrol is the reduction in emissions on cold starting. In theory, the use of lean-burn engines, which have certain advantages if biogas is the fuel rather than petrol, is quite conceivable, but in practice broadly the same difficulties arise in both cases. Before a well functioning catalyst for NO_X reduction of surplus air becomes available the interest in gas-driven, lean-burn engines in light vehicles will probably remain at the theoretical level. Theoretically, there is also the possibility of using direct-injection of gas in accordance with the principles described above for petrol and alcohol . The problems associated with finding an effective catalyst are, however, more serious than in the case of the other fuels.

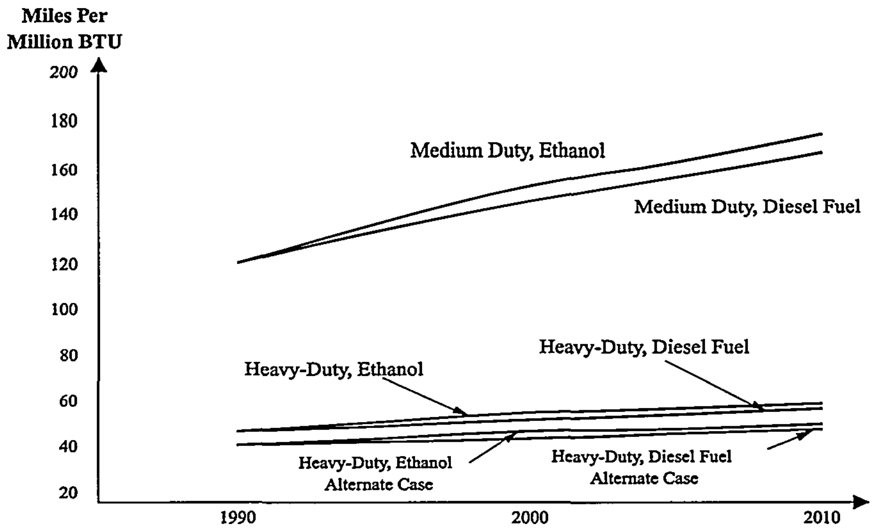


Figure 6.8. Difference in fuel consumption per equivalent energy unit for different types of heavy vehicle running on diesel engine principle (Olsson L-O. 1996).

The gas-driven otto engine with a three-way catalyst (TWC) could make use of many of the components and systems that are currently under development for petrol engines. These systems, which, however, require further development, are injection systems for gas, and control systems. Certain problems pertaining to durability, and difficulties in connection with methane reduction also exist here, but these are less than in the case of engines for heavy vehicles.

Engine concept	CO g/km	HC g/km	NO_x g/km	Formaldehyde mg/km	Acetaldehyde mg/km
Generation 1 (Scania DS 1125 with cat.). 1984-86	0.90	1.51	17.11	59	190
Generation 2 (Scania DSI 11E) 1986-88	0.14	0.12	10.06	11	58
Generation 3A[1] (Scania DSI 11E) 1991-93	0.40	0.19	6.73	10	82
Generation 3B[2] lab.test 1994-95	0.26	0.45	6.09	8	153

[1] This bus has a strongly oxidising catalyst which produces acetic acid.
[2] This bus has a less strongly oxidising catalyst which produces less acetic acid.

Table 6.1. Emission figures for bus engines of various generations (Månsson T. 1995).

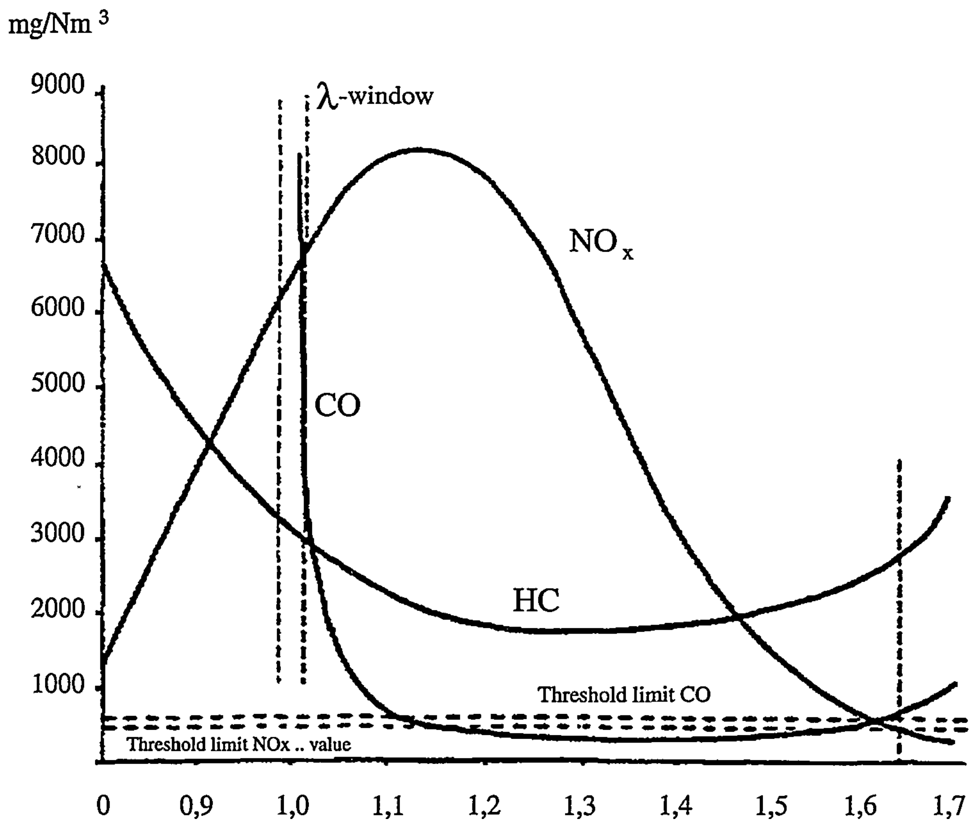


Figure 6.9. *Formation of NO_x, CO and HC during combustion of biogas in an otto engine at different lambda values (λ) – a value which indicates the mixture of air and fuel in the combustion process. The lambda window is the range in which the mixture of air and fuel has to be maintained in order for a three-way catalyst to produce the best possible emission values. The lambda value for a petrol engine is approximately 1 while in the case of a biogas engine it is 1.6 (Brolin L. et al, 1995).*

Technique for heavy vehicles

Ethanol

Alcohol engines for heavy vehicles are at present without exception of the diesel type, i.e., thermodynamically the cycle is of the same type as in a diesel engine that uses diesel except the fuel is alcohol. As the diesel engine operates on a slightly different principle from the otto engine alcohols do not have the same potential to generate improvements in diesel engines as they do with the otto engine.

It must, however, be emphasised that under existing conditions the diesel engine is considerably more efficient than the otto engine, particularly when running at low loads (**Figure 6.8**). Even if the otto engine is optimised to use ethanol, its efficiency will not match that of a diesel engine running at low loads. Nor can any significant improvement in efficiency be expected if ethanol is mixed with the diesel fuel.

In Sweden, the work on the development of ethanol vehicles has largely been focused on heavy vehicles, mainly buses, and Sweden and the Swedish automotive industry are world leaders in this area. Initially diesel engines which had been converted to run on ethanol were used. As the development work progressed, new generations of engine were developed which has resulted in the gradual emergence of increasingly environmentally friendly vehicles (**Table 6.1**).

Biogas

The technique involved when biogas is used as a fuel for buses and trucks is in all essential the same as for natural gas. The type of engine in question is a further development of a spart ignition engine. The engines being used are converted diesel engines which are operated using the lean-burn technique (**Figure 6.2**). The lean-burn technique involves the use of a fuel-air mixture that is very lean, i.e., it contains a very small quantity of fuel in relation to the quantity of air. This requires precise control of the flow of fuel into the engine.

Combustion takes place at low temperatures, which produces relatively small quantities of NO_X, CO and hydrocarbons. An oxidising catalyst is normally used to further reduce the quantities of CO and hydrocarbons. In the case of biogas operating, the hydrocarbon emissions consist for the most part of methane. Lean-burn has a slightly higher efficiency than stochiometric combustion but a lower effect. In order to compensate for this lean-burn engines are often complemented with a turbo charger. **Figure 6.9** shows emissions as a function of the lambda value – a value which indicates the relative proportions of air and fuel during combustion. In a petrol engine the lambda value is approximately 1 and in the case of biogas combustion in a lean-burn engine the lambda value is 1.6. A lambda value of 1.6 means there is 60 per cent more air than the quantity required for combustion of the fuel.

Both lean-burn and stochiometric combustion can be complemented with EGR. EGR reduces NO_X formation and can also improve engine efficiency.

Conclusions

- Techniques are currently available for using ethanol or biogas as a fuel in both light and heavy vehicles. In order to obtain a technically and environmentally sound product, however, these vehicles would need to be optimised to realise the full environmental potential of the ethanol and biogas. This requires further development work on engines and catalysts.

- A central area for engine development is the optimisation of ethanol engines for heavy vehicles which do not require the addition of ignition improvers to the fuel. Various types of such engines could be based on systems involving sparking plugs, glowplugs or the like.

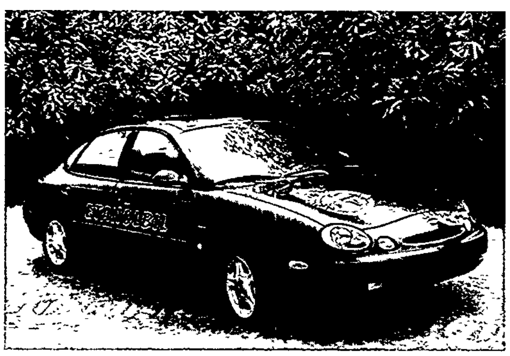
- Trials with EGR (Exhaust Gas Recirculation) on ethanol engines of the diesel type have demonstrated considerable potential to achieve low emission values. This method needs to be demonstrated in practical application before it can be gradually introduced on a large scale.

- Development work on various types of catalysts has demonstrated significant environmental potential. This work needs to be continued with a focus on demonstrations and market introduction.

- In the long term other promising methods might become available, such as fuel cells, which when mounted on a vehicle can convert a liquid fuel (e.g. ethanol, methanol, petrol) into hydrogen, which produces clean exhaust fumes.

Demonstrations and fleet trials – experience of operation

- *Ethanol buses*
- *Ethanol trucks SVENOL*
- *FFV*
- *Fuel blends*
- *Biogas*
- *Conclusions*



Chapter 7

DEMONSTRATIONS AND FLEET TRIALS – EXPERIENCE OF OPERATION

KFB's programme included the testing of new equipment and methods in practical operation as well as carrying out measuremnets and follow-up activities of various types.

As the environmental potential is believed to be greatest for buses and trucks, KFB's programme focused on these types of vehicles. The programme included field trials covering more than a hundred buses, a hundred or so cars (mainly FFV) and around fifty trucks which were driven more than 10 million kilometres. A hundred extensive tests on a selection of these vehicles were carried out within the programme.

Ethanol buses

Örnsköldsvik

Trials on the use of ethanol buses have been carried out in Örnsköldsvik since 1985. One of the results of this early start is that the two first test buses have now covered more miles on alcohol fuel (approximately 625,000 kilometres per bus) than any other buses in the world, and they are now approaching the end of the normal service life for diesel-engined buses.

Since it started 12 years ago, the ethanol bus project in Örnsköldsvik has been through a number of different phases in which different generations of ethanol engines and fuel blends have been tested. Initially the trails related to Scania's "Brazil technique", i.e. engines with normal or only slightly elevated compression ratios, and using the then available additives to raise the cetane number. Later, after certain problems emerged, including pumping problems, this additive was replaced by different ones without nitrates, the compression ratios of the engine's were increased to help minimise the use of

	Year		Fuel blend (volume %)
Phase I	1993-95	90%	Ethanol (azeotropic blend, i.e. with 5% water by volume)
		7%	Ignition improver (Beraid from Akzo Nobel)
		3%	Denaturising agent
		250 ppm	Corrosion inhibitor
Phase II	1995-96	85,5%	Ethanol (azeotropic)
		7%	Beraid
		3%	Denaturising agent
		4,5%	Water (deionised, "extra")
		250 ppm	Corrosion inhibitor
		5 ppm	Red colorant
Phase III	1996-97	88%	Ethanol (azeotropic)
		5%	Beraid 3540
		3%	Denaturising agent
		4%	Water (deionised, "extra")
		250 ppm	Corrosion inhibitor
		5 ppm	Red colorant

Table 7.1. *Fuel blend (volume %) for ethanol fuel used during the three phases of the Western Norrland project (Larsson E, 1997).*

additives, new and more advanced catalysts were developed and introduced, etc. This has resulted in some technical benefits at the cost of a slightly more expensive fuel.

The "Western Norrland" project which was carried out with funding from KFB, has enabled those trials that had already began in 1985 to continue and be developed to include a new content. The project, which was administered by Örnsköldsvik Buss AB, was carried out in three stages during the 1993-1997 period.

In all, the company's bus fleet included nine ethanol buses. All of them were manufactured by Scania of which two had converted ethanol engines, and two had new ethanol engines which replaced those in buses delivered earlier. There were also five new ethanol buses.

Scania's new ethanol buses have a high engine compression ratio (24:1), turbo charging and input air cooling. The engine power is 191 kW at 2,000 rpm. The buses were also fitted with newly-developed oxidising catalysts. The fuel used was 90 per cent ethanol in phase I and ethanol with an extra addition of 5 per cent water in phase II. During phase III a new fuel blend has been tested with a newly-developed type of Beraid as the ignition-improver (**Table 7.1**).

The buses have been running in regular traffic in Örnsköldsvik and in this respect were on the road as much as diesel-engined buses, and their reliability was the same. The overall distance covered in the project was some 1,200,000 kilometres and the average fuel consumption was 0.76 litres of ethanol per kilometre.

Measurements and tests of exhaust gas emissions from ethanol buses were made regularly throughout the entire period of the trial (**Table 7.2**).

Project phase	Year	CO g/kWh	HC g/kWh	NOx g/kWh	Particles g/kWh
Phase I	1993-95	0.01	0.05	4.8	0.2
Phase II	1995-96	0.06	0.10	4.1	0.2
Phase III	1996-97	0.01	0.065	4.02	0.17

Table 7.2. Average value from emission tests on ethanol buses fitted with catalysts in Örnsköldsvik 1993-1997. Trials carried out in accordance with ECE R49 (Larsson E, 1997).

Stockholm

The largest fleet trial took place within the SL (Stockholm Metropolitan Traffic Company) project that was started in 1990 and which involved 32 ethanol buses in Stockholm. The project was completed and reported in 1993 (Rydén C, 1994). This project demonstrated that the use of ethanol in modified engines can markedly improve emission values. The environmental targets agreed at the time can be regarded as having been reached. The reliability of the buses and infrastructure (filling stations) turned out to be very good. One problem identified during these early trials of ethanol buses was that of odours. Measures to deal with this were begun during the first phase.

After the fleet trial was completed in June 1993, SL has gone ahead with its plans to increase the number of ethanol buses, despite their higher costs. In total SL now has some 200 ethanol buses in operation in Stockholm and the company's aim is that all inner city buses should be running on ethanol by 2000.

In a follow-up of the operating results for SL's fleet of buses between 1994 and 1997 (Rydén C, 1996) it was noted that the ethanol buses were available just as much as the equivalent diesel-engined buses. However, one problem was reported, namely, that of deposits on filters, injection pumps and on fuel injectors. The problem is probably due to a combination of reactions between ethanol, ignition-improver (Beraid) and engine oil. The problem can be solved by more frequent servicing, but this could result in higher operating costs. These questions

Regulated emissions	"1994" Diesel (g/kWh)	Initial goal (g/kWh)	Measured result (g/kWh)	Long-term goal (g/kWh)
Nitrogen oxides NOx	9.0	4.5	3.8	1-2
Monoxide CO	5.0	0.1	0.05	0.05
Hydro carbons HC	1.2	0.2	0.16	0.1
Particles (soot)	0.4	0.05	-	-

Table 7.3. Result of emission measurements on 32 ethanol buses in Stockholm (average value) (Rydén C, 1995)

were therefore examined in a comparative analysis of bus fleets around the country (Rydén C, 1997). The study shows that none of the ignition-improvers so far used (AVOCET, BERAID 3525 and BERAID 3540), which have been in use over the past seven years, will be acceptable in the long term. Nitrate esters and polyethylene glycol both have distinct shortcomings since they give rise to problems with formation of deposits when mixed with engine oil.

One operating problem that was identified with the first fleet of buses was the distinctive vinegary odour produced by ethanol buses. One of the reasons for this was leaking fuel injectors. The leaking fuel is not combusted but passes through the engine in uncombusted form along with the gases. In the catalyst this fuel then reacts with the reactive surface on the catalyst (ethanol and acetaldehyde are oxidised) and it is this that causes the characteristic odour of vinegar. In order to deal with this the distributor nozzles were changed at shorter intervals. Another measure is to change to a different type of catalyst.

In view of these problems with odours, an extensive development project was started with the support of KFB to develop new types of catalysts.
A new generation of catalysts is now available on the market and is used in the second wave of ethanol buses after the first batch of 32, that are now in operation in Stockholm. With the old buses, whose catalysts were not replaced, the problems associated with the vinegary smell still remain. It would also appear as if the problem of smell is a matter of attitude – people become familiar with and accept new smells once they know they are harmless.

The ethanol buses in Stockholm have undergone regular emission testing. The results show that they were significantly below the relevant statutory requirements (**Table 7.3**).

Skaraborg

A project involving ethanol-driven buses was begun in the County of Skaraborg in 1993 in order to test the potential for designing an environmentally-friendly public transport system in rural areas. This project, which was carried out with the support of KFB, involved continuous evaluation and collection of data. The purpose of the project was to achieve:

- an *environmental target*: the ethanol-engined vehicles should generate lower emissions than the best available diesel-engined vehicles
- a *reliability target:* the ethanol-engined vehicles should be available for service just as much as the existing diesel vehicles

Emissions g/kWh	**Standard diesel bus**	**Best diesel (Euro II)**	**Best diesel + catalyst**	**Ethanol project Skaraborg**
Particles (soot+sulphur)	0.7	0.15	0.05	0.04
Nitrogen oxides (NOx)	14.0	7.0	6.3	3.93
Carbon monoxide (CO)	5.0	4.0	0.1	0.13
Hydrocarbons (HC)	1.5	1.1	0.1	0.09
Carbon dioxide (CO_2) which contributes to the greenhouse effect	Yes	Yes	Yes	No

Table 7.4. Result of emission tests on buses in the Skaraborg project (Berg R, 1997).

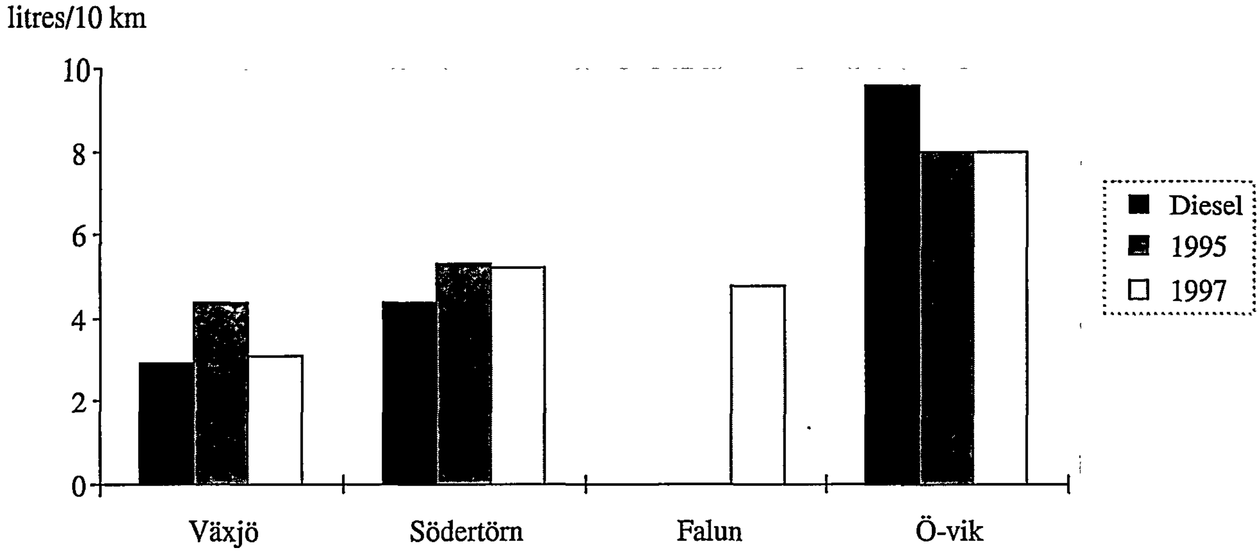


Figure 7.1. Comparison between ethanol and diesel consumption of trucks in Svenol project (Ekelund M, 1997)

- a *cost target*: by the end of the test period the cost of owning and running ethanol buses should be comparable to the cost for diesel-engined vehicles, account being taken of the economic effects which can be estimated due to the reduction in emissions of hazardous substances.

The Skaraborg project involved a fleet of 15 buses, of which 10 were a series of older buses that had been converted, and five were newly-acquired Scania buses with third generation ethanol engines. Experiences with the converted vehicles were very good.

The vehicles' engines were replaced and the existing fuel systems (tanks and pipes) were cleaned with ethanol. After the converted buses were recommissioned they were driven approximately 2,000 kilometres, after which the fuel system filter was replaced in order to prevent deposits and breakdowns.

The costs of converting the buses at the start of the project was around 100,000 kronor per bus, or the same order of size as the additional cost of a new ethanol bus. However, these costs would now be much lower.

Between 1993 and 1996, the buses covered a total of some 2,550,000 kilometres, during which information was regularly collected on fuel consumption, operating and maintenance costs, etc. Numerous checks and tests were carried out on the buses. More detailed emission tests were carried out on four of the 15 buses in the project at the Motor Test Centre (MTC) in Jordbro. The results of these tests are presented in **Table 7.4.**

To sum up, it was noted in the final report on the project (Berg R, 1997) that the technique involved in the use of ethanol as a fuel for bus engines functions on a large scale. Ethanol buses are available for service just as much as diesel-engined buses.

Emission tests show that the environmental targets were achieved, i.e. emissions of oxides of nitrogen, carbon dioxide and solid particles from ethanol buses are lower than from diesel buses. However, the direct costs of introducing them into service is higher if the conventional diesel technique is used. However, there are further benefits in the form of an improved urban environment which have to be considered when the profitability of the project is being assessed.

Ethanol trucks – SVENOL

As a result of a joint development project involving Chalmers University of Technology, Volvo and KFB, trials were begun in 1995 on four ethanol-engined trucks. The project was named Svenol I, and included four trucks manufactured by Volvo with 7-litre ethanol engines. Two of the trucks were intended for delivery purposes and the other two were refuse trucks. At a later stage, Svenol II, three more vehicles were introduced into the test.

The engines used in the vehicles in the Svenol project were Volvo's conventional diesel engines which had been modified in some respects to run on ethanol. The trucks in the two phases of the project were also different. The lessons learned from the practical running of the first four trucks were put to use when the second generation of trucks was developed for stage II.

Bilspedition, Södertörns Refuse Company (SRV) and the Municipalities of Örnsköldsvik and Falun tested the vehicles under practical operating conditions for three years and one year respectively. During the period of the trials, logs were kept and certain special tests were carried out, as well as emission tests. The vehicles were observed to have two characteristics, firstly problems associated with deposits on the fuel filter, and some problems in connection with cold starting in the winter. However, the drivers otherwise found the vehicles to be "more lively" than diesel-engined trucks. The problems noted did not, however, cause any breakdowns or keep the vehicles off the road.

During the project, the fuel consumption noted was slightly higher than expected. This was due partly to problems with the ignition-improver but also to the engines not being optimised for ethanol running. However, there were also wide variations between the different vehicles which can to some extent be explained by the different operating conditions (**Figure 7.1**). Volvo has a further explanation, namely, that the engines were optimised for low emissions rather than low fuel consumption. With a corresponding engine running on diesel, emissions of some 7 g NO_x/kWh were emitted, whilst ethanol trucks showed half that level of NO_x emissions (approximately 3.5 g NO_x/kWh) in emission tests in MTC.

To sum up, it was noted in the final project report (Ekelund M, 1997) that the trucks functioned very satisfactorily. All in all the seven trucks covered some 200,000 kilometres without any serious breakdowns and with the same availability as diesel trucks. The drivers and others involved were satisfied with the vehicles. With regard to the further development of the engines and vehicles, further engine and noise optimisation are recommended in order to improve efficiency, improve starting characteristics and to replace the lining of the fuel-line components so that the fuel filter does not get blocked by deposits.

FFV

The purpose of the KFB-funded FFV project that has been carried out by the Swedish Ethanol Development Foundation (SSEU) was to demon-

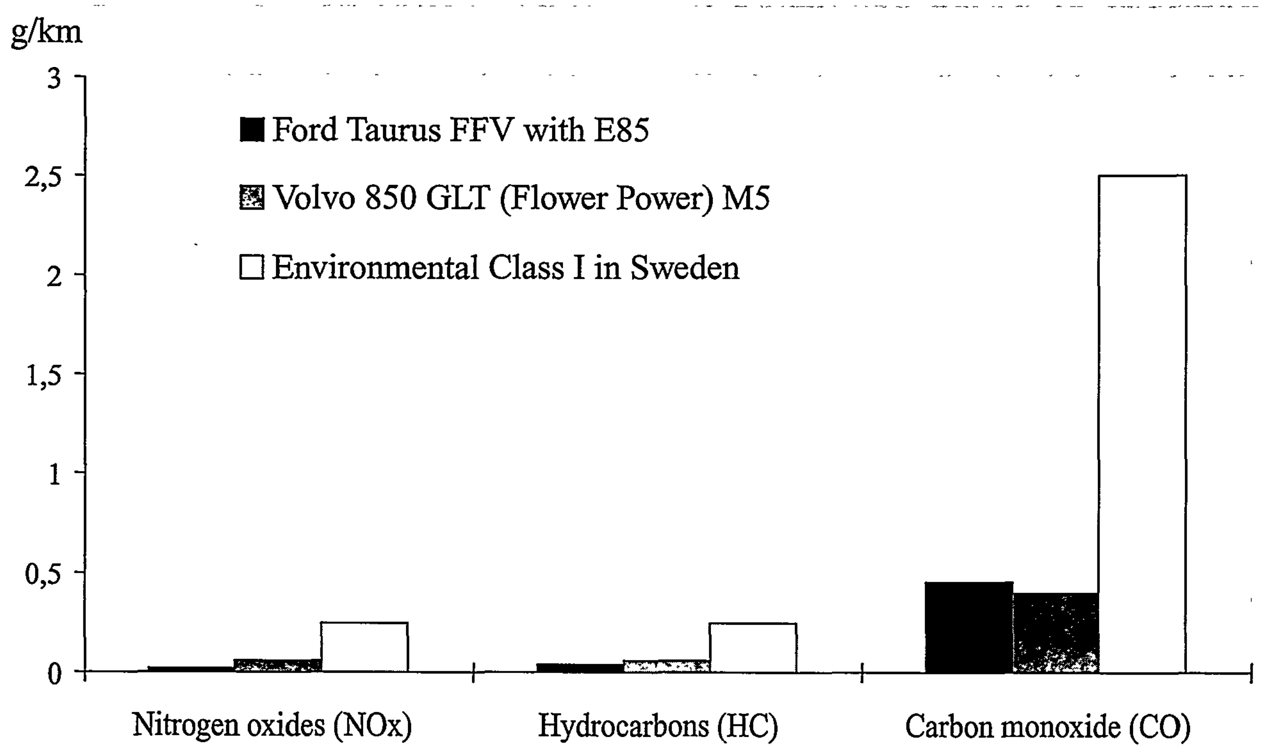


Figure 7.2. Comparison of exhaust emissions from Ford Taurus FFV and Volvo 850 GLT (Berg R, Rydén C, 1997).

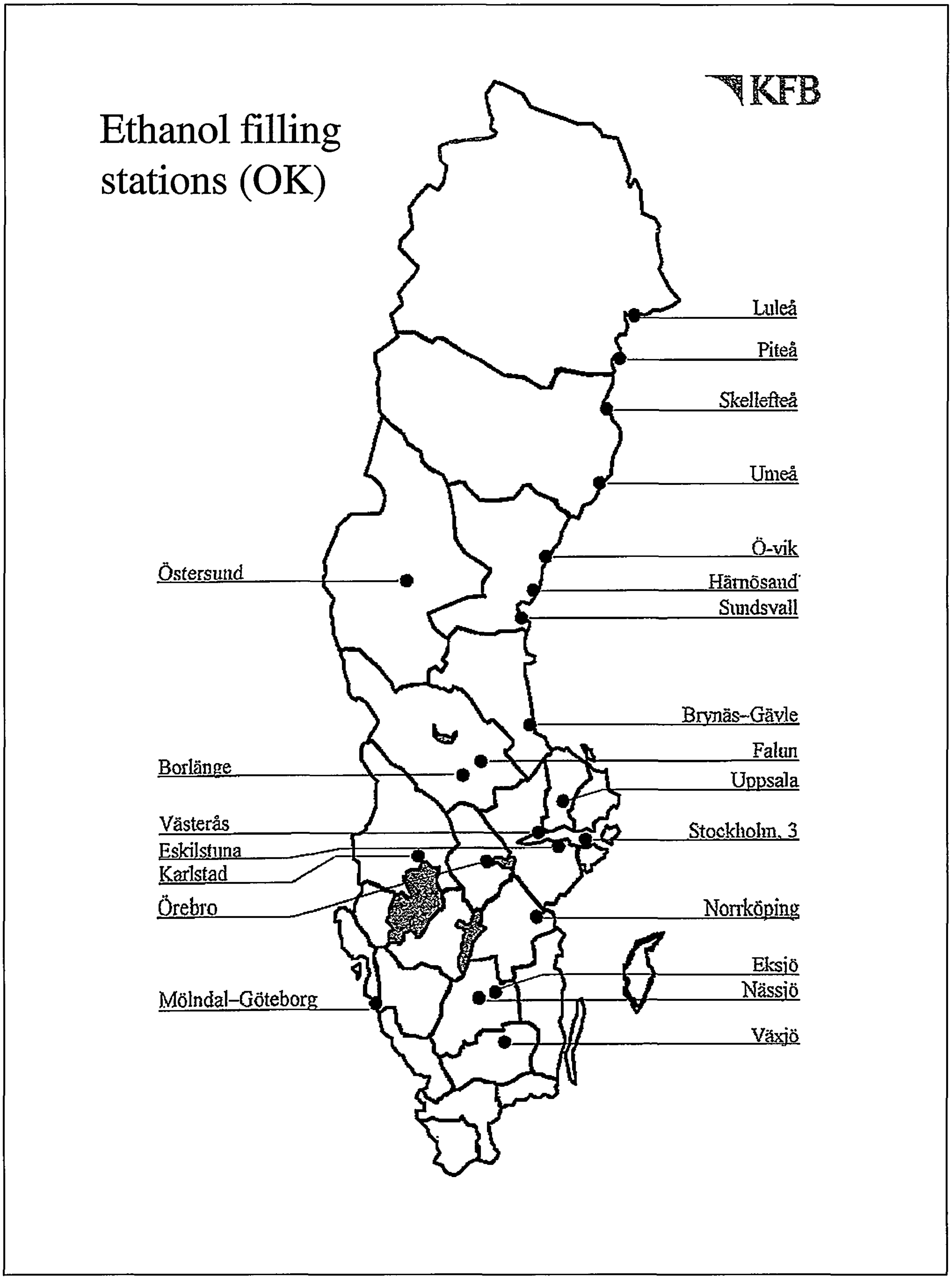


Figure 7.3. Cities with FFV and filling stations (E85), (december 1997).

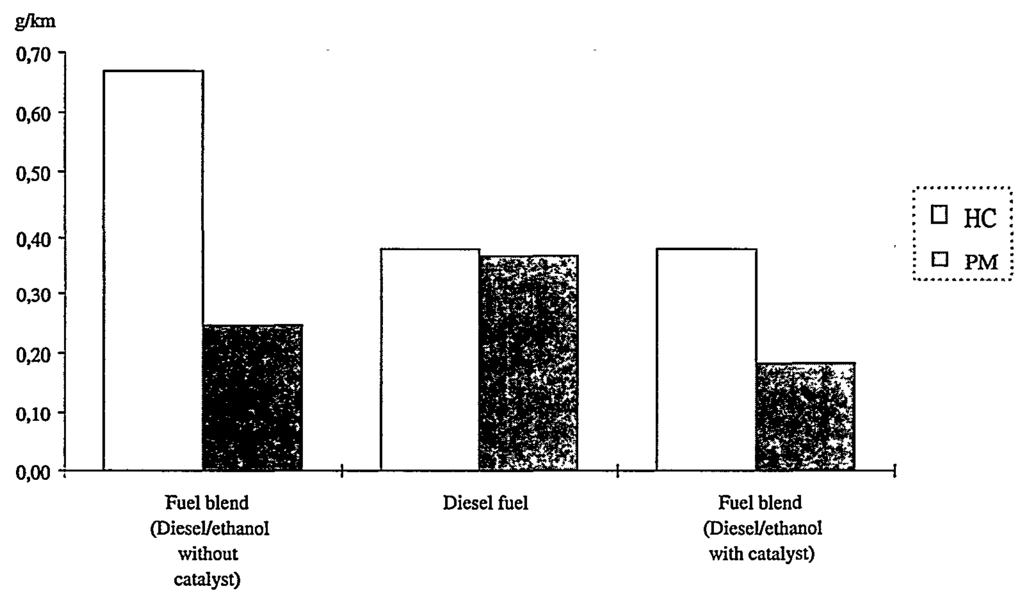


Figure 7.4. Emissions from trucks running on ethanol/diesel fuel blends (Berg R, 1997).

strate on a broad front the potential for using a renewable fuel (ethanol) in passenger cars and to evaluate its operating characteristics and emissions. A further purpose of the project was to make possible the successive construction of a network of filling stations around the country. As the result of an agreement with OK, it was guaranteed that it would be possible to fill-up with ethanol in any town where there were 10 or more FFV vehicles.

SSEU's tests on its fleet of FFV vehicles covered 50 vehicles in the first stage and a further 250 in the second stage. Despite certain shortcomings with regard to cold-starting characteristics, the vehicles broadly functioned without any problems at all. Fuel consumption averaged 0.115 litres per kilometre in the case of petrol-engined vehicles and 0.156 litres per kilometre for E85. In general, it may be noted that emissions were low and that the difference between emissions from petrol engines and from ethanol engines was small, with a few exceptions. This was mainly the case with regulated emissions but also with unregulated ones (**Figure 7.2**).

The FFV project has created a beginning – an embryo – from which to expand the infrastructure to include E85 filling stations throughout Sweden (**Figure 7.3**). The conversion of a number of filling stations to include E85 pumps is turning out to involve fewer problems than was initially expected. Often existing systems and equipment could be used.

Fuel blends

Blending ethanol with diesel fuel is rather more complicated than mixing ethanol with petrol. A blend of ethanol and diesel fuel is normally not very stable, and it requires an emulsifying agent to enable

Emissions-component g/kWh	KFB´s specifications	First set of measurements	Second set of measurements
HC	1.1	0.20	1.15
CO	0.3	0.014	0.014
NOx	2.0	3.12	3.78
NO_2	0.5	0.19	0.09
Soot	0.05	0.008	0.004
CO_2	as diesel	0.64	0.64

Table 7.5. Emission tests of a biogas-powered bus from Linköping. Tests carried out in accordance with 13-Mode cycle (Egebäck K-E, Brolin L, 1997a).

the two components to blend. As experience of practical use of ethanol/diesel blends was limited, KFB initiated practical fleet trials in 1995. The aim of the project was to develop a fuel consisting of a blend of ethanol and diesel that could be used in existing engines and would generate lower emissions than MK1 diesel.

The project included characterisation of emissions from different blends of ethanol and diesel, engine tests with different blending conditions and full-scale trials on 20 vehicles.

The results of this project showed that a suitable admixture of ethanol into diesel is around 15 per cent. At this level there were no problems with runnability, except for a slight reduction in engine power at rated engine speed. Fuel consumption showed no significant differences compared with diesel.

As regards emissions, the project demonstrated a reduction in emissions of solid particles whereas hydrocarbon emissions rose (**Figure 7.4**). However, if a catalyst has been installed these hydrocarbon emissions can be reduced.

The conclusion drawn in the final report (Berg R, 1997) is that a fuel blend of 15 per cent ethanol in diesel (Environmental Class I) has a superior environmental profile compared with diesel and it has no runnability problems. However, the new fuel has not been tested with an emulsifying agent for stability during long-term storage. Nor has the fuel been tested for such a long time that it is possible to reach any conclusions on possible long-term effects on the vehicle.

Biogas

Linköping

The first pilot project in the country involving biogas-engined buses was started in Linköping at the beginning of the nineties. The lessons learned from these early trials with biogas buses, which incidentally are still in operation, were very encouraging. The municipality and a number of local companies therefore decided to broaden the scope of the biogas project. A programme was begun in 1996 with support from KFB and others which included the construction of new biogas production capacity and a project intended to result in the running of all inner-city buses in Linköping on biogas.

After detailed studies and discussions, Tekniska

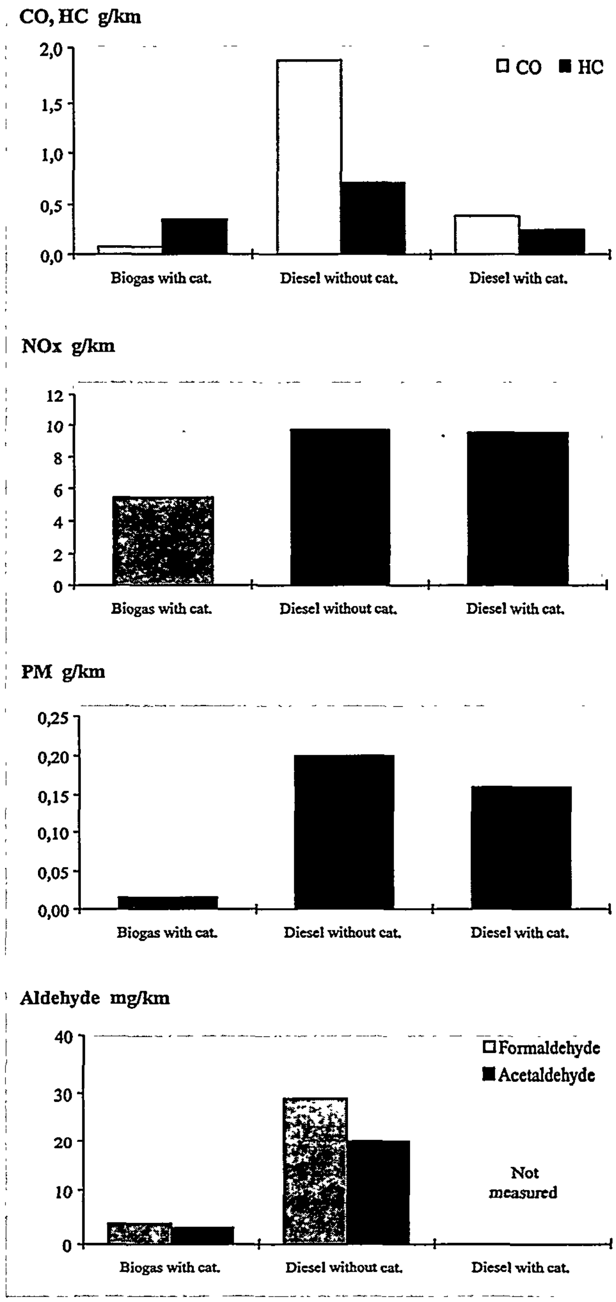


Figure 7.5. Emissions from biogas buses in Trollhättan. Results of tests in accordance with the bus cycle (Lingsten A et al, 1997).

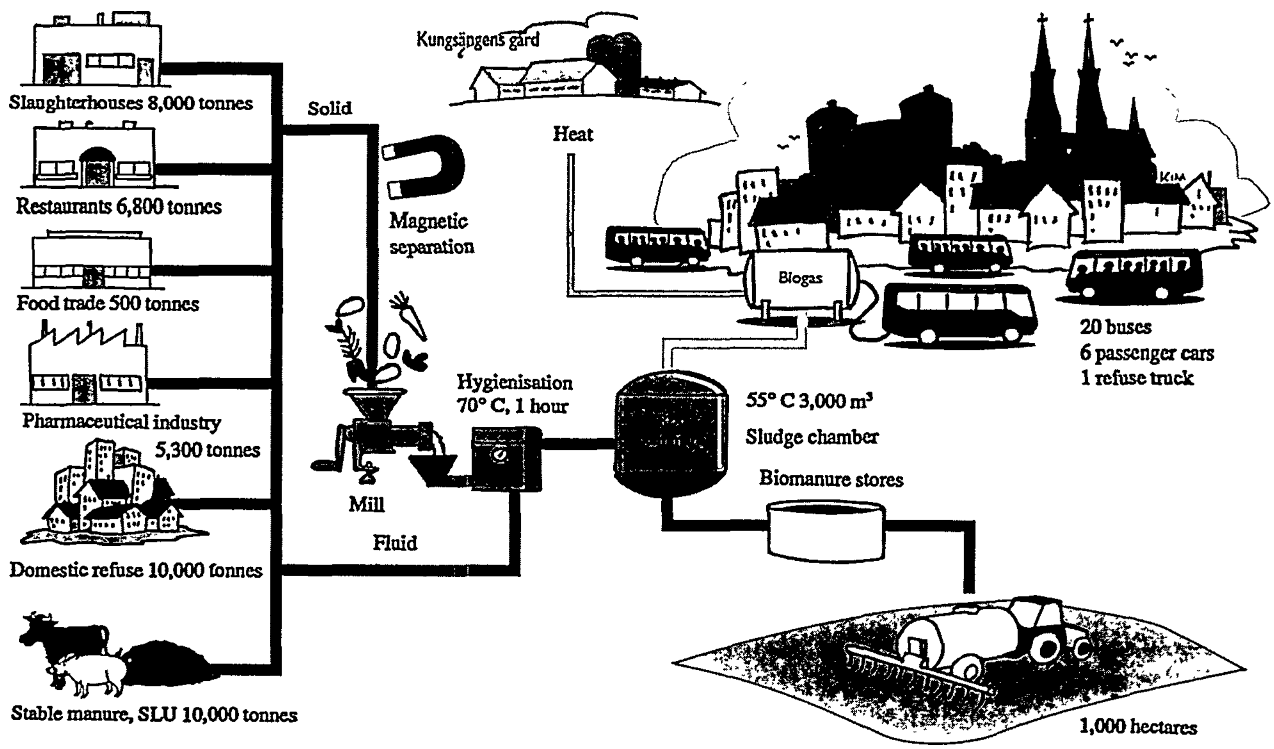


Figure 7.6. Natural cycle and biogas recovery – the city of Uppsala.

Verken Linköping AB and Scan Farmek, LRF and Konvex (three agricultural organisations) formed a jointly-owned company (Linköping Biogas AB). This company constructed and now runs a biogas plant to process organic waste, mainly slaughter-house waste and stable manure. The gas is distributed to filling stations in the town and is mainly used as fuel for inner city buses. In the long run, a further aim is that taxis should also be able to run on biogas.

Emission tests have been carried out on two occasions on one of the buses in Linköping, a Volvo B10L. The results of these emission tests indicate that the specifications established by KFB (see **Table 7.5**) have not yet been satisfied for all parameters, especially for emissions of nitrogen oxides.

Trollhättan

A biogas project involving buses and trucks has been carried out in Trollhättan with KFB's support. The purpose of the project was to demonstrate the potential for increasing the available biogas production from existing sludge chambers at the sewage works, and for using the gas as a fuel for a fleet of local city buses and trucks. The network of filling stations was

Emission component g/kWh	KFB´s specifications	First set of measurements	Second set of measurements
HC	1.1	0.044	0.089
CO	0.3	0.22	0.019
NOx	2.0	1.50	5.47
NO_2	0.5	0.00	0.00
Soot	0.05	0.01	0.007
CO_2	as diesel	0.624	0.622

Table 7.6. Emission tests on a biogas-powered bus from Uppsala. Tests carried out in accordance with 13-mode cycle (Egebäck K-E, Brolin L, 1997b).

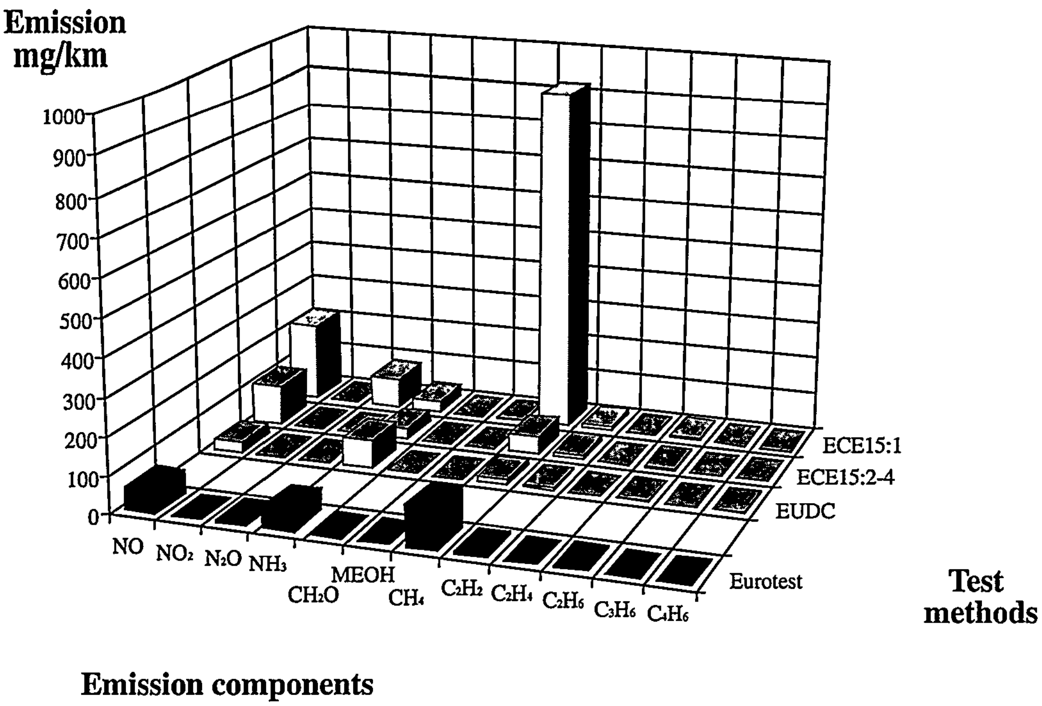


Figure 7.7. Emission levels for a variety of unregulated emission components from a biogas-engined passenger car – BMW 518, tested in accordance with various EU tests (Eurotest, EUDC, ECE15:2-4 and ECE 15:1)

gradually expanded and the fleets now includes 15 vehicles, mainly buses. The project also involved demonstrating the potential to produce sufficient biogas from existing sludge chambers to supply fuel to local fleets of vehicles. It also included designing a system for gas cleaning and filling.

The facility in Trollhättan has made it possible to put organic waste produced in the region to good use. Waste is received from a fish processing plant and an animal feed plant, which for the most part used to be deposited on tips. The biogas production is consequently part of an ecological cycle for biological waste. The dry solids content in the waste received varies from 5 per cent to 10 per cent and the waste has to be delivered in pumpable condition.

The gas is distributed from the sewage plant to the bus terminal in a pipeline which can take pressures of up to four bars. The filling procedure has worked well, although there were some teething troubles with the measurement system, but these have now been overcome. The design of the gas storage system and the reserve gas system has turned out to be technically more complicated and costly than was initially planned.

The biogas buses have been in operation without any serious interruptions. Drivers and passengers all appreciate the new environmentally-friendly vehicles. Special modifications have been made by Volvo, the supplier of the vehicles, in order to achieve the emission targets **(Figure 7.5)**

Uppsala

A gas processing installation at the sewage works in Uppsala was commissioned in the autumn of 1996. The raw materials for the process are mainly organic waste and manure, and the unit is intended to produce biogas as a fuel, during the first phase for 20 buses, six cars and a refuse truck **(Figure 7.6)**.

Operating experiences from Uppsala are good with regard to the facility for producing gas as well as the practical aspects of operating the vehicles. On account of the short duration of the trials it is, however, still too early to draw any conclusions regarding availability or running costs.

Emission tests have been carried out on two occasions on one of the buses in Uppsala – a Neoplan bus.

The results of the emission tests shows that the specifications established by KFB (see **Table 7.6**) were satisfied for all given parameters on the first occasion. However, the result of the second series of tests shows seriously elevated emission values for nitrogen oxides. The reason for this cannot be determined definitely without more detailed investigations. One explanation could be that the control of the fuel flow failed to function satisfactorily

Stockholm

Biogas is currently being produced in large quantities at the sewage works in Stockholm. Stockholm Vatten AB has therefore began to explore the potential for using the gas as a fuel for vehicles. A pilot project, which has the support of KFB and others, was therefore started at the sewage treatment plant in Bromma in 1995.

After some delays with the commissioning of the gas processing facility, the first gas-driven vehicles began to fill up with biogas in the summer of 1996. The fleet has expanded rapidly and was some 60 vehicles (Volvo 850 Bi-Fuel, VW Golf, VW Transporter, BMW 316g and 518g) in the end of 1997. With the odd exception, the vehicles were able to fill up to the required extent once the plant was in operation. The gas-engined vehicles have functioned very well and have been well received by the drivers. The vehicles run on gas for 80-90 per cent of the time. The tank only holds enough gas for 150-200 kilometres of driving, which is regarded as a drawback. The tank can be filled quickly, but the nozzle on the pipe is awkwardly designed, and in some cases it is difficult to get it into place.

Emission tests were carried out in 1997 on five vehicles from three manufacturers, Volvo, BMW and VW. The results of the tests show that emissions of regulated substances were low for all tested vehicles. All the vehicles more than satisfied current requirements and one of them, the BMW 518, also satisfied the most stringent threshold values proposed within the EU for 2000 (**Figure 7.7**). Emissions of aldehydes are low and in the case of formaldehyde well within the maximum level of 2-2.5 mg/km. In contrast with earlier established opinion, the measurements also show that emissions of ammonia are low. Emissions of hydrocarbons were also lower than expected. Emissions of nitrogen dioxide were detected in only three cases out of 15.

This project has aroused considerable interest. The Stockholm Environmental Vehicles Project and Zeus (a joint European project for the procurement of environmentally friendly cars) have both shown great interest in biogas vehicles. According to current plans, the City of Stockholm will have about 200 biogas vehicles in operation in the near future as well as a system of mobile gas storage tanks for distributing gas to filling points at petrol stations throughout the Stockholm region.

Conclusions

- As a result of the extensive demonstrations carried out in the country on vehicles of various types and involving various fuels, a number of solutions have been tested under practical operating conditions. This has helped to stimulate interest in biofuels and new fuel technology among various categories of user.

- Developments have advanced furthest in the case of ethanol buses. Equipment and techniques have been developed specifically for buses. In the case of trucks, progress has not been so fast. However, in principle as there is no significant difference between ethanol engines for a city bus and for a truck the potential for developing improved ethanol trucks is quite favourable. In the case of biogas, the demonstrations show that this fuel is at present the most environmentally friendly alternative. However, engines require further development for both ethanol and biogas if their environmental benefits are to be exploited to the full and the new technology is to be made available on sound financial conditions.

- By blending 15 per cent ethanol in diesel fuel with the aid of an emulsifying agent a fuel can be obtained of a quality with superior environmental characteristics to the currently best diesel grade available, without any deterioration in running characteristics. Before this method is applied on a large scale, however, long-term testing of vehicles and fuels will be required as well as the development of an efficient, large-scale method for blending ethanol, together with an emulsifying agent, with diesel.

- The introduction of a flexible fuel vehicle, FFV, marks the start of the construction of a nationwide ethanol distribution network. The FFV project has thus demonstrated how the chicken and egg problem can be solved in practice.

International experiences

- *Brazil*
- *USA*
- *France*
- *Other parts of the world*
- *Stockholm Conference 1997*
- *Conclusions*

Chapter 8

INTERNATIONAL EXPERIENCES

Brazil has been the leading nation in the world in the use of ethanol as a vehicle fuel ever since the middle of the seventies. All passenger cars in Brazil (approx. 10 million) now run on ethanol. In the USA, the volume is not so high – ethanol accounts for about one per cent of the fuel market – but large-scale and extensive development and demonstration projects are in progress. Seen from an international perspective, Sweden's contribution in this field also arouses respect. This emerged at KFB's international conference on "Creating the Market", which was held in Stockholm in October 1997.

Brazil

Brazil's *Proalcohol* programme was begun in 1975 in the wake of the first oil crisis in 1973/74 with the aim of becoming the first stage in the gradual introduction of ethanol-petrol blends as a fuel. In 1979, in the wake of the second oil crisis, the programmes were accelerated and the aim was altered to that of introducing pure ethanol as a fuel.

The main reason for starting Proalcohol and for broadening the programme in 1979 was the country's heavy dependence on steadily rising imports of oil coupled with the fear of continuously rising oil prices, which were making a serious dent in the trade figures. In 1975, Brazil had to pay 4.5 times more for its oil imports than in 1973 and in 1979 no less than 10 times more. The Iran-Iraq conflict made itself felt most dramatically in everyday life in Brazil, as more than half the country's oil imports came from this region, and they suddenly ceased. Although many petrol stations were compelled to close, the early pure ethanol pumps were kept running. Since substantial oil reserves were discovered in Brazil later, and the Proalcohol programme was started at the same time, it has been possible to reduce oil imports by 30 per cent, despite the steadily growing use of oil (up by 33 per cent between 1974 and 1993), and dependence on imports has been halved.

The factor which made the ethanol venture possible was the considerable expertise and tradition that existed in the cultivation of sugar cane and production of alcohol combined with the political determination to create jobs in rural areas. Back in

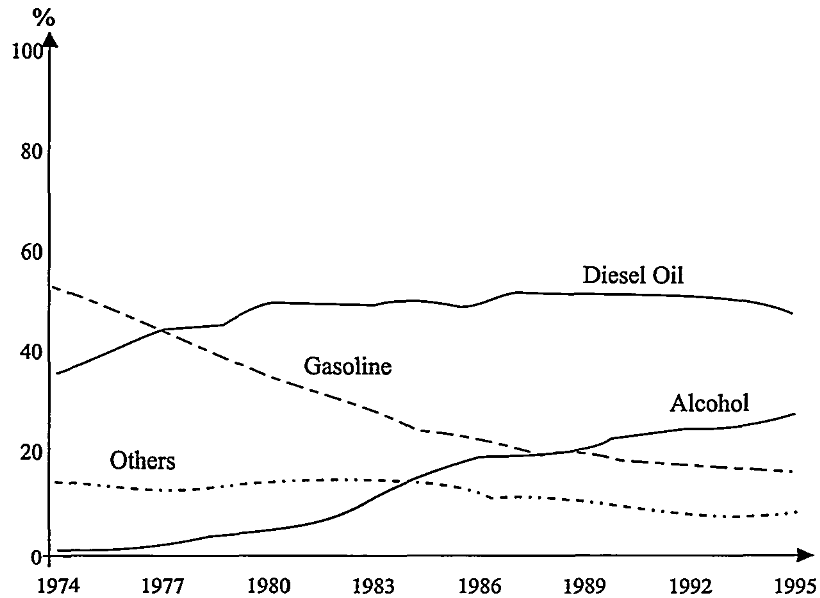


Figure 8.1. Changes in the use of fuel in Brazil 1974-1995 (Pilo C, 1997).

the 1930s, ethanol was already being mixed into petrol with the aim of moderating fluctuations in the global market price of sugar. During the World War II the blend was raised to 50 per cent ethanol (E50). During the 1950-60s, however, ethanol ceased to be used as a component in fuel.

Brazil is well placed to produce sugar cane and ethanol. Sugar cane is cultivated in all populated regions, so ethanol can be produced and used locally, thus avoiding extensive transport and distribution.

A fundamental factor behind the broadening of Proalcohol was that the decision to start was jointly prepared by the government and industry in close consultation. Representatives of the automotive industry and the oil industry were drafted into the government office and instructed to draw up the basic documentation for the decision. An agreement was reached in 1979 between the government and the auto industry (Chrysler, Fiat, Ford, General Motors, Mercedes-Benz, Saab-Scania, Volkswagen, etc.). The government, for its part, guaranteed that ethanol fuel (E96) would be made available in all major cities, and the automotive industry undertook to manufacture and sell cars designed to run on ethanol. The government also guaranteed that the state oil company *Petrobras* would buy certain given quantities of ethanol.

The government also provided financial incentives to ethanol manufacturers in the form of loans at low interest rates during the 1980-1985 period. In total, these loans amounted to US$ 2 billion, corresponding to 29 per cent of the necessary investments. At the beginning of the 1980s, the World Bank granted a US$ 250 million loan, which put the project on a creditworthy footing on international financial markets.The Brazilian programme is by far the largest experiment that has ever been made with the object of replacing conventional fuels (petrol) with a biofuel on a large scale and commercially. Even if the Brazilian programme is based on slightly different conditions from those by Sweden, it still has some important lessons for Sweden.

The main problem with the Proalcohol programme was balancing the supply and demand for fuels and vehicles. Repeated crises occurred. The ethanol market collapsed in 1981 and again in 1989. In 1979, 100 per cent of all new cars were petrol-engined whereas in 1987, 94 per cent of all new cars ran on pure alcohol (E96), and in 1995, 95 per cent of all new cars ran on ethanol-petrol fuel blends (E22). These extensive fluctuations have naturally been most unfortunate.

During the changeover work, numerous technical problems occurred, especially due to corrosion of materials in connection with both the distribution of pure ethanol and its use in vehicles. However, these are now believed to have been overcome. At present, more than 4 million cars run on E96 and the remaining 5 million run on E22. In total this means that ethanol accounts for half of all the fuel consumed by petrol-engined vehicles.

When the alcohol programme was introduced, the intention was that heavy vehicles should also run on ethanol. Scania was involved in this development work, which was broken off for technical and financial reasons. However, Brazil has displayed renewed interest in restarting the project with a view to enabling heavy vehicles also to run on ethanol.

The fact is there is great interest in reducing the use of diesel fuel (see **Figure 8.1**).

During the initial phase the Proalcohol programme was heavily subsidised at both the production and consumption stage. Now, however, most of these subsidies have phased out.

USA

There are at present more than 7,000 registered fuels on the American fuel market, but petrol (gasoline) and diesel totally dominate the market. The USA is now also more dependent than ever on foreign sources of oil, and this is the factor driving the development of alternative fuels.

By alternative fuels Americans mean domestic fuels which are capable of replacing fuel or raw materials, such as crude oil, that are currently imported. Apart from security of supply, environmental considerations are also beginning to move increasingly into focus. The environmental effect the Americans primarily wish to reduce by introducing alternative, clean fuels is the formation of low-level ozone. The emissions they are therefore endeavouring to reduce are primarily nitrogen oxides and hydrocarbons.

Energy supply and the air environment are regulated in a number of acts (such as the Clean Air Act, Energy Policy Act, The Climate Change Action Plan, Intermodal Surface Transportation Efficiency Act, etc). In practice, however, these statutory means of control interact with other measures, via development contracts between the government and the automotive industry, subsidies for investments and official demands for certain numbers of alternative vehicles in public vehicle procurement programmes.

Ethanol has been available on the fuel market for a long time in the form of "gasohol" (E10). Ethanol production is based on corn, and in certain corn-growing states gasohol accounts for as much of 40 per cent of all petrol consumed. At present ethanol production in the USA amounts to some 4,000 billion litres/year or approximately one per cent of total fuel consumption. The typical ethanol producer is a small factory in the Middle West which bases its production on corn, but there are also numerous ethanol plants in California, for instance, which base

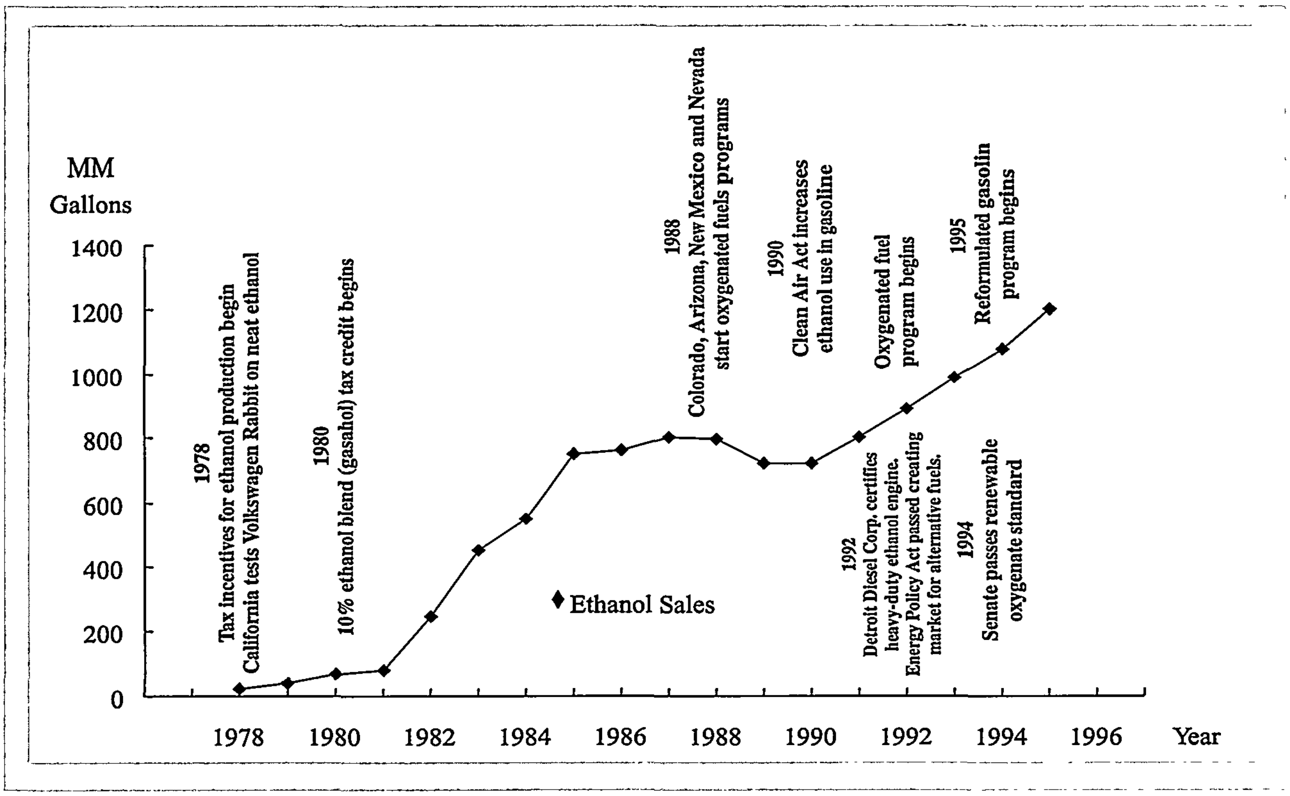


Figure 8.2. Changes in ethanol sales in the USA and some important mile posts in the development process (1 US gallon = 3.785 litre) Bucksch S., Månsson T. 1996).

their production on organic waste from brewers and the food industry.

The main reason why state authorities have imposed legislative demands on the transport sector is that they are expected to satisfy the federal *Clean Air Act*. As different areas are exposed to different degrees of air pollution, the statutory requirements differ markedly from one state to another. Those areas which do not attain the requirements for air quality (*non-attainment areas*) have to introduce many different measures. Some of them demand or encourage vehicle owners to buy alternative fuel vehicles (natural gas, methanol, ethanol or electricity). Other states prefer to demand that refineries supply reformulated petrol (at least 2 per cent by weight of oxygen and a maximum of 1 per cent by weight of benzene).

Policies in most states are neutral in terms of fuel, i.e., as long as the state can demonstrate that it has a plan capable of satisfying the Clean Air Act it is a matter of indifference which fuel is used.

Apart from statutory requirements, tax relief is also provided on the introduction of alternative fuels. Both the federal government as well as individual states endeavour in various ways to stimulate an increase in the supply of ethanol in the USA. At present there are two federal means of control, firstly the Alcohol Fuels Tax Credit which allows a tax reduction of 54 cents per gallon for fuel suppliers who supply fuel mixtures (E10), and secondly a *Small Producers Credit* which allows tax relief (of 10 cents per gallon) to small (< 60 million litres/year) ethanol producers. Some states also provide financial support for ethanol production, including Iowa, Kansas, Minnesota and Missouri, which subsidise production by 20 cents per gallon, and North Dakota, which provides a subsidy of 40 cents per gallon.

	1997	1998	1999	2000	2001
Fast-growing trees			US S 45-60 per tonne	To plant 2-4 fully tests species of tree in northern USA	
Grass	Start a new project in Georgia together with USDA and start tests in northern USA		Start five factories in northern USA and 10 in south-eastern USA		
Analysis of raw materials	Identify cost-effective factories				
Ethanol production (one tonne per day)	Complement plans for a factory to produce ethanol from waste	Integrate selected improvements to improve raw material from waste		Integrate further improvements into process that can reduce costs	
Ethanol production (50-100 tonnes per day)	Support to help industry design first generation factories				Support for industry to design further new factories

Figure 8.3. *Estimated time schedule and goals for US Department of Energy's ethanol development programme (Wingqvist A. 1997)*

Extensive activities are being carried out with the support of the US Department of Energy involving government authorities, cities and transport companies throughout the whole of the United States. One development goal from 1992 *(Energy Policy Act, EPACT)* is to replace 30 per cent of the oil products in fuel by non-petroleum based fuels by 2010, including not only biofuel but also natural gas, electricity and, in the longer run, hydrogen.

The law stipulates that the federal government, suppliers of alternative fuels (producers, distributors and vendors), state and local authorities, as well as private vehicle fleet operators must purchase a given number of alternative vehicles.

It also stipulates the rate at which the vehicles shall be replaced. The Department of Energy has also laid down in great detail in the act what rules shall apply to vehicle procurement. At present a new legislative requirement is being discussed which would mean that private and municipal vehicle fleets are also included. One

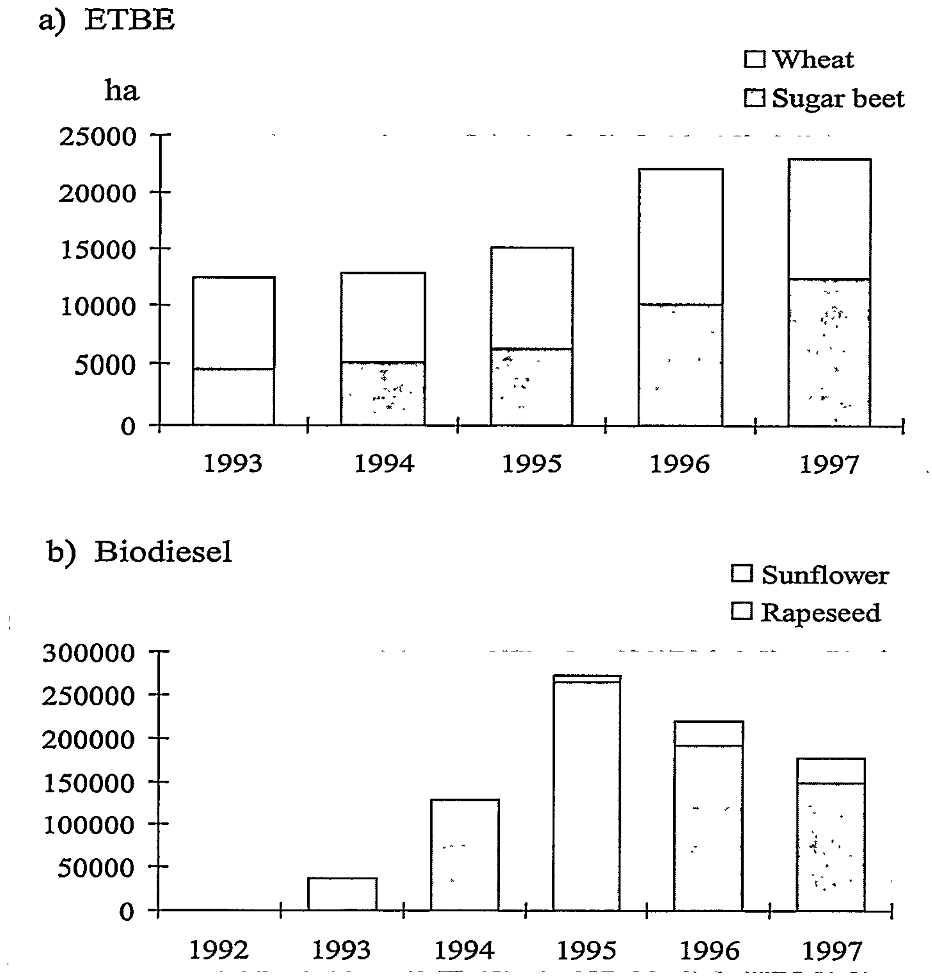


Figure 8.4. Production development of biofuels in France 1992-97 described in the form of land use for a) cultivation of biofuel crops for production of ETBE and b) for cultivation of vegetable oil products for production of bio-diesel (Pilo C. 1997).

proposal, for example, is that 20 per cent of private and municipal fleet operators' purchases must be alternative vehicles in 2002, followed by 40 per cent in 2003, 60 per cent in 2004, and 70 per cent in 2005. This legislative proposal will cover vehicle fleets of 20 or more vehicles which can be refuelled centrally and which operate in cities with more than 250,000 inhabitants.

Extensive development activities are also financed via DOE with the object of developing new cost-effective methods of producing ethanol.

The federal Clean Cities programme, as well as the Governors Ethanol Coalition, an initiative on the part of the governors of a number of farming states are examples of activities intended to support and encourage cities and other local players to raise their use of biofuel.

The Clean Cities programme is run and financed by the Department of Energy. Its purpose is to accelerate and extend the use of alternative vehicles in cities and towns throughout the country and to offer facilities for refilling and maintenance. The Clean Cities programme encourage local authorities and organisations to form public-private partnerships to develop markets for new fuels and vehicles. At the time of writing more than 1,000 partnerships in 40 cities have affiliated. These cities are estimated to have a total of some 60,000 vehicles running on alternative fuels on their roads.

The largest individual fleet operator using alternative fuels for heavy vehicles is in Los Angeles, where MTA, the city bus company, has a fleet of some 300 buses which run on methanol and ethanol. Initially, they concentrated on methanol, but now all the buses have been converted to run on ethanol. The reasons were partly technical and partly financial.

When it come to the longer-term development of alternative vehicles, the USA (especially California) has focused on Zero Emission Vehicles (ZEV), a concept that was thought up in 1990 by the Californian Air Resources Board (CARB). CARB introduced statutory rules making it obligatory for the output of the leading car manufacturers in the USA, as well of the sales of the largest car importers, to produce and sell at least 10 per cent of zero emission vehicles by 2003. This is regarded by many as the most far-reaching initiative to date aimed at inducing the car industry to take some interest in technical development. This initiative has since been followed up by President Clinton, in his *Partnership for a New Generation of Vehicles* programme, which was launched in 1993. The object of PNGV is to persuade American vehicle manufacturers to concentrate on developing new, competitive types of vehicles that are extremely fuel efficient and which can run on alternative fuels.

The three leading American car manufacturers, GM, Ford and Chrysler, are involved in this partnership between the federal authorities and the industry. The long-term aim is to develop a new generation of passenger cars whose fuel consumption is one-third of the current level.

France

Among the countries in Europe it is mainly France, apart from Sweden, which is showing most interest in biofuel. There they have concentrated on biofuel as one aspect of their measures to find alternative production for farmers.

Experiments with the introduction of biofuels in France have so far been limited to fleet trials on a semi-commercial scale. These trials have included 3,000 vehicles (which may be compared with about 700 in Sweden). A majority of the French projects have related to buses which are largely tested with various types of low blends of rapeseed methyl ester (RME) and ethanol-based ethers (ETBE). However, fleet trials are also being carried out in some cities with city buses running on pure alcohol.

The question of compulsory admixture of biofuel into both petrol and diesel was raised in 1992. Trials extending over several years have shown such good results that a decision has now been made to introduce a legislative demand that RME be blended with diesel, and ETBE in petrol, from 2000. The aim is to have reached a level where RME accounts for 5 per cent of diesel consumption by 2004 and ethanol accounts for 5 per cent of petrol consumption by volume.

France has provided tax relief on biofuel since 1992. This has led to the construction of a number of production units for RME and ETBE. Several of these new production units are jointly owned by oil companies and farming interests. At present the annual production volumes amount to 320,000 tonnes of RME and 230,000 tonnes of ETBE, but these volumes will increase when the proposal for compulsory admixture of biofuels come into effect.

The French biofuel programme, as well as other earlier large-scale programmes in France, was based on the assumption that the business sector would already be deeply involved from the very beginning. Once the domestic industrial sector had gradually managed to adapt it would then look for international partners as a means of reducing costs.

Other parts of the world

Apart from France and Sweden, there is very little interest in biofuels elsewhere in Europe. In so far as there are any development projects for biofuels at all in other EU countries they are concerned with the use of RME and vegetable oils. Countries such as Italy, Germany, Belgium and Austria, as well as France, have began to build up their capacity to produce vegetable oils which can be used for blending in diesel for buses, trucks and diesel-engined passenger cars. As a result of changes in the tax rules, this is beginning to become increasingly worthwhile in several European countries. The total annual volume of biodiesel produced (RME and vegetable oils) is estimated at some 600,000 tonnes, with France accounting for almost half of this total (Pilo C. 1997).

The technique used in Sweden for mixing the ethanol and diesel (15% ethanol in diesel with an emulsifying agent) was in some respects based on an Australian model. In Australia the federal government has been financing fleet trials with buses and trucks for several years, which involve ethanol and diesel being mixed and used in existing vehicle fleets. Since these trials have turned out well and have demonstrated great potential to reduce carbon dioxide emissions more than would be possible by changing over from diesel to natural gas (which is the main alternative at present), interest in alcohols has increased.

In a special inventory of international experiences relating to the use of biogas vehicles (Brolin L. 1997) it was noted that some interest exists in running vehicles on biogas in various countries around the world. In total 35 facilities in 12 countries have been identified, most of which are used as reference projects by the suppliers who have been involved in the

	BRAZIL	USA	FRANCE	SWEDEN
Key players	Sugar industry Oil companies (state) Government Automotive industry Taxi owners	Farming interests (corn growers) Oil companies (private) Government (federal, state) Automotive industry Ethanol producers	Oil industry Farming interests Ethanol/RME producers Government Consumers Automotive industry	Oil industry Farming interests Ethanol producers Automotive industry Consumers/Users Government
Driving forces	Oil crises Falling sugar prices Environment (local, global)	Oil crisis/oil dependence Falling demand for corn Environment	EU agricultural rules Environment	Environment (local, global) Lower dependence on oil New markets for farm produce
Infrastructure	Established (ethanol blends since thirties) Competition between pure alcohol and petrol	E10 established Niche use Ethanol vehicle fleets	ETBE and RME blends in petrol	Limited Niches/Fleets
Policy	Sugar prices (controlled) Price of fuel blends (controlled) Support for pure alcohol R&D Government vehicle fleets Support for taxis	Federal financial aid State aid of different types R&D State vehicle fleets with FFV and other AFV	Heavy tax subsidies for investments R&D	R&D Limited tax support
Results	Rapid introduction of E18-E22 Significant intro. of pure alcohol Saturated market Regional development New job opportunities Alliances ceased in 1986 Technical development and maturity	World's second largest ethanol programme but limited market (in %) FFV to build up infrastructure Regional concentration New job opportunities Less support for farmers Higher valuation of benefits required	Limited market penetration Uncertain future	Demonstration phase Sound technical fact base Distinct environmental benefits Limited interest among participants
Conclusions	Joint approach and support need to be restored Environmental costs need to be internalised Subsidies need to be phased out International co-operation, incl. trade, a key issue	Broad alliances required Environmental costs need to be internalised Subsidies need to be phased out Technical maturity/development need to be accelerated International co-operation, incl. trade, a key issue	Broad alliances required to move out of pilot phase Environmental costs need to be internalised Subsidies need to be phased out Technical maturity/development need to be accelerated International co-operation, incl. trade, a key issue	Non-technical questions need to be given greater emphasis Broad alliances required to move out of pilot phase Environmental costs need to be internalised Subsidies need to be phased out Technical maturity/ development need to be accelerated International co-operation, incl. trade, a key issue

Table 8.1. Comparison of biofuel programmes in Brazil, USA, France and Sweden (Pilo C. 1997).

Swedish biogas projects. Many of the facilities have been in operation for many years and serve vehicle fleets of between 30 and 70 vehicles. Apart from those in Sweden, most of these biogas projects are in the USA, France, the Czech Republic, and New Zealand.

There is growing interest in using biofuel elsewhere in the world, not least in developing countries. In many countries there is considerable potential that can be utilised for this purpose, but there are also competing interests; China and India are cases in point, where any available land is needed to produce food. These countries, however, often have considerable volumes of unused organic materials which are currently regarded as waste, but which could, in the longer term, have some potential for the production of fuel. However, the conditions for this need to be studied in more details.

Stockholm Conference 1997

The 1997 International Conference on Use of Biofuels for Transportation – Creating the Market was the name of the international biofuel conference arranged by KFB in Stockholm from September 29 to October 1, 1997. The purpose of the conference was to stimulate increased international exchange of experiences and to intensify international co-operation between key players in the field. The conference attracted 130 delegates from 25 countries. Ten national and international networks also participated in the conference. Most important players, including governments and central government agencies, the automotive and oil industries, fuel producers and fuel distributors, as well as vehicle users, including private haulage companies and municipalities, were represented at the conference.

The conference provided a broad overview of the state of current developments in those countries which at present have made most progress in the biofuel area, namely, Brazil, the USA, France and Sweden. It was noted that there are many similarities between the programmes but that there are also differences in local conditions (**Table 8.1**). The common key questions which were highlighted included the importance of:

- central players (*Stakeholders*) being brought into the programme at an early stage in order to facilitate the introduction of biofuel onto the market,
- bringing into being partnership programmes for mutual co-operation between state, business and users at both national and international level, and
- ensuring that gaps in the available knowledge were identified jointly and solved jointly by government and industry via joint R&D programmes.

The following points also emerged from the discussions:

- The automotive industry could supply vehicles for pilot and demonstration projects **but** not in any significant volumes before they can see an economically functioning market for them.
- The vehicle industry could develop new vehicles to run on biofuel with a lead time of 1-2 years for biogas and 2-3 years for ethanol and methanol.
- The fuel industry can produce and supply biofuels **but** needs to be subsidised during an introductory phase.
- Users are willing and interested in trying out biofuels and new vehicles **but** not on any significant scale until this is financially attractive.

A special session at the conference was devoted to discussing what joint international action should be taken in the future to bring about broader market penetration for biofuels. There was widespread agreement among the delegates that what is lacking at present is an international forum where players representing various interests such as government, the petroleum industry, fuel producers with connections with farming and forestry interests, and private and public vehicle users with large fleets can exchange experiences and ideas and, hopefully, eventually agree on a joint strategy that would lead towards a sustainable society.

The conference proposed that an initiative should be taken to set up a *Stakeholders Forum* – an international forum where various parties could jointly draw up strategies and proposals for the future use of biofuels in the transport sector.

Conclusions

- At present Brazil, the USA, France and Sweden are mainly leading developments in the biofuel area, but growing interest may be noted among other countries in alternatives to fossil fuels.

- There are several general experiences regarding how alternative fuels should be best introduced. Government will play a role by initiating change processes. By far the most difficult challenge will be to persuade key players, not least users, that the measures and projects are to be taken seriously, that they are long term, that they will not be radically altered the next time a new government takes over, or in the event of an economic crisis or shift in the state of public opinion.

- Stronger and intensified international co-operation is required, both within the EU and with outside partners. One proposal is to set up an international network – a Stakeholders Forum. The idea is that this would provide a forum where key players could meet regularly to jointly develop an international action plan for creating a market for biofuel. Numerous networks of different types already exist which could play an important role, not least the many user networks in which municipalities and city authorities form joint organisations for the procurement of new fuels and vehicles.

Biofuels – their potential for health and the environmemt

- *Emissions*
- *Hazards to health*
- *Noise*
- *Emission testing methods*
- *Conclusions*

Chapter 9

BIOFUELS – THEIR POTENTIAL FOR HEALTH AND THE ENVIRONMENT

Changing over from petrol and diesel to biofuel has the potential to lead to cleaner vehicles with lower emissions of harmful substances. What benefit we can derive from this health and environmental potential depends, however, on several factors, and the selection of technique, for instance, is of great importance.

Emissions

Emission testing has played a central role in KFB's demonstration projects. In total one hundred vehicle tests have been performed. These have largely been carried out at Svensk Bilprovning's engine test centre (MTC) in Jordbro, just outside Stockholm. Professor K-E Egebäck had responsibility for the overall analyses and evaluation of the results. Based on these, an assessment has also been made of the future environmental potential.

In his report, Egebäck (1997a) presents emission factors for various groups of vehicle and fuel. These emission factors are based on data, in so far as they were available, and on estimates in those cases where no data were available. The division into years is 1988 (base year), 1993, 1996, 2000, 2005 and 2010 without any abrupt changes for each year. The emission factors can be regarded as reflecting the ongoing technical development of vehicles and exhaust cleaning techniques, taking into account the potential of the fuel in question and the steady release onto the market of new vehicles with more advanced equipment.

The emission factors include alcohol operation and biogas operation with petrol-engined or diesel-engined operation as the reference alternatives for passenger cars, trucks and buses. In the case of running on alcohol, both ethanol and methanol are included. Even if there is a difference in emission profiles, especially in the case of aldehydes, they are regarded as one fuel. The reasons for not distinguishing between them are that:

- Emission factors have been determined on the basis of a technique in which a catalyst is used for cleaning of exhaust gases, which means that differences in emissions of formaldehyde and acetaldehyde can be regarded as minimal.
- The accuracy of the stated emission levels is not such that it can be regarded as meaningful in this context to differentiate between ethanol and methanol.

Passenger cars

Relatively reliable information is available on petrol-engined and diesel-engined passenger cars for estimating regulated emissions. On the other hand, more or less no data are available for non-regulated emissions from diesel-engined vehicles. The emission values for the period after 1996 have been estimated on the basis of experience of how specific technical developments to engines and the use of certain exhaust cleaning methods affect emissions. In the case of petrol-engined passenger cars, the estimates are based on technical advances resulting in improvements to the functioning of the catalyst system in connection with cold starting, and the use of exhaust gas recirculation EGR. This results in lower fuel consumption and also lower emissions of nitrogen oxides.

In the case of alcohol- and biogas-driven passenger cars, the information available for calculating emission levels is more limited. In the case of alcohol engines, emission data from measurements of fuel-flexible vehicles (FFV) have mostly been used. As these vehicles are not optimised to run on alcohol, they offer considerable future potential for improvements to emission levels. The measurements on FFV vehicles produced low values, which supports the view that more favourable emission levels can be achieved, provided the engine manufacturers concentrate on further development of the engines.

In the case of biogas vehicles it may be noted that these also produce very low emission levels. Naturally this depends on the gas being of a satisfactory and uniform quality and that the environmental potential of the fuel is used to the full. The composition of a well-cleaned biogas is simple, since it mostly consists of methane. It also turns out that the hydrocarbons emitted in the exhaust fumes consist almost solely of methane. Unfortunately, a catalysts requires a higher temperature to oxidise methane that the temperature needed to oxidise other hydrocarbons. This means that methane emissions can be quite high if the catalyst system is not adapted specifically to oxidise methane.

Trucks

Some emission data are available for trucks, although not at all to the extent required for statistical representativeness. In the case of ethanol running, the emission data are based on measurements for the distribution vehicles in the SVENOL project. In the case of biogas-driven trucks, some of the vehicles are running in the KFB-funded biogas project in Trollhättan. However, at the time the report was being prepared emission data were not available for these vehicles. The report is therefore based on data from trucks running on natural gas (the LB50 project). The following are some of the conclusions/comments that can be made:

- CO emissions are highest in the case of diesel-engined trucks, mainly because they do not have catalysts. It has been assumed that vehicles for alcohol and biogas running are fitted with cata lysts. Should the comparison have been made without catalysts, diesel would probably have shown the lowest CO emissions.
- Hydrocarbon emissions (total) are highest in the case of biogas. This was due to the engine in question being an otto engine, and partly to the conversion ratio of the catalyst being low for methane. As methane, which accounts for the vast majority of the hydrocarbon emissions, is not toxic, methane can be deducted from hydrocarbon emissions to give NMHC (no methane hydrocarbons). However, it is not that easy to measure NMHC, and the technique is based on the use of two different methods to measure hydrocarbons, after which the difference between these gives the value of NMHC. As the margin of error can be a few per cent in each case, an NMHC level of the odd per cent is recognised as being very difficult to

PASSENGER CARS

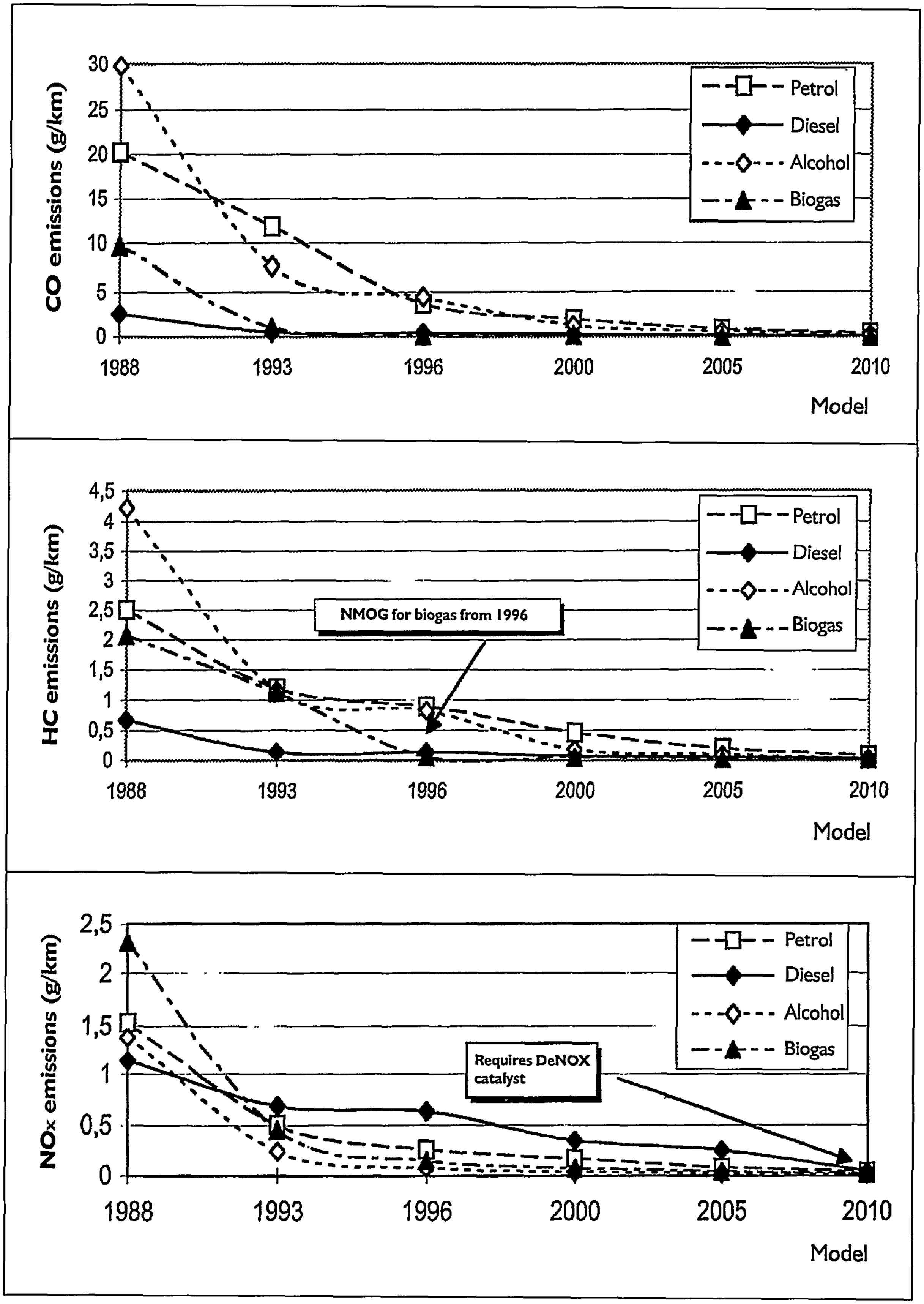


Figure 9.1. CO, HC and NO_X emissions from use of petrol, diesel-alcohol and biogas as fuels for passenger cars (Egebäck K-E. 1997a).

SMALL HEAVY TRUCKS

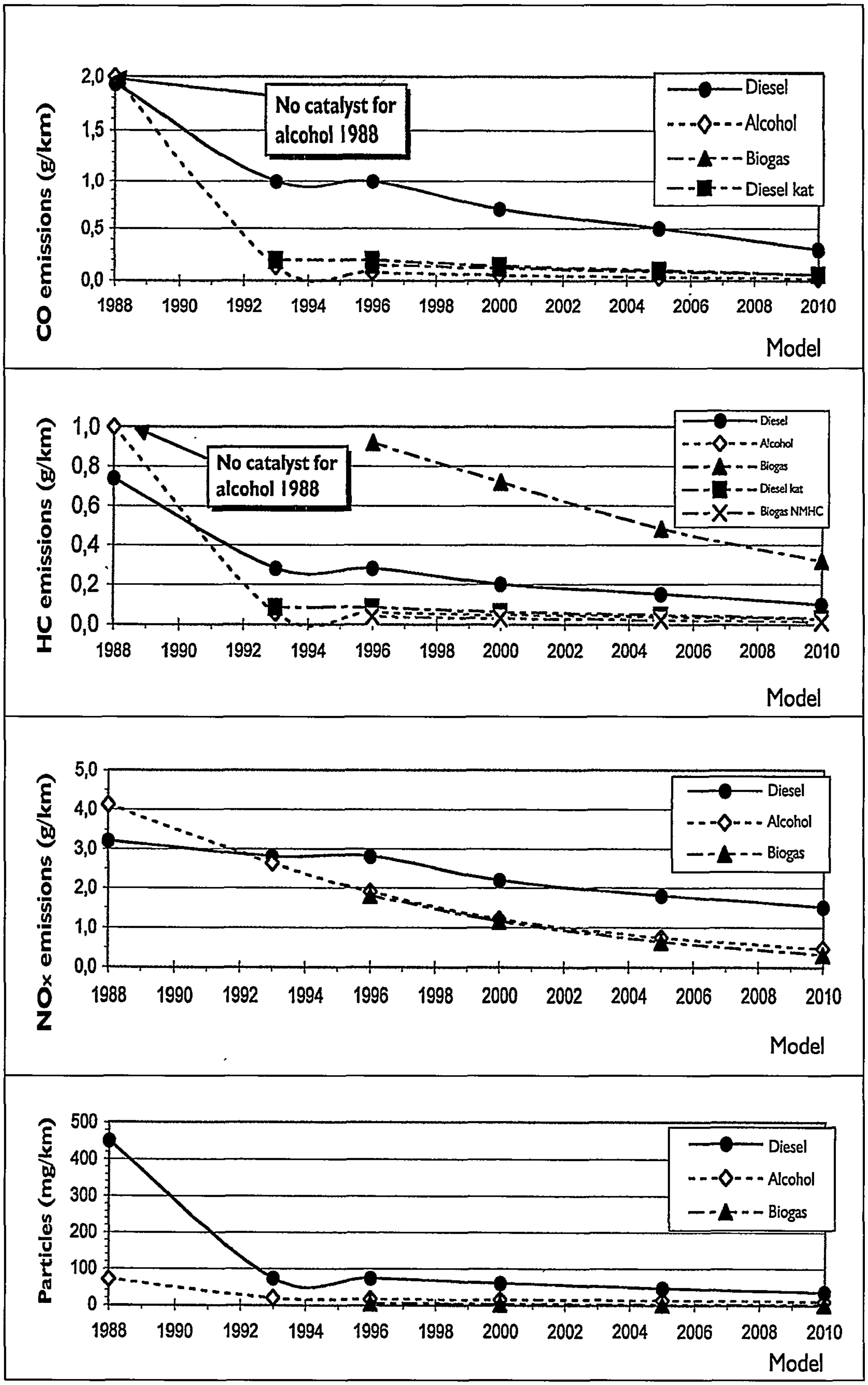


Figure 9.2. *CO, HC and NO_x and solid substance emissions from use of diesel, alcohol and biogas as fuels for small heavy trucks (Egebäck K-E. 1997a).*

HEAVY TRUCKS

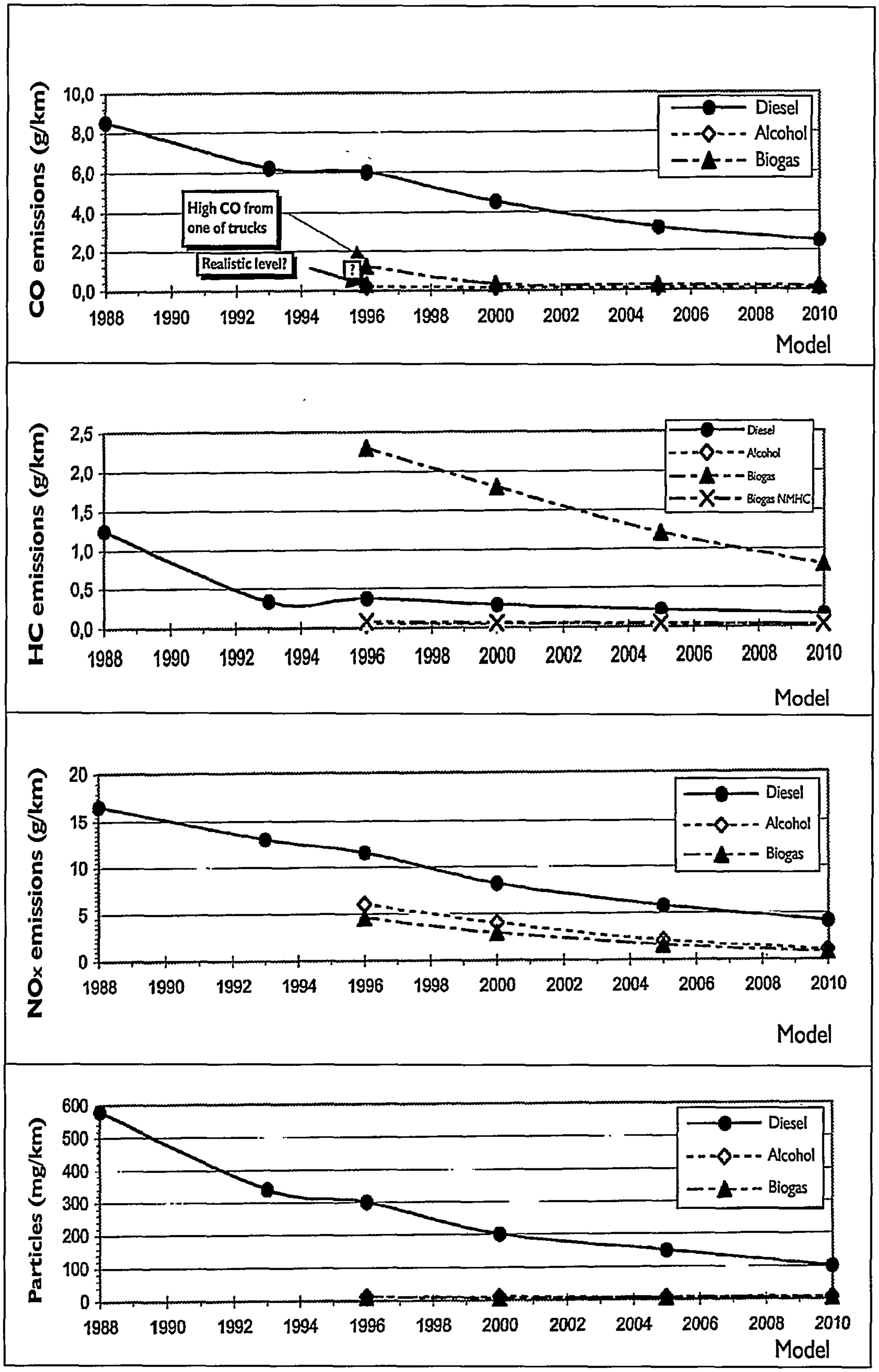


Figure 9.3. CO, HC and NO_X emissions from the use of petrol, diesel alcohol and biogas as fuels for heavy trucks (Egebäck K-E. 1997a).

measure. In these calculations it has been assumed instead that NMHC accounts for 3 per cent of total hydrocarbon emissions. As the alcohol-driven heavy trucks are assumed to have catalysts, these emissions will be very low. No catalysts are assumed in the case of diesel.

- As expected, NO_x emissions are highest in the case of diesel. The difference between alcohol and diesel is greater for heavy trucks than for buses, probably since the trucks used in these tests had a EURO 1 engine. The difference between alcohol and diesel is also expected to decrease in absolute terms in the future. Biogas is the fuel producing the lowest NO_x emissions.

Buses

City buses are the type of heavy vehicle for most emission data have been produced in recent years. Diesel-engined city buses account for a high proportion of these results. As many tests have also been made on buses running on alternative fuels there are more possibilities to make relevant comparisons for this type of heavy vehicle than for other categories.

Since the very first ethanol-driven buses were introduced as long ago as the early 1980s, a great deal of development has taken place. Even so, the consensus view is that there is still considerable potential to further reduce bus emissions, especially of NO_x. However, this requires further concentration on alcohol fuels, i.e., it is a task for both engine and vehicle manufacturers. Each fuel/engine combination requires adjustment to and development if the fuel's unique characteristics are to come into their own. This will not occur automatically, but will only be the result of dedicated effort. The following are some of the conclusions/comments that may be made:

- Diesel-engined buses have the highest CO-emissions if the comparison is made for engines without catalysts. As catalysts are nonetheless fairly common on city buses, a curve for this case has also been included in the figure. A catalyst turnover of 80 per cent has been assumed for CO. This is slightly lower than for alcohol and biogas, partly because it is a conservative estimate, but also because many diesel catalysts are designed for use with sulphur-containing fuels, and therefore have lower activity. The effect of catalysts can also be seen in the case of alcohol-driven buses in the form of a dramatic reduction in emissions when they were introduced.
- Emissions of hydrocarbons are highest for biogas, partly because the tests were made on otto engines, and partly because the oxidation of methane is lower than for all other hydrocarbons (and alcohols). As methane does not represent a hazard to health, emissions of NMHC are also included. In view of the difficulty in measuring methane exactly the content of heavy hydrocarbons has been assumed to be 3 per cent. This is lower than the approximately 10 per cent which is often referred to in the literature, but the measurements made in this study indicate that emissions of heavy hydrocarbons are especially low. Emissions of hydrocarbons from engines without catalysts are normally slightly higher for alcohols than for diesel and significantly lower than for gas. With the introduction of catalysts, on the other hand, hydrocarbon emissions from alcohol engines are very low. Hydrocarbon emissions from diesel-engined buses have been included in the figure with and without catalysts, in the same way as for CO. A catalyst turnover of 70 per cent has been assumed in this case.
- NO_x emissions are highest in the case of diesel. With the latest technology NO_x emissions are 30 per cent lower for ethanol than for diesel and this relative difference is expected to increase to more than 50 per cent in the future. The reason in this case is that EGR, which could be introduced in the future, has a greater potential to reduce NO_x in the case of alcohol engines than with diesel engines. NO_x emissions are lowest for biogas, mainly because the engine type used is an otto engine with lean burn, which generally produces low NO_x emissions. The other two types of engine are diesel engines. It is curious to note that an otto-engined car running on alcohol will probably produce lower NO_x emissions than a gas engine, thanks to the lower combustion temperature of the first fuel. This fact is also apparent for NO_x emissions levels from light vehicles running on alcohol and biogas respectively. However, no heavy diesel engines converted into otto engines for alcohol running

are commercially available. This is due to the complicated nature of such conversions and also to the efficiency of the otto engine being considerably lower than that of the diesel engine.

- Emissions of solid particles are highest for diesel engines, as may be expected. As effective particle filters are commercially available for diesel engines, the emissions for solid particles for this type of engine are stated separately.

However, as the emission requirements discussed for the future can be satisfied without particle filters, the market for this technique will probably be very limited for the foreseeable future. Only for certain categories of vehicles such as city buses will particle filters come into widespread use. Emissions of particles by alcohol and biogas engines are very low, which is easy to understand as these fuels do not produce any visible fumes. However, emissions of particles from alcohol

	Type of effect	***Critical* organ**	***Health risks***		**Comparison of concentration between ethanol- and diesel-fuelled buses**
			Ethanol fuelled buses	**Diesel fuelled buses**	
Ethanol	Inflammation	Airways	*a*	*a*	
Methanol	Inflammation	Eye, upper airways	*a*	n.e.d.[1)]	
Acetic acid	Inflammation	Upper airways	*a*	*a*	
Butadiene	Tumour	Several organs	*b*+	*b*	About 2 times higher concentration for ethanol
Ethene	Tumour	Several organs	*a*+	*a*	About 10 times higher concentration for ethanol
Propene	Tumour	Several organs	*a*+	*a*	About 10 times higher concentration for ethanol
Acetaldehyde	Inflammation, tumour	Eye, upper airways	*a*+	*a*	4-8 times higher concentration for ethanol
Formaldehyde	Inflammation, tumour	Eye, upper airways	*a*	*a*+	1.4-5 times higher concentration for diesel
Acrolein	Inflammation	Eye, airways	n.e.d.[1)]	*a*	
Benzene	Tumour	Bone marrow, lymph system	n.e.d.[1)]	*a*	
Benzo(a)pyrene	Tumour	Airways	*a*	*a*	
NO_2	Inflammation	Lung, airways	*b*	*b*+	1.6-1.8 times higher concentration for diesel
Particles	Inflammation, tumour	Lung, airways	*a*	*a*+	5-10 times higher concentration for diesel

[1)] no emission data given

a denotes that the concentrations are well below limit or low risk values.
b denotes that the concentrations from the buses alone or in combination with concentrations from other sources slightly exceed limit or low risk values.
\+ denotes that the risk is higher for one type of fuel compared to the other fuel.

Table 9.1. Comparison of hazards to health due to buses running on ethanol and diesel (Boström et al, 1996).

BUSES

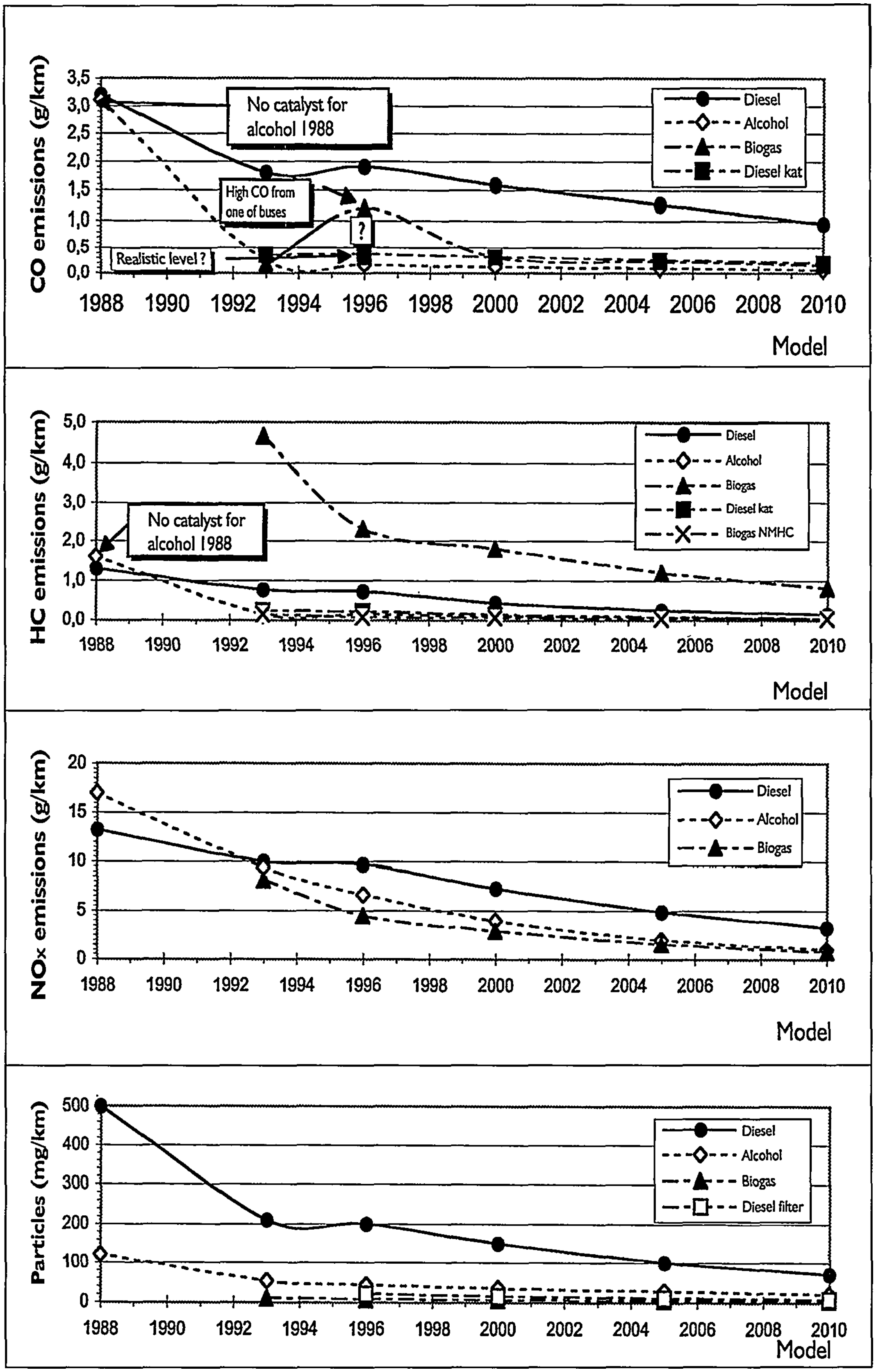


Figure 9.4. CO, HC, NO_x and solid substances emissions from use of diesel, alcohol and biogas as fuels for buses (Egebäck K-E. 1997a).

engines require separate analysis. In the case of ethanol-driven buses these emissions are considerably higher than for buses running on biogas.

Hazards to health

The Institute of Environmental Medicine (IMM) in Sweden has carried out studies (Boström et al, 1996) into the health hazards associated with the use of ethanol as a fuel for buses. The study is based on emission data produced by the Luleå University of Technology, the Stockholm University and AB Svensk Bilprovning. In addition, SMHI has made model calculations for the concentration in five typical urban areas (Omstedt G, Kindell S, 1997).

The evaluation concentrated on emissions that are believed to be potential hazards to health arising out of the use of ethanol as a fuel. The emissions selected were ethanol, methanol, acetic acid, butadiene, ethene, propane and formaldehyde, acetaldehyde, and acroleine. Certain emissions which are normally present in the exhaust fumes from vehicles running diesel fuel or petrol and which are regarded as hazards to health were also assessed. Examples of these are benzene, polycyclical aromatic hydrocarbons (PAH), NO_2 and solid substances.

The model calculations, together with the following risk evaluation, are summarised in **Table 9.1.**

To sum up, only two of the emissions exceeded their threshold value or low risk levels. These were butadiene and nitrogen dioxide (NO_2). It should, however, be noted that the information available for assessing the low risk level for butadiene is rather limited and relates only to a small number of animal tests and is thus not very reliable. In the case of NO_2, on the other hand, a large volume of experimental data for both animals and humans is available, including epidemiological studies. Moreover effects on humans can be demonstrated at concentrations close to the threshold values. This means that if the threshold value for NO_2 is exceeded there is a dis-

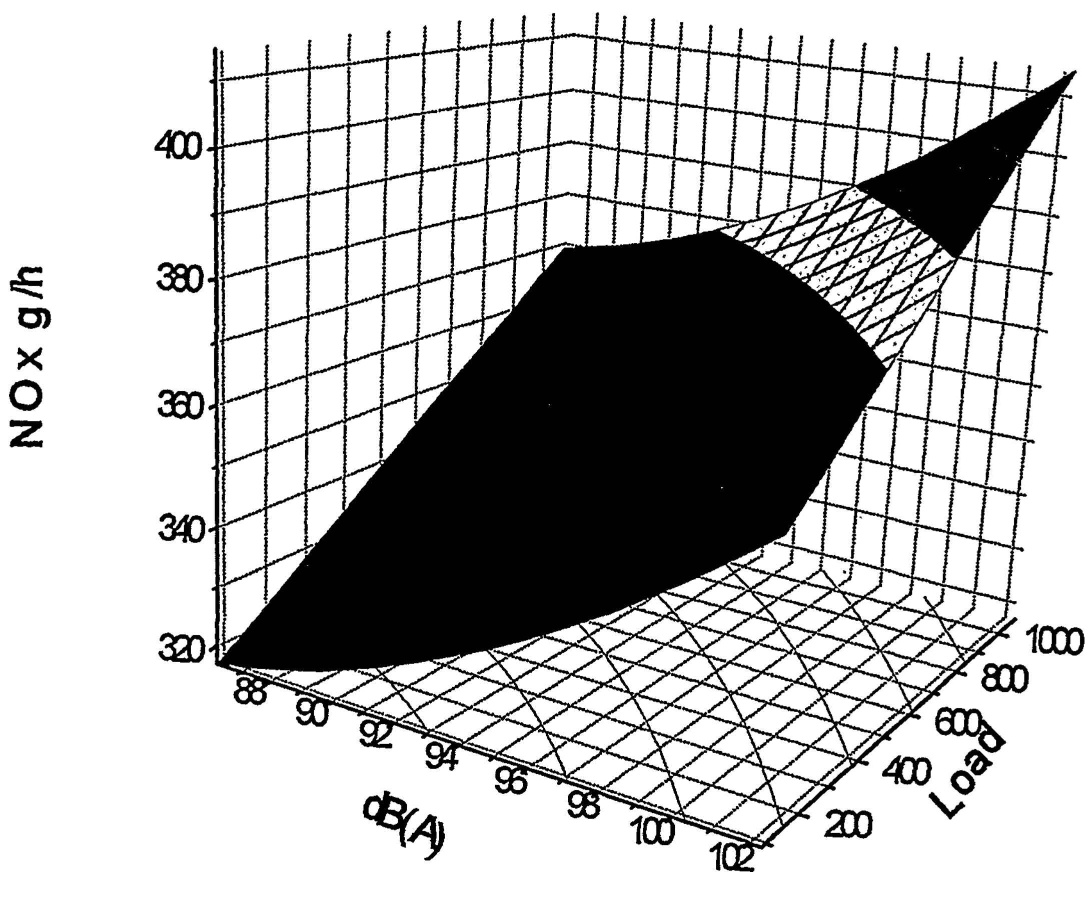


Figure 9.5. Connection between noise, NO_x emissions and engine load. (Zurita G. 1997).

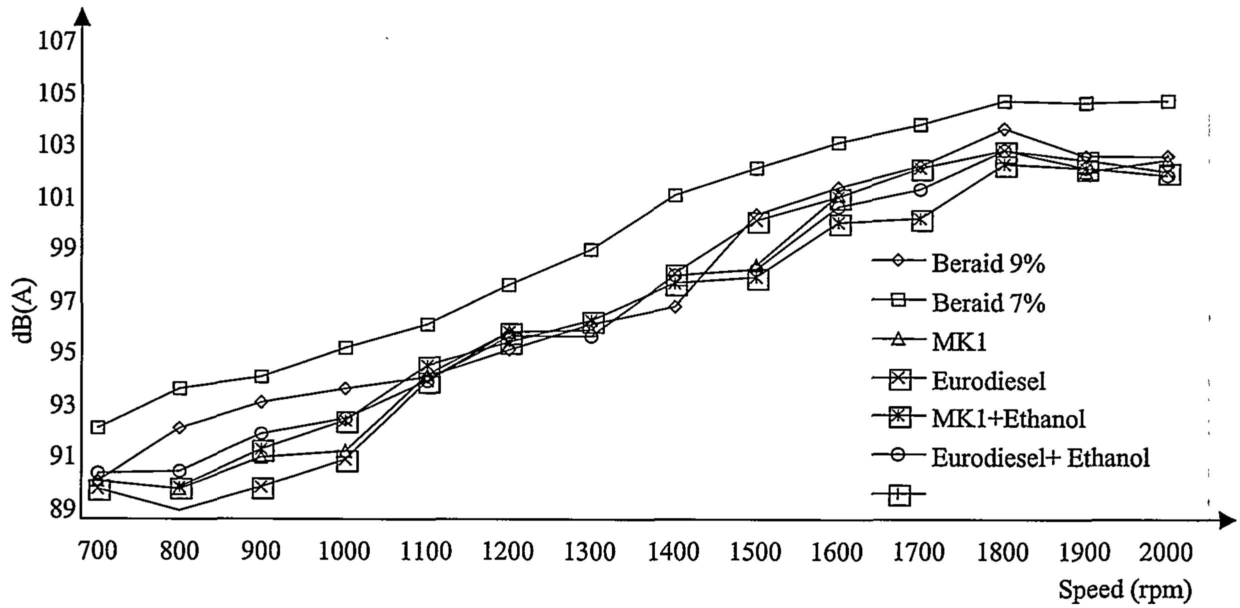


Figure 9.6. Connection between noise and speed for certain different types of fuel (Zurita G. 1997).

tinct risk of an effect on human health. If the low risk level for butadiene is exceeded, it is not so certain that this involves a health hazard.

In view of these results, the greatest importance should be attached to cases when the threshold value for NO_2 is exceeded. In the view of the authors, it is also important to draw attention to the fact that the assessments are all based on data which are more or less unreliable. Moreover, the assessment is also based on the thirteen contaminants selected. Other contaminants or possible synergies have not been taken into account.

It is also pointed out in the study that the technique upon which ethanol engines are based has reached a totally different stage of development than the technique for engines running on diesel, and that

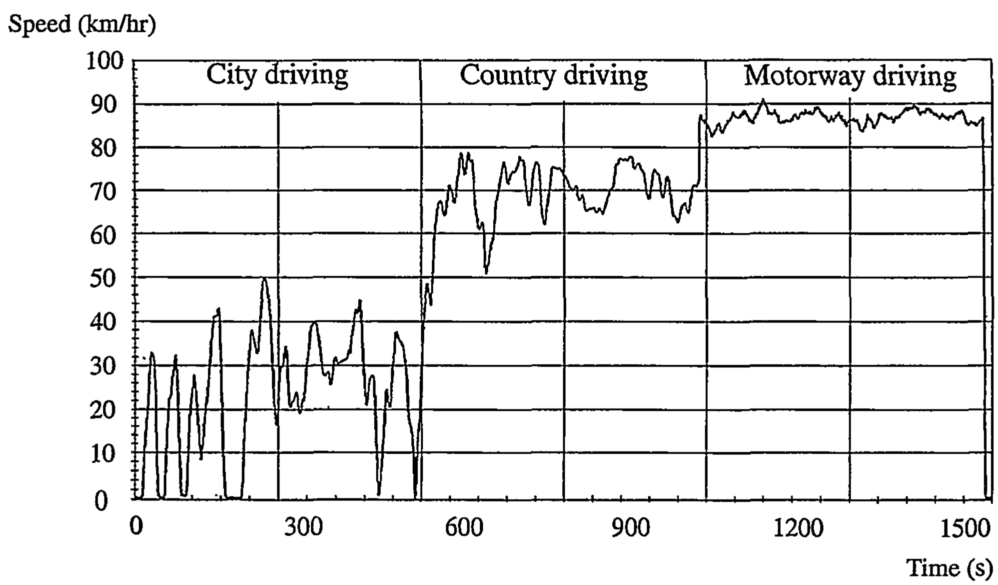


Figure 9.7. The Fige running cycle is proposed as the EU standard for testing of heavy vehicles. (Egebäck K-E, Westerholm R. 1997).

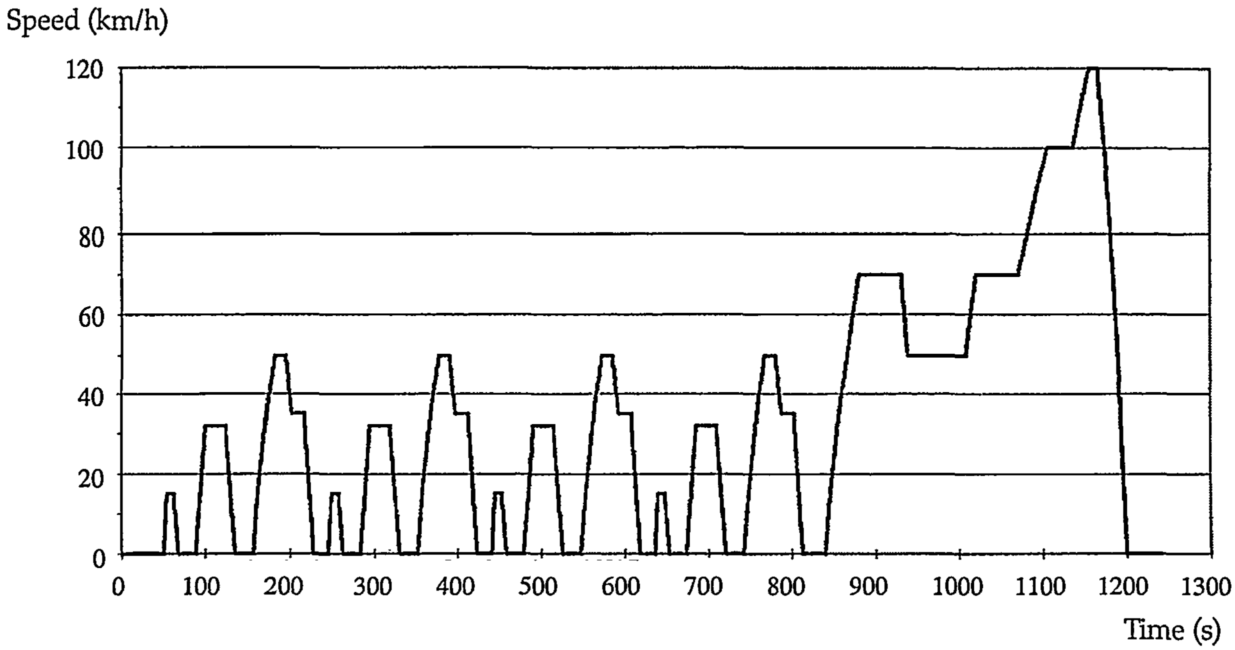


Figure 9.8. ECE running cycle for light vehicles (Egebäck K-E et al. 1997).

these new types of ethanol engines therefore offer considerably greater potential for health and the environment in the future.

Noise

Studies carried out at the Luleå Institute of Technology have shown that there is a definite connection between the selection of fuel, emissions, load conditions and noise. It has been possible to study theses relationships in more detail by making analyses of the interaction between different variables (multivariate data analysis) (Zurita G. 1997). The method verifies that noise and hydrocarbon emissions are largely influenced by speed, whilst NO_X emissions are largely dependent on load conditions.

The fact that the noise level tends to be higher in connection with ethanol running in diesel engines is due to the compression ratios in the ethanol engine being higher and the combustion sequence being different that with diesel running. The way this works in practice has been studied in the Svenol project (Ekelund M. 1997), which involved testing seven ethanol-engined trucks (see Chapter 7). All the trucks in the first stage of the Svenol project were tested for noise. These studies confirm elevated noise levels in connection with ethanol running. There were, however, extensive differences between the different vehicles.

Measuring noise levels in this way is a difficult process, and the results depend on numerous factors such as temperature, tyre condition, etc. The differences between the combustion characteristics of diesel and ethanol do, however, indicate that noise levels generally tend to be higher for engines running on ethanol. If the vehicle designer is aware of these connections, problems due to noise can be overcome fairly simply, for example by introducing noise baffles, etc. at the right place in the engine compartment. It is also possible to make modifications that take account of noise by optimising the engine. The most significant reduction in noise can, however, be brought about by increasing the ease of ignition of the ethanol, which will also increase efficiency and reduce fuel consumption.

Emission testing methods

The methods in current use for measuring, determining and evaluating emissions from various types of fuel, as well as their effect on the environment and health, were designed for use with fluid fossil fuels, i.e., petrol and diesel. This means that certain problems arise when the methods are used to evaluate alternative fuels.

In an evaluation of different test methods (Egebäck K-E, Westerholm R. 1997) it was noted that an assessment of the characteristics of the fuel

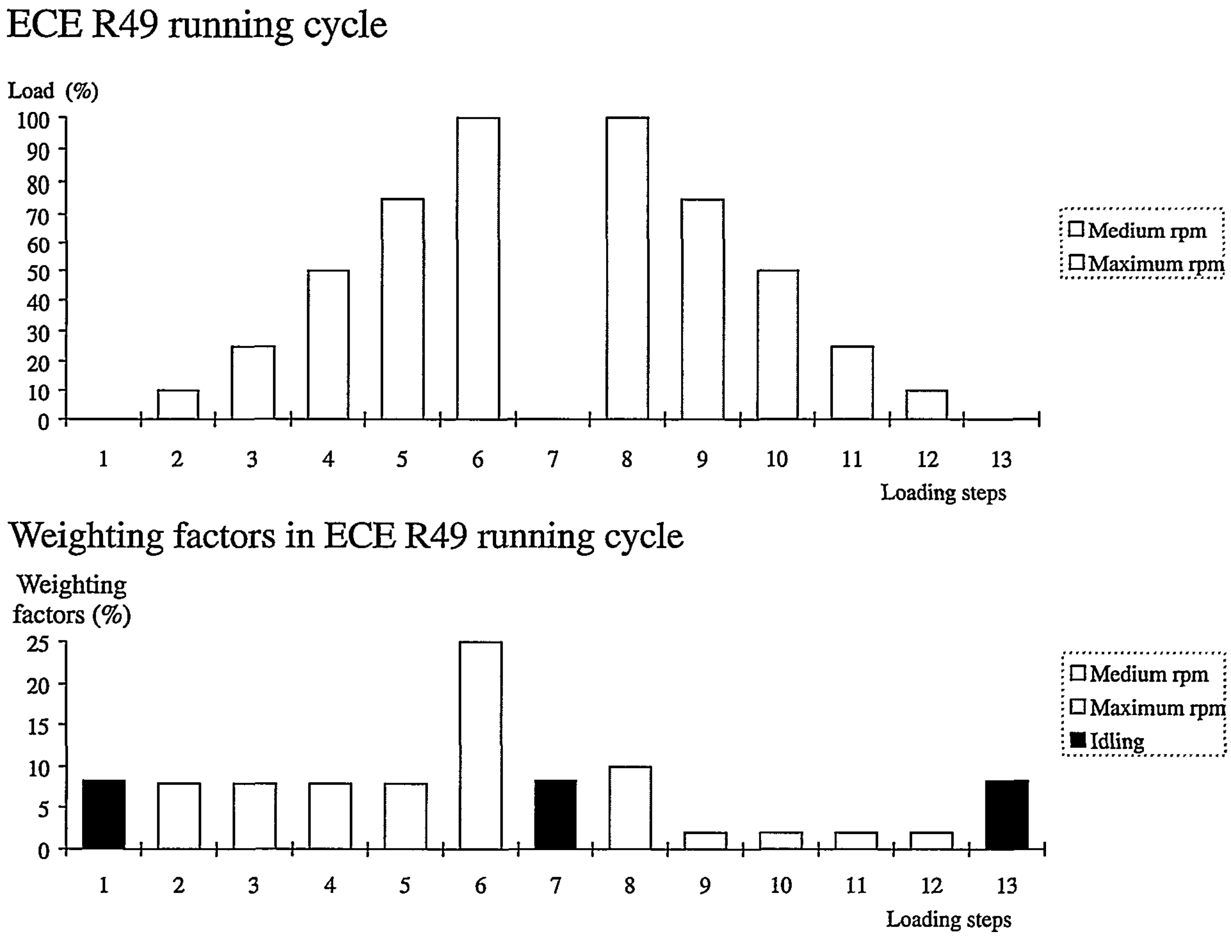


Figure 9.9. ECE R49 running cycle (also known as the 13-mode cycle) for heavy vehicles (Egebäck K-E et al. 1997).

Regulated emissions	**Non-regulated emissions**
Carbon monoxide, CO	Polyaromatic hydrocarbons, PAH
Hydrocarbons, HC	Aldehydes (formaldehyde, acetaldehyde)
Nitrogen oxides, NOx	Benzene, toluene
Particles	Butadiene, ethene, propene
	Alkyl nitrites (ethyl and methyl nitrites)
	Carbon dioxide, CO_2

Table 9.2. Examples of regulated and non-regulated emissions. Regulated emissions include contaminants which are statutorily regulated, while non-regulated emissions are those which are not subject to statutory requirements.

requires investigations which go far beyond the standardised methods currently available. For example, it is important to use running cycles which emulate actual conditions to a greater extent, by which is meant that the test methods must emulate cold starting and hot running at varying speeds and load conditions (**Figure 9.7**).

There are a number of different test methods in use around the world which in various ways attempt to emulate actual operating conditions. That in current use in the EU is the ECE running cycle of which there are two versions, one for light vehicles and one for heavy vehicles (**Figures 9.8 - 9.9**). However, a proposal has been put forward in the EU to replace this with the Fige running cycle (Figure 9.7) for heavy vehicles, as this is considered to reflect actual running conditions more accurately.

Numerous other test methods are used for testing engines and vehicles. In the USA, for example, a test method (FTP-75) is used for passenger cars which was also used in Sweden before the country joined the EU. Another test method that is used in Sweden is the Braunschweig cycle or bus cycle. This method was specifically developed to reflect the running cycle of buses in city traffic with frequent stopping and starting at bus stops. Such tests have been carried out as a matter of routine on those bus fleets which were included in KFB's fuel programme.

Another central question is what emission components shall be covered by the tests. At present, a distinction is made between *regulated* and *unregulated* emissions (**Table 9.2**).

As an aid for the coming development work, Egebäck and Westerholm have proposed certain assessment criteria and a method involving phased assessment of the characteristics of the vehicle-fuel combinations. The selection of exhaust components should be limited to such contaminants as have been shown by experience to occur in such quantities in exhaust fumes that they could be of importance in an assessment of potential effects on health and the environment.

Conclusions

- The replacement of petrol or diesel by biofuel would, at present in most applications and especially in the case of diesel engines, significantly reduce both regulated and unregulated emissions. The advantage over conventional fuels is expected to persist in the future even though technical developments to these fuels are also expected.

- The replacement of fossil fuels by renewable fuels would reduce the net introduction of carbon dioxide into the atmosphere. Consequently, biofuels would help to reduce the risk of greenhouse effects.

- In order to give a fair picture of the potential advantages to health and the environment of biofuels regulatory systems needs to be supplement with tests and requirements which also include some of the substances which are not at present subject to regulation (unregulated emissions).

Effects on the economy – an analysis

- *Production, distribution and vehicle costs*
- *Evaluation of global environmental effects*
- *Evaluation of local and regional environmental effects*
- *Arriving at an economic balance*
- *Means of control*
- *Conclusions*

3

Chapter 10

EFFECTS ON THE ECONOMY – AN ANALYSIS

An analysis of economic effects involves an attempt to balance resource input against effects of different types. This type of analysis for biofuel is for natural reasons largely concerned with analysing and evaluating environmental costs since biofuel is being introduced with environmental goals in mind.

Production, distribution and vehicle costs

On the cost side, the cost of producing fuel is the single most important component in such an analysis. As Chapters 3 and 4 explain, biofuel cannot at present be made available at a price that is competitive in relation to petrol or diesel. In the longer term, however, the technical potential exists to lower the price to a level equivalent to the oil prices that are likely at that time, but this will require increased internalisation of environmental effects, i.e., a reflection in the price of the cost of environmental effects to the economy. This can be brought about by raising the CO_2 tax in the future. In addition to this, oil prices will probably have to rise in the long term, as the availability of oil will become more limited (see **Table 10.1**).

In an initial phase, there are also certain additional costs associated with vehicles and the infrastructure. However, in connection with a commercial introduction these costs would disappear. Olsson L-O (1996) notes that the parameter which had the greatest impact on the economic calculations is the price of fuel. Other equipment in the vehicle, and thus the costs, are largely independent of which fuel is used. Looking back at changes in fuel costs for passenger cars during the past 15 years, we can note, for instance, that prices have moved at least in line with the consumer price index (**Figure 10.1**). The major event during this period of time was the introduction of catalysts, a technique that many initially thought would involve car owners in considerable additional

Vehicle	Fuel	Current running costs excluding taxes	Running costs 2020 without CO_2 tax	incl. present CO_2 tax	incl. higher CO_2 tax
Passenger cars	- Petrol	2.1	1.8	2.4	2.9
	- Ethanol from farm crops	5.2 – 5.4	2.3	2.3	2.3
	- Ethanol from cellulose	9.1	2.9	2.9	2.9
	- Methanol from natural gas	4.1	2.7	2.7	2.7
	- Methanol from cellulose	8.6	3.4	3.4	3.4
	- Electricity	9 – 10	3.1	3.1	3.1
Trucks, light	- Diesel	7.9	6.9	9.0	11
	- Ethanol from farm crops	20 – 21	12	12	12
	- Ethanol from cellulose	34	14	14	14
	- Methanol from natural gas	17	15	15	15
	- Ethanol from cellulose	33	17	17	17
Trucks, heavy	- Diesel	11.3	10	13	16
	- Ethanol from farm crops	29 – 31	17	17	17.
	- Ethanol from cellulose	55	21	21	21
	- Methanol from natural gas	25	21	21	21
	- Methanol from cellulose	47	25	25	25

Table 10.1. Estimated running costs (SKr/10 km) for petrol, diesel and alternative fuels today and in 2020 (KFB, NUTEK, SIKA, 1997).

costs. Statistics show that the introduction of catalysts did not lead to any such cost increases. A similar situation can be expected in connection with the introduction of biofuel.

Assessment of global environmental effects

The effects of biofuel on the global environment are mainly the greenhouse effect and specific emissions of carbon dioxide, CO_2. The assessment of the economic effect of changes in CO_2 emissions is of crucial importance when it comes to evaluating the overall economic effects. The divergences in the value of CO_2 between different calculations and different studies are quite wide. This is due not only to differing political evaluations of the greenhouse effect, but also to the uncertainty of the economic calculations because of the considerable measure of scientific uncertainty regarding the effects of higher CO_2 emissions.

In the surveys made by KFB during the past few years two evaluation alternatives have been used for CO_2, namely:

- Evaluation of CO_2 which is the same as the current level of CO_2 tax circa 0.37 kr/kg CO_2, which corresponds to a CO_2 tax per litre of petrol of 0.86 kr and of 1.05 kr per litre of diesel fuel.
- Evaluation of CO_2 corresponding to the tax assumptions in the communication committee[1]

[1] The Communication Committee was a parliamentary committee set up to investigate how a future transport sector should be designed for sustainability. (New Direction in Traffic Policy, SOU 1997:35).

for 2020 of around 1.15 kr/kg CO_2, which corresponds to CO_2 tax of 2.70 kr per litre of petrol and 3.11 kr per litre of diesel.

In calculations of cost per kilogramme of reduced CO_2 it is naturally important to attempt to quantify how much CO_2 emissions will decline per litre of replaced petrol or diesel. Such a quantification must also be based on a life cycle assessment. As noted in Chapter 2 it may be assumed that net emissions of CO_2 from biofuel will correspond to some 10-15 per cent of those from fossil fuels.

The greenhouse effect resulting from CO_2 emissions is a global environmental problem. It is a matter of indifference, as far as Sweden is concerned, whether the emissions come from Sweden or from other countries. The environmental benefit in Sweden of a reduction in carbon dioxide emissions in Sweden would be very moderate. On the other hand there would be some environmental benefit in other countries from a reduction in Sweden. In these economic calculations, a political valuation will be used as a measure of environmental benefit. This valuation is probably (at least in the short term) considerably higher than the direct domestic environmental benefit of lower CO_2 emissions. The valuation could instead be regarded as a "shadow price" for CO_2 emissions to enable Sweden to comply with international commitments and possibly also a value associated with speeding up international developments by taking the lead.

Evaluation of local and regional environmental effects

As note in Chapter 9, biofuel will make it possible to bring about improved health and environmental improvements at both local and regional level. The potential environmental benefit has been valued in Johansson O (1997). His study is based on the emission results obtained and investigations carried out within KFB's biofuel programme, which were discussed earlier in this report. The environmental evaluations are based on previous research into environmental costs. The environmental values used are shown in **Table 10.2.** As this table indicates, the difference in effects on health in rural areas and city

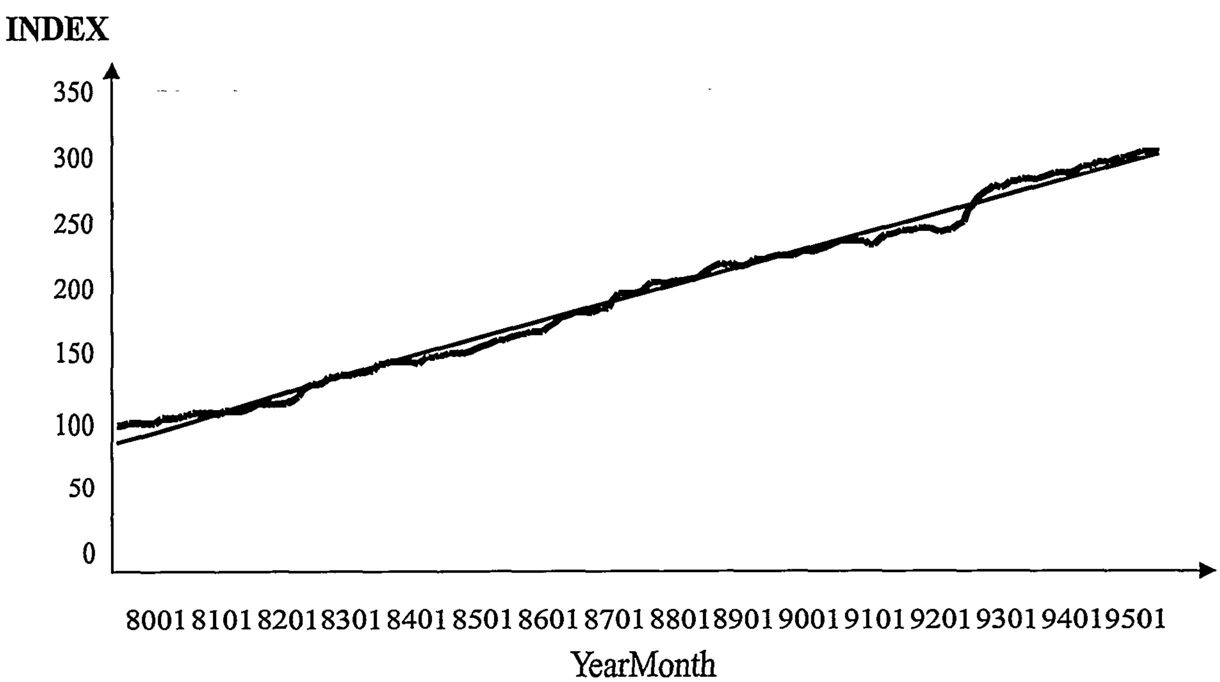


Figure 10.1. Index showing price trends for new cars compared with CPI base year 1980. Conclusion – the introduction of catalysts has not affected cost trends (Olsson L-O, 1996).

	Harm to nature	Effects on health, SKr/kg		
	SKr/kg	Rural areas	Urban areas, average	Inner city areas
VOC, conventional fuels	17	0	49	245
VOC, alcohols	0 – 17	0	0 – 49	0 – 245
NOx	40	0	49	245
Particles	0	180	904	4,520

Table 10.2. Environmental values used to evaluate local and regional environmental effects (Johansson O. 1997).

areas are regarded as being very wide, and even within a city between an average value and a value for the centre, where congestion and traffic jams, etc. all help to produce high levels of CO_2 emissions.

By combining the environmental values as shown above with the issue emission factors for different years (which are taken up in Chapter 9) we can calculate the external costs caused by emissions for various types of vehicle and use. **Table 10.3** summarises the local and regional environmental benefits which can be expected to be generated by running passenger cars and trucks on biofuel instead of fossil fuel.

As Table 10.3 shows there is a not insignificant environmental benefit to be derived from using biofuel under existing conditions. Naturally, the greatest effect will be produced in city centres and from the use of biofuels by buses and trucks in city traffic. We can also see from Table 10.3 that the difference in environmental costs between petrol, diesel and biofuel will eventually narrow, and that we should expect further technical development of conventional types of vehicle. In the case of buses and other heavy city traffic, however, there will also be not insignificant environmental benefits in the future. With buses, for example, the environmental benefit from changing over now from diesel to ethanol running, on the assumptions in these calculations, would be some 0.34 kr/kilometre in light city traffic and 1.26 kr/kilometre in dense city traffic. Although this environmental benefit will be lower in the future, it is still not insignificant – 0.18 kr/kilometre in light city traffic and 0.63 kr/kilometre in dense city traffic.

Naturally calculations of this type involve some simplification and rough assumptions and they, therefore, do not represent an absolute measure of the economic benefit to society. However the calculations can serve as a rough guide to the order of size of the environmental benefit, and indicate in which vehicle segments the total economic benefit would be greatest for any fuel replacement strategy. The calculations also indicate that the order of size of the cost of local and regional environmental effects on health and the environment is relatively modest, by comparison with the estimates of global environmental effects.

When coupled with other benefits from a reduction in CO_2 (which can be priced in accordance with the previous section), local employment effects, and possible cost of deposits e.g. for bio gas raw materials, and so on, a valuation of local and regional environmental effects will nonetheless play an important part in the total cost analysis.

Economic balance

When arriving at a balance at national economic level between various measures (such as subsidising the introduction of biofuel or doing nothing) an attempt is made to balance the advantages and disadvantages as well as the benefits and costs that can be related to various measures in relation to each other. If this is to be possible it is generally practical to convert all effects into monetary units. Such a procedure necessarily involves a great deal of simplification, but it can nonetheless, if correctly performed, give a picture of what effect alternative fuel strategies will have on society. It can also give an indication of the relationship and orders of magnitude of costs and benefits, i.e., indicate what is large and what is small.

When the government engaged KFB to throw light on alternative strategies for the introduction of biofuel, a special study was made of their effects on the economy (KFB, NUTEK, SIKA, 1997). **Figure 10.2** show how the economic effect of a low blend of alcohol with petrol would be determined by what value/price society places on the greenhouse effect and what production cost for ethanol is believed to be possible to achieve. A more extensive, theoretical analysis of the possibilities and problems associated with overall economic analyses in the biofuel field is also provided in KFB's system study report (Sterner T. 1997).

As this report shows, when the economic effects of the introduction of biofuel are analysed in this way, there are two factors above all that will influence the final balance: firstly, an assessment of the future cost of producing biofuels, and secondly an evaluation of the greenhouse effect – CO_2. Both of these factors give rise to genuine uncertainty. As the previous section shows, the cost of producing ethanol is currently running at around 3.50-4.50 kr/litre, but this could eventually be halved as a result of successful development work. As regards a valuation of the greenhouse effect this is mainly a political issue and pricing it must be based on scientific uncertainty and international agreements. What values would apply in the future for these two factors we can at present only guess.

	Year	Environmental costs without CO_2 (öre/10 km)		
		Country roads	Urban, average	Urban, inner city
Petrol-engined passenger cars	1996	29	97	369
	2010	3	10	38
Diesel-engined passenger cars	1996	39	127	479
	2010	5	22	92
Passenger cars running on alcohol	1996	10	34	128
	2010	0	2	7
Passenger cars running on biogas	1996	7	22	80
	2010	1	3	12
Diesel-engined buses	1996	402	999	3,383
	2010	131	325	1,103
Buses running on alcohol	1996	293	659	2,122
	2010	60	142	473
Buses running on biogas	1996	214	501	1,644
	2010	55	133	445
Heavy diesel-engined trucks	1996	467	1181	4,036
	2010	167	419	1,427
Heavy trucks running on alcohol	1996	260	564	1,780
	2010	44	98	314
Heavy trucks running on biogas	1996	214	501	1,644
	2010	42	105	358

Table 10.3. Evaluation of local and regional environmental costs for passenger car, busses and trucks running on various fuels (Johansson O. 1997).

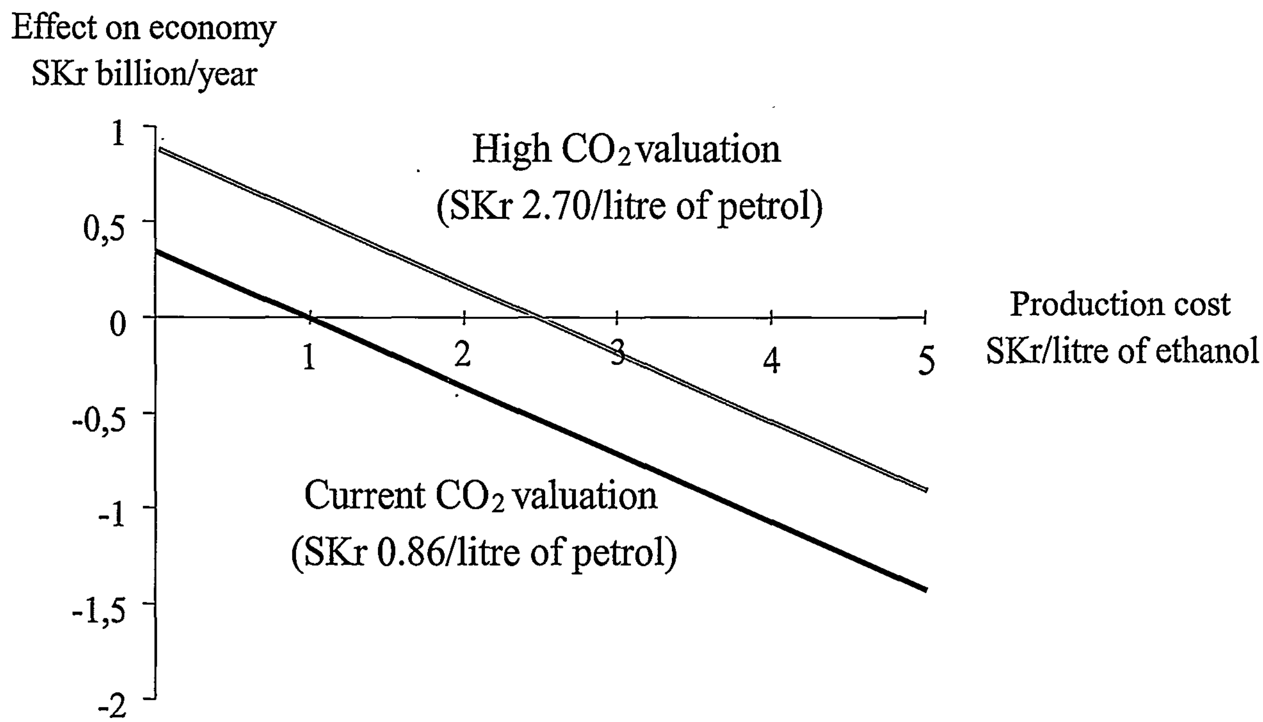


Figure 10.2. Estimated annual effect on economy of a low mixture of ethanol in petrol related to various assumptions regarding production costs for ethanol and government's evaluation of greenhouse effects today and in the future – CO_2 evaluation (KFB, NUTEK, SIKA. 1997).

Means of control

Theoretically, in an efficient economy, the total economic cost for the last unit consumed should equal the benefit derived from consuming this unit, i.e., the marginal cost at national level shall equal the marginal benefit. One way of steering the market towards the economically best solution is to correct the price of the environmental effects which arise. This could be done by introducing an environment tax which is equal to the external marginal cost. Physical controls of various types generally do not result in the same cost efficiency.

However, in practice it is not easy to internalise environmental effects in this way, as the costs and benefits cannot be readily valued in a way upon which everyone can agree. The process always involves some type of assessment. A further problem is that the transport sector is international. One country cannot depart too far from other countries without it having significant adverse effects on competition. The selection of means of control thus becomes a question of political considerations which must include both financial means of control as well as regulations. The means of control (both taxes and charges as well as other policy measures) which could be considered and which are of major significance for any biofuel ventures are the following:

- Carbon dioxide tax, which should be based on the fuel's content of fossil carbon and should be the same for all types of traffic.
- Energy tax on fuel differentiated on the basis of quality or environmental classification.
- Vehicle tax, differentiated on the basis of the vehicle's characteristics in accordance with an environmental and safety classification.
- Charges on cars in urban areas.

- Environmental zones which regulate the free use of cars in urban areas.
- Environmental norms and standards which regulate permitted exhaust emissions and noise from vehicles and which are neutral in terms of technique/equipment.
- Agreements or regulations concerning fuel consumption, e.g., in connection with the procurement of new vehicles.
- Environmental classification and environmental labelling of vehicles and fuels.

The provision of support for research and development can also be regarded as a means of control available to government. By supporting R&D the state stimulates the development of new equipment and expertise which can be used freely by everyone in society as a means of driving the transition towards environmental goals and the use of environmentally friendly technology.

Activities in connection with Agenda 21 have also demonstrated that local environmental requirements and local action programmes are playing an increasingly important role in environmental activities. In connection with the introduction of biofuel this may mean that during the initial phase certain local and regional benefits must be revalued, as previously explained. Environmentally friendly procurement practices will also assume growing importance. Work in the City of Stockholm (described in Chapter 7) illustrates one way in which international co-operation can help to increase the number of vehicles purchased with new technical equipment, and thus make demands on fuel and vehicle suppliers.

Individual companies and private individuals are also showing growing interest in environmental profiles. Companies might be willing, during the introduction stage, to accept these additional costs. In the long term, however, companies would not be prepared to subsidise new technology, although in the long term it could be likely that society will place a higher value on the environment in view of the emergence of income effects. The fact is that we tend to place a higher value on the environment as we become richer (Johansson O. 1997).

Conclusions

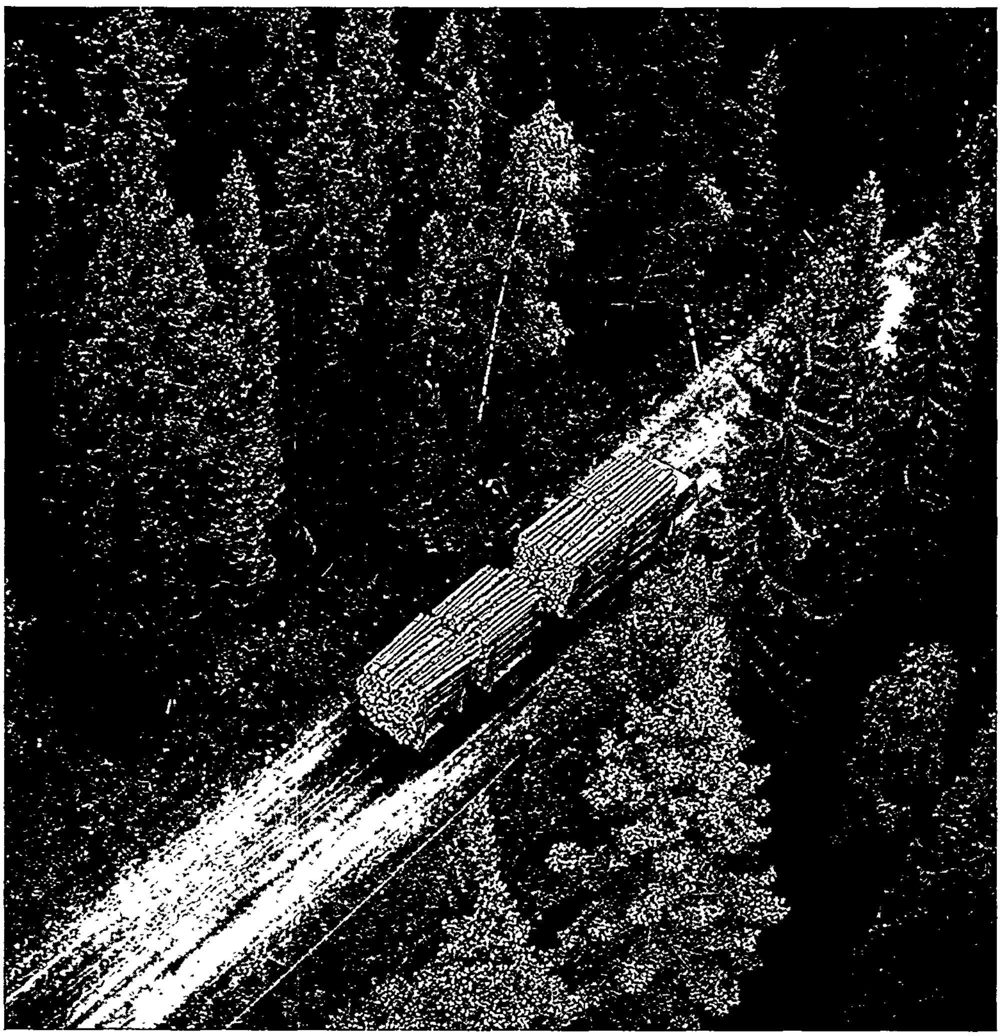
- In order to make the use of biofuel economically worthwhile, considerably lower production costs than at present are essential. In the longer term, it would appear that changing technical conditions will help to reduce price levels to the equivalent of the then prevailing oil price.

- The environmental effects that should be priced and which play a major part in the overall economic profitability of biofuel are the greenhouse effect, and local environmental and health effects in urban areas. The cost of these effects needs to be reflected in the fuel price, i.e., internalisation of environmental effects. This can be done by regularly raising the carbon dioxide tax and other environmental charges to reflect the efficiency of the economy. This would also improve the profitability of biofuel.

- In order to steer society towards environmentally-adapted fuels, regulations and other means of control are required, in additional to financial control instruments. Support for research and development is one such means of control. In order to create credibility and involvement on the part of vehicle users, the car and oil industry and new players in the biofuel industry it is essential that the various means of control used by the state all tend to have the same effect and that they are sustainable.

Strategies for the future

- *To create a market for biofuels*
- *Strategies for the introduction of biofuels*
- *Obstacles to this introduction*
- *Gaps in knowledge*
- *Conclusions*



Chapter 11

STRATEGIES FOR THE FUTURE

A change-over in the transport system towards a sustainable society requires government input of various types. However, in a market economy this is not merely a question of working out detailed plans for the future. Instead, it is a matter of creating long-term conditions for players on the market. Different strategies for introducing biofuels are necessary to indicate the desired direction and to stimulate proposals for various means of control which may be needed to meet the environmental targets.

Creating a market for biofuels

Experiences from KFB's biofuels programme show that the introduction onto the market of new fuels, such as ethanol and biogas, needs to be preceded by practical demonstrations for various users around the country. These demonstrations are aimed at developing and testing new solutions and showing in practice that they actually work. These demonstrations thus help to interest key players in the automotive and oil industries, as well as various vehicle users (public transport companies, haulage contractors, taxis, companies with large fleets of cars, etc.) and involve them in the development process. In order to progress from demonstration to marketing it is necessary to have the right economic conditions for the market players to invest in production equipment and vehicles that run on biofuels. During such a transition phase new technology is more expensive than existing technology and the state therefore needs to intervene with subsidies, which should then be gradually phased out. Another condition (which is discussed in Chapter 10) is that environmental effects should be reflected in the price of fossil fuels and environmentally harmful fuels. As this is a question of large and long-term investments, the players on the market require the government to apply means of control that are consistent and long term in character.

Strategies for introduction of biofuels

In the summer the 1996 the Communications Committee, KomKom, engaged KFB, NUTEK and SIKA to work out a basis for a strategy for the introduction of biobased fuels by 2010. The point of departure for this task was the aim to raise the proportion of biobased fuels to 15 per cent of total fuel consumption by road traffic in Sweden by 2010.

Three different strategies for introduction are

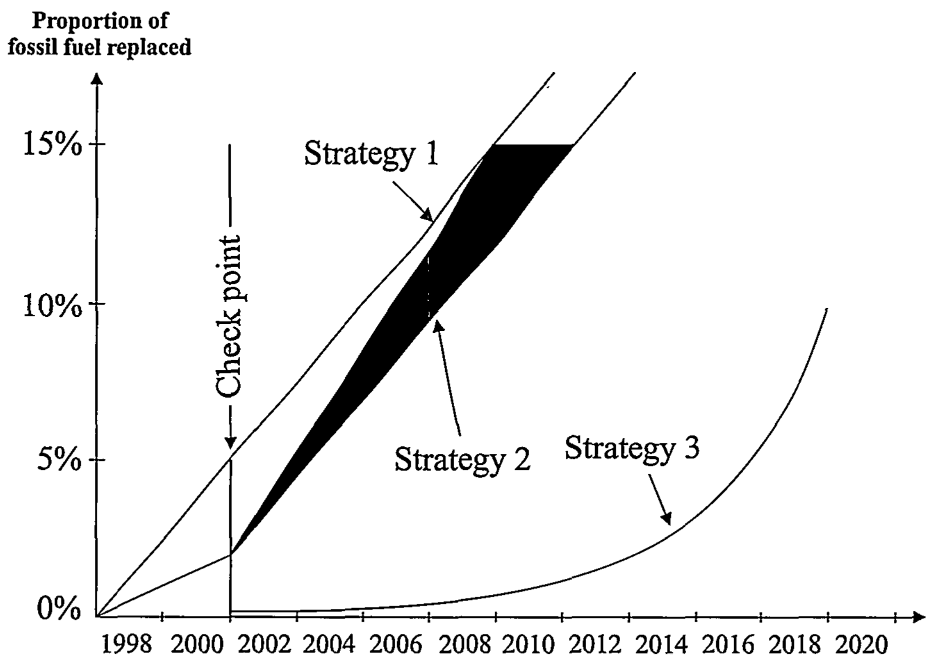


Figure 11.1 Three scenarios for introduction of biofuels (KFB, SIKA, NUTEK 1996).

Strategy 1 involves continued research, development and demonstration activities with various types of vehicles and fuels (ethanol/biogas/electricity), low blends of ethanol and petrol and the phasing in of FFVs.

Strategy 2 involves a check point being inserted to monitor progress in the year 2002. As strategy 2 involves a time delay at the initial stage, there is some risk that the target introduction

illustrated in **Figure 11.1.** The proposal means that ethanol would be given a dominant role and be used mainly in FFV vehicles (55 per cent), heavy vehicles (25 per cent) and in the form of low blends with petrol (20 per cent).

Strategy 1 is based on the assumption that the 15 per cent target will be reached by 2010. This strategy means immediately bringing into effect the incentives and taking the decisions necessary to initiate a process that would lead to this target being reached. Far-reaching adaptations would need to be made on both the supply and the demand sides to achieve this target.

The implication of strategy 1 is that no new technology for production can be expected that would involve significantly lower costs than at present being brought into use to any great between now and 2010. Even if certain technical breakthroughs are made, a forced introduction could create deadlocks that would make the phasing in of new technology difficult.

It is also assumed that the government will take a more active role in the build-up of production capacity for ethanol. We also assume that industry will take an active role in the implementation of this strategy in the form of production of fuels and supply of vehicles.

date cannot be set at 2010. On the other hand, this strategy would make it possible to contain and control economic costs and consequences for public finances. Strategy 2 assumes that an introduction starts almost immediately, but that this will take place at a lower intensity than in strategy 1, up to the check point. It is also assumed in strategy 2 that the state will not take an active part in the construction of production facilities for ethanol, as the state would wish to retain its freedom of action during the period before the check point. Between now and 2002 a large proportion of the ethanol consumption can be covered by imports regulated in short-term agreements, etc. This would cause greater dependence on the world market price for ethanol, but will limit the consequences of potentially faulty investments in production plants.

Strategy 3 assumes a slower introduction rate and is limited to R&D and demonstration input up to the check point in 2002. Strategy 3 means that it would not be possible to reach the target of introduction by 2010. This would postpone the need for a decision on introduction to the check point, with the aim of reducing total costs and making it possible to take an unbiased stand on the mixture of alternative fuels and thereby on the various production and introduction alternatives.

In 1997 KFB was given new instructions, namely to investigate in greater detail certain issues relating to the introduction of biofuels for running vehicles. The report on this study (KFB, NUTEK, SIKA, 1997) concludes that a low admixture of ethanol throughout the entire petrol pool would be technically feasible by 2002, but that this would involve substantial costs, in terms of the national economy and also in terms of public finances. Instead the possibility of a broader focus is being discussed, in which the volume of biofuels would be approximately the same as in the low admixture case.

If there is to be a supply of ethanol available for blending throughout the entire petrol pool by 2002, it will be necessary for the ethanol to be based on grain. The technology for this type of production is available now, but it will take time to build up domestic production capacity. The rapid introduction of ethanol thus assumes, at least initially, relatively high imports of alcohol.

Biofuels can be introduced in various ways. It is technically possible to blend in low volume percentages throughout the petrol pool (5-6 per cent) directly with existing vehicles, and this would rapidly result in a given volume of ethanol being used in the transport sector. This type of strategy would provide environmental benefits in the form of lower carbon dioxide emissions. Ethanol in the form of pure alcohol can also be introduced in more limited vehicle segments, such as buses and other heavy traffic in urban areas. This provides an environmental benefit in the form of lower carbon dioxide emissions and cleaner air in cities. As shown in Chapter 10, this represents a not insignificant benefit to society. The use of ethanol and biogas in heavy vehicles would thus generate the maximum benefit from the positive environmental effects of biofuels. Targeted introduction aimed at heavy vehicles, primarily in urban areas, would also make it possible to limit the cost to the national economy and the effect on public finances.

KFB also observes that an introduction strategy should have a broad aim to develop several different biofuels and that a long-term perspective should be adopted. The scope and direction of the various inputs must therefore be based on a long-term assessment of the potential of the various fuels and engine and vehicle technologies in the short, medium and long term.

Obstacles to introduction

The studies referred to in the foregoing chapter noted that there is no significant technical obstacles to prevent the widespread introduction of biofuels from being started. A number of vehicle fleets exist where the use of ethanol and biogas can begin. As shown in earlier chapters, technology for using biofuels in both otto engines and diesel engines has been developed under the aegis of KFB's biofuel programme.

KFB's bio-fuel programme has also demonstrated the existence of numerous players who are interested and willing to start using biofuels in their vehicles, provided that the additional cost is not prohibitive.

The high cost of producing ethanol would appear to be the major obstacle to bringing about prodution on a larger scale. However, in the long term new technology could mean that the market price of biofuels can be reduced.

International developments and Sweden's membership of the EU also constitute factors which have grown stronger as obstacles, but which also offer opportunities for the more widespread introduction of alternative fuels. So far the mineral oil directive and the tariff barriers on the import of motor alcohols have been a powerful obstacle preventing greater use of ethanol in Sweden, since the tariffs have pushed up the price of ethanol. In the long term, however, there are opportunities for achieving better conditions in both Sweden and other EU countries, by influencing EU regulations. At present, though, the EU lacks a coherent policy for alternative fuels. Questions relating to biofuels are currently the responsibility of several different directorates, who consider them from partially different starting points, which makes concerted, long-term effort difficult. It is therefore necessary for Sweden to work purposefully and strategically through networks in the EU.

The EU's Altener programme includes a development goal, namely to replace 5 per cent of fossil fuels with biofuels by 2005. Another recently established goal that would favour biofuels is the EU Commission's carbon dioxide target, viz. to reduce emissions by 15 per cent, compared with 1990 levels, by 2010, assuming that other industrial nations follow suit.

Successful activities at EU level would require that Sweden obtains support from other countries, both within and outside the EU. Developments within the International Energy Agency have shown that countries with a common strategy and shared views have been able to pursue various key issues effectively. It is therefore also important to develop and intensify this collaboration in the biofuels field. This can also be a factor driving the EU collaboration. The creation of a Stakeholders Forum, which was one of the recommendations made by delegates to KFB's international conference in Stockholm in the autumn of 1997, could be one means of bringing about greater international involvement.

Finally, the greatest and most serious obstacle to the introduction of more biofuels into the transport sector is the effect on the costs incurred by vehicle users. This in turn depends partly on the development of costs for new fuels and vehicles and partly on which means of control the community decides to avail itself of. Further progress will depend on development input to produce new, cost effective methods of production for biofuels and new environmentally-optimised vehicles, and on political measures of various types. By engaging the various players of the market in the change process at an early stage, the new, sustainable technology can be diffused at the same rate as knowledge is built up.

Gaps in knowledge

New production techniques

One precondition for the more widespread use of biofuels is that they can be produced more cheaply than is currently the case. As a result of research and development work in Sweden and abroad new, promising production methods are emerging, such as enzymatic hydrolysis of cellulose, which in the long term could make possible ethanol production at competitive prices. The next stage in the development process is to begin building a number of pilot plants which can provide the facts required for the market to be willing to invest on a large scale.

As regards techniques for producing biogas, a number of different solutions are currently being tested in the few demonstration plants built in recent years. These plants need to be followed up and evaluated, to provide facts on which to base the design of future plants. If more extensive production of biogas, e.g. with grass crops, becomes a possibility, then more extensive development work will be required to develop the entire production system "from meadow to tank".

New vehicle technology

KFB's biofuel programme has demonstrated that a number of different technical solutions exist for using ethanol or biogas as fuels in private cars, trucks and buses. Several of these solutions are now available on the market, but to obtain environmentally-optimised vehicles which function on a large scale and under normal operating conditions it is necessary to have:

- Development and demonstration of a pure alcohol engine for heavy vehicles which does not require the addition of an ignition improver. Engine concepts which are based on spark plugs and glow plugs have been partly developed, but need to be further developed, e.g. to reduce costs and optimise entire vehicle systems (engines, ignition systems, fuels, catalysts and possibly EGR).
- Long-term tests of blended fuels (15 per cent ethanol with an emulsifier in diesel) are needed to test the vehicle's durability. Further trials with the fuel are also needed to test its stability and to develop a practically functioning blending technique.
- Practical running and measurement of emissions from biogas vehicles have been under way for too short a time to draw any definite conclusions for the future. Continued engine and catalyst development for heavy vehicles is required.
- There is a need for a continuous analysis and evaluation of various fuel alternatives and their potential in various aspects. Additionally, no suitable test methods are available which are capable of measuring the alternatives against one another in a fair and simple way – development in this area is needed.

Systems knowledge

The environmental problems which arise from transportation have so far often been dealt with one by one, from a narrow perspective. A number of different measures need to be taken by many different players in order to create a sustainable transport system. This makes demands with regard to participation and commitment, but also for improved understanding of systems connections and how individual decisions can further or weaken the process of transition.

One way of building up knowledge of systems connections may be to carry out system demonstrations in a number of municipalities. These system demonstrations should include tests of new fuels and vehicles, and trials with environmental zones, environmentally-friendly public procurement and various measures to influence attitudes towards car-pooling, public transport and cycling, for example. System demonstrations should also be connected to local Agenda 21 activities.

Starting up local system demonstrations will help to create development environments which can serve as "test platforms" with different goals and where several generations of vehicles can be tested under practical operating conditions. This type of continuity in test conditions also makes it easier to have an independent and objective evaluation process.

Conclusions

- A change-over towards a sustainable transport system which involves a transition from fossil fuels to biofuels is a long-term process, but to succeed it needs to be started now. Pilot and demonstration plants for the production of biofuels are thus necessary, as are fleets of vehicles which can run on these new fuels. Biofuels should be introduced within a broad and long-term programme which includes both a blends of ethanol in petrol and targeted measures aimed at the use of ethanol in heavy vehicles, FFVs and various biogas applications.

- The state will play a key role in bringing about greater use of biofuels. This responsibility should include an unambiguous and clear adaptation of taxes and charges on fuels, so that fuel prices to consumers reflect effects on health and the environment. As this involves substantial, long-term investments from the new players who will be involved in the build up of a new market for biofuels, it is necessary that the state employs consistent and sustainable means of control.

- KFB's biofuel programme has demonstrated that a number of different technical solutions can be considered for using both ethanol and biogas as fuels for private cars, trucks and buses. Several of these solutions are now available on the market, but to obtain environmentally-optimised vehicles which operate on a large scale and under normal operating conditions, it is necessary to ensure the development of vehicle technology and the commitment of the automotive industry.

- Experiences from KFB's biofuel programme show that the market introduction of new fuels, such as ethanol and biogas, needs to be preceded by practical demonstrations for various users around the country. Such system demonstrations create development environments which can serve as test platforms, with various aims and where several generations of vehicles can be tested under practical operating conditions. This type of continuity in test conditions also makes it easier to have an independent and objective evaluation process.

REFERENCES

Chapter 1. Introduction

- *Månsson T (1996).* Let's move from vision to practice. Enviro No 21, September 196.
- *Shell (1996).* The Evolution of the World's Energy Systems.
- *IPCC (1997).* Background material for IPCC's work received by Bert Bolin, IPCC's central chairman.
- *KFB, SIKA, NUTEK (1996).* Background material for assessing the introduction of alternative fuels. Report compiled at the request of the Communications Committee (KomKom). KFB Information 1996:13.
- *Faugert S, Olsson L-O (1994).* From technology to systems – an assessment half-way by KFB's programme for bio-fuels. KFB ref. no. 94-31-742.
- *Hedman J (1996).* KFB's biofuels programme. Field study carried out by IM-gruppen at the request of the National Audit Bureau. KFB Information 1996:7.
- *Sterner T. (1997).* Biofuels in the Swedish transport sector. An economic analysis. KFB Note 1997:7.
- *Arnold E, Thuriaux B,* Bernhardt W, McGill R, Weide J (1997). The Biofuels Programme at KFB, 1991-97. An Evaluation. KFB Information 1997:11.

Chapter 2. Vehicles, fuels and the environment

- *The National Environment Protection Agency (1996a).* On the road towards an environmentally-adapted transport system. Final report from the MaT collaboration. Report 4636.
- *Pilo C. (1996c).* Transportation – on the road towards a sustainable society? Engineers for the Environment's transport group. KFB Note 1997:20.
- *The National Environment Protection Agency (1996b).* A changing climate – causes, effects, measures. IPCC's latest facts. The National Environment Protection Agency 9781-4.
- *Ministry of the Environment (1997).* Programme for the continued implementation of Agenda 21. Final document from UNGASS 19. The national committee for Agenda 21. Report 1997:1.
- *Blinge M, Arnäs P-O, Bäckström S, Furnander Å, Hovelius K (1997).* Life cycle analysis (LCA) of fuels. KFB Note 1997:5.
- *Ecotraffic AB (1992).* Life of Fuels. Motor Fuels from Source to End Use. Ecotraffic AB, Stockholm.

Chapter 3. Motor alcohols

- *Olsson L-O (1996).* The influence of vehicle costs in the use of bio-fuels. KFB Note 1996:28.
- *Egebäck K-E, Walsh M, Westerholm R (1997).* The Use of Methanol as a Fuel for Transportation. KFB Note 1997:15)
- *Brandberg Å, Johansson A (1991).* Motor alcohols – regulations. KFB Note 91-215-742.
- *Egebäck K-E, Larsson E, Laveskog A (1997).* Methanol. Handling, safety and occupational health. Preliminary report, December 1997.
- *Pilo C (1997).* Creating the Market. A report from KFB International Conference in Stockholm 1997. KFB Note 1997:27.
- *Johansson B (1996).* Energy balances. Possibilities for replacing petrol and diesel with fuel from Swedish biofuels. KFB Note 1996:22.
- *KFB, NUTEK, SIKA (1997).* Various introduction strategies for bio-fuels. KFB Information 1997:10.
- *Zacchi G (1996).* Ethanol from ligno-cellulose. Working report, May 1996.
- *Sivers M, Zacchi (1996).* Ethanol from ligno-cellulosics: A review of the economy. Bioresource Technology 56.

Chapter 4. Biogas

- *Maltesson H Å (1997).* Biogas for vehicle operation. Quality specifications. KFB Report 1997:4.
- *Lindberg A (1996).* Biogas plants in Sweden. KFB Report 1996:21 (VA-Research Report 97:4).
- *Brolin L, Hagelberg M, Norström A. (1995).* Biogas as a fuel for vehicles. KFB Report 1995:3.
- *Dalemo M, Edström M, Thyselius L, Brolin L (1993).* Biogas from crops. Technology and economy for large-scale biogas production. JTI Report 162.
- *Sundberg M, Johansson W, Hjortsberg H, Hansson K, Oostra H, Berglund K, Elmquist (1997).* Biogas in future agriculture and the eco-cycle society. Effects on the earth, environment and economy. JTI Report – Recycling & Waste, No. 12.
- *Lingsten A, Johansson M, Bjarne E, Ax R, Berg R, Svensson R (1997).* Biogas as a fuel in vehicles. Final report from the Trollhätte project. KFB Report 1997:18.
- *Rahm L, Brolin L (1997).* Biogas as a fuel for vehicles – Stockholm. KFB Report 1997:37.
- *Egebäck K-E, Brolin L (1997a).* Biogas as a fuel for vehicles – Linköping. KFB Report 1997:38.
- *Egebäck K-E, Brolin L (1997a).* Biogas as a fuel for vehicles – Uppsala. KFB Report 1997:39.
- *Brolin L (1997).* International biogas experiences. KFB Note 1997:28.
- *Ekelund M, Kullbjer T. (1995).* Biogas-driven buses in Linköping. KFB Report 1995:14.

Chapter 5. Other fuel alternatives.

- *Elam N (1997).* DME – Dimethyl ether in Växjö. Conditions for the production and use of an alternative fuel from renewable raw materials. KFB Note 1997:29.
- *Brandberg Å, Sävbark B, Landälv I, Lindblom M (1997).* DME – fuel for diesel engines. Production, distribution and use. KFB Note 1997:30.
- *Kemlin J, Salén I (1997).* The development of Volvo truck engines for DME. KFB Note 1997:31.
- *Pilo C (1997).* Creating the Market. A Report from KFB International Conference in Stockholm 1997. KFB Note 1997:27.
- *KFB, NUTEK, SIKA (1997).* Various introduction strategies for biofuels. KFB Information 1997:10.

Chapter 6. Engine and vehicle development

- *Olsson L-O (1996).* The influence of vehicle costs in the use of biofuels. KFB Note 1996:28.
- *Pettersson L, Wahlberg A, Järås S (1997).* Exhaust Gas Catalysts for Heavy-Duty Vehicles Fuelled by Alcohol or Biogas. KFB Report 1997:11.
- *Tingvall B, Hellberg S, Johansson Ö, Pettersson E, Nordström F (1997).* EGR on ethanol-fuelled diesel engines. KFB Report 1997:25.
- *Gjirja S. (1996).* Engine Design Optimization for Running on Ethanol with Low Emissions. KFB Note 1996:10.
- *Marforio K (1997).* Performance and emissions for Scania DS 11 diesel engines with diesel/ethanol admixture as fuel. KFB Note 1997:21.
- *Pettersson L, Wahlberg A, Järås S (1997).* New Catalysts Formulations for Vehicles Fuelled by Biobased Motor Fuels. KFB Report 1997:40.
- *Pettersson E. (1997).* Characterisation of exhaust fumes from ethanol-fuelled heavy vehicles when tested with five different catalysts. KFB Note 1997:32.
- *Gjirja S, Olsson E (1997).* Ether as Ignition Improver and its Application on Ethanol Fuelled Engines. Chalmers internal document No. 1997/15.
- *Brolin L, Hagelberg M, Norström A. (1995).* Biogas as a fuel for vehicles. KFB Report 1995:3.
- *Bucksch S, Månsson T (1996).* Alternative fuels and vehicles in the USA. Report from a study trip February 1996. KFB Note 1996:7.
- *Månsson T (1995).* Biofuels for sustainable mobility. KFB Note 1995:3.

Chapter 7. Demonstrations and fleet trials – experience of operation

- *Berg R (1997).* Bioethanolbuses in Skaraborg. Final report. KFB Report 1997:14.
- *Ekelund M (19979.* Ethanol-powered trucks. Final report for the SVENOL project. KFB Report 1997:20.
- *Larsson E (1997).* The Western Norrland project. Field tests of ethanol-powered buses in Örnsköldsvik. Final report. KFB Report 1997:36.
- *Rydén C (1997).* Operation problems when using ethanol as fuel for buses. KFB Note 1997:33.
- *Olsson L-O, Andersson P-O (1996).* Evaluation of operational problems for ethanol-powered buses. KFB Note 1996:18.
- *Rydén C (1996).* What happened then? Operational experiences 1994-1996 from the SL-project. KFB Note 1996:25.
- *Ekelund M (1996).* Ethanol-powered trucks in urban environment. KFB Report 1996:9.
- *Rydén C (1994).* Fleet trials with 32 ethanol-powered buses at SL. KFB Report 1994:2.
- *Rydén C, Egebäck K-E (1997).* Fleet trials with 53 Flexible Fuels Vehicles, FFV. KFB Note 1997:11.
- *Alin L (1997).* Diesohol - diesel-fuel blend with 15% ethanol. Final report. KFB Report 1997:23.
- *Berg R (1997).* Fuel blends. Final report. KFB Report 1997:35.
- *Rydén C, Berg R, Egebäck K-E (1997).* Field tests with FFV. Final Report. KFB Report 1997:41.
- *Aspen (1997).* Alkyls and ethanol fuels. KFB Report 1997:26.
- *Aspen (1996).* Diesohol – fuel blends diesel/ethanol. KFB Note 1996:19.
- *Egebäck K-E, Brolin L (1997a).* Biogas as fuel for vehicles – Linköping. KFB Report 1997:38.
- *Egebäck K-E, Brolin L (1997b).* Biogas as fuel for vehicles – Uppsala. KFB Report 1997:39.
- *Lingsten A, et al (1997).* Biogas as fuel for vehicles – Trollhättan. KFB Report 1997:18.

Chapter 8. International experiences

- *Pilo C (1997).* Creating the Market. A Report from KFB International Conference in Stockholm 1997. KFB Note 1997:27.
- *Bucksch S, Månsson T (1996).* Alternative fuels and vehicles in the USA. Report from a study trip February 1996. KFB Note 1996:7.
- *Wingqvist A (1997).* Fuel and vehicle development in the USA. KFB Note 1997:8
- *Brolin L (1997).* International biogas experiences. KFB Note 1997:28.
- *Pilo C (1996a).* Analysis of experiences from the introduction of bio-fuels. KFB Note 1996:20.
- *Pilo C (1996b).* Biofuels. International literary survey. KFB Note 1996:21.

Chapter 9. Health and environmental potential for biofuels

- *Egebäck K-E, Ahlvik P, Westerholm R (1997a).* Emission factors for vehicles run on fossil fuels and alternative fuels respectively. KFB Note 1997:22.
- *Egebäck K-E, Ahlvik P, Laveskog A, Westerholm R (1997b).* Emission factors for vehicles run on bio-fuels. Background material to KFB Note 1997:22. KFB Report 1997:23.
- *Egebäck K-E, Westerholm R (1997c).* Test methods and emissions on the use of alternative fuels. KFB Note 1997:24.
- *Egebäck K-E, Westerholm R (1997d).* Environmental potential of the alternative fuels biogas, ethanol, methanol, natural gas, rapeseed methyl ester and dimethyl ether. KFB Note 1997:4.
- *Boström C-E, Camner P, Egebäck K-E, Ewetz L, Ljungquist S, Omstedt G, Pettersson L, Törnqvist M, Westerholm R (1996).* Health Risk Assessment of Ethanol as a Bus Fuel. KFB Report 1996:19.
- *Zurita G (1997).* Combustion Noise Analysis. Diesel and Ethanol Engines. KFB Note 1997:18.
- *Haupt D. (1996).* Method development for the analysis of hydrocarbons and combustion products in ethanol-driven vehicles. Sub-report. KFB Note 1996:26.

- *Omstedt G, Kindell S (1997).* On the environmental impact of ethanol and diesel buses. KFB Note 1997:34.
- *Otson R, Westerholm R, Fellin P, Davis C. (1997).* Exposures due to emissions from ethanol and diesel fuelled buses in Stockholm. KFB Note 1997:35.
- *Grafström R. (1997).* In vitro assessment of human airway toxicity from major aldehydes in automotive emissions. KFB Note 1997:2.
- *Haupt D, Nordström F, Niva M, Bergenudd L, Hellberg S (1997).* Survey of regulated and some unregulated emissions from engines fuelled with mixed fuels, diesel oil and ethanol. KFB Note 1997:16.
- *Westerholm R, Christensen A, Törnqvist M, Ehrenborg L, Haupt D (1997).* Chemical and Biological Characterisation of Exhaust Emissions from Ethanol and Ethanol Blended Diesel Fuels in Comparison with Neat Diesel Fuels. KFB Note 1997:17.

Chapter 10. A socio-economic analysis

- *Sterner T. (1997).* Biofuels in the Swedish transport sector. An economic analysis. KFB Note 1997:7.
- *Durvala D (1997).* Economic evaluation of biofuels with general balance model. KFB Note 1997:36.
- *Brandberg Å, Sävbark B. (1996).* Distribution of motor alcohols. KFB Note 1996:23.
- *Johansson O (1997).* Can a reduction in the costs occasioned by damage to health and nature motivate an investment in biofuels? KFB Note 1997:1.
- *Östman A (1996).* Production costs for ethanol, methanol and biogas. KFB Note 1996:29.
- *KFB, NUTEK, SIKA (1997).* Various introduction strategies for biofuels. KFB Information 1997:10.
- *Olsson L-O (1996).* The influence of vehicle costs in the use of biofuels. KFB Note 1996:28.

Chapter 11. Strategies for the future

- *KFB, SIKA, NUTEK 81996).* Background to an assessment of the introduction of alternative fuels. Survey carried out at the request of the Communications Committee (KomKom). KFB Information 1996:13.
- *Brandel M. (1997).* Plan for the introduction of alternative fuels. Background to KFB's, SIKA's and NUTEK's report to the Communications Committee. KFB Note 1997:3.
- *Sterner T. (1997).* Bio-fuels in the Swedish transport sector. An economic analysis. KFB Note 1997:7.
- *Johansson B (1996).* Energy balances. Possibilities of replacing petrol and diesel with fuels from Swedish bio-fuels. KFB Note 1996:22.
- *KFB, NUTEK, SIKA (1997).* Various introduction strategies for bio-fuels. KFB Information 1997:10.
- *Pilo C (1997).* Creating the Market. A Report from KFB International Conference in Stockholm 1997. KFB Note 1997:27.

GLOSSARY

Acetaldehyde, aldehydes	Aldehydes are formed during combustion and are thus present in engine exhaust fumes, but can also be formed through secondary reactions of other exhaust components in the atmosphere. The predominating aldehydes in exhaust fumes are acetaldehyde and formaldehyde. Formaldehyde mostly causes allergies, but can also be carcinogenic. In the case of acetaldehyde, the carcinogenic effect predominates.
Acidification	Sulphur dioxides and nitrogen oxides are converted in the atmosphere into sulphuric acid and nitric acid. These acids are precipitated in rain and cause acidification.
Ames' test	Biological test to measure hazards to health from exhaust fumes and fuels.
Aromatic hydrocarbons	Aromatic hydrocarbons are thus named because they contain benzene rings. This gives them their special characteristics. Aromatic hydrocarbons have a much greater anaesthetic effect (cause tiredness) than the corresponding paraffin hydrocarbons. Aromatic solvents irritate the mucous membrane and respiratory passages. Persons exposed to them sometimes develop symptoms similar to those for asthma.
Biodiesel	Biodiesel is a collective name that sometimes used for the various types of fuel, e.g. RME, which are produced from vegetable oils.
Biogas	By biogas is meant a product resulting from the fermentation in the absence of oxygen (digestion) of biological raw materials, e.g. municipal sewage sludge, slaughterhouse waste, specially-cultivated crops and even farmyard manure. It mostly consists of methane. The raw gas (which is sometimes called digester gas) usually contains 55-75 per cent methane with an energy content of around 4.5-8 kWh/Nm_3. The remainder consists mainly of carbon dioxide and water vapour, as well as traces of sulphur and nitrogen compounds. For use as a vehicle fuel it requires cleaning and an increased concentration of the raw gas. After this process a methane content of around 95 per cent is achieved (the rest is CO_2) with an energy content of some 9.5 kWh/Nm_3.
Braunschweig	See driving cycle.
Carbon dioxide CO_2	Carbon dioxide (CO_2) and water are formed when hydrocarbon in the fuel is combusted with oxygen in the air. One litre of petrol gives rise to around 2.35 kg carbon dioxide, one litre of diesel to 2.6 kg. Carbon dioxide is a greenhouse gas and the increased emissions are feared to contribute to the change in the earth's climate. Carbon dioxide emissions are in direct relation to the consumption of fossil fuels.

Carbon monoxide CO

Carbon monoxide (CO) is a lethally toxic product of combustion which has no odour and is invisible. Carbon monoxide consists of uncombusted residue from fuel and lubricants. Emissions of carbon monoxide have declined through the introduction of catalyst technology.

CASH Weak oxygen hydrolysis

The CASH process (Canada, America, Sweden, Hydrolysis) refers to hydrolysis in two stages, with diluted sulphuric acid and the accompanying fermentation into ethanol. The process also produces a by-product in the form of solid fuel. The process has been developed to produce ethanol from ligno-cellulose, primarily wood in timber remains and waste, such as sawdust, branches and treetops. Engineers' studies of the CASH process with softwood as raw material indicate, according to the Swedish Foundation for Ethanol Development (SSEU), that up to 30 per cent of the energy content of the raw material can be obtained as ethanol. In addition there is the solid fuel, which corresponds to around 40 per cent in energy terms.

Catalyst

Catalyst is a collective term for a number of different techniques where one substance speeds up a reaction without being consumed itself. A catalytic exhaust gas filter system includes other components in addition to the catalyst. To simplify, one can say there are four different catalyst principles: one-bed reduction and oxidation catalysis in two beds with secondary air, one-bed oxidation catalysis with exhaust circulation (EGR), one-bed reduction and oxidation catalysis, i.e. three-way catalysis. A catalytic exhaust gas filter system is built up of an active material fitted with a carrier. The carrier is enclosed in stainless steel and placed after the intake and exhaust manifold in the exhaust system. The use of catalysts requires very careful control of the air-fuel ratio.

Cetane number

The cetane number is a measure of how easily a fuel ignites (opposite of the octane number). A fuel for an otto engine should have the highest possible octane number. A fuel for a diesel engine should, on the contrary, have a high cetane number. Some fuels are thus more suited to otto engines and some to diesel engines. Although there are technical solutions for combining otto engines with low octane number and diesel engines with high number, the general rule is that the higher the octane number is for the otto engine and the cetane number for the diesel engine, the greater the capacity for the engine designer to optimise the engine for low exhaust emissions and low energy consumption.

CHAP
Concentrated Hydrochloric

Acid Process The Concentrated Hydrochloric Acid Process is based on hydrolysis with a strong hydrochloric acid and the accompanying fermentation into ethanol. It provides a high ethanol yield, up to 35 per cent of the energy content, according to SSEU, but requires a lot of energy and produces no by-products in the form of solid fuel. The process has been developed for production from cellulose-rich raw materials, such as waste paper.

Chassis dynamometer

Chassis dynamometers are used in vehicle testing. The method is based on the vehicle being driven with the drive gear on rollers, similar to the brake tests carried out by the Swedish Motor Vehicle Inspection Co.

Compression engine

The diesel engine (sometimes called the compression engine) is a combustion engine with compression ignition in accordance with Rudolf Diesel's process. The air introduced is compressed in the diesel engine, along with a small amount of waste gas from the previous cycle, into a high pressure in the motor cylinder, after which the fuel is injected at high pressure into the combustion chamber when the plunger is close to the upper dead centre.

Compression ratio

The ratio to each other of the volumes over the piston when it is at its highest and lowest positions respectively.

Diesel engine

The diesel engine (sometimes called the compression engine) is a combustion engine with compression ignition in accordance with Rudolf Diesel's process. The air introduced is compressed in the diesel engine, along with a small amount of waste gas from the previous cycle, to a high pressure in the engine cylinder, after which the fuel is injected at high pressure into the combustion chamber when the plunger is close to the upper dead centre.

Diesel fuel

Diesel fuel is used in compression engines (diesel engines) and ignites at a high pressure and high temperature. Its most important properties are ease of ignition (cetane count) and fluidity (viscosity and filterability) at low temperatures. Diesel is sold in three environmental grades in Sweden – MK1, MK2 and MK3.

Dimethyl ether DME

Dimethyl ether, DME, is a fuel which becomes gaseous at room temperature and atmospheric pressure, but can easily transform into a liquid during light compression. Its chemical formula is CH_3-O-CH_3. DME's boiling point is -250 C, so it must be handled under pressure. DME is currently produced from natural gas or carburation of oil and is mainly used as a propellant in spray cans. As DME can be manufactured directly from synthetic gas, it can have both fossil and biobased origins.

Driving cycle

A driving cycle is a test method based on applied driving patterns to reflect real traffic. The driving cycles consist of the four sub-sections engine running on empty, acceleration, continuous driving and retardation. There are two basic types – stationary which are intended for motor tests and transient tests of the whole vehicle, e.g. in chassis dynamometers. There are different standard driving cycles, such as: Braunschweig(sometimes called the bus cycle and refers to driving cycle tests with chassis dynamometers). ECE R49/A 30 (a stationary driving cycle used in Sweden for heavy vehicles) FTP-75(applied in the USA) Fige cycle (a method which is under development and is intended to apply to engine tests, but which should take into account actual running conditions through various correcting factors)

EGR

EGR, Exhaust Gas Recirculation, is a method of returning some of the exhaust fumes to the engine's combustion chamber. This is a method which is used to reduce NO_x emissions. One problem with EGR for normal diesel engines is the increased build-up of soot. However, this problem is eliminated with alcohol running and EGR therefore seems a good way of obtaining low NO_x emissions when motor alcohols are used in diesel engines.

Emulsifier

An emulsifier is an additive which is required in blended fuels (ethanol/diesel) as diesel oil and ethanol do not mix into a stable blend. However, the addition of an emulsifier can provide a stable and uniform emulsion. Dalco is the brand name of an emulsifier used in Sweden.

Environmental grading

Environmental grading is a method of pointing out products which are considered good from an environmental and health aspect. In Sweden there is an environmental classification system for both cars and fuels. These are distributed into three environmental grades – MK1, MK2 and MK3 – where MK3 is the mandatory requirement and the two other grades are higher but voluntary ones, which involve some form of financial compensation.

Enzymatic hydrolysis

Enzymatic hydrolysis, biodegrading, into simple sugar types involves a simple, but also slower breakdown with the aid of special enzymes. To give the enzymes a large active surface, the wood material needs to be pre-treated.

Ethanol

Ethanol (drinking alcohol), (C_2H_5OH), is the simplest of the alcohols after methanol and is thus well suited for use as a fuel. Ethanol has a boiling point of 780°C and is liquid at room temperature. Ethanol is not classed as a toxin, but must be denatured when used as a fuel, because of the risk of misuse. Safety measures for the handling of ethanol are much less extensive than for handling methanol and petrol. Ethanol is produced in a biochemical manner through the fermentation of, for instance, sugar-cane, maize and other agricultural products or of forestry products (cellulose). The energy content per litre of ethanol is around two-thirds, compared with petrol. As ethanol has a high octane number, 130/96 RON/MON, it is possible to increase compression and thus the energy efficiency in the engine. This means that consumption does not increase as much as the reduced energy content would motivate.

Ethyl tertiary butyl ether ETBE

Ethanol can be used, by reacting it with isobutane, to produce ethyl tertiary butyl ether (ETBE), which can be used to mix in petrol. ETBE has a boiling point of 730°C and is fluid at room temperature. The energy content is calculated per litre at around 80 per cent of the energy content in petrol. As ETBE is not aromatic and also has a high octane number, 118/102 RON/MON, it can be used for reformulating petrol – a means of reducing the hazards to health and the environment caused by petrol exhaust fumes.

Eutrophification

Seas, lakes and soil are over-fertilised by nitrogen oxides from vehicles and fertiliser emissions from farming. Over-fertilisation, or eutrophification, in the sea leads to an unchecked growth of plankton algae. In the beginning this has positive effects, the fish have more to eat. But the plankton die and fall to the bottom of the sea, where they consume oxygen while biodegrading. Finally, all animal life is suffocated.

Fige cycle

See driving cycle.

Flexible Fuels Vehicle, FFV

FFV is short for Flexible Fuels Vehicle. Such a vehicle can run on both petrol and motor alcohols.

Formaldehyde

See aldehydes.

Fuel cell

A fuel cell functions more or less like a normal battery, two electrodes on each side of an electrolyte, but unlike a battery the electrodes are not used up. Around the electrodes there is hydrogen gas and oxygen gas, which stream into the cell all of the time. The hydrogen gas comes from the fuel used and the oxygen gas comes from the air. This makes the fuel cell smaller and lighter than a normal battery. The fuel cell generates a continuous current, which can then be converted by an alternator into an alternating current. By converting chemically bonded energy in fuel without going via heat energy, the efficiency is high, around 40-60 per cent of the fuel's heat value. A number of different fuel cell techniques are currently being developed, but none of them are yet commercially available.

Greenhouse effect

The earth's atmosphere functions rather like the glass in a greenhouse. The gases and clouds in the atmosphere prevent the heat from radiating out into the atmosphere. Without this natural phenomenon the earth's average temperature would be around -180°C. This is the greenhouse effect. The problem is that the balance is being impaired. The greenhouse gases in the atmosphere are increasing as a result of man's activities. This means that more heat is being prevented from radiating out into space, the temperature of the earth is raised and we have changes in climate with effects that are difficult to predict, such as a higher sea level and extended desert areas.

Greenhouse gases

Greenhouse gases is a collective name for the gases which contribute to increasing the greenhouse effect. Carbon dioxide is the most important greenhouse gas. Carbon dioxide is formed during all combustion of fossil fuels. Other greenhouse gases are methane, CFC (e.g. freon) and nitrous oxide.

Hybrid vehicle

A hybrid vehicle is a vehicle which is fitted with more than one type of energy transducer and energy storage system. The energy transducer can be, for instance, an otto cycle engine, an electric engine or a fuel cell. Hybrid running allows a vehicle to use one fuel in traffic in densely populated areas (e.g. electricity in city traffic) and another on country roads (e.g. petrol/diesel/ethanol).

Hydrocarbon HC

Hydrocarbon (HC) is a common name for chemical compounds built up from only carbon and hydrogen. Hydrocarbons are usually divided into the following groups: paraffins (alkanes) aromatics (arenes) naphthalines olefines (alkenes) Exhaust fumes normally contain thousands of different hydrocarbons. Hydrocarbons contribute to the creation of ground ozone and have negative effects on health. The use of catalysts can help to reduce hydrocarbon emissions considerably.

Internalisation

Internalisation of costs involves control which forces or provides incentives for decision-makers to take into account the consequences for others. Internalising can be done through demands or economic incentives. Internalising makes external costs internal.

Knocking

Combustion in an engine normally occurs so that a spark which is ignited by the ignition plug propagates itself in the combustion chamber at an even rate, 10-30m/s until the entire fuel-air mixture is completely consumer. During combustion the unburnt residue gas is compressed in from of the flame and the temperature rises. The residue gas can then self-ignite or ignite by incandescence and combusts so quickly, 300-500 m/s that a pressure wave arises and causes the audible knocking. The normal combustion results in useful work, while the uncontrolled combustion causes knocking and counteracts the normal combustion. The knocking can also cause damage to the engine.

KomKom
Communication committee

The Communications Committee, KomKom, was a parliamentary committee which investigated how future transport systems should be designed to become economically, socially and environmentally sustainable. Its final report 'New course in traffic policy', SOU 1997:35 includes proposals for how to control the development and infrastructure of traffic towards socio-economic efficiency and long-term durability.

Lambda value, Lambda probe

The lambda value (λ) is a value which states the ratio of air to fuel during combustion. During combustion in a petrol engine the lambda value is approximately 1 and for the combustion of biogas in a lean-burn engine is ($\lambda = 1.6$). A lambda value of 1.6 means that there is a 60 per cent surplus of air in relation to the consumption of fuel for combustion. A lambda probe is used in a catalyst to control the air-fuel ratio, the 'lambda value'.

Lean-burn

Lean-burn means a combustion process where the fuel-air mixture is very lean, i.e. little fuel per volume of air.

Life-cycle assessment (LCA)

In order to assess a product or operation's total emissions and/or influence on health and the environment, as well as energy consumption, one usually carries out a life-cycle analysis, LCA. There are many ways of making an LCA, which means that different analyses of the same event can give varying results. One problem is the limitation in time and space (from 'the cradle to the grave'), another is how one makes the necessary generalisations required to make an LCA a practical tool.

Methane gas

Methane gas (CH_4) comes in the form of fossil natural gas and as biogas. Methane is colourless and non-toxic. When used as a fuel, odour substances are added to make it possible to detect leaks. Methane has a boiling point of -1620°C and an explosion limit in air of 5-14 volume per cent.

Methanol

Methanol, (CH_3OH), is the simplest of all of the alcohols and can be used as a fuel in both its refined form and in admixtures. Methanol has a boiling point of 650°C and is fluid at room temperature. Methanol is poisonous to humans and is classed as a toxin. Methanol is a corrosive, which places special demands on pipes and other materials.
The main raw material for methanol is currently natural gas. However, methanol can be produced from almost all gasifiable organic substances.

Methyl tertiary butylether MTBE

Methanol can be used to produce methyl tertiary butyl ether (MTBE) through a reaction with isobutane (a by-product from refineries). The MTBE can then be used to mix into petrol. MTBE has a boiling point of 550°C and is fluid at room temperature. The energy content is calculated per litre at around 80 per cent of the energy content in petrol. As MTBE is not aromatic and also has a high octane number, 118/100 RON/MON, it can be used for reformulating petrol – a method of reducing the danger to health and environment from petrol exhaust fumes.

Nitrogen oxides NO_X

Nitrogen oxides (NO_X) are formed when the oxygen and nitrogen in the air react together in the engine. The formation of nitrogen oxides is also aided by a high combustion temperature. Nitrogen oxides contribute to the over-fertilisation of soil and water, to acidification and also have negative effects on health. The introduction of catalytic converters on private cars has reduced nitrogen oxide emissions.

Over-fertilisation

Seas, lakes and soils are over-fertilised by nitrogen oxides from vehicles and fertiliser emissions from farming. Over-fertilisation, eutrophification, in the sea results in the unchecked growth of plankton algae. At the beginning, this has a positive effect – the fish have more to eat. But the plankton die and fall to the bottom of the sea, where they consume oxygen while biodegrading. Finally, all forms of animal life are suffocated.

Oxygenates

Oxygenates are added to petrol, partly to raise the octane count. Oxygenates include methanol, ethanol and their ethers MTBE and ETBE.

Ozone

There is both too much and too little ozone. On the one hand, there is too much ozone at ground level. This is formed when emissions of hydrocarbons and nitrogen oxides from cars and industry are exposed to sunlight. The ground level ozone influences plants' capacity to breathe and produce nourishment. On the other hand, there is too little of the ozone which is a few miles up in the atmosphere and which protects us from the sun's UV rays. The thinner this layer becomes, the greater risk we run of suffering skin cancer. The ozone layer is primarily attacked by freons.

Particles

Particles have negative effects on health and contribute to pollution. The introduction of cleaner fuels, better engines and cleaning equipment have reduced emissions.

Petrol

Petrol is used in combustion engines with electric ignition (otto engines). Important properties in petrol are the octane count, which is a measure of the petrol's anti-knock characteristics, and steam pressure, which is a measure of how easily the petrol evaporates. Petrol consists of a large number of individual hydrocarbons each of which has different characteristics and different degrees of harmfulness to health and the environment. Petrol can also contain various additives for improving its functioning.

Polluter Pays Principle PPP

The Polluter Pays Principle (PPP) says that whoever is responsible for pollution should also be responsible for the cost of solving the problem. This principle has been adopted internationally as a general principle by, for instance, the EU Commission.

Polyaromatic hydrocarbons PAH

Polyaromatic hydrocarbons, PAH, is a collective term for thousands of different types of hydrocarbon. These hydrocarbon types are built up of rings consisting of six carbon atoms (bensen rings) on which there can be a large number of assorted groups of other substances. PAH is mainly found in diesel exhaust fumes. PAH is assumed to be carcinogenic and influences hereditary disposition.

Rapeseed methyl ester, RME

Rapeseed methyl ester, RME, is a fuel produced by re-esterification of rapeseed oil, which can be used in existing diesel engines without needing any major adjustments to the engine. RME has a high flash point (1210°C), which means that it is not inflammable. RME is not a fluid, not is it poisonous, it does not induce allergy or cancer. RME has an approximately 6 per cent lower energy content per volume unit than diesel oil.

Reformulated petrol

Reformulation of petrol is a method applied by a large number of states in the USA. This involves a requirement that the fuel should contain a higher oxygen content (at least 2 per cent) and low bensen content (below 1 per cent). This is achieved by mixing alcohols, either methanol or ethanol, ETBE or MTBE into petrol.

Regulated emissions

Emissions into air are usually classified as regulated and unregulated emissions. Regulated emissions are those which are subject to statutory maximum limits. These emissions include carbon monoxide (CO), hydrocarbon (HC), particles, sulphur dioxide (SO_2) and nitrogen oxides (NO_x). Unregulated emissions are other emissions of some significance which do not have statutory maximum levels, but which as a result of their effect on health and the environment should be reduced or eliminated. Important unregulated emissions include polyaromatic hydrocarbons (PAH), formaldehyde, acetaldehyde, bensen, butadiene, ethylene, etc. PAH is assumed to be carcinogenic and influences genes.

Specific fuel consumption

States fuel consumption per unit of effect and unit of time, e.g. in grams per kilowatt hour (g/kWh).

Stochiometric combustion

Stochiometric combustion means that the amount of oxygen is completely adapted to the amount of fuel. Stochiometric combustion with three-way catalysts is used in modern petrol vehicles.

Sulphur oxides

Sulphur oxides (SO_x) are emitted by the combustion of fossil fuels, as these fuels contain a certain amount of sulphur. Sulphur dioxide (SO_2) contributes to acidification, corrosion and is a health problem. The rapid introduction during the 1990s of cleaner diesel fuel has meant a large reduction in sulphur dioxide emissions.

TCDD

The TCDD (receptor affinity test) is a biological test to examine hazardous substances in exhaust fumes and fuels.

Vegetable oils

Oils based on vegetable matter can often be used in diesel engines. The raw materials for the oils, like access to them, vary from country to country. In Sweden and Europe the dominant raw material is rapeseed. Rapeseed oil is obtained through squeezing and/or extraction of rapeseeds. Rapeseed oil has a higher viscosity and an even higher freezing point than diesel oil. This makes is less suitable as a fuel in diesel engines. It has therefore been decided to re-esterify with an alcohol and convert it into a rapeseed ester. The rapeseed ester which has been tested to date is rapeseed methyl ester (RME). RME has properties which enable it to be used in a diesel engine after only marginal adjustments.

VOC

VOC (volatile organic compounds) is used as a collective term for a number of important, volatile organic compounds. Apart from the risks which may be connected with specific compounds, which can be mutagenic and even carcinogenic, the màin problem with VOC is that it is a primary factor in the formation of ozone.