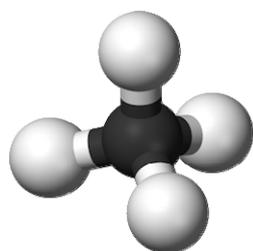
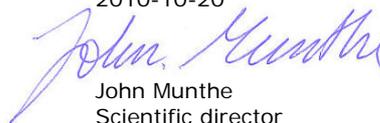


Market conditions for biogas vehicles



Tomas Rydberg, Mohammed Belhaj,
Lisa Bolin, Maria Lindblad,
Åke Sjödin, Christina Wolf
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John Munthe
Scientific director

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| Author Tomas Rydberg, Mohammed Belhaj, Lisa Bolin, Maria Lindblad, Åke Sjödin, Christina Wolf | |
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| Summary <p>With a present share of biofuel used in the Swedish road transport sector of 5.2%, the opportunity for reaching the binding target of 10% by 2020 seem promising. It is both likely and desirable that biogas vehicles may make a significant contribution to fulfill Sweden's obligation under the biofuels directive. It is likely because the stock of biogas (bi-fuel/CNG) vehicles in Sweden is increasing, as is the supply and demand of biogas. It is desirable, because biogas use in the road transport sector has not only climate benefits, but also benefits from an environmental (e.g. improved air quality due to lower emissions of regulated and unregulated air pollutants) and socio-economic (e.g. domestic production, employment) point of view.</p> | |
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Summary

The present report, prepared by the Swedish Environmental Research Institute (IVL) on behalf of the Swedish Road Administration, analyses the market prerequisites for biogas vehicles and biogas used as motor fuel in view of the EU biofuels directive and the Swedish national target to switch to a fossil fuel independent vehicle fleet by before 2030. In particular the extent to which market barriers for biogas vehicles and biogas use in the road transport sector can be reduced or eliminated has been analysed. In addition, the analysis includes the production of biogas and other biofuels/renewable fuels, their costs and impacts (environmental and socio-economic). Finally, the results of four previously conducted market/stakeholder surveys on biofuels and biofuel vehicles in Sweden have been analysed in more detail to achieve a better understanding of different positions on biogas vehicles' future development, and help propose measures for an increased use of biogas in the Swedish road transport sector. The study apparently has a Swedish focus, but it is believed that much of the outcome of the analysis can be transferred to other countries.

With a present share of biofuel used in the Swedish road transport sector of 5.2%, the opportunities for reaching the binding target of 10% by 2020 seem promising. It is both likely and desirable that biogas vehicles may make a significant contribution to fulfill Sweden's obligation under the biofuels directive. It is likely because the stock of biogas (bi-fuel/CNG) vehicles in Sweden is increasing, as is the supply and demand of biogas. It is desirable, because biogas use in the road transport sector has not only climate benefits, but also benefits from an environmental (e.g. improved air quality due to lower emissions of regulated and unregulated air pollutants) and socio-economic (e.g. domestic production, employment) point of view.

The national goal to have established a "fossil fuel independent" road vehicle fleet by 2030 is apparently a much tougher challenge. To reach this target, it is obvious that much stronger incentives than today must be created to increase both the demand of biofuel vehicles and other vehicles considered to run on renewable energy (i.e. electric or hybrid vehicles), *and* the supply of biofuels and renewable energy (i.e. electricity). In line with the both feasible and desirable increase of biogas vehicles and biogas use in the road transport sector pointed out above, biogas vehicles should be an important element also in achieving the ambitious national target for 2030, particularly since the potential for biogas production in Sweden, taking into account both first generation (mainly waste) and second generation processes (forest products mainly), is very high, estimated to overall some 55 TWh.

However, the future use of biogas as motor fuel depends on many parameters. First of all, if the future production potential is realised to a significant extent by 2030, there will be a competition for biogas use in the transport sector from the stationary sector, for e.g. heat and electricity production. The future use of biogas in the road transport sector will also depend on the future relative costs for biogas as motor fuel and electricity, which is also foreseen as an important energy carrier in the road transport sector in the future (and may readily be produced from biogas). Finally, the supply of several other (second generation) renewable fuels/biofuels options is also likely to increase significantly until 2030, the most likely ones being ethanol, biodiesel (FAME or HVO), synthetic diesel (produced from biogenic sources), methanol and DME.

An overall conclusion of the study is that, on a long term, the supply and demand of biofuels/renewable energy in general must be driven by the market, and not by subsidies.

To promote the growth of the biogas vehicle fleet and the use of biogas as motor fuel, various supports, not least financial, to the supply side (production plants, production and distribution processes, increased availability of filling stations etc.) are of particular importance. Of crucial importance at least on a short term are also various subsidies to lower the market price of biogas or to create other economic incentives for motorists to use biogas.

Sammanfattning

På uppdrag av svenska Vägverket har Svenska Miljöinstitutet (IVL) analyserat marknadsförutsättningarna för biogasfordon och biogas som används som motorbränsle, med utgångspunkt i EU direktivet om biodrivmedel och det svenska nationella målet en fossiloberoende fordonsflotta till år 2030. Analysen belyser i vilken utsträckning marknadshinder för biogasfordon och biogas i vägtransportsektorn kan minskas eller undanröjas. Dessutom belyses produktion av bio-gas och andra biobränslen / förnybara bränslen, deras kostnader och effekter (miljömässiga och socioekonomiska). Fyra tidigare utförda marknads-/intressentundersökningar av biodrivmedel och biodrivmedelsfordon i Sverige har analyserats mer i detalj för att uppnå en bättre förståelse för biogasfordonens marknadsförutsättningar, och hjälpa föreslå åtgärder för en ökad användning av biogas i den svenska vägtransportsektorn. Studien har fokus på svenska förhållanden, men resultatet av analysen kan ses som relativt allmängiltigt.

Med en nuvarande andel biodrivmedel som används i den svenska vägtransportsektorn på 5,2%, förefaller möjligheterna att nå det bindande målet på 10% till 2020 lovande. Det är både sannolikt och önskvärt att biogasfordon kan ge ett betydande bidrag för att uppfylla Sveriges skyldighet enligt direktivet om biodrivmedel. Det är sannolikt, därför att beståndet av biogas (bi-fuel/CNG) fordon i Sverige ökar, liksom utbud och efterfrågan av biogas. Det är önskvärt, eftersom biogasanvändningen i vägtransportsektorn har fördelar på emissioner av klimatgaser liksom andra ämnen (t.ex. förbättrad luftkvalitet på grund av lägre utsläpp av reglerade och oreglerade luftföroreningar), och också medför socioekonomiska fördelar (t.ex. inhemsk produktion, sysselsättning).

Det nationella målet att ha etablerat en "fossiloberoende fordonsflotta" år 2030 är en mycket tuffare utmaning. För att nå detta mål är det uppenbart att mycket starkare incitament än i dag måste skapas för att öka både efterfrågan på fordon som går på biodrivmedel och andra fordon som kan köras på förnybar energi (dvs. el-eller hybridfordon), samt leverans av biodrivmedel och förnybar energi (dvs. el). Biogas bör vara en viktig beståndsdel även för att uppnå det ambitiösa nationella målet för 2030, särskilt eftersom potentialen för biogasproduktion i Sverige, med hänsyn till både första generationens (främst avfall) och andra generationens processer (skogsprodukter främst), är mycket hög, totalt cirka 55 TWh.

Den framtida användningen av biogas som drivmedel beror dock på många faktorer. Till exempel finns konkurrens om biogas mellan användning i transportsektorn och i stationära anläggningar, för t.ex. värme-och elproduktion. Den framtida användningen av biogas i vägtransportsektorn kommer också att bero på framtida relativa kostnader för biogas som drivmedel och el. El förväntas också bli en viktig energibärare i vägtransportsektorn i framtiden (och kan lätt framställas från biogas). Slutligen kommer sannolikt tillgången på flera andra drivmedel av andra generationen också att öka markant fram till och bortom 2030. De mest aktuella alternativen är etanol, biodiesel (FAME eller HVO), syntetisk diesel/bensin (som framställs av biogena källor), metanol och DME.

En övergripande ambition på lång sikt bör vara att utbudet och efterfrågan av förnybara drivmedel i allmänhet ska drivas av marknaden, och alltså inte av subventioner. I ett övergångsskede är det dock nödvändigt med olika former av stöd för att främja tillväxten av biogasfordon och användning av biogas som drivmedel. Detta är av särskild betydelse för utbudssidan (investerstöd till produktionsanläggningar, distributionsvägar, ökad tillgänglighet av drivmedelsstationer mm), eftersom produktionskapaciteten för närvarande är flaskhalsen i systemet. Av betydelse åtminstone på kort sikt kan också vara olika subventioner för att sänka priset på biogas eller skapa andra ekonomiska incitament för bilister att använda biogas.

Table of contents

| | |
|---|----|
| Introduction | 5 |
| 1 Biogas - potential, production, costs, environmental and socio-economic aspects | 7 |
| 1.1 Biomethane, Biogas, and Bio-SNG..... | 7 |
| 1.2 Biogas potential in Sweden..... | 8 |
| 1.3 Swedish biogas production..... | 9 |
| 1.4 Production and costs | 9 |
| 1.4.1 Supply side | 9 |
| 1.4.2 Demand side and the transport sector..... | 10 |
| 1.5 Environmental aspects | 12 |
| 1.6 Socio-economic aspects | 13 |
| 2 Competing vehicles and fuels - barrier 1 | 14 |
| 2.1 Vehicles..... | 14 |
| 2.1.1 Environmental vehicles | 15 |
| 2.1.2 Costs | 15 |
| 2.1.3 Efficiency..... | 16 |
| 2.1.4 Voices from the market..... | 16 |
| 2.2 Fuels | 17 |
| 2.2.1 Environmental aspects..... | 18 |
| 2.2.2 Fuel accessibility | 19 |
| 2.2.3 Market development | 20 |
| 2.2.4 User friendliness | 21 |
| 2.2.5 Legal aspects..... | 21 |
| 2.2.6 Biofuels and the over-compensation principle | 22 |
| 3 Competition for biogas - barrier 2..... | 23 |
| 3.1 Electricity and biogas..... | 23 |
| 4 Synthesis | 24 |
| 4.1 Synthesis/summary of chapters 1-3 for biogas | 24 |
| 4.2 Barriers for increased market penetration of biogas | 25 |
| 4.2.1 Present policy measures..... | 26 |
| 4.2.2 Potential policy measures | 28 |
| 5 Conclusions and recommendations | 30 |
| 6 References | 32 |

Appendix A: Biofuels and biofuel vehicles with special emphasis on biogas and biogas vehicles:
A summary of surveys

Appendix B: Market conditions for biofuels other than methane

Introduction

Within the EU there are various directives in force aiming at increasing the use of renewable energy, in order to reduce the climate impact of fossil fuels, in particular:

Directive 2003/30/EC, the so-called “biofuels directive” adopted in spring 2003, is not a binding law, but an indicative target. The EU directive sets a target of 2 percent of petrol and diesel should be exchanged for renewable fuels by 2005. In 2010, the amount of biofuels should be 5.75 percent. Member States may apply for tax exemptions for particular biofuels until 2012. An extension is possible, but the biofuels directive and its effects are currently under review and new or changing incentives or directives can be expected in a near future.

Directive 2009/28/EC on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, the Renewable Energy Directive, RED. This Directive, which came into force on 25 June 2009, establishes a common framework for the use of energy from renewable sources in order to limit greenhouse gas emissions and to promote cleaner transport. To this end, national action plans are defined, as are procedures for the use of biofuels. Each Member State has a target calculated according to the share of energy from renewable sources in its gross final consumption for 2020. This target is in line with the overall '20-20-20' goal for the Community. Moreover, the share of energy from renewable sources in the transport sector must amount to at least 10 % of final energy consumption in the sector by 2020. The Directive takes into account energy from biofuels and bio-liquids. The latter should contribute to a reduction of at least 35 % of greenhouse gas emissions in order to be taken into account. From 1 January 2017, their share in emissions savings should be increased to 50 %. The Directive is part of a package of energy and climate change legislation which provides a legislative framework for Community targets for greenhouse gas emission savings. It encourages energy efficiency, energy consumption from renewable sources, the improvement of energy supply and the economic stimulation of a dynamic sector in which Europe is setting an example (Directive 2009/28/EC).

In recent years, the directives have led to different strategies in the different Member States. In Sweden, various instruments have been developed and implemented to achieve a higher share of renewable energy in general and a wider use of biofuels in particular. At present the share of renewable fuels in the Swedish road transport sector is about 5%. The Swedish parliament has set down a national target, aiming at that the vehicle fleet in 2030 should be “fossil fuel independent”.

On behalf of the Swedish Road Administration, IVL Swedish Environmental Research Institute has analyzed and clarified the role of biogas and biogas vehicles in achieving the objectives laid down in the mentioned EU directives, in particular the extent to which market barriers for biogas vehicles and biogas use in the road transport sector can be reduced or eliminated. Biogas is an interesting biofuel for Sweden, due to a high production potential, not least on a long term, and having major benefits on both climate and environment, e.g. air quality, when used in the road transport sector. In addition, the analysis includes the production of biogas and other renewable fuels, their costs

and their impacts (environmental and socio-economic). Furthermore, the automotive market and determining factors for its development - regarding in particular the shift from fossil to renewable fuels - are analysed for both light-duty and heavy-duty vehicles. Finally, the results of four previously conducted market/stakeholder surveys on biofuels and biofuel vehicles in Sweden have been analysed in more detail to achieve a better understanding of different positions on biogas vehicles' future development, and help propose measures for an increased use of biogas in the Swedish road transport sector.

1 Biogas - potential, production, costs, environmental and socio-economic aspects

1.1 Biomethane, Biogas, and Bio-SNG

Biogas consists of methane, just like natural gas. Traditionally, biogas is produced by anaerobic digestion of organic matter, such as sewage, manure, food wastes, organic material in landfills, etc. Raw biogas is mainly composed of 65% methane (CH₄) and 35% carbon dioxide (CO₂) as well as small amounts of other gases. For biogas to be used as a motor fuel or to be injected to the natural gas network it must reach natural gas quality, which is achieved in an upgrading plant where the gas is purified. In this process, corrosive components, particles, water and carbon dioxide are removed. By removing carbon dioxide the methane content and the energy value increases. Biogas can also be used for generation of electricity and heat.

The most common raw material used to produce biogas is waste, such as sewage sludge, household waste and waste from food. In farm plants manure is the main raw material, of which 30 000 tonnes were used for biogas production in Sweden in 2005. Manure is also an important input in many co-digestion plants. However, the use of crops in the production of biogas has so far been very limited in Sweden and only reached 230 tonnes in 2005.

When analysing production potentials of biogas (and biofuels in general) one has to distinguish between first (1G) and second (2G) generation processes. Biogas production by anaerobic digestion is considered 1G. Methane can however also be produced by gasification of (ligno-cellulosic) biomass into synthesis gas which is subsequently reacted into methane. The product is often referred to as Bio-SNG to distinguish from conventional biogas, where SNG means synthetic natural gas, or substitute natural gas. The general term for methane formed from any of these processes is bio-methane. The gasification process is thus considered a 2G process for bio-methane. In summary, therefore biogas is a 1G bio-methane and bio-SNG is a 2G bio-methane.

World production of bio-methane until now has been achieved solely as 1G, i.e. biogas by anaerobic digestion of organic materials including waste materials. The amounts of available, digestible, material sets the limit for conventional biogas production. The 2G biogas production is primarily based on residues from agriculture and forestry, and non-food energy crops. The 2G biofuels including bio-SNG are currently in a pre-commercial stage of development.

After enrichment with regard to methane, biogas can be used as a motor fuel. Theoretically, automobile engines can be adapted to operate with the "raw" biogas, but the high development costs oblige the use of engines originally designed for gasoline or diesel. By enrichment of biogas, this can be used as motor fuel in the same manner as natural gas. Furthermore, other reasons to enrich biogas when used by vehicles is the need to have as energy-rich fuel as possible and to have a uniform quality, so that vehicles perform optimally regardless of where refueling occurs (Wågdaahl, 1999).

1.2 Biogas potential in Sweden

The present gross potential for production of biogas in Sweden varies between 14 and 17 TWh per year according to estimates. **Table 1.1** brings these Figures together.

Table 1.1 Estimated biogas potentials (GWh) in Sweden.

| Source | JTI 1998 | SGC 2005 |
|-----------------------------|--------------|--------------|
| Cultivated crops | 3250 | 7190 |
| Manure | 2940 | 2560 |
| Straw | 7140 | 0 |
| Tops+ potatoes | 920 | 920 |
| Bait | 60 | 60 |
| Households waste | 600 | 940 |
| Garden waste | 230 | 230 |
| Restaurant + business waste | 60 | 0 |
| Park waste | 240 | 240 |
| Sewage sludge | 970 | 970 |
| Drain sludge | 30 | 30 |
| Paper and pulp industry | 110 | 90 |
| Other industry | 820 | 820 |
| Sum | 17370 | 14050 |

Source: Adapted from Nordberg (2006)

As shown, agriculture, e.g. cultivated crops, is the largest potential source of biogas production in Sweden. However, production costs based on this source are the highest; therefore there is a need for measures including research and investments to reduce these costs (Nordberg, 2006).

In a recent study carried out on behalf of Swedish Waste Management, the Swedish Biogas Association, the Swedish Gas Centre and the Swedish Water & Wastewater Association (Linné *et al.*, 2008), the gross potential for biogas production in Sweden was estimated to 15.2 TWh, see **Table 1.2**. According to these estimates the agricultural sector has the largest potential with a biogas production potential reaching around 11 TWh, or 70% of the total Swedish potential. Hence, these estimates are in line with those presented in **Table 1.1**. Linné *et al.*, (2008) also considered practical limitations given by economic realities and drew the conclusion that the potential with limitations amounts to 10.6 TWh/year.

Table 1.2 Potential of biogas production in Sweden from various sources (Linné *et al.*, 2008).

| Source | TWh | % |
|----------------------------------|-------------|------------|
| Agriculture | 10.792 | 71 |
| Food waste | 1.368 | 9 |
| Parc & garden waste | 0.304 | 2 |
| Food industry and other industry | 1.976 | 13 |
| Sewage sludge | 0.76 | 5 |
| Sum | 15.2 | 100 |

In the long term biogas may also be produced by thermal gasification of wood (lignocellulose). The industry estimates that around 40 TWh of biogas may be produced through gasification technology

in the future. Hence, the potential future production of biogas in Sweden is in the range of 55 TWh (Gasföreningen, 2007).

1.3 Swedish biogas production

Sweden has made significant advances in the production and use of biogas as an energy source both in the road transport sector and other sectors. The total annual production of biogas in Sweden was approximately 1.5 TWh in 2005, i.e. about 10% of today's potential. There were 233 biogas plants with the production distributed as presented in **Table 1.3**.

Table 1.3 Biogas production based on various types of plants in Sweden in 2005 (Nordberg et al., 2006).

| | Number of plants | % of production (GWh) |
|-------------------------|------------------|-----------------------|
| Sewage treatment plants | 139 | 43 |
| Co-digestion plants | 13 | 13 |
| Landfills | 70 | 36 |
| Industry sewage | 4 | 7 |
| Farm plants | 7 | 14 |

Only 4% of the produced biogas is used in the transport sector, road mainly. The remaining 56% is used for heat production, 19% is injected to the gas network, 13% is flared and 8% is used for electricity production.

1.4 Production and costs

1.4.1 Supply side

As discussed above, the most common raw material used in Sweden to produce biogas is waste, including sewage sludge, household waste and waste from food. The reason for the use of waste is the low costs, see Table 1.4. (Lantz & Börjesson, 2010). When crops are used for biogas production, the farmer has to be paid and this is leading to higher production costs, this is partly compensated by a lower cost while handling crops, since there is no need for i.e. hygienisation. (Nordberg, 2006).

Table 1.4 Production cost and cost to reduce GHG-emissions for biogas from three groups of substrates. (Lantz & Börjesson, 2010)

| | Substrate type | | |
|---|----------------|-----------|-----------|
| | Manure | Waste | Crops |
| Production cost [SEK/kWh] | 0.15-0.45 | 0.15-0.35 | 0.30-0.55 |
| Reduction cost [SEK/kg CO ₂ -eq] | 0.40-1.30 | 0.50-1.30 | 1.50-2.70 |

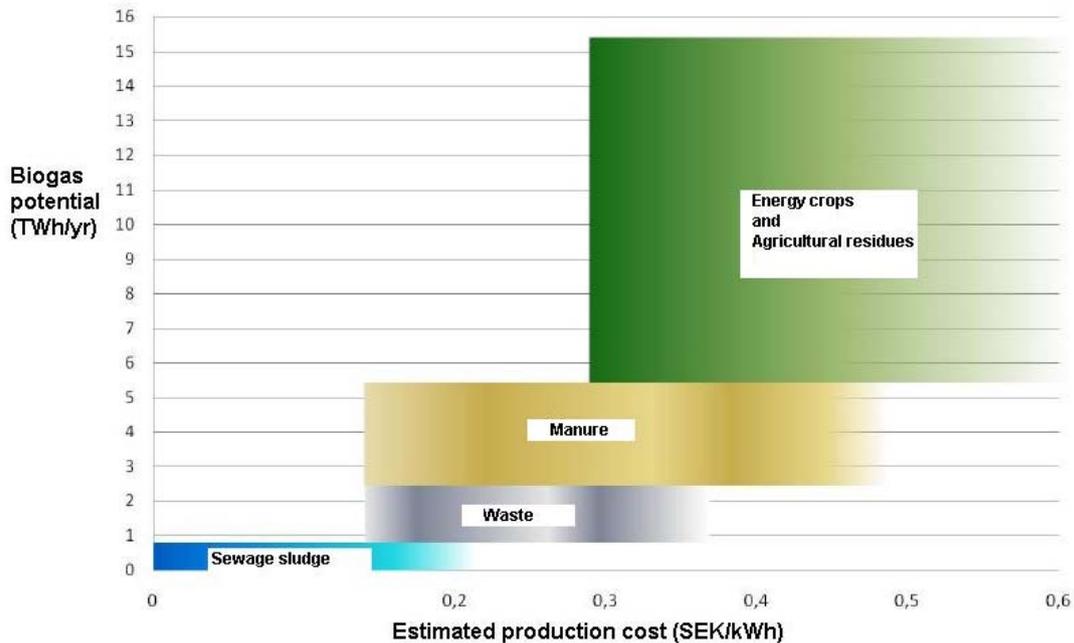


Figure 1.1 Estimated production cost and production potential for different substrate categories (Lantz & Börjesson, 2010)

Figure 1.1 gives an overview of the production cost and potential of biogas (upgrading and compression not included) for different substrates. Furthermore, a cost which is not included in the Figure above and which sometimes has been identified as the main factor leading to higher biogas prices is the distribution cost. This cost represents about 38% of the biogas price, compared to only approximately 11% for gasoline (K(2006)849)

1.4.2 Demand side and the transport sector

Although increasing, the demand of biofuels in general and biogas in particular in the Swedish road transport sector is low compared to the demand of fossil fuels such as gasoline and diesel. In 2006 the share of biofuels was 3.3% of the total fuel consumption and 5.2% in 2008. For biogas, although its proportion relative to natural gas is increasing, the share was 0.3% in 2006 and 0.4% in both 2007 and 2008 (Miljöfordon, 2009).

Regarding biogas/natural gas vehicles, the highest yearly increase of 3,900 vehicles took place between 2006 (from 6,600 new registered vehicles) and 2007 (to 10,500 new registered vehicles). For the years 2007 and 2008 the biogas/natural gas vehicle demand was 12,900 and 15,000 vehicles, respectively. Figure 1.2 shows the annual growth rates for biogas demand and biogas/natural gas vehicles since 2001. As shown the annual growth rate for the demand of biogas is correlated with the growth rate of biogas/natural gas vehicles. The annual growth rate in biogas vehicles has been rather constant between 2001 and 2008, with the highest growth rates in 2002 and 2006. The annual growth rate in biogas demand is slightly higher.

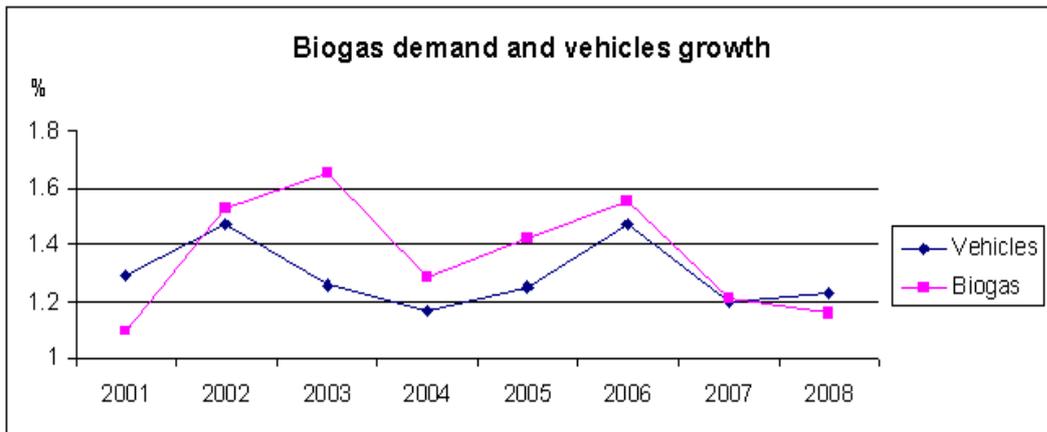


Figure 1.2 Annual growth rates for biogas demand and biogas/natural gas vehicles in Sweden 2001-2008.

Although fuel costs for a biogas vehicle are about 20% lower compared to an equivalent gasoline vehicle, the reasons to the low demand of biogas vehicles as well as biogas may be found in the following:

- Biogas vehicles are in general more expensive than gasoline vehicles.
- Although increasing, the number of filling stations providing biogas is still very limited and unevenly distributed in Sweden¹.
- The costs to build a filling station providing biogas are higher than for stations only providing liquid fuels.
- Poor knowledge and awareness among potential car buyers of the existence and advantages of biogas vehicles.

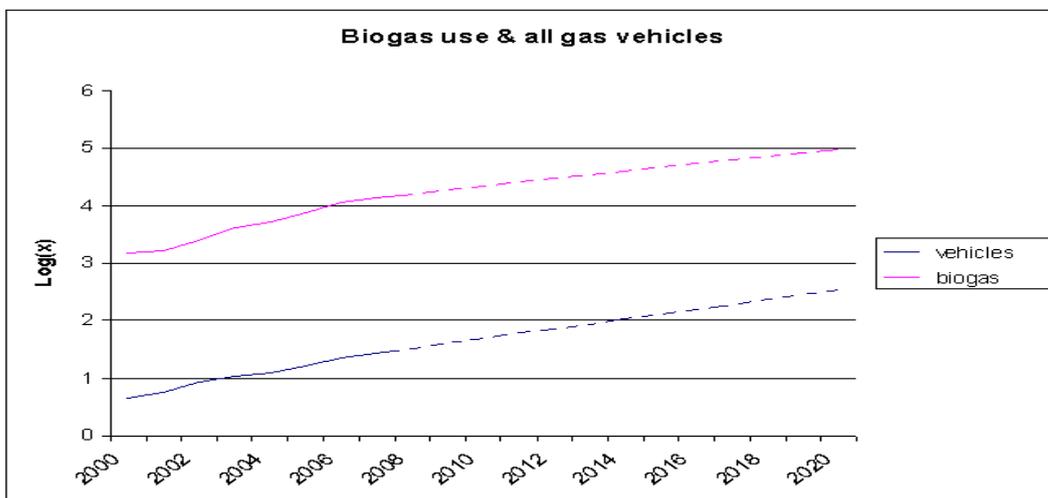


Figure 1.3 Past trend 2000-2008 and forecasts 2009-2020 for the demand of biogas and biogas vehicles.

Since data to assess the impact of the number of vehicles in use on the biogas demand is very limited, forecasts for year 2020 are based on similar growth rates used by the Swedish Energy Agency, cf. Figure 1.3. Furthermore, estimating correlation between biogas demand and vehicles in

¹ For instance, several gas stations in Stockholm area have had problems to meet the increasing demand of biogas leading to slower demand of biogas.

use may be done using elasticities. Although the number of observations is very limited regression analysis leads to elasticity equal to 1.29, i.e. when the number of vehicles in use increases by 1%, biogas demand would increase by 1.29%.

It may be misleading to rely on these forecasts that are linear extrapolations of past trends, partly because of recent observations that the Swedish market share of biogas vehicles is increasing while sales of ethanol cars are decreasing. However, this increase in demand/registration of new biogas vehicles may also be a temporary trend.

1.5 Environmental aspects

Depending on its socio-economic and environmental benefits, biogas production and utilisation has become a major part of the rapidly growing renewable energy sector. Unlike fossil fuel combustion, biogas production may lead to a whole range of benefits. Biogas production often leads to significant improvements of resource efficiency and environmental impacts compared to current waste handling and agricultural production practices (Börjesson *et al.*, 2003; 2005; Swedish Board of Agriculture, 2005a). Besides leading to reduced emissions of greenhouse gases, biogas systems may lead - among other things - to reduced eutrophication and improved air quality.

Table 1.5 Average emission factors for the Swedish passenger car fleet in 2007 (Vägverket, 2009).

| | CO g/km | CO ₂ emission kg/km | CO ₂ wtw ^b kg/km | HC g/km | NO _x g/km | PM g/km | SO ₂ g/km |
|----------------------|-----------------|--------------------------------------|--|-----------------|-------------------------|---------------------|-------------------------|
| Rural driving | | | | | | | |
| Gasoline | 1.7 | 0.17 | 0.2 | 0.31 | 0.32 | 0.0012 ^a | 0.0011 |
| Diesel | 0.17 | 0.15 | 0.18 | 0.03 | 0.52 | 0.030 ^a | 0.0002 |
| E85 | 0.55 | 0.04 ^d | 0.06 | 0.13 | 0.11 | 0.0012 ^a | 0.00022 |
| CNG | 0.56 | 0.07 | 0.1 | 0.04 | 0.024 | 0.0012 | 0.00031 |
| Biogas | -- ^c | 0 ^d | 0.04^c | -- ^c | -- ^c | -- ^c | -- ^c |
| Urban driving | | | | | | | |
| Gasoline | 4.4 | 0.23 | 0.27 | 0.85 | 0.45 | 0.0047* | 0.0014 |
| Diesel | 0.48 | 0.2 | 0.24 | 0.06 | 0.64 | 0.03 | 0.00026 |
| E85 | 2.2 | 0.05 | 0.07 | 0.45 | 0.19 | 0.0047* | 0.00026 |
| CNG | 0.99 | 0.09 | 0.13 | 0.1 | 0.04 | 0.0047* | 0.0004 |
| Biogas | -- ^c | 0 ^d | 0.05^c | -- ^c | -- ^c | -- ^c | -- ^c |

^a Emissions factors according to the EMV-model,

^b wtw = well to wheel, i.e. LCI emission factor

^c no data specifically for biogas; should be very similar to data for CNG. For CO₂ wtw, data for biogas are derived from Directive 2009/28/EC

^d Biomass fuel components are assigned zero CO₂ emissions. For E85, the contribution originates from the fossil part only

Table 1.5 displays data for selected emissions of different fuels. Notably, CNG offers advantages over gasoline and diesel for most emissions (the exception being CO emissions compared to diesel), but is inferior to E85 in particular for well-to-wheel emissions of CO₂. Assuming that tailpipe emissions from combustion of biogas are equivalent to those CNG (which should be valid as fuel quality biogas is as pure as fuel quality CNG), biogas offers advantage also compared to E85 for these well-to-wheel emissions of CO₂.

1.6 Socio-economic aspects

In order to evaluate socio-economic impacts of biogas production one needs to consider the life cycle of biogas, involving production, upgrading and compression, as well as distribution.

Due to limited data and knowledge, the relation between biogas production and employment is not easy to quantify. However, biogas production is stated to be an activity that is not labour intensive, unless you take into account the construction of biogas plants, which are temporary events.² Employment is relative to the plant size and since Swedish production plants are in most cases small, production of biogas has not yet had any significant impact on employment.

Estimates of the employment creation potential for various bioenergy options differ substantially. Liquid biofuels based on traditional agricultural crops seem to be the most employment-intensive option, at least in the short term. Thus, promoting biofuels for transport might be regarded as a logical strategy for increasing the use of bioenergy in order to reach climate targets and reduce the dependency on imported fuels (see e.g., *EC, 2004b*). However, the notion that biomass use within the transport sector is preferable to biomass use for heat and power production from an employment creation perspective seems valid only for first-generation biofuels that are produced from traditional agricultural crops. The use of second-generation biofuels from lignocellulosic feedstock within the transport sector can be expected to lead to an employment creation that is similar to that arising from biomass use in the stationary sector; the same feedstocks are used and economies of scale favours large conversion facilities for second-generation biofuels (*Hamelinck, 2004*), with relatively low labour requirement

Yet, maximizing climate benefits cost-effectively is in conflict with maximizing employment creation. The former perspective proposes the use of lignocellulosic biomass in the stationary sector, while the latter requires biofuels for transport based on traditional agricultural crops.

² In Skövde, for example, estimated workload to produce biogas is two (2) employees, and in Ulricehamn labour input for biogas production is part of the ordinary workforce.

2 Competing vehicles and fuels - barrier 1

Biogas vehicles are facing several specific challenges, i.e. these already pointed out in Section 1.4.2.:

- Biogas vehicles are in general more expensive than gasoline vehicles.
- The availability of service stations to refuel biogas is limited and unevenly distributed.
- The decision process for the construction of biogas plants as well as the expansion of the network of biogas refueling stations are far too slow to meet the demand.
- The costs to build a filling station providing biogas are generally higher.
- Poor knowledge and awareness among potential car buyers of biogas vehicles.

More generally speaking, the market opportunities for bio-fuelled vehicles including biogas vehicles are mutually dependent on the parallel development of fuel supply systems. The following sections therefore elaborate the general development trends regarding vehicles and corresponding alternative (non-fossil) fuels. Several new biomass-based fuels are entering the market and an overview of some market conditions of selected non-methane biofuels are given in Appendix B.

2.1 Vehicles

The total average annual car sale in Sweden in 2004-2009 was 265000 cars, with the peak sales in 2007 of 307000 cars, and the lowest number during the period of 213000 cars in 2009.

In heavy vehicles (trucks and buses) diesel is clearly the leading fuel. For passenger cars, petrol is the most common fuel, but the share of diesels is steadily increasing. In 2007, a total of 42 TWh diesel and 46 TWh petrol were used in the Swedish transport sector (*Energimyndigheten, 2008*). Generally speaking, the rate at which the vehicle fleet is replaced is an important factor in how rapidly new technologies can be introduced on the market. With regard to passenger cars, in 2007 33% of the total traffic work (the total distance driven) in Sweden was carried out by cars that were 0-5 years old or less (*SIKA, 2008*). The corresponding figure for heavy duty trucks was 51%. In recent years, the share of diesel passenger cars and light-duty trucks has also increased. The share of diesel-powered light-duty trucks increased between 1993 and 2003 from 15 to 56%. At the end of the period, more than 80% of new light-duty truck sales were diesels (*Johansson and Nilsson, 2004*). Regarding passenger cars, the proportion of diesel vehicles in new car sales increased from 10 to 35% in 2005-2007 (*BIL Sweden, 2008*).

2.1.1 Environmental vehicles

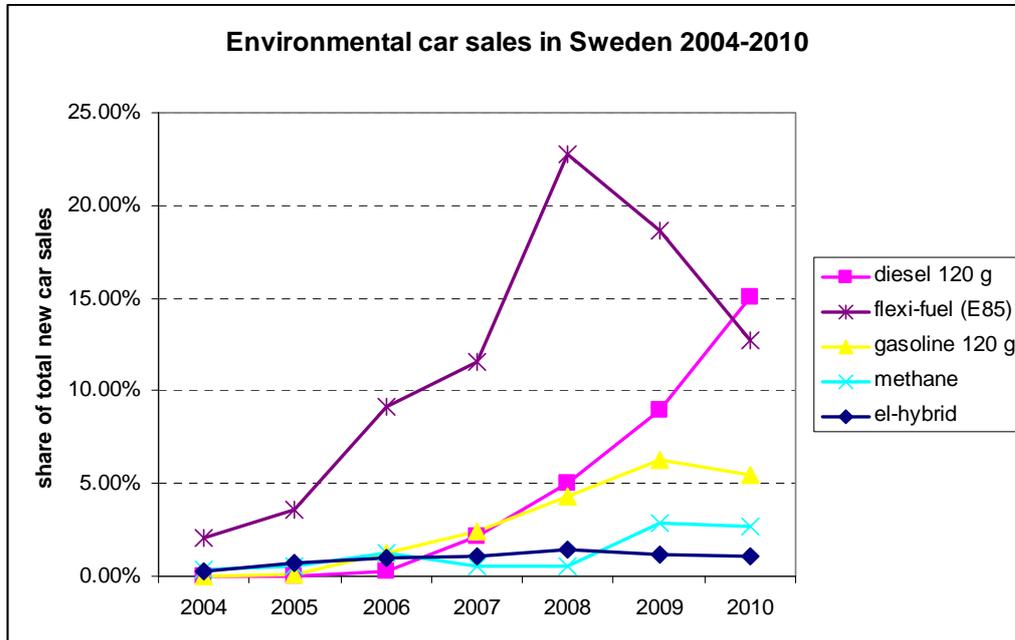


Figure 2.1 The share of cars sold in Sweden 2004-2010, belonging to different environmental classes

In recent years, the sale of cars conforming to the requirements for environmental vehicles has increased rapidly and is now around 40 per cent. Figure 2.1 displays the share of the total car sales of the different available types of "environmental vehicles" in the Swedish market in the years 2004-2009 (full years), and 2010 (jan-jun), based on statistics from Bil Sweden (www.bilsweden.se).

2.1.2 Costs

Table 2.1 highlights the price differences between bi-fuel (biogas/CNG/gasoline) cars and their gasoline-powered equivalents. These are often mentioned as a barrier for potential car buyers to choose the bifuel alternative. As shown, the price difference between a bifuel car and the equivalent gasoline-powered model is about 13 % for a Volvo S60 and about 11 % for a Volvo V70. For other market leading brands the price difference is in the range 12 % (Opel Zafira) to 22 % (VW Variant).

Table 2.1 Prices (SEK) of new bi-fuel vehicles and equivalent gasoline models on the Swedish market in February 2005.

| Vehicle | Ratio bifuel/gasoline |
|---------------------|-----------------------|
| Volvo S60 | 1.13 |
| Volvo S80 | 1.12 |
| Volvo V70 2.4 | 1.11 |
| Opel Astra 1.6 CNG | 1.20 |
| Opel Zafira 1.6 CNG | 1.12 |
| VW Golf Variant 2.0 | 1.22 |
| MB E 200 Sedan | 1.17 |

Sources: Volvo = Bilia AB, Opel = BEKÖ Bil AB, VW = Din Bil AB, MB = Hedin Bil AB.

An additional often raised question is related to the resale value of biofuel vehicles. Most car dealers that were contacted within the scope of this study argued that in general there is no difference in the level of resale value between bifuel cars and their gasoline powered equivalents. Since new biofuel cars are more expensive and since the level of the resale value is roughly the same as for their gasoline equivalents, regardless of brand and model, the relative resale value of biofuel vehicles is lower than for gasoline cars.

In an interview with a car dealer (Bra Bil AB, Gothenburg) in December 2009, regarding why sale figures for biogas cars are low, the following explanations were given:

- For companies, biogas cars have a better taxable value of fringe benefits (*in Swedish: "förmånsvärde"*); this is why they are often chosen as company cars. However, this is not a benefit offered to private car owners.
- The former Volvo bi-fuel cars were equipped with a smaller tank for biogas/CNG, which led to shorter driving distances between refillings.
- Recent models of the Volvo bi-fuel cars are equipped with a larger tank. However, this has led to a smaller luggage space, considered as a disadvantage of this car compared to the equivalent gasoline car.

2.1.3 Efficiency

Some newly introduced diesel cars on the market consume on average 4.5 liter diesel/100 km or even less. This development may shift car sales to diesel cars having these characteristics.

The question is if the growing supply and demand of such fuel efficient diesel cars could hamper the sales of biofuel cars in general and of biogas cars in particular. Another consequence of the introduction of such cars on the market may be the rebound-effect – since they are cheaper to drive they may lead to a more frequent use of the car and for longer distances. According to the conducted Swedish market surveys on biofuel vehicles summarised in Appendix A (see also subsequent section), the total cost of car ownership - capital costs, service costs and fuel costs - is crucial for the customer. Another risk is that cheaper vehicles and/or vehicles with a high fuel economy will compete with public transport. Furthermore, highly fuel efficient cars will be comparatively more expensive than “ordinary” cars, and thus may become a class prejudice.

2.1.4 Voices from the market

The results of the four recently conducted market surveys in Sweden related to the development and potential of biofuels in the short and long term are presented in Appendix A and B (the latter in Swedish). Below is a summary of the outcome of these surveys, highlighting the potentials and barriers for biogas and biogas vehicles.

In general, from a climate and environmental point of view, biogas is considered to be the best option of the biofuels presently available on the market. However, the decision process for the construction of biogas plants as well as the expansion of the network of biogas refueling stations are far too slow to meet the demand. Below are the general findings from the outcome of four markets surveys:

- Encouraging and enforcing the demand of biogas requires technology development and support of biogas as motor fuel, infrastructure development, and that the national grid of refueling stations providing biogas expands at a much faster pace.
- Biogas is expected to have significant challenges in terms of production, upgrading, distribution and vehicle development; greater than for high-admixture and pure liquid biofuels. However, if the gasification technology becomes more efficient, then commercial biogas possesses major advantages in terms of access to biomass.
- The raw material is cheap and in the case of waste and manure biogas has a high potential in terms of reducing climate impact of motor fuel use.
- Eventually, biodiesel from gasification and cellulosic ethanol could be of great importance. However, the competition with corn production will increase when biogenic raw material will be exploited at a maximum.
- Some of the interviewees believe that, in the long term, renewable fuels will only account for a small fraction of the energy use within the transport sector in Sweden.
- Small changes, like reduced forest products, increased pellets and biofuel production, as well as increased exports of biofuels, can be expected but production will gradually move where feedstocks and raw materials are cheapest.
- Biogas is considered to be of great importance on a long term basis, but this requires various kinds of support to increase both the supply and demand. In particular the biogas production needs to increase to meet the demand. For example, in Stockholm the demand for biogas exceeds the supply.
- In the short term, biogas and diesel vehicles will increase at the expense of gasoline vehicles. Biogas will be increasingly interesting over time.

According to the surveys, biogas vehicles have a future. Some believe that biogas vehicles manufactured in Sweden should be promoted, to support the domestic automotive industry. However, customer acceptance is still relatively low partly because of the higher vehicle price. For a detailed summary of all surveys, including other biofuels, see Appendix A and B (in Swedish).

2.2 Fuels

The demand for biomass and renewable energy is growing and plays an increasingly important role in the Swedish energy system. There are numerous studies about the future availability and potential of biomass of various types for the processing into vehicle fuels. The studies present different values and include various assumptions which lead to often wide intervals for the assumptions.

Methane as vehicle fuel is already competing with other fuels in the market. These are conventional fossil fuels as well as first generation (1G) bio-fuels, predominantly ethanol (for Otto engines, replacing gasoline) and rapeseed-methyl-ester, RME (for diesel engines, replacing fossil diesel fuel oil). Figure 2.2 shows the use of alternative fuels in recent years in Sweden, based on statistics from SPI (2010) and Energigas Sverige (2010).

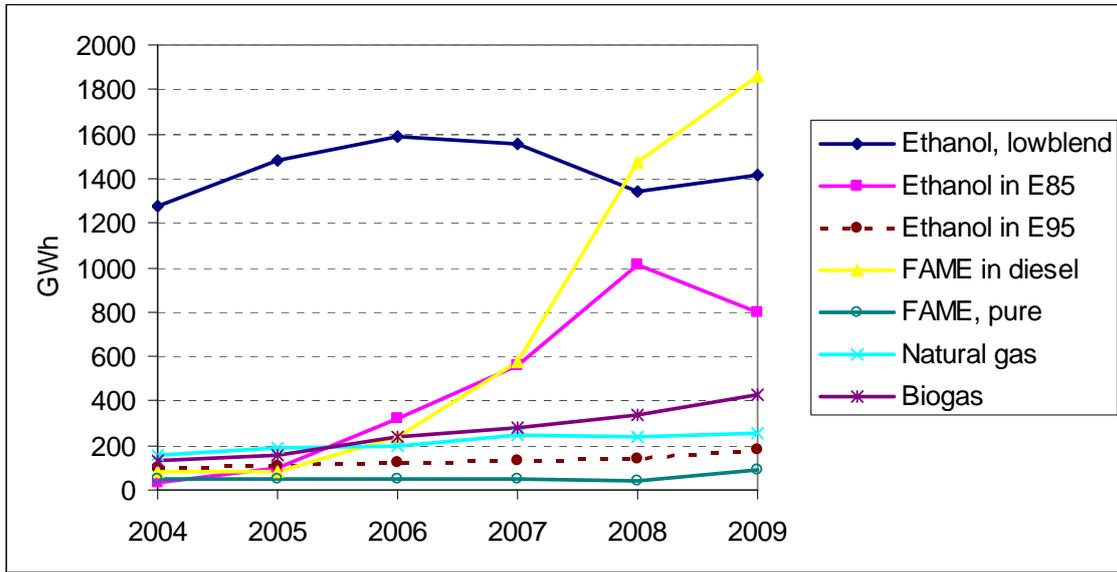


Figure 2.2 The alternative fuel supplied to the Swedish transport sector during the years 2004-2009, as pure fuel or in fuel blends.

2.2.1 Environmental aspects

It is assumed that the 2G biofuels will offer a possibility for larger CO₂-emission reductions at lower costs than 1G fuels (Suurs & Hekkert, 2009). Furthermore, the sustainability of 1G is under review, as is the possibility of creating undue competition for land and water used for food and fiber production (Renewable Energy World, 2009). The EU has, for instance, committed to 2G rather than 1G biofuels as a clean alternative for transportation (Euractive, 2009).

When it comes to biogas, the reduction of greenhouse gases is greater for biogas than for several other bio fuels, such as ethanol and RME, see Table 2.2. Biogas from residues such as MSW, industrial waste or manure, gives a higher reduction of greenhouse gases. Using manure as substrate reduces the emissions with 148 %, comparing to the use of fossil fuels. This is because of the avoided emissions of methane that otherwise will occur if the manure is stored and then spread on the farmland without the process of anaerobic digestion. This is also shown in Figure 2.3, where the well-to-wheel emissions for compressed biogas can be seen.

Table 2.2 Reduction of greenhouse gases from bio fuels in per cent, compared to fossil fuels. (Börjesson et al. 2010)

| Bio mass | Bio fuel | Reduction of Greenhouse gases [%] | |
|------------------|------------------|-----------------------------------|--|
| | | Mean value | Including emissions of biogenic N ₂ O, but excluding biogenic CO ₂ |
| <i>Crops</i> | | | |
| Wheat | Ethanol | | 77 |
| Sugar beet | Ethanol | | 83 |
| Sugar beet | Biogas | | 87 |
| Rape seed | RME | | 76 |
| Ley | Biogas | | 86 |
| Corn | Biogas | | 78 |
| Wheat | Ethanol & Biogas | | 71 |
| <i>Residues</i> | | | |
| MSW | Biogas | 103 | |
| Industrial waste | Biogas | 119 | |
| Manure | Biogas | 148 | |
| <i>Imports</i> | | | |
| Suger cane | Ethanol | 79 | |



Figure 2.3 Well-to-wheel GHG balance for compressed biogas pathways (JRC, 2006)

2.2.2 Fuel accessibility

The access to methane that can be used as vehicle fuel differs drastically between different parts of Sweden. This is due to the lack of a gas network in most parts of the country. The gas network in Sweden is limited to an area around the west coast. This probably has to do with Sweden’s history of cheap power supply from hydro power and later also nuclear power, and thus the independency of fossil fuels for power production. In the part of Sweden that has a gas network, produced biogas is often injected to the natural gas network, and most filling stations are supplied by gas from this

network. Hence, the gas that is used in the vehicles is a blend of natural gas and biogas. This means that in a case of biogas shortage, the motorist can still use his biogas vehicle using natural gas.

In parts of Sweden where there is no natural gas network, i.e. all parts except for the west coast area, fuel accessibility is a problem, since the local community is dependent on locally produced biogas. And there is no easy supply of natural gas to replace the biogas in case of a biogas shortage.

Looking at the development in recent years, it is clear that for ethanol vehicles, a large-scale market introduction took place in parallel with a large-scale deployment of ethanol pumps, see Table 2.3. Public economical instruments, provided by e.g. the Swedish government, which promoted biofuel car owners, also supported this development. For gas vehicles, however, market success has been slower, at least in part being explained by a limited access to filling stations. However, this is currently changing. Today there are about 100 filling stations in Sweden (Table 2.3), but the ambition of the stakeholders within the gas motor fuel business in Sweden is to double or triple this number by 2020. Only by then we can start talking about biogas as a "generally available".

Table 2.3 The number of filling stations for alternative motor fuels in Sweden by the end of each year 2003-2009 (SPI, 2009).

| | Dec -03 | Dec -04 | Dec -05 | Dec -06 | Dec -07 | Dec -08 | Dec -09 |
|----------------|---------|---------|---------|---------|---------|---------|---------|
| Methane | 31 | 47 | 62 | 74 | 87 | 89 | 103 |
| E85 | 92 | 206 | 300 | 706 | 1053 | 1332 | 1493 |
| RME | 0 | 0 | 23 | 17 | 16 | 13 | 14 |

2.2.3 Market development

The total potential of gasification from wood biomass alone is considered to be 84 TWh/year (SGC, 2007). The potential for biogas production by gasification of biomass from residues from forestry and agriculture is estimated to about 26 TWh/year (Gasföreningen, 2006).

Today, there are just above 100 commercial filling stations for biogas in Sweden (Table 2.3). In some areas, mainly in the eastern parts of Sweden, there has been irregular and insufficient supply of biogas to the filling stations. In order to avoid this problem, the biogas and natural gas in Western Sweden are using the same distribution system.

In several EU countries financial investment support has been introduced to encourage renewable technologies, which has led to an increased interest in biogas technology. Denmark has been a leading country in the introduction of regulatory frameworks and subsidies for biogas technology. In recent years, Germany, Austria, and Sweden followed suit with rules and support from the Danish experience. Currently, it is estimated that the biogas production in the world is 52 billion cubic meters per year, of which 80% is from landfill. The production quantity is in the order of 1-1.5 % of the current global (natural) gas production (e.g. Van Herle et al., 2004; BP, 2008). Depending on different scenarios, the potential to double the area used for biofuel production is highest in the U.S. and in Asia.

The integration of biomethane production in refineries could lead to the production of GTL (gas to liquid), which is considered the most cost-effective biofuel alternative for the road transport sector within Europe (CEC, 2006). On the supply side, the cost of production, upgrading and

compressing is higher for biogas than for natural gas.³ Although biogas is not subject to any taxes, the production costs especially for biogas from farming are very high (even compared to natural gas prices when taxes are added), thus biogas is not always competitive to natural gas. For biogas to gain significant shares of the overall gas market in the long term, it needs to be supported by subsidies, streamlining and improved distribution etc.

2.2.4 User friendliness

In recent years the market interest in gas-fuelled passenger cars has increased, as has the number of popular makes and models offering gas-fuelled alternatives, e.g. the new Volkswagen Passat. The demand of buses running on biogas is also increasing, since municipalities are becoming more and more aware of its advantages compared to diesel, e.g. biogas is a locally produced fuel, and the vehicles emit less pollutants and less noise compared to the corresponding diesel alternatives. There are not yet as many heavy duty trucks running on gas, since the technology is less developed. However, the development is rapid. For instance, Volvo has presented a biogas-fuelled truck and, if including hybrid power and so-called dual-fuel technology, there may be several models available on the market in the near future. With dual-fuel technology, heavy-duty vehicles are run with both biogas and diesel in order to obtain higher power at all engine speeds.

2.2.5 Legal aspects

In autumn 2006, a carbon-based vehicle tax was introduced. For light-duty vehicles, the yearly vehicle tax is made up of a basic tax that is equal for all cars (currently SEK 360) and a premium tax which is determined by the vehicle's estimated carbon dioxide emission per kilometer (currently SEK 15 per gram in excess of 100 g/km). For cars that can run on alternative fuels (i.e. biogas, E85), the additional charge is SEK 10 per gram in excess of 100 g/km. Gas-powered heavy-duty vehicles are taxed at approximately SEK 1,000 per year, compared to diesel-powered trucks that are taxed at 3,000 – 6,000 SEK, and coaches that are taxed up to SEK 20,000 per year.

Currently, the taxes on all alternative fuels (excluding electricity) are subsidized in Sweden. Compared with gasoline, diesel oil is taxed at 70% (calculated from the energy content), natural gas and LPG propane at about 20%, and RME, biogas and ethanol at 0%. The full tax exemption for biofuels has been extended until 2012.

With regard to heavy vehicles, it might be added that the dual-fuel technology (in the case of heavy trucks consisting of a fuel mix of diesel and methane) is intensely discussed in Europe. However, what is still lacking on a European scale is a legal framework for the type approval process for this kind of vehicles. Neither does a method exist for the measurement of the emissions for this fuel mix. It might be possible to obtain special approval for certain vehicles, but this would of course not be sufficient for the mass-introduction of dual-fuel heavy-duty vehicles on the market. The Swedish Transport Agency follows this subject closely and has initiated discussions with other agencies and stakeholders in Sweden as well as with other European countries. They are also in contact with Clean Air Power in the UK who have developed dual fuel technology in two product variants and have even completed demonstration vehicles for the Volvo Group (an FM9 (9-litre) vehicle for Europe and a Mack Pinnacle (13-litre) for the USA) (Clean Air Power, 2007).

³ The costs for natural gas are assumed to be 1.20 SEK/Nm³

2.2.6 Biofuels and the over-compensation principle

An over-compensation takes place when an alternative fuel as a result of tax reduction or tax exemption, would be cheaper than fossil fuel it replaces. Sweden has agreed to submit annual monitoring reports to the European Commission to show that no compensation is made and, should if it occurs, adjust the scheme. The Swedish Energy Authority is given the task each year to the government to disclose information about tax exemptions for biofuels. Although there are cases where tax exemption constitutes pilot studies, this should be reported

3 Competition for biogas - barrier 2

Biogas can be readily used in all applications designed for natural gas such as direct combustion including absorption heating and cooling, cooking, space and water heating, drying, and gas turbines. It may also be used in fueling internal combustion engines and fuel cells for production of mechanical work and/or electricity. If purified up to adequate standards it may be injected into gas pipelines and be used for e.g. steam production. Finally, through a catalytic chemical oxidation methane can be used for the production of methanol.

Today's use of methane as vehicle fuel is very small compared to the overall use of methane for various purposes in Sweden – only 0.6 TWh of the overall use of 11 TWh. There are different ways to interpret these Figures. In the distribution for methane as motor fuel in West Sweden, biogas and natural gas are mixed, so the overall ratio is close to 50:50. There are several advantages, regarding fuel supply security and also distribution, since some filled stations are served by the same pipeline. However, also some of the main users of natural gas for other purposes (than as motor fuel) are using the same pipeline, why they compete for the same supply.

The use of methane for other use than as vehicle fuel is much bigger than the use of methane as vehicle fuel. This can be discussed from two different angles. From one angle it means that the supply of methane is there already and the use in vehicles can be increased (by using natural gas as the source) quite much from current level as the demand can be fulfilled also beyond the level of biogas supply.

From the other angle it can be assumed that current industrial users of methane (i.e. natural gas) are also looking at opportunities to make their business greener by, e.g., trying to use biomass-based methane as an alternative methane source. This may lead to increasing competition for biogas and consequently higher prices.

3.1 Electricity and biogas

Since there are no studies making cost benefit analysis related to the most known fuels including both bio- and fossil ones, comparison of actual and future environmental benefits using biofuels is much higher than the benefits derived from fossil fuels (Norrman et al., 2005).

However, it is not easy to make unambiguous projections of future production and use of different fuels. For instance, the SASM-EU (Swedish Agricultural Sector Model for EU) model has recently been used to analyse future production of bioenergy in general and biofuels in particular within the Swedish agricultural sector (Belhaj et al (2010, forthcoming)). Based on the one hand on the projections of future energy prices made by the Swedish Energy Agency's, which are high, and on the other hand by OECD/FAO, that are predicted to be lower, future biogas production would be equal to zero. The reason for this is the overall poor cost efficiency for biogas compared to other fuels. According to this study production of electricity based mainly on Salix and to a certain degree on stow would be more cost effective in the long run, as would production of REM and ethanol, which would be substantial in the future according to the model.

4 Synthesis

4.1 Synthesis/summary of chapters 1-3 for biogas

Based on the studies cited in this report as well as the discussion related to the socio-economic aspects, a “meta-analysis” assessment leads to the following. To start with, assuming that production of biogas in general implies an overall (net) positive effect for the environment and the climate, biogas production will be supported and will bring subsidies to this sector with the purpose of maintaining and increasing the production. According to most studies, the use of biogas in the road transport sector is positive for the employment, but the effect is rather marginal at the national level, since it is temporary and mainly related to the construction of biogas plants. Increased demand for biogas in the transport sector would substitute fossil fuels leading to lower emissions of CO₂ in particular and greenhouse gases (GHG) in general. Based on the fact that an increase in the biogas vehicle fleet would lead to a subsequent increase in biogas demand, an increase in the demand of biogas vehicles is very dependent on biogas being subsidised. CO₂ and GHG emissions will be reduced, but the reduction will be marginal since biogas consumption in the transport sector is low.

The long-term implications of a higher production of biogas in general and in the transport sector in particular, are very dependent on the policy instruments in use, since the possibilities for increased efficiency of the production processes for biogas that would lead to lower costs in the short run are limited. Hence, the following has to be considered:

- If subsidies at today’s levels sustain and overcompensation does not occur, i.e. supply price of biogas will not be higher than the competing fossil fuels; the production of biogas would continue to increase. However, it is very difficult to predict the rate of this increase, since other factors such as the fuel efficiency of fossil fuel vehicles, e.g. diesels, as well as the vehicle price would be very important. For instance, a diesel vehicle consuming less than 4 l/100 km and with a price lower than a similar biogas vehicle is hard to compete with.
- If the production of biogas (to be used as motor fuel) would become more efficient, leading to lower production costs and lower prices of biogas, subsidies would cease. The implied effects of this hypothesis are difficult to predict. Again, the fuel efficiency and the price of diesel vehicles have to be considered, as well the supply of biodiesel on a national scale. So the increase in biogas demand in the road transport sector would proceed being positive. However, in order to reach a higher growth rate other policy instruments, e.g. information measures and to increase the energy and CO₂ taxes on fossil fuels substantially.

Other measures to promote and increase the use of biogas are:

- Tax exemption for biogas vehicles, reduced parking fees and congestion fees
- Requirements of “low-carbon” vehicles in procurements
- Tax rules and requirements related to business trips and company cars
- Higher availability of biogas
- Smart and technically feasible investment subsidies for biogas vehicles

- Investment subsidies for production and distribution of biogas; this is mainly in the short run but its impact is not positive according to mainstream economics
- A concise definition by the government of the term “environmental car” (i.e. cars subject to subsidies, due their performance from an environmental and climate point of view) is needed to increase both the demand and use of these kinds of cars. A very strict limit for CO₂ emissions (around 50 gram/km) would make 100 % biogas the only option in practice to clear this limit.

However, most of these recommendations are directly or indirectly based on subsidies which may have some impacts in the short run. In the long run subsidies are not recommended (because it would be against all established economic theories and science).

Regarding impacts of biogas demand in the transport sector on CO₂ and other GHG emissions, these will be positive, i.e. less emissions. However, the magnitude of these impacts is again dependent on the actual demand of biogas.

4.2 Barriers for increased market penetration of biogas

Production costs for biogas

Production of biogas within the agricultural sector, e.g. from cultivated crops, is the largest potential source, but has the highest production costs. Therefore, there is a need for measures, including research and investments, to reduce these costs (*Nordberg, 2006*). A main factor leading to higher costs for biogas is the distribution that represents about 38% of the price of biogas, whereas corresponding costs for gasoline only make up about 11% for the price. Biogas is the most efficient fuel, but is complicated and expensive to distribute.

Biogas from crops versus waste

The most common raw material used for biogas production in Sweden is waste since the costs are lower compared to the costs for production based agriculture crops (0.15 to 0.35 SEK/kWh compared to 0.30 to 0.55 SEK/kWh). However, upgrading of biogas from crops is slightly lower than from other waste. The supply of biogas from landfill in Sweden is despite the low cost very limited, due to limited access or limited opportunity to use biogas from this source. This is in line with the market surveys, predicting that in the long run renewable fuels will only account for a limited amount of the energy use within the transport sector in Sweden. The production will gradually be moved to the countries where the raw materials are cheapest.

Biogas vehicles versus gasoline and diesel vehicles

A new biogas vehicle is in general more expensive than an equivalent gasoline vehicle. However, when it comes to the resale value it is more or less the same for a biogas vehicle compared to a similar gasoline vehicle. Due to the very good fuel economy of in particular new diesel cars, customers may choose a diesel car before a biogas car when switching car, if the price difference is not too high.

Limited number of refuelling stations for biogas

Although increasing, the number of service station to refuel biogas is too limited and unevenly distributed. The cost to build a service station providing biogas is higher than for gasoline and diesel. The decision process for the construction and building of biogas plants is far too long and the expansion of the network of biogas filling stations is far too slow to meet the increasing biogas demand. To bridge the gap between supply and demand of biogas a better and more spread infrastructure regarding production facilities is required. In the long run, it is assumed that biofuels will be serving the same market. The local distribution of biogas need to be expanded which requires technological and infrastructure development.

Lack of information and marketing of biogas cars

There may not be sufficient awareness among motorists that biogas cars present a realistic alternative when switching cars, partly due to lack of both information (from national, regional and local governments and authorities) and marketing from car manufacturers and their retailers.

4.2.1 Present policy measures

Apart from VAT, which is an indirect tax on the value added in sales of goods and services, taxes related to fossil fuels and biofuels in Sweden are:

Energy tax

The energy tax is related to fossil fuels. Tax rates are determined from year to year and vary between different fuels. In 2007, the tax on unleaded gasoline was 2.95 SEK/l and for diesel it was 1.23 SEK/l. This tax is not valid for natural gas and biogas, neither for fuels used to produce electricity, nor in the agriculture, forestry and aquaculture sectors. Furthermore, for the manufacturing industry there is no energy tax on the fuel used in the manufacturing process.

For transport there are different tax rates depending on the fuel's environmental classes. Gasoline and diesel taxes in environmental class 1 and 2 were increased by 29 and 55 cents per liter, respectively, including VAT the first January 2008. At the same time the vehicle tax for diesel cars was reduced by 4.5%. For diesel and fuel oils used in commercial shipping, rail transport and aviation no energy tax is paid. From 1 July 2008, however, aviation fuel used for private purposes is taxed. RME and biogas are exempted from energy and carbon dioxide tax, while natural gas in the transport sector is exempted from energy taxes.

CO₂ tax

The CO₂ tax rates vary between different fuels depending on the fuel's carbon content. The CO₂ tax on gasoline and diesel in 2007 was 2.34 and 2.88 SEK/l, respectively. The overall level of the CO₂ tax was increased by 0.06 SEK by January 1, 2008 and amounts to 1.01 SEK per kg of CO₂. Since January 1, 2008 energy and CO₂ taxes are adjusted to price changes.

For natural gas/biogas and LPG the tax in 2007 was 1.28 and 1.58 SEK/m³, respectively. As is the case for the energy tax, the production of electricity is also exempted from the CO₂ tax. Agriculture, forestry, aquaculture and manufacturing industries pay only 21 percent of the tax rate.

At the end of the year 2008-2009 the CO₂ tax on gasoline increased by 0.2875 SEK/l incl. VAT and on diesel by 0.22375 öre/l incl. VAT (Statiol, 2010).

Table 4.1 shows applied fuel taxes excl. VAT by January 2007.

Table 4.1 Applied fuel taxes in Sweden in January 2007.

| Fuels | Energy | CO ₂ | Total tax | SEK/kWh |
|--|--------|-----------------|-----------|---------|
| Gasoline, unleaded (SEK/l) | 2.95 | 2.34 | 5.3 | 0.585 |
| Diesel (SEK/l) | 1.23 | 2.88 | 4.1 | 0.413 |
| Naturalgas/methane (SEK/m ³) | - | 1.28 | 1.3 | 0.116 |
| LPG (SEK/kg) | - | 1.58 | 1.6 | 0.124 |

Source: Swedish Energy Agency

Subsidies

Besides taxes, there are subsidies that are defined sometimes as negative taxes when they take the form of a tax exemption. The most known Swedish subsidies with regard to biofuels are the so-called Climate Investment Programs (KLIMP), the objectives of which are to support local authorities and other stakeholders to contribute to long-term investments that reduce the emissions of greenhouse gases on the local (municipal) level.

For transport, there are other instruments with a view to encouraging the use of environmentally friendly cars such as parking subsidies for green vehicles.

Quota obligation ("Kvotplikt")

Quota obligation means that each fuel producing company is obliged to sell a certain percentage of biofuel. Quota obligations are according to Per Kågeson a way to shift responsibility to fuel distributors without telling them how to meet the requirements (Kågeson, 2009). It creates freedom for them to act in accordance with their prerequisites. The approach also involves that there is no need of subsidising biofuels through tax exemptions. The Swedish Energy Agency is currently investigating quota obligation for biofuels.

4.2.2 Potential policy measures

As a summary of the outcome of the market survey presented in Appendix A, the following potential short-term policy measures to promote the introduction of biofuels in general (including biogas) can be listed:

- Technology-neutral regulation framework for support and subsidies in the early development phase of biofuel production.
- Financial support for new infrastructure, production of renewable biofuels as well as technology development for basic research to implementation in vehicles.
- EU-regulation: Implementation of emission standards for CO₂ emissions for passenger cars and light-duty trucks, including the 95g/km target for passenger cars for 2020.
- National regulation: The light-duty vehicle fleet owned and used by all public bodies in Sweden should represent “state-of-the-art” as regards low climate impact.
- Introduce a “Polluters Pay Principle (PPP)” for fuel production: Producers of fuels having a high climate impact should pay an earmarked tax to producers of fuel having a low(er) climate impact.
- Certification of raw materials and fuels to increase biofuel credibility and sustainable production. Sustainability and traceability requirements should be put on all fuels, including fossil fuels.
- Carbon taxes: are considered to be the most important instrument to affect the demand of fossil fuels.
- Subsidies are believed to be the most efficient way to reduce emissions from the transport sector and also to increase the use of biofuels. The subsidies will be maintained in the short term, but it is uncertain what will happen in the longer term. Many believe that subsidies for “green cars” will persist.
- Interference requirements and/or quota duty is considered necessary to achieve the goal of at least 10% biofuel share by 2020 in Europe.
- Media may have a crucial role for how potential conflicts between biofuels production on the one hand and human rights and food production on the other are perceived and interpreted by the public, which may either support or hamper the use of biofuels.
- Because of the present (2009-2010) difficult economic situation, climate change tends to be perceived by some as a “luxury problem”, but the progress to reduce fossil CO₂ emissions must continue, not least through support from national, regional and local governments.

As a summary of the outcome of the market survey presented in Appendix A and B, the following potential *long-term* policy measures to promote the introduction of biofuels in general (including biogas) can be listed:

- The Swedish policy instruments to reduce fossil CO₂ emissions in the road transport sector have been mainly focused on the demand side (fuels), and through the current energy and carbon dioxide taxes. A consensus according to the market survey is that this strategy needs to be complemented with instruments on the supply and production

side, such as production and investment, to accelerate the achievement of results and technology procurement.

- Development of fuel requires stable global and long-term solutions
- Research and development in the EU is crucial to develop improved electric vehicle technologies including batteries and second-generation fuels.
- Carbon taxes and subsidies for biofuels in general and those with the lowest climate and social impact in particular.
- Combined energy efficiency measures; energy efficiency, fuel switching, lifestyle change, transportation-efficient urban structure and an increased effective use of public transport.

Another view is that a ban should be introduced, which means a deadline for when fossil fuels in transport is to be phased out.

5 Conclusions and recommendations

At present, Sweden - as any other EU Member State through the EU Directive 2003/30/EC (known as the “biofuels directive”) - faces the challenge to increase the share of fuels of biogenic origin in the transport sector to 10% (in energy terms) by year 2020. In line with a parallel draft directive (N2008/1203/E), this can be accomplished by (and is encouraged to) using admixtures of biofuels in gasoline up to 10% and in diesel up to 7%, respectively, complemented by an increased use of “pure” biofuels such as biogas, ethanol (E85) and biodiesel, or renewable electricity.

With a present (2008) share of biofuel used in the Swedish road transport sector of 5.2%, the prerequisites for reaching the binding target of 10% by 2020 seem very promising. It is both likely and desirable that biogas vehicles may make a significant contribution to fulfil Sweden’s obligation to the biofuels directive. Likely, because the stock of biogas (bi-fuel/CNG) vehicles in Sweden is increasing, as is the supply and demand of biogas. Desirable, because biogas use in the road transport sector has not only climate benefits, but also benefits from an environmental (e.g. improved air quality due to lower emissions of regulated and unregulated air pollutants) and socio-economic (e.g. domestic production, employment) point of view.

The national goal to have established a “fossil fuel independent” road vehicle fleet by 2030 is apparently a much tougher challenge, also when interpreted as that all road vehicles should only *be able* to run on renewable fuels, not necessarily actually also doing so.

To reach this target, it is obvious that much stronger incentives than today must be created to increase both the demand of biofuel vehicles and other vehicles considered to run on renewable energy (i.e. electric or hybrid vehicles), *and* the supply of biofuels and renewable energy (i.e. electricity). In line with the both feasible and desirable increase of biogas vehicles and biogas use in the road transport sector pointed out above, biogas vehicles should be an important element also in achieving the ambitious national target for 2030. Particularly since the potential for biogas production in Sweden, taking into account both first generation (mainly waste) and second generation processes (forest products mainly), is very high, estimated to overall some 55 TWh. In relation to the future production potential, today’s use of biogas in particularly the transport sector of about 0.4 TWh and the use in other sectors of about 1.1 TWh, is quite marginal. However, the extent of the use of biogas as motor fuel in the future will depend on many parameters. For instance, if the future production potential is realised to a significant extent by 2030, there will of course be a competition for biogas use in the transport sector from the stationary sector, for e.g. heat and electricity production. The future use of biogas in the road transport sector will also depend on the future relative costs for biogas as motor fuel and electricity, which is also foreseen as an important energy carrier in the road transport sector in the future (and may readily be produced from biogas). Finally, the supply of several other (second generation) renewable fuels/biofuels options is also likely to increase significantly until 2030, the most likely ones being ethanol, biodiesel, synthetic diesel (produced from biogenic sources), methanol and DME.

An overall conclusion is that, on a long term, the supply and demand of biofuels/renewable energy in general, regardless of the type of fuel, must be driven by the market, and not by subsidies.

In order to promote the demand of biogas vehicles and biogas as a motor fuel on a short and long term (up to 2030) the following policy measures, that can be introduced on a national or EU level, are recommended (which does not exclude similar measures to promote other biofuels/renewable fuels within the transport sector):

- Technology-neutral regulation framework for support and subsidies in the early development phase of biogas production. The Swedish policy instruments to reduce fossil CO₂ emissions in the road transport sector have been mainly focused on the demand side, and through the current energy and carbon dioxide taxes. This strategy needs to be complemented with instruments on the supply side (production, infrastructure investment, distribution grids, filling stations) etc., otherwise the potential to boost the market for biogas vehicles will not be exploited.
- Various subsidies of biogas to lower the market price or to create other economic incentives for motorists to use biogas.
- EU-regulations: Implementation of emission standards for CO₂ emissions for passenger cars and light-duty trucks, including the 95 g/km target for passenger cars.
- National regulations: The light-duty vehicle fleet owned and used by all public bodies in Sweden should represent “state-of-the-art” as regards low climate impact.
- Certification of raw materials and fuels to increase biofuel credibility and sustainable production. Sustainability and traceability requirements should be put on all fuels, including fossil fuels.
- (Higher) taxes on fossil fuels, fossil CO₂ emissions, and on the energy use in road vehicles in general.
- Interference requirements and/or quota duty to assure achievement of the goal of at least 10% biofuel/renewable energy share in the transport sector by 2020 within EU.
- Support of basic and applied research regarding biogas production technologies and improved biogas engine/vehicle technology.

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Appendix A

Biofuels and biofuel vehicles with special emphasis on biogas and biogas vehicles: A summary of surveys

During the past three years (2007-2009) IVL has conducted four market surveys regarding the potential for development of biofuels in the short and long term^{4, 5, 6}. This appendix is a shortened summary of the outcome of these surveys⁷,

By most subjects of the interviews biogas is considered to be the best option of the biofuels presently available on the market from a climate and environmental point of view. However, to fully benefit from its potential, the policy measures for the construction of biogas plants as well as the expansion of the number of refueling stations have to be enforced. Biogas is considered to be of great importance in the long run, but this requires support and investments to above all increase the production to meet the demand.

For example in Stockholm, the demand for biogas presently (2009) exceeds the supply. Increased biogas production requires development of both engine technology (dual fuel) and biogas catalysts (methane). A combination of diesel and biogas is considered to be more common in the short term, but biogas is considered to be commercially in the long term. Another view is that hydrogen could be an alternative motor fuel in the future. In the long term the subjects in the survey believe that a wider variety of biofuels will be serving the same market.

Below is a review of the outcome of the four market surveys, divided into five main areas: Renewable fuels, Raw materials and production technologies, Vehicles, Transportation and Infrastructure and Policy instruments, respectively. Within each area, the consensus and trends as well as conflicting opinions among the interviewees are analysed for short and long term perspectives, respectively. These are summarized also in a separate table. Representatives from some 15 different companies and organizations in both the private and public sectors in Sweden responded to the survey.

⁴ Rydberg, T. et al. (2008), IVL report U2273 (not public), for E.ON.

⁵ Rydberg, T. et al. (2009b), Road vehicles and fuels – future development. Report within The Energy Study Phase 2 (in Swedish): Office of Regional Planning, Stockholm County Council. June 2009. IVL Report B1945.

⁶ Rydberg, T. et al. (2009d) BIODRIV – Collaborative project between IVL and Chalmers/Gothenburg University, financed by SIVL and Preems miljöstiftelse, on selected technology paths for future biofuels, containing market surveys in 2 stages, IVL report B1884, 2010.

⁷ Lindblad, M., Biobränslen och biobränslefordon med särskild fokus på biogas och biogasfordon: En sammanfattning av fyra intervjuundersökningar, IVL report 1946, 2010.

| Short term (2020) | Long term (2030 and longer) |
|--|---|
| Renewable fuels: | |
| <p>Agreements /trend <u>Predominating fuels:</u> - Liquid fuels <u>Cross-over mechanism:</u> - Ethanol and FAME <u>Increased share/importance:</u> - BTL, FT-diesel and DME <u>Future potential:</u> - Biogas and natural gas</p> | <p>Agreements /trend <u>Predominating fuels:</u> - BTL, DME, RME and FAME <u>Cross-over mechanism:</u> - Combination between diesel and biogas <u>Increased share/importance:</u> - Biogas and electricity <u>Future potential:</u> - Hydrogen gas, LMPG and biogas in liquid form</p> |
| <p>Disagreements /other <u>Potentials:</u> - Ethanol 10%, biodiesel 7% - Cellulose ethanol</p> | <p>Disagreements /other <u>Potentials:</u> - Fuel cells (methanol, CCS, renewable electricity) - Hydrogen gas (liquid form)</p> |
| Raw material and product technology: | |
| <p>Agreements /trend <u>Swedish production</u> - Import is needed - Corn production, ethanol and RME <u>Determinant factors</u> - The price of raw material - Capacity to pay <u>Future potentials</u> - Bio-diesel from gasification</p> | <p>Agreements /trend <u>Swedish production</u> - Import is needed - Forest raw material <u>Determinant factors</u> - Waste and rest products - The costume duty - Competition with the corn production <u>Future potentials</u> - Bio-diesel from gasification - Cellulose ethanol - Biogas production</p> |
| <p>Disagreements /other <u>Potentials:</u> - Limited forest raw material - Competition if the ethanol production increases</p> | <p>Disagreements /other <u>Potentials:</u> - Electricity production - Black liquor gasification</p> |
| Vehicles: | |
| <p>Agreements /trend <u>The development of technology:</u> - International global market <u>Vehicles:</u> - Fuel-efficient vehicles</p> | <p>Agreements /trend <u>The development of technology:</u> - International global market <u>Vehicles:</u> - El-hybrid and plug-in hybrid - Gas-vehicles <u>Determinate factors:</u> - The battery performance for electric vehicles - Electricity-distribution infrastructure - “Green” electricity production - Change of the vehicle fleet <u>Future potentials</u> - Swedish production of gas-vehicles</p> |
| <p>Disagreements /other</p> | <p>Disagreements /other <u>Potentials:</u> - Hydrogen gas</p> |

| Transport and infrastructure: | |
|---|--|
| <p>Agreements /trend</p> <p><u>Filling station:</u></p> <ul style="list-style-type: none"> - Gas-fuels <p><u>Railway:</u></p> <ul style="list-style-type: none"> - Begin the enlargement <p><u>Public transport:</u></p> <ul style="list-style-type: none"> - Begin the enlargement | <p>Agreements /trend</p> <p><u>Transport:</u></p> <ul style="list-style-type: none"> - Decrease the transport volume - Effective conveyance of goods <p><u>Filling station:</u></p> <ul style="list-style-type: none"> - Gas-fuels filling stations - Electricity loading stations <p><u>Railway:</u></p> <ul style="list-style-type: none"> - Enlargement and efficiency <p><u>Public transport:</u></p> <ul style="list-style-type: none"> - Enlargement and efficiency |
| <p>Disagreements /other</p> | <p>Disagreements /other</p> <p><u>Potentials:</u></p> <ul style="list-style-type: none"> - Environmental-friendly rail-vehicle - Helium-balloon for transport of forest raw material |
| Policy instruments: | |
| <p>Agreements /trend</p> <p><u>The EU:</u></p> <ul style="list-style-type: none"> - 95g/km year by 2020 (as limit for fossil CO₂ emissions from passenger cars) <p><u>Political instruments:</u></p> <ul style="list-style-type: none"> - Energy- and carbon dioxide taxes - Tax-subsidy - Low-addition demand / Allocation of quotas - Costumes on ethanol - Vehicles tax to increase the carbon dioxide differentiation - Kilometer tax - Road-charge - More efficient tax-system on company cars <p><u>Distribution:</u></p> <ul style="list-style-type: none"> - Filling stations for biogas-vehicles | <p>Agreements /trend</p> <p><u>Political instruments:</u></p> <ul style="list-style-type: none"> - Strongly increased fuel-taxes - Energy- and carbon dioxide taxes - Kilometer tax - R&D on electric vehicles |
| <p>Disagreements /other</p> <p><u>Potentials:</u></p> <ul style="list-style-type: none"> - Certification/ indication of origin raw material and bio-fuels - Low-additional fuels - Subvention for environmental friendly vehicles - Technique-neutral frame work - Reverse the trend of purchasing behaviour - Sustainable and traceable requirements on bio-fuels and other fuels. - Better definition on environmental friendly vehicles | <p>Disagreements /other</p> <p><u>Potentials:</u></p> <ul style="list-style-type: none"> - Purchasing behavior - Behaviour and lifestyle changes |

Renewable fuels

Short term

The interviewees believe that the first generation biofuels will be predominating in the short term, since second generation biofuels will still be too expensive. First generation fuels are under continuous improvement which will lead to improvement of climate and energy performance of the best option available in the market, such as biogas. Biogas and natural gas use is deemed to be important in the long run, but it requires development of the infrastructure. The development of technology and energy will not increase as fast as the increased demand of transport.

Ethanol and FAME in light duty vehicles and biodiesel in heavy duty vehicles are considered as the best large-scale solutions. However, ethanol and FAME are considered to be replaced by more efficient solutions in the future. High quality biodiesel (BTL) and long term FT-diesel and possibly DME for heavy duty vehicles are considered to become important biofuels. Some of the subjects in the surveys believe that cellulose-ethanol can replace diesel in passenger cars with good performance.

Long term

Since the exchange rate in the Swedish vehicle fleet is slow, liquid fuels will still be predominant by 2030. High involvement of biofuels requires large investments in infrastructure as well as in vehicle development. Diesel and diesel engines have a very good availability and efficiency and diesel is therefore considered to remain as an important fuel in the long term. Diesel and DME for heavy duty vehicles, and ethanol and diesel for light duty vehicles are considered to be the most likely liquid fuels by 2030. Interesting fuels for the future are the ethanol-based diesel ED 95, biodiesel from Fischer-Tropsch plants and synthetic diesel, that may have a significant share of the market in 2030. For heavy duty vehicles MDE (methane diesel engine - dual fuel) may be an effective alternative. Future potential fuels are hydrogen, LPG and liquid biogas. However, hydrogen is difficult to store and fuel cells are very expensive. The development of fuel cells has in recent years competed against battery development, which has received major credence. Some believe that hydrogen light and heavy duty plug-in-hybrids will be introduced on the market in the long term.

It is considered important to make long-term investments in biofuels all over Europe, so that vehicle manufacturers, fuel producers, importers and distributors can develop optimized vehicles and production methods. There are some different opinions among the interviewees concerning the development of biogas as biofuel since it is expected to have significant challenges in terms of production, distribution and vehicle development. Gaseous fuels are the most efficient, but expensive and difficult to distribute. The distribution of biogas has to be expanded to cover the demand, which will require technology development and subsidies. The challenges with biogas can be greater than for high-involved and low-polluting liquid biofuels. On the other hand, the gasification technology is effective and a commercial advantage in terms of access to biomass. A combination of diesel and biogas is expected to become more common in the future. However, customer acceptance is relatively low because of the higher vehicle price.

Raw material and production technologies

Short term

Ethanol and RME will dominate the Swedish production of biofuels. However, the Swedish production of biofuel will not account for the largest proportion of biofuels in either the short or the long run. If the cellulosic technologies will be developed and through increased biogas-production half of the biofuel demand may be from domestic production. A shift towards forest raw material is also considered to increase the domestic production, since increased competition will drive the price of raw materials upwards. The prices of forest raw materials and oil are considered to be the key determinants of the profitability of the Swedish biofuel production, which is also affected by increased competition for forest raw material and crops for food production and industrial use. Sweden will be dependent on imports in view of the fact that the domestic supply of forest raw material will be limited in the future.

Long term

The overall perceptions of the interviewees are that as long as fossil fuels dominate the world market, biofuels will be affected by fossil fuels prices. However, fuels from the gasification of waste and biomass may become more commercial. Some believe that biofuels will only cover a limited amount of the energy demand in the transport sector in Sweden. Small changes in the combined heat and power supply, reduced activity in the forest industry, increased pellet and bio-fuel production, as well as increased exports of biofuels can be expected, but production will gradually move to the parts of the world where raw materials are cheaper. Synthetic diesel, DME, Fischer-Tropsch-diesel, gasification of black liquor and other biomass are assumed to be alternative biofuels in the long term to a limited extent. Black liquor gasification is considered to have the potential to cover the whole demand in Sweden of renewable fuels on a large scale, despite its disadvantages (energy loss, heating of the input material and poorly developed technology). The possibility also exists to modify the current fossil fuel based on oil with different types of admixtures, such as hydrogen produced from biomass. The challenge for electric vehicles is mainly the vehicle technology development. Electricity generators will play a greater role in the transport sector in the long term and is an important factor in reducing fossil CO₂ emissions.

Vehicles

Short term

Vehicle technology development must take place on the global scale is a basic viewpoint of the interviewees. The vehicle market is global and so is the biofuel market, therefore technology development must occur on a global scale.

Long term

The viewpoint is that there are large uncertainties about what the market wants, a "Catch 22" situation, where everyone is waiting on each other: the fuel industry, the automotive industry and the legislation. Vehicle manufacturers do not just focus on one model or technology, but several, which mean that investment costs will be higher. Different fuels, engines and technologies available for production confuse the market players. Most interviewees agree that a fuel that does not have an international distribution network can not be a commercial success, because no one is developing and producing new fuels if no demand exists on the market. Some believe that the automotive industry has an old and outdated structure and has stucked to the internal combustion

engine technology for too long, and have not yet shown the rethinking that is required for a new major development. "Let all flowers bloom" may be a strategy in the early stages of development, according to some of the interviewees. Some have the perception that there is too much optimism about future solutions (new fuels, new engines, etc.), so that not enough investments are made in the existing alternatives to fossil fuels.

Flexi-fuel vehicles are considered to be the most successful solution so far, because of the good availability of filling stations (E85), and since it is possible to mix E85 with gasoline in all proportions in one common tank. Gas vehicles are considered as a very promising technology for the future, but their success depends on the development of infrastructure which at present only involves about 100 filling stations in Sweden.

Most agree that the introduction of electricity as an energy carrier in road vehicles may be the biggest step forward in the foreseeable future and the most reasonable form of energy as long as electricity is environmentally and climatically produced. Plug-in hybrids can also be adapted to heavier vehicles and combined with small engines running on biofuel have great potential to be cost effective. Today, there is already an existing distribution network for electricity from hydroelectric and nuclear plants, and eventually the use of mainly wind power but eventually also wave and solar power will increase in the future. An important position is that electric vehicles should only be fueled with "green electricity" a rule that must be applied all over Europe. The development of electric vehicles requires a development of batteries, as well as faster and better infrastructure of charging. Battery performance is a major problem because of production costs and operating time, as well as the lack of metals. Another barrier for electric vehicles is the safety issue. The total cost for the car owner is also crucial, i.e. the sum of the capital cost of the car, servicing costs and fuel costs are important factors. Some believe that there is a risk that a major break through of electric vehicles will be a serious threat to public transport, or become a social class issue. In a collaborative project between Volvo and Vattenfall, an electric passenger vehicle is expected to be in production by 2012. This vehicle will run on both electricity and diesel.

The advantages and disadvantages for all different future motor fuel options have a common factor - costs. Supply, demand, technology, emission levels, etc. are governed by cost. The key is the energy efficiency from a lifecycle perspective. Most agree that a fuel shift is crucial and must be rather rapid to be adapted to the existing vehicle fleet in order to reach a significant reduction of the climate impact, i.e. the majority of the fleet must switch to renewable fuels. However, in order to maintain mobility, it requires that a portion of the fleet still uses liquid fuels. Much of the vehicle technology (engines etc.) available on the market today will still be in the vehicle fleet in 2030, because they are supported by the existing fuel distribution system. The first installations of plants for production of very large volumes of biofuels is considered to be at least five years ahead.

Transport and infrastructure

Short term

The main view is that there is a need of a better infrastructure for the distribution from biofuel production plants to refueling stations. In particular the number of filling stations for gas vehicles needs to be expanded at a faster pace. Public transport should also be expanded to establish a competitive alternative means – to the car - of passenger transport.

Long term

Freight traffic requires efficient and better combined transport systems, which can be accessed through traffic integration between trucks, rail and shipping. This will require investments in particular in the railway network. There are uncertainties about whether the increase in energy efficiency of new vehicles occurs at pace rapid enough, so that improved fuel economy will compensate the increased number and average distances of transports.

A special point of view is that “green cars” on rail could be developed and linked with transfer stations for both passengers and freight. Another futuristic idea that might be considered earlier than predicted is the use of helium balloons for transportation of e.g. timber from forests.

Policy instruments

Short term

Consensus exists regarding the need for financial support for new infrastructure, new production of renewable fuels, as well as technology development from basic research to large scale implementation. For example, EU regulations should involve limits for carbon dioxide emissions for new light duty vehicles (95g/km target for 2020). Carbon taxes are considered as the most important policy instrument for the reason that it affects the price of fossil fuels. However, the most effective way to reduce emissions from transport and also increase the share of biofuel use is considered to be by tax subsidies. Existing subsidies will be maintained in the short term, but it is uncertain what will happen to these on the long term. Most believe that biofuels will continue to be exempt and that subsidies for green cars will remain. Involvement requirements and/or quota obligation of biofuels is considered necessary to achieve the ambition of at least 10% bio-fuel share by 2020 in Europe. There is also consensus regarding that the duty on ethanol shall be maintained so that domestic production can compete with imported ethanol, but it is uncertain whether the duty will remain on the long term. Some of the interviewees believe there is a need for a technology-neutral regulatory framework for support and subsidies in the early development phase. Some state that a good policy instrument is to have a "production support system" in which producers of fuel with a poorer performance from a climate point of view pay an earmarked tax to producers of fuel that exhibit a better performance. Another viewpoint is that certification of raw materials and biofuels is a good way of increasing the credibility of biofuel and to promote the sustainability of biofuel production.

Environmental image is considered by the most subjects in the surveys to be of minor importance in the long run. Biofuel production in itself may be commercial and should be sufficient to attract companies. Some believe that the debate in public media has an increasingly critical role for biofuels production versus human rights and food production.

Long term

There is consensus on that Sweden is affected by the development within EU and internationally. Global and long-term policy measures are considered to be the solutions for the development of biofuel, which requires stability, long-term investments and a consistent energy policy. Legislations and policies are integrated, and automotive industries are intertwined with the evolution of technology. The Swedish policy instruments for encouraging the introduction of biofuels have been mainly focused on the demand through the current energy and carbon dioxide taxes. A consensus is that this strategy needs to be complemented by instruments on the supply and production side,

such as production and investments, to accelerate the achievement of results and technology procurement. Some claim that political action can have unpredictable effects because of unnecessary restrictions. It is therefore important to have clear guidelines when providing policy instruments. It is also of importance to make sure that local solutions are considered from an economic perspective.

Most interviewees agree that energy and carbon dioxide taxes are viable measures that should be applied since sharply rising fuel and oil prices pushed down the energy use development and the use of oil in the long term. Competition among the different biofuels alternative is also an important parameter that may be regulated by tax policies. The interviewees believe that environmental taxes applied to the transport sector are effective instruments to control the development. There is consensus regarding the need of a combination of policy measures of energy efficiency, fuel switching, lifestyle change, transportation-efficient urban structure and an increased effective use of public transport. There is also a need of behavior changes among people to choose smaller "green" vehicles, as well as stronger willingness to pay as incentives for environmental friendly transportation solutions. Some believe that certification and verification of biofuels are a good way towards more environmental friendly and energy efficient biofuels, with a high public credibility. Another view is to introduce a "deadline" when the use of fossil fuels in the transport sector should be phased out. However, lifestyle changes and active choices are considered to be the most relevant measures.

Politicians must promote fuels with a low climate impact, so that these will be competitive towards fossil fuels. Sweden has a good chance to become a "test-site" for new technologies and fuel development. It is important to make Sweden an interesting country to invest in, e.g. in the energy sector. Technological breakthroughs are expected to have a significant impact on the biofuels development. A "standard" agreement between the automotive industry, fuel industry and lawmakers may be a good idea within the EU, but also globally. Similarly, it is important to have common standards for fuels and distribution systems in the neighboring countries.

Developments in the EU are crucial for R&D and demonstration support in Sweden. Sweden needs to invest in research and development, and efforts to influence attitudes, disseminate information, advice, etc. The consensus is that research efforts and policy measures to develop vehicles as well as biofuels are necessary.

Appendix B

Market conditions for biofuels other than methane

This appendix provides a short overview over market conditions for a range of alternative fuels other than methane:

- Ethanol
- Fatty acid alkyl esters including RME
- Synthetic diesel/gasoline
- HVO, Hydrogenated vegetable oils
- Methanol
- Dimethyl ether
- Hydrogen
- Electricity

Ethanol

Market development

Globally ethanol and biodiesel dominates the use of biofuels in the transportation sector. The global production of fuel ethanol has increased rapidly during the last decade, between 2000 and 2007 the production went from 17 billion litres to 52 billion litres and in 2009 the production was nearly 74 billion litres (*RFA, 2010*). About 90 % of the world production of ethanol comes from Brazil and USA and almost all of the produced ethanol comes from agricultural products such as corn, wheat and sugar cane. Only a very small part comes from woody biomass.

During the last years various issues has been discussed concerning ethanol. Most of them relate to the environmental and economic impacts of the production of ethanol. One question that has been widely debated is the use of farmland for growing ethanol crops. Since there often is competition between ethanol crops production and food production, ethanol production might lead to decreased supply of food and higher food prices.

Other issues concerning ethanol production is deforestation and soil erosion, impact on water resources, human rights issues and energy balance and efficiency. These questions might impact the future ethanol production.

In Sweden all sold gasoline has 5% ethanol content. The amount of flexifuel cars has increased in Sweden during the last years, and while the use for ethanol low-blended in gasoline has been on a steady amount for some years now, the use of ethanol in E85 has increased. However, in the years after 2007 this increase seems to have flattened out, and between 2008 and 2009 the delivery of ethanol to Swedish pumps decreased (*SCB, 2010*).

In 2007 about 85 % of the ethanol consumed in Sweden was imported, mainly from Brazil but also a small part from Europe. The Swedish ethanol mainly comes from Agroetanol in Norrköping, where ethanol is produced from wheat. In 2008, Agroetanol opened a new expanded production line to produce in total about 200,000 m³/year, and covers now about half the Swedish fuel ethanol consumption. A smaller part of the ethanol comes from production of ethanol from fermentation of sulphite pulp liquor (*Andersson, 2006*).

User friendliness

A great benefit with ethanol is that it can be used in the same way as regular gasoline and can be used in an otto engine.

Fatty acid alkyl esters including RME

Market development

The total world production of biodiesel is reported to be 70 TWh, which means that 5 % of the world production of vegetable oil is used for production of biodiesel. The bulk of biodiesel production, 53 TWh, is produced in Europe (CERA, 2007). Within the EU mainly rapeseed, sunflower and soybeans are grown for the production of biodiesel. Rapeseed production has increased significantly due to an increased demand for rapeseed oil, mainly for admixtures with conventional diesel oil.

The world production of oil seeds has increased more than 50% during the past ten years. The production of palm kernel and soybean shows the largest increase (100% and 80%, respectively), whereas rapeseed oil has increased by about 40% (Jordbruksverket, 2006). Major oil seed producers in the world are US (particularly soybean) and Malaysia (palm oil) (Andersson, 2003). Other countries that have a significant potential to produce pine oil are Canada, Finland and Russia.

Today, 2 TWh of biodiesel is produced in Sweden, which means that Sweden's annual biodiesel production is 4% of the European production and 3% of the global production. In Sweden, rape, rape seed and rape seed oil are almost exclusively used to produce biodiesel (Haaker, 2008). RME, rapeseed methyl ester, which is the most common biodiesel today, was used in 129 million liters biodiesel in Sweden in 2007 (corresponding to 1.2 TWh), mostly as ad-mixtures in diesel fuel (Bioenergiportalen, 2009).

User friendliness

Biodiesel can be used directly but is more aggressive against materials than conventional diesel. To run on 100% biodiesel, re-adjustments of the engine are necessary. A large number of filling stations provide RME, especially in urban areas, but also more sparsely populated areas have tank facilities, and the number keeps growing. The disadvantage of RME is that it competes with food and animal feed. For the production of biodiesel, also decay products and byproducts are interesting, because these oils usually do not have any competition when the raw material is based on forest products and/or forest waste, and the process therefore does not compete with food production. The access is however very limited.

Synthetic diesel/gasoline

Market development

The terms synthetic diesel, synthetic gasoline, or more general, synthetic fuels, refer conventionally to fuels which have been made from synthesis gas (syn-gas). This way, liquid vehicle fuels are already produced large scale, e.g. in South Africa by SASOL, through gasification of Coal, or using natural gas as precursor for the syn-gas, in a process normally referred to as Fischer-Tropsch synthesis. If instead syn-gas is produced by gasification of biomass, a biomass-based synthetic fuel could be achieved. Synthetic diesel is in terms of characteristics almost equivalent to conventional

diesel and can be used in conventional diesel vehicles. From this perspective, synthetic diesel from biomass has an advantage compared to other biofuels that require custom vehicles, such as DME. The potential market for synthetic diesel is thus large since it requires no conversion of the existing vehicle fleet, but the anticipated production cost is still a barrier, and the fact that no large scale wood gasifier exist in commercial operation.

User friendliness

Synthetic diesel can be used in conventional diesel engines and requires no conversion of either vehicle fleet or distribution system.

Legal aspects

In the Swedish transport sector there are currently a number of legal instruments, of which one of the most important is fuel taxation. Gasoline and diesel are subject to energy and carbon dioxide taxes. In 2008, the carbon tax increased to SEK 1.01 per kg of carbon dioxide, which corresponds to SEK 2.34 per litre petrol and SEK 2.88 per litre diesel. The energy tax amounted to SEK 2.95 and 1.23 per litre for petrol and diesel, respectively (*Energiläget, 2008*). In addition, a VAT of 25% is added to both the product price and the tax. In autumn 2006, a carbon-based vehicle tax was introduced for light-duty vehicles, see also chapter 2.2.1. The yearly vehicle tax is made up of a basic tax that is equal for all cars (currently SEK 360) and a premium tax which is determined by the vehicle's estimated carbon dioxide emission per kilometre, currently SEK 15 per gram in excess of 100 g/km for diesel and gasoline light-duty vehicles. Moreover, for diesel cars apply that the sum of these components is multiplied with a factor (currently 3.3) on the grounds that diesel cars have higher emissions of particulates and nitrogen oxides as well as a compensation for the lower energy tax on diesel fuel compared to petrol (*Energimyndigheten och Naturvårdsverket, 2007; Skatteverket, 2009*).

In order to boost the introduction of biofuels, and thereby enabling Sweden to fulfil the EU's biofuel directive, biofuels are currently exempt from carbon dioxide and energy taxes. Regarding vehicle taxes, vehicles that can run on alternative fuels are entitled to a lower "carbon surcharge" (*Energimyndigheten och Naturvårdsverket, 2007; Skatteverket, 2009*).

In case of an increasing share of biofuels, the impact on government finances, e.g. of a tax subsidy, will soon become noticeable and already now the trend in the EU goes from tax credits to mandatory targets and quota obligations (*Energimyndigheten och Naturvårdsverket, 2007*). None of today's legal instruments focus on synthetic diesel. In contrast, it can be noted that when the fuel tax is lower for diesel than for gasoline, the state tax subsidy is lower for biofuels replacing diesel than for biofuels replacing gasoline.

HVO, Hydrogenated vegetable oils

Market development

Chemically, vegetable oils such as rape seed oil are fatty acids, i.e. hydrocarbon chains with a carboxylic functional group (-COOH) at the end of the molecule. Many fatty acids also contain one or several double bonds. In methyl esters such as RME, the OH group has been chemically replaced by a methoxy group (-OCH₃).

An alternative way to modify the vegetable oils is by hydrogenation, which will lead to a saturation of the molecule, i.e. hydrogen will be added at double bonds to eliminate these, and the oxygen in the -COOH group will be reformed to a -CH₃ group, and two water molecules will be formed.

The process is much more complicated than the esterification process, but the resulting molecules are essentially pure straight-chained hydrocarbons. An additional process called isomerisation, produces branched molecules which resembles even better conventional diesel fuel.

Neste has produced HVO since a few years. It is based on palm oil, and due to the debate about non-sustainable palm plantations, Swedish fuel distributors have chosen not to import and promote this fuel.

In the early autumn 2010, Preem took into operation a plant for HVO production, with a capacity of about 250000 tonnes/year, integrated in its refinery in Gothenburg to secure hydrogen supply. The main source of vegetable oil will be tall oil, which is produced at a new plant in Piteå by the company Sunpine. Other vegetable oils, e.g. rape seed oil, can be used as feedstock as well.

Cost

The cost for HVO production is predominantly determined by the cost for the vegetable oil. The operation cost for the production is on the similar level as conventional diesel.

User friendliness

HVO can be used in conventional diesel engines and requires no conversion of either vehicle fleet or distribution system.

Legal aspects

One significant advantage with HVO compared to FAME is the possibility to mix it into diesel fuel in much higher share. Current fuel standards allow up to 7 % of RME in diesel, but HVO can be used well beyond this limit

Methanol

Market development

Biomethanol - methanol based on biomass - can be produced through gasification of various feedstocks, from primary wood fuels or from the residual product black liquor, or from other cellulose containing material, e.g. coppice. Internationally, today methanol is produced mainly from natural gas, but also several other feedstocks are possible. How much raw material that is possible to extract from the forest varies from source to source. According to the Swedish Forest Agency an increasing abstraction of remnants of logging and clearance and a collection of stumps at final felling is estimated to allow for additional forest fuel removal from the forest (Skogsstyrelsen, 2008). A long-term potential of approximately 100 TWh could be feasible.

At present methanol has no market share in Sweden, except for the small amount used in the esterification of RME and as precursor chemical in MTBE. International access to methanol is considered relatively good. In case of an introduction of methanol as fuel - either for direct use or after further processing - rapidly increasing volumes can be met in line with a growing demand. This gives methanol great flexibility and supply stability (*Ecotraffic, 2009*).

Costs

The cost of production of methanol from biomass today is higher than for gasoline, because almost two liters of methanol are used per liter gasoline. By contrast, the advantage of economies of scale

is high and costs in a future market are likely to be lower (*Ecotrafic, 2009*). Well-to-wheel studies show that methanol and DME from gasification possess the lowest costs, cf. Table B-1.

Table B-1 Production costs for biomethanol as fuel.

| Fuel | Costs (SEK/gasoline equivalents) | Reference |
|--|--|--------------------------|
| Methanol (from biomass/firewood) | 5,60 | <i>Ecotrafic (2007)</i> |
| Methanol (from wood raw material) | 6 | <i>Värmlandmetanol</i> |
| Methanol, DME from gasification of black liquor | 3-6 | <i>Skogsindustrierna</i> |

User friendliness

The technology for the production, distribution and utilization of methanol fuel is currently under development and continuously evaluated. According to the car manufacturers, the automotive components which are currently used for ethanol engines are already approved for methanol, and thus no additional costs for component replacement will be required.

Methanol can be blended with gasoline in low proportions (M3) in the same manner as is currently done with ethanol, resulting in lower conversion costs for distribution systems, filling stations and vehicles (*Ny Teknik, 2008*). The use of methanol for blending in gasoline is regulated by the EU fuel directive (98/70/EC), which today allows a maximum admixture of 3 percent methanol. 3% of the Swedish gasoline sales (5 253 000 m³ for the year 2007) corresponds to approximately 160 000 m³ of methanol.

Methanol can also be used as fuel in fuel cells. Methanol can even replace diesel fuel in existing diesel engines, by being converted into dimethyl ether (DME). Methanol is also present as a component in FAME.

Some vehicle manufacturers have developed prototypes of fuel cells based on methanol – Daimler/Chrysler, Ford (Th!nk), GM (Zafira), Honda, Toyota and Nissan.

Legal aspects

The EU fuel directive (98/70/EC) allows a maximum involvement of 3 % methyl alcohol (5 % ethanol). There is currently no discussion within the EU to develop a standard for methanol as fuel; however, there are discussions on raising the allowed maximum admixture of ethanol to 10 %.

The EU Commission's draft directive on renewable energy (N2008/1203/E) proposes stricter requirements and a significantly increased use of renewable fuels, but methanol is not explicitly mentioned in the directive.

Already today there are instruments for biofuels in force that would promote also methanol as fuel, for example:

- reduced taxable value of fringe benefits,
- parking subsidies,
- tax credits for biofuels.

Di-methyl ether, DME

Market development

Most of the DME that is produced at present is produced from coal or natural gas and is not a renewable fuel. But the process to produce DME might as well be used for biomass, to produce so called BioDME. Today a large share of the DME produced globally is blended with LPG, and often used for household applications such as stoves. An other use is as propellant in aerosol canisters. At the moment DME is not used as a vehicle fuel to any large extent. However, in Sweden Volvo has developed trucks that run on DME and also opened a filling station for DME, this project is however still in a research phase. (Energimyndigheten, 2010)

User friendliness

Only moderate modification is needed to convert a diesel engine to burn DME. Since DME is handled as a liquid at a pressure of 5 bar, the filling station has to be designed in a different way than for conventional fuels.

Hydrogen

Market development

In Sweden, the hydrogen production is dominated by gasification of biomass or waste, together with steam-reforming of natural gas or biogas. Internationally, the hydrogen production is dominated by coal gasification technologies, but research on hydrogen production based on chemical or biological processes is on-going.

There is only one filling station for hydrogen in Sweden (in Malmö), while another two are planned (in Stenungsund and Gothenburg). Scandinavian Hydrogen Highway Partnership, a collaboration between Hydrogen Sweden, HyNor (Norway) and Hydrogen Link (Denmark), target 15 filling stations, 30 satellite stations, 100 buses and 1,000 cars or special vehicles in the region in 2015 (*SHHP, 2008*). With support from the EU 6th Framework Program, 33 hydrogen-powered fuel cell buses are now operating in nine cities in the world, and 14 buses with hydrogen internal combustion engines are operating in Berlin (*HyFLEET, 2008*). Also the EU 7th Framework Program (2007-2012) aims at accelerating the development of hydrogen and fuel cells. The goal is that these technologies shall be commercialized before 2020. It will also be easier to import hydrogen cars into the EU, since the European Commission decided that if a vehicle is approved in one member country, the approval will be valid throughout the EU (*Vätgas Sverige, 2009*). The automotive industry (mainly in Japan, Germany and the US) keeps intensifying the development of hydrogen vehicles, based on both internal combustion and fuel cells.

Within the EU and the US, hydrogen is regarded as a promising and attractive alternative future fuel for the production of electricity and heat, and as a motor fuel primarily using fuel cells, but also in internal combustion engines in the short term. Major research efforts are being made regarding production technologies, storage and distribution, as well as in the development of fuel cell technology and hydrogen powered vehicles.

Costs

The costs of producing hydrogen from biomass gasification vary between the studies carried out. *IEA (2001)* estimated costs at 12-13 USD/GJ. Other studies (*Spath and Dayton, 2003*) report costs

from 7 USD/GJ to 21/GJ. *CONCAWE (2007b)* estimates production costs for gasification at 5.9-12.1 Euro/GJ (approximately 4.5-9.3 USD/GJ)⁸, depending on the cost of the biomass feedstock.

According to estimates, the overall costs for hydrogen being used as a motor fuel are significantly higher compared to fossil alternatives and liquid fuels through gasification of biomass. The latter is mainly due to the significantly higher distribution costs for hydrogen, which are estimated to 7.9 USD/GJ compared to 2 USD/GJ for gasoline and 6.4 USD/GJ for natural gas. Hydrogen from renewable electricity by electrolysis yields the lowest total costs (the same total costs as for gas-to-liquid from biomass), followed by hydrogen from natural gas. If only the production costs are taken into account, the costs of hydrogen as a motor fuel mostly (i.e. for several of the possible hydrogen production pathways) are comparable to those of conventional gasoline.

User friendliness

In principle, any kind of hydrocarbon chain can be used for hydrogen production via thermal gasification. All forms of biomass can be used, but research has so far concentrated on gasification of wood chips, wood pellets and black liquor. Energy crops such as willow, switch grass and reed canary grass can also be used. Current potential feedstocks are agricultural residues (e.g. tops and straw), bark, stumps, recycled wood, demolition wood and mixed dry organic waste.

The availability of "green" hydrogen from electrolysis depends on the development of cheaper and more efficient electrodes and future supply of renewable electricity, primarily from wind, solar or wave power. Hydrogen is an alternative to batteries for storing excess energy from the effect-varying renewable electricity sources. Hydrogen produced directly from natural gas (with carbon capture storage) or biogas through steam reformation may be used close to natural gas pipelines or local biogas production units.

In recent years the automotive industry has made significant progress in developing hydrogen-powered vehicles. BMW and Mazda have presented hybrids running on gasoline or hydrogen in a combustion engine. Instead of liquid hydrogen (at -253 ° C) BMW invests in their Hydrogen 7, which allows larger tanks, while other car manufacturers focus on pressurised gaseous hydrogen. The Toyota Prius Hydrogen with its range of 160 kilometers is also a hybrid with an internal combustion engine. About a hundred Mercedes B-Class with fuel cell technology has been manufactured, having a range of 400 kilometers and efficiency around 50-60%. Also GM has invested heavily in hydrogen-powered fuel cell technology in their hybrid electric HydroGen4, which is now being tested in real-world traffic. Hydrogen is stored in 700-bar tanks and provides a range of more than 300 kilometers. Ford has launched a new concept consisting of a plug-in hybrid with a fuel cell. The battery has a range of 40 kilometers and at fuel cell operation a range of 320 kilometers. Honda and the Norwegian electric car producer Th!nk have also recently launched hydrogen cars (*Vätgas Sverige, 2009*). The technology for hydrogen vehicles has therefore come a long way and will be ready for mass market launching in the near future. The biggest bottleneck right now is the limited availability of hydrogen and hydrogen filling stations.

Legal aspects

The same reasoning as for methane (biogas and natural gas) applies to large parts.

⁸ Based on 1 dollar = 0.77 Euro.

Electricity

The availability of electricity in general is not considered a limiting factor, at least not in Europe. More critical is how the electricity is produced, i.e. whether it could be considered as renewable or not. The most recently published projections with the PRIMES model, which simulates the potential impact of EU's climate and energy policies, show that for EU 27, 20% of the electricity generation will stem from renewable sources by 2020 (23% in 2030). However, 59% will still be from fossil fuels and 20% from nuclear power by 2030 (Capros *et al.*, 2009). The price of electricity is expected to increase.

Electricity as a fuel is already established in Sweden, but requires an expansion of the distribution system. Internationally, the breakthrough of electric hybrids and electric vehicles is directly dependent upon the performance of batteries. Today's grid lacks the opportunities for storage of surplus production, as well as the back-up power stations⁹ needed to meet peaks in electricity demand or loss of power.

In recent years, electric cars attracted attention as an opportunity to respond to overproduction of electricity and to smooth out electricity network peaks and troughs. Theoretically, electric vehicles connected to the network are charged with excess electricity produced that otherwise cannot be used. In the case of e.g. wind power, much of the electricity is produced during night time when both domestic and industrial needs are low, but which is the most appropriate time to charge vehicles. The other way round, it is possible to discharge the batteries from electric cars and bring power back to the grid. The principle is called "virtual power plants" and of course requires agreement between network operators and car owners through clear rules on when power may be transferred between vehicles and the network, and under which conditions.

The competition between electricity and biofuels as energy carriers in the road transport sector is partly dependent on the net climate benefit of the electricity, which is strictly linked to the fuel mix used to produce the electricity. In countries such as Sweden, the climate benefit (calculated based on the average electricity production mix) of cars running on electricity is large, since the bulk of the electricity is produced from hydropower and in nuclear power plants. However, a competition between electricity and biofuels may not always be the case, since electric hybrids could use biofuels instead of gasoline or diesel.

Costs

Electric hybrids (e.g. Toyota Prius) are regarded as having higher fuel efficiency corresponding to a 20% reduction in fuel consumption compared to conventional (spark ignition) engines.

Unfortunately, however, it is hardly a cost saving for a car owner to invest in a hybrid, due to the higher investment costs (compared to conventional cars of similar size and standards).

User friendliness

Apart from electric hybrids, electric vehicles are practically non-existing on the Swedish market. The big breakthrough for electric hybrids and electric vehicles is directly dependent on the development of batteries with a higher performance than today's batteries. Mass production of

⁹ Traditional backup plants are clearly dominated by fossil fuels. In Sweden, the majority consists of oil condensate and natural gas power plant turbines.

lithium ion batteries with greater storage capacity than NiHM batteries is expected to start in 2010 or shortly thereafter. There are plans to open a lithium mine in the Finnish Österbotten in 2010.

Examples of on-going investments in electric or hybrid electric vehicles within the automotive industry are:

- GM, BMW and ex Daimler-Chrysler all have development programs for hybrid electric cars and have shown demonstration prototypes.
- Volvo Trucks: hybridization to heavy vehicles powered by combustion engines and electric motors.
- In 2008, China produced 2,100 electric cars and has the goal to increase production to 500,000 electric cars in 2011.
- BYD Auto in China launches the world's first mass-produced electric hybrid already 2009/2010. The F3DM model has a range of about 100 kilometers.
- Toyota Prius: The first generation was launched in Japan already in 1997.
- Fiat has launched their EV ADAPT programme, with the intention to convert the Fiat 500 to pure electric mode. The first 400 cars entered the market in September 2009.

The next step for the automotive industry is to develop primary propelled electric motors where the internal combustion engine acts as a supplement to increase the range. In parallel, pure electric vehicles are also developed. Toyota is expected to launch a mass produced electric hybrid at the earliest in 2010.

From a user perspective, electric propulsion has little direct benefits when running, but a couple of severe barriers are there: to refuel the vehicle (charging) takes considerably longer for electricity than for conventional fuels, and the range per charge is limited. The major automobile manufacturers and electricity producers in Europe have recently agreed on a universal connector for charging, which will require a voltage of 400 volts. A voltage of 400 volts decreases the charging time considerably, which depending on the battery can vary between 3 and 10 hours for vehicles present on today's market.

Legal aspects

The existing legal instruments seem to be increasingly adapted to introduce electric cars under the same conditions as biofuels. This is supported by the fact that in the EU's climate and energy package, renewable fuels are discussed rather than biofuels.