The Cost-effectiveness of Measures for Reducing the Environmental Impact from Buses and Official Cars in Stockholm, Gothenburg and Malmö.

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Abstract

Throughout the 1990s, Swedish towns and cities made considerable efforts to promote a shift to environmentally benign bus traffic and municipal vehicle fleets. This paper examines measures taken by the cities of Stockholm, Gothenburg and Malmö, and, where public buses are concerned, the greater regions of these three cities.[1] The aim is to analyse to what extent the measures have been cost-effective and to identify how the local and regional authorities implicitly value reductions of carbon emissions from cars and buses. The analysis points to good profitability for particle filters and biogas buses and to a slight economic deficit for natural gas buses. Stockholm's investment in ethanol buses is seen to be socio-economically unprofitable. The training of bus drivers in gentle and economical driving has the highest profitability of all the measures studied. The commitment to alternative cars appears to be less successful. The cities in question have

[1] This paper is based on some of the results of a report on behalf of the Swedish National Road Administration, Kågeson, P. "Miljökrav vid upphandling av bilar, taxi och busstrafik. En analys av utvecklingen i Stockholm, Göteborg och Malmö, Vägverket, Publikation 1999:83, Borlänge, Sweden.

neglected the negative side-effects of the transition to new fuels, such as increased use of primary energy and excessive costs. Vehicle size and specific fuel consumption appear to be more important parameters for reducing carbon emissions than a shift to biofuels.

Introduction

Mobile sources are responsible for 30-80% of Sweden's emissions of carbon dioxide (CO_2), hydrocarbons (HC), particulate matter (PM) and nitrogen oxides (NO_x). It is widely recognised that the national emission targets cannot be reached without significant reductions in the transport sector. In 1988 the Swedish Riksdag (parliament) decided on the introduction of a 'sectoral responsibility for the environment' which meant that state transport agencies, counties and local municipalities among others were expected to contribute towards more sustainable transport. The 1992 Rio Declaration on sustainable development and the launch of Agenda 21 provided additional encouragement, and many Swedish cities and towns started to work actively on the introduction of cleaner vehicles and non-fossil road fuels. The country's three largest cities, Stockholm, Gothenburg and Malmö, have been among the forerunners. This paper examines the measures taken by the three cities and, where public buses are concerned, the greater regions of these three cities. The aim is to analyse to what extent the measures have been cost-effective and to identify how the local and regional authorities implicitly value reductions of carbon emissions from cars and buses.

Stockholm is the capital city of Sweden and has a population of 750 000. The greater Stockholm region has around 1.5 million inhabitants. Gothenburg, on the Swedish west-coast, has 450 000 inhabitants and the region around 650 000. Malmö, located in the south (just opposite Copenhagen), has a population of 250 000 (350 000 including suburbs).

Bus traffic

The Greater Stockholm region decided in 1990 that by the year 2000, and in spite of growing volumes of traffic, total permissible emissions of carbon dioxide from its buses should not exceed those of 1988 (SL 1996, 1998). Emissions of nitrogen oxides (NO_x) per vehicle kilometre should be reduced by 50% relative to the level of 1980. The regional public transport company, Storstockholms Lokaltrafik (SL), has achieved these objectives by shifting to 218 ethanol-fuelled buses in the inner districts of Stockholm and by restricting the maximum and average age of the buses. In addition, SL owns half a dozen hybrid buses (ethanol/electricity). At present buses over 15 years old are not accepted, and the average age of the fleet must not exceed eight years. Diesel-fuelled buses must use diesel oil of Swedish Environmental Class 1 (low sulphur). CRT-filters (Continuously Regenerating Trap), which remove 80-90 per cent of the emission of particles, will gradually be installed on the diesel buses, but at present less than 5% of the fleet has been equipped.

Stadstrafiken AB, the public transport authority in Gothenburg, requires its operators to gradually reduce their emissions of NO_x and PM 10 (particulate matter). The objective for 1999 is to reduce the average emissions of NO_x and PM 10 below 5.0 and 0.11 grams per kWh respectively. In addition, 10% of the fuel should come from renewable resources in the year 2000. In 1998, the city bus fleet consisted of 117 diesel buses with CRT-filter, 94 diesel buses without a filter and 38 biogas or natural-gas-fuelled buses (Stadstrafiken 1996, 1998).

The Greater Malmö region has not adopted clear environmental targets for its bus traffic. The main measure, however, has been to reduce NO_x and PM 10, and to a smaller degree CO_2 by shifting from diesel to natural gas. The regional bus traffic now includes 120 natural-gas-fuelled buses in Malmö and an additional 24 in nearby Lund. In addition, trials are in progress with a few hybrid buses (electricity/natural gas). The rest of the fleet is diesel-powered and will gradually come to be equipped with CRT-filters (Länstrafiken Malmöhus 1998, Skånetrafiken 1998).

Summing up, **t**he public transport companies in Sweden's three largest cities have taken five different measures to reduce the environmental impact from the bus traffic:

- Restrictions on the average and maximum age of the buses
- Use of low sulphur diesel
- Installation of CRT-filters on diesel-fuelled buses
- A partial shift to ethanol buses (Stockholm)
- A partial shift to biogas or natural gas fuelled buses (Malmö and Gothenburg)

There is no evidence that any of the three regional public transport companies considered options other than those selected. None of them engaged in an examination of the pros and cons of non-preferred options (such as biogas in Stockholm or ethanol in Gothenburg).

City car fleets

In all three metropolitan cities, most official cars are gathered within a municipal enterprise which purchases the vehicles on behalf of the authorities and municipal companies concerned. The greening of these vehicles is being made to focus on a transition to non-fossil fuels. Stockholm has made most headway (Miljöförvaltningen i Stockholm 1996). Its official car fleet (not including perk cars) now includes about 200 biogas cars, about 30 electric cars and upwards of 20 cars capable of running on E85 (85% ethanol, 15% petrol). Gothenburg has 15 natural gas/biogas cars and the same number of electrically-powered cars. In Malmö a new traffic environment programme (Malmö Stad 1997), over and above the procurement of two cars powered by natural gas and 20 electric cars, has led to extensive purchases of diesel cars running on RME (rape methyl ester).

The municipal purchasing companies cannot control their customers' choices. The customers' decisions are governed by their own considerations of needs and economics and by the types of vehicle regarded as ecological in the municipal action programme. It is still the municipal authorities which decide which sizes and models they want.

None of the three cities has any definite stipulations concerning the fuel consumption and exhaust emissions of the cars purchased. Table 1 shows how the official car fleets of the three cities are distributed on different types of cars and fuels. Table 2 shows the division on vehicle size. No attempt was made within this study to examine why end-users made different choices in the three cities.

Insert table 1 about here

Insert table 2 about here

There is an interesting difference between the cities on one point. In Stockholm, 43% of official cars come in the two largest size classes, as against only 28% in Gothenburg. Despite similarities of use, Stockholm chooses considerably larger vehicles. This tendency becomes even more palpable if we compare cars purchased by Stockholm in 1994 and 1998. Whereas in 1994 they constituted 24% of new acquisitions, in 1998 the two largest size classes raised their share of new acquisitions to 60%. All in all this means that specific fuel consumption is now about 10% higher in Stockholm than in Gothenburg and is increasing.

The reason for this large proportion of large cars in Stockholm is the commitment to environment-friendly vehicles. City authorities and companies have to a great extent opted for large biogas cars (Volvo S70, Volvo 855, BMW 518 Touring) and for the Ford Taurus FFV ethanol car (weighing 1.8 tonnes and with a 3.0 l engine). This means that the ecological car project has led to a heavy increase in average vehicle size and fuel consumption. In Stockholm, moreover, 90% of the vehicles purchased have automatic gearboxes, which increases fuel consumption by between 0.6 and 1.0 litre per 100 km compared with a manual gearbox. Gothenburg and Malmö have few cars with automatic gearboxes (Nettby 1998, Landqvist 1998).

The breakdown in size of the Stockholm City car fleet is remarkable, considering that a questionnaire survey commissioned by the City showed that about 95% of cars and estate vehicles normally have one passenger at most (Inregia/Atrax Energi 1996). In addition, 90% of the car users and 60% of the estate users state that a load volume of 200 litres is sufficient for their needs. Compact cars generally meet these requirements by a generous margin.

None of the three municipal purchasing companies has made much effort to train or inform its customers. Written information refers only to the importance of switching to renewable fuels and electricity. In no case have questions of vehicle size, engine power or choice of gearbox been raised, nor has any information been supplied concerning the effect of fuel and engine choices on exhaust emissions. No mention has been made either of the effect of driving style on exhaust emissions and fuel consumption.

Valuation of environmental damage and cost-efficiency

The implicit valuation by the bus transport companies and the municipalities of the benefit of reducing carbon dioxide emissions can be calculated by working out the additional cost of a transition to new vehicles and fuels per kilo of carbon dioxide after deducting the portion of the cost which can be deemed referable to reduced emissions of nitrogen oxides, hydrocarbons and particles. The latter are valued here with the aid of the official calculating values of the Swedish transport authorities for various pollutants (Samplan 1995). For cars the emission values presented by the manufacturer at the time of EU certification have been used. The difference in exhausts between biogas, ethanol and petrol-fuelled cars are small. Alternatively fuelled buses and buses with CRT have been credited for lower exhaust emissions as measured by the Braunschweig cycle (table 3).

Insert table 3 about here

The measures taken by the transport companies and municipalities can be compared with measures which have not been taken but are perfectly conceivable, such as training in economical driving (based on data from Finnish experiments) and, in the case of Stockholm, the choice of manual gearboxes. Table 4 shows the outcome for bus traffic and table 5 that for passenger cars. In both tables, the alternative measures are compared with reference vehicles. For buses the reference is to diesel power in vehicles conforming to current exhaust requirements for new vehicles, and for cars reference is made to the

Opel Astra 1.6 with an automatic gearbox (by far the commonest vehicle in the City of Stockholm car fleet). For the Renault Clio Electric, the comparison is instead made with the petrol-driven version of the same vehicle (Renault Clio 1.4). In addition, the Volvo V70 is compared with the Volvo V70 bi-fuel.

Insert table 4 about here

Insert table 5 about here

The left-hand columns in the tables show the agents' implicit valuation of carbon dioxide. The right-hand columns show the benefit-cost ratio for the different measures, using the average present energy and carbon dioxide taxation of fossil fuels in Sweden (SEK 0.80/kg) to calculate the benefit of reduced carbon dioxide emissions. The benefit of reduced emissions of hydrocarbons, nitrogen oxides and particles as per the official Swedish valuation is also included. Values exceeding 1.0 indicate that the measure is socio-economically profitable.

The approximate additional cost to bus traffic of switching to alternative fuels has been calculated on the assumption of an annual mileage of 70 000 km, 4% interest and a depreciation period of ten years (six years for CRT). Gas buses are presumed to cost SEK 300 000 more than diesel buses to purchase (Nyström 1999), ethanol buses SEK 120 000 more (fire extinguishers included) (Wickström 1998) and CRT SEK 50 000 (Samuelsson 1999). The extra maintenance cost of the ethanol bus, including the annual value of faster engine wear, is estimated by SL at SEK 50 000 per year and bus (Wickström 1998). The additional cost of fuel and other maintenance (CRT and gas) comes from unpublished input data for Magnusson (1998).

Fuel consumption in urban traffic is presumed to be 0.42 l/km for the diesel bus. Efficiency is presumed to be 12.5 and 25% lower for the ethanol and natural/biogas bus respectively, compared with the diesel bus (Ekelund 1999).

Emissions of fossil carbon dioxide are presumed, in a life cycle perspective for ethanol and biogas, to be, respectively, 30 and 10% of the LCA emission for diesel (Alternativbränsleutredningen 1996). In a response to the author's Swedish report, the Swedish Biofuel Development Foundation (1999) makes the objection that 30% is too much for ethanol produced from wood residuals. The Foundation claims 7% to be a more accurate figure (and 15% for ethanol produced from grain). The Foundation says that once a fuel efficient FFV car becomes available the cost of reducing CO_2 by using ethanol from a cellulose-based production facility would be as low as SEK 0.20 per kilo (the value of the tax exemption not included).

The SL ethanol bus commitment suggests a very high implicit valuation of carbon dioxide. The venture is not profitable when reduced emissions are valued at SEK 0.80 per kilo. A transition to natural gas comes quite near the socio-economic profitability limit in such a valuation of CO_2, while biogas shows good profitability.

By way of comparison, installation of the CRT particle filter (which, however, does not affect CO_2) has a benefit-cost ratio of 1.50. Arranging training in an economic style of driving is according to Finnish experience even more profitable. The long-time effect on fuel consumption of training drivers of heavy duty vehicles in Finland has on average been minus 11 per cent (Donner 1999). This is equivalent of a benefit-cost ratio of 10.70. Minus 5 per cent corresponds to a ratio of 5.40. The measure is even more profitable if secondary benefits in the form of lower exhaust emissions, fewer accidents and less wear and tear are accounted for.

If the transport companies put a higher value on the regulated pollutants than the Swedish transport authorities do, this reduces the cost of carbon dioxide reduction. A very high valuation of exhaust emissions is needed, however, in order to make any notable difference to the implicit valuation of CO_2 emerging in table 4. It should also be noted that the Braunschweig cycle (like ECE R-49) is performed at room temperature. Consequently the cycle does not capture the possibility of emissions being higher at temperatures below freezing. With diesel and gaseous fuels, emissions are relatively unaffected by the outdoor temperature, whereas emissions from ethanol operation grow steeply when the temperature drops (Nylund and Eklund 1998). Röj (1998) maintains that the emissions of ethanol buses over their complete life cycle are comparable with those of diesel and in some cases worse.

Table 5 is based on figures from the City of Stockholm concerning differences in internal rental prices (Alexandersson 1998). Figures for costs and effects on fuel consumption of training in "eco-driving" come from Finnish Motiva (Donner 1999).

Apart from a change to a manual gearbox and training in an economical style of driving, a change to the BMW 316g Compact and 100% biogas is the only one of the measures studied which is cost-efficient. The positive outcome here, however, is partly due to the very low pricing of the BMW 316 compared to the open market

Table 5 shows the profitability of arranging training in an economical style of driving for employees to be heavily dependent on the individual person's annual mileage in the course of duty. At 15 000 km this measure is profitable even if only the value of reduced fuel purchasing is credited. But the gentler style of driving also reduces the cost to the company/authority of wear and tear, maintenance and damage, as well as the cost to society of exhaust emissions, noise and traffic accidents. In addition, this training in all probability also influences the employees' private driving habits.

For a strict socio-economic valuation, we also have to consider that ethanol, biogas and natural gas are partly or wholly exempt from energy and carbon dioxide tax. This tax exemption can be taken as an expression of the Swedish Parliament's implicit valuation of the benefit of reducing emission of air pollutants and carbon dioxide by switching to alternative vehicle fuels. This means that, in order to achieve a complete picture of the valuation of the benefit by the transport companies and the cities, the value of the tax exemption must be added to the additional cost incurred by the transport companies and cities respectively. In the case of ethanol buses, the tax exemption corresponds to SEK 1.26 per vehicle km. Adding this subsidy to the additional cost of switching to ethanol, and after crediting for reduced emissions of pollutants, we arrive at a figure of no less than SEK 4.82 per kg carbon dioxide. No such calculation is possible for biogas and natural gas, due to these fuels being priced according to the alternative cost to the customer.

Stockholm's commitment to relatively large biogas cars will probably lead, in total figures, to unchanged emissions of fossil carbon dioxide, because this measure has led to an increase in specific fuel consumption, the authorities and municipally owned companies run these flexible-fuel cars at least 70% on petrol (rather than gas) and future second-hand purchases are expected to use petrol. All other measures lead to a reduction of carbon dioxide emissions, but at greatly varying cost.

If Stockholm had refrained from its investment in alternative cars and instead concentrated most of its purchases of official cars (not including perk cars) on petrol-driven cars in the compact class (with a manual gearbox), carbon dioxide emissions would have declined by at least as much as is now the case. The cost would have been MSEK 4.5 less per annum.

The value of contributing towards development

One possible argument in favour of municipalities and county councils being prepared, for a transitional period, to incur considerable additional expense by using non-fossil fuels is that the initial demand for these fuels could act as a prerequisite of continuing technical progress and falling costs. Without pioneers, the process may grind to a halt. Mechanisms which could lead to falling costs and thus, eventually, to reduction of carbon dioxide emissions entailing far less sacrifice include:

- lower production costs of the alternative fuel,
- economies of scale in the manufacture of engines and other equipment,
- cleaner engines (= higher crediting for reduced emissions of regulated substances).

Of these factors, only the first is really applicable to ethanol, since biogas and natural gas are a subject of alternative cost pricing. Production costs need to be dramatically reduced in order for a reduction of carbon dioxide by means of ethanol fuelling to come down to a cost level capable of competing with biogas or the use of forest fuels for power and heat production.

Economies of scale may conceivably influence the cost of switching to gas-fuelled buses. Since gas, though as yet mostly in the form of LPG, is becoming an increasingly common fuel for urban buses in Europe, it is not unlikely that production costs can be pushed down in the next few years. The additional cost compared with diesel buses can presumably be halved if demand for gas buses climbs to a few thousand units per annum (Nyström 1999). In such an eventuality, natural gas buses will become definitely socio-economically profitable (ratio 1.65). It should be borne in mind, however, that exemption from energy tax constitutes an additional item of expenditure in a national economic perspective.

With longer production runs, the ethanol bus will also become cheaper to manufacture. Given a series of a few thousand vehicles, the additional cost can possibly be reduced by a factor of 3 (Nyström 1999). The likelihood of such long production runs of ethanol buses, however, is smaller than in the case of gas buses, the reason being that so few countries are investing in ethanol buses, and even if all Swedish public transport companies were to follow the example of Stockholm, this would still only correspond to 2% of demand for urban buses in Western Europe.

It is very unlikely that engines adapted to alternative vehicle fuels will improve more rapidly, in terms of combustion and exhaust treatment, than conventional diesel and internal combustion engines. The EU 2005 requirements will force manufacturers to provide heavy diesel vehicles with a particle trap, and even if the nitrogen oxide requirement can perhaps be met without a special NO_x catalyst, the emission limits of the next step (2008) will probably require such a catalyst. This will mean a reduction in the difference between diesel and alternative fuelling, and particle traps are bound to become cheaper when they are produced in longer runs and factory-fitted. A Swedish-developed low-pressure EGR (Exhaust Gas Recirculation) is currently being tested and looks capable of reducing NO_x emissions from diesel engines by 40 or 50% without increasing the fuel consumption (Eriksson 1999). This system requires low particle concentrations (diesel buses have to be fitted with CRT). Magnusson (1999) puts the additional cost (for vehicles already fitted with CRT) at SEK 8-10 000 per annum. All in all, this means that crediting to ethanol and gas buses of lower exhaust emissions will decline in value. In addition, the ethanol buses will probably need to be fitted with both a particle trap and EGR in order to meet the long-term requirements. The gas buses should meet Euro 4 without both particle trap and EGR but may need the latter technique in order to pass Euro 5 (2008).

In ten years' time, moreover, the ethanol- and gas-powered engines will come up against competition from fuel-cell-powered buses, which, however, may conceivably obtain their hydrogen from ethanol or natural-gas-based methanol, among several alternatives.

It is probable that increased demand for natural and biogas cars in Sweden and the outside world will lead to a fall in manufacturing costs. It does not seem unreasonable that the additional cost of production compared with petrol-driven cars could be halved. Given continued alternative fuel pricing of biogas, this could reduce the cost to a level of just under SEK 1 per kg carbon dioxide, so long as vehicles are available in the size classes which the customers need. For natural gas cars, subject to the same conditions, the cost comes to about SEK 2.40 per kg CO_2. In both cases cars are assumed to run on gas only for the whole of their lifetime. If natural gas for vehicle fuelling is made subject to energy tax, this will reduce the possibilities of gas suppliers delivering gas at the customer's alternative cost.

E85 cars ought not to cost more to make than conventional petrol-driven cars, given a large enough production volume. The question here is whether Sweden is capable of creating the necessary base, either alone or in partnership with other markets. Given the present price of fuel, continued tax exemption and the same manufacturing cost as for standard cars, the cost to the customer per kg of carbon dioxide could stop at SEK 0.28/kg, so long as E85 cars are available in the size classes corresponding to the needs of municipal enterprises and authorities. If the hidden cost which exemption from energy tax constitutes is also allowed for, the cost comes to SEK 2.59 per kg carbon dioxide for a compact class car consuming 7.6 litres of petrol per 100 km. The cost of producing ethanol will have to be reduced by virtually SEK 4 per litre in order for the E85, under comparable conditions, to be capable of competing in price with petrol.

Swedish agents, including the three largest cities, tried during the spring of 1999, in a joint procurement of 1 000 cars, to prevail on the vehicle industry to develop a smaller, more energy-efficient ethanol car than the Ford Taurus FFV. They were not successful, however. The buyer consortium did not receive any offers (Rydén 1999).

By taking part in a European procurement of electric cars, Stockholm recently had the opportunity of purchasing the Citroën Berlingo Electrique for SEK 95 000 (exclusive of VAT). The batteries are leased at a separate cost of SEK 10 800 per annum (exclusive of VAT). The variable costs, batteries included, still differs by about SEK 6 000 per annum (at 15 000 km). This corresponds to about SEK 2 per kg carbon dioxide and shows how critical continued battery development is for the possibilities of achieving profitability.

Conclusions

The analysis points to good profitability for CRT filters and biogas buses and to a slight economic deficit for natural gas buses. Stockholm’s investment in ethanol buses is seen to be socio-economically unprofitable, and it is doubtful whether technical progress can reduce the costs to a level where profitability occurs. The training of bus drivers in gentle and economical driving has the highest profitability of all the measures studied. Both expenditure and emissions are reduced.

The commitment of Sweden's metropolitan cities to alternative cars and fuels appears to be less successful. The cities in question have neglected negative side-effects of the transition to new fuels, such as increased use of primary energy (Stockholm and Gothenburg) and increased exhaust emissions (RME in Malmö and Gothenburg). Stockholm's extensive commitment to biogas, like the electric vehicles, means low emissions, but in both instances at heavy cost.

In order to achieve a cost-efficient solution, the cities would need to chart the actual needs of authorities and companies for vehicles and vehicle services and then go on to optimise the size and composition of the car fleet. The establishment of official car pools could be a way of optimising the use of the car fleet and avoiding investments in too many large cars. Stockholm could reduce both carbon dioxide emissions and expenditure by going in for manual gearboxes. The market launch of ethanol will be better and less expensively encouraged by stipulating low admixture than by purchasing oversized, fuel-guzzling vehicles.[2] Training employees who drive long distances in the course of a year in an economic style of driving is a cost-efficient measure.

Biogas in the Stockholm region is a limited resource, which implies a different situation from that prevailing in Malmö and Gothenburg, where biogas can be complemented by natural gas. This prompts the question of the best way in which to make use of this limited resource. In Stockholm at present, biogas is on the whole being used for light vehicles only. Use of this kind has very little effect on exhaust emissions. The environmental effect of biogas is greater in heavy vehicles, because particle emissions are virtually eliminated and nitrogen oxide emissions are reduced by 60 or 70%. The use of biogas in an urban bus has about 17 times the effect on regulated emissions compared with substituting the same quantity of gas for petrol in a Volvo V70 bi-fuel. The disadvantage of using gas as a bus fuel is that it has a low efficiency compared with diesel.

In addition, biogas distribution (small quantities in trailers) has proved to be very expensive, something like SEK 1 per litre petrol equivalent compared with about SEK 0.10 for petrol. This leads to a scattered network and relatively long distances to fuelling points, which may help to account for the low use of biogas in Stockholm City bi-fuel vehicles. The benefit-cost ratio for biogas buses is far higher than for biogas cars: 1.57 for buses as against 0.46-1.26 for biogas cars (assuming that the latter are run entirely on biogas and that it is not necessary to chose a larger model than is really needed).

A recent Swedish government commission, Biogasutredningen (1999), comes to a similar conclusion concerning the use of biogas in road vehicles. The commission says that for economic reasons, only a small part of the technical potential (17 TWh) for producing biogas in Sweden can be utilised. Total production can be expected to rise from 1.5 TWh (1998) to 1.8 TWh. Most of this is used for heat and power production and the commission believes this will not change much in the future. It says the best option for using biogas as a road fuel is in heavy duty vehicles in large cities.

There are also reasons for considering in which areas of application the limited potential of biofuel confers the greatest benefit. In this connection, differences of both efficiency and

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[2] Stockholm and Gothenburg have agreements with a number of oil companies for the sale of E10 at

total economics have to be taken into account. Conditions differ considerably between biogas and ethanol produced from timber waste.

Biogas from wastewater processing plants and landfill sites has to be destroyed, because methane is a powerful greenhouse gas. The additional cost of upgrading gas to vehicle gas is relatively small. The effect on the local environment of using gas in road vehicles is good. What on the other hand may argue against such use is that the efficiency is lower than with diesel and low compared with what can be achieved in gas-fired CHP plants. In the latter, the electrical power yield can be about 50% of the energy input. If such electricity is used in electric vehicles, the total efficiency will be slightly higher than with direct utilisation of the gas as a propellant. In addition, the CHP uses most of the waste heat for heating purposes.

The use of timber waste for producing ethanol must, if a high level of efficiency is to be achieved, take place in a combined facility where electricity and district heat (or pellets) are also produced. A system of this kind has a total efficiency of about 72%, with 16% of the energy input being turned into electricity (Ericson and Odéhn 1999). This can be compared with about 90% in a chip-fired CHP with an electricity yield corresponding to about 40% of energy input. In terms of cost, we have a long way to go before the ethanol combined facility can compete with the chip-fired CHP. Thus bio raw materials should only be used for the production of vehicle fuel if this can be done at roughly the same cost and with roughly the same yield as in the power and heating sector.

There are residuals from the forest industry and a grain surplus from agriculture that can be used for large-scale production of ethanol. Agroetanol AB has recently decided to build

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some filling stations.

a facility for an annual production of 50 000 m^3, and another firm (Roma Etanol) is planning for a production of 60 000 m^3, also from grain. A research and small scale pilot facility for production from cellulose is also being considered (Swedish Biofuel Development Foundation 1999). If 20% of the current demand for petrol were to be shifted to E5 (a 5% ethanol blend), this would correspond to approximately 50 000 m^3 per annum. To reach this level of demand by introducing flexible fuel vehicles that can run on E85 would take much longer and involve about 60 000 cars. At present fewer than 600 cars and buses use ethanol in Sweden.

On the basis of present-day technology and costs, it should be possible for biofuels to be used in heavy vehicles, above all in the form of biogas. Where cars and other light vehicles are concerned, it is more important and far more cost-efficient to give priority to low fuel consumption. Then again, the technical potential for reduced consumption is far greater for cars than for heavy vehicles.

Table 1. Official car fleets, by type of car. Percentages.

Type of car and fuel	Stockholm	Gothenburg	Malmö
Gasoline	51.4	86.3	83.2
Diesel (including RME)	2.4	1.8	11.1
Biogas/natural gas	36.7	8.0	0.5
Ethanol (E85)	4.1	0.0	0.0
Electric	5.4	3.8	5.2
Total	100.0	99.9	100.0

Table 2. Official car fleets, by vehicle sizes. Percentages.

	Subcompact	Compact	Intermediate	Large	Total
Stockholm	9.1	48.2	8.4	34.3	100.0
Gothenburg	25.3	47.2	3.9	23.6	100.0
Malmö	17.3	42.1	16.8	23.8	100.0

Table 3. Emissions from buses according to the Braunschweig cycle. g/km

	HC	NO_x	PM 10
Diesel Euro II	0.72	9.7	0.20
Diesel with CRT	0.07	9.7	0.02
Ethanol	0.15	6.6	0.04
CNG	0.20*	4.5	0.01

* Methane not included

Source: Egebäck et al 1997.

Table 4. Implicit valuation of carbon dioxide based on differences in annual overall cost and carbon emission entailed by shifting from a conventional diesel bus to other alternatives, and the benefit-cost ratio of the shift with carbon dioxide valued at SEK 0.80/kg.

Bus type	Valuation of CO_2, SEK/kg	Benefit-cost ratio
Ethanol	3.10	0.39
Natural gas	1.28	0.91
Biogas	0.23	1.57

Exchange rates (6 July 1999): USD = SEK 8.50, Euro = SEK 8.70

Table 5. Implicit valuation of carbon dioxide based on differences in annual overall cost and carbon emission entailed by shifting from the Opel Astra 1.6, Renault Clio 1.4 and Volvo V70 to other alternatives, and the benefit-cost ratio of the shift with carbon dioxide valued at SEK 0.80/kg.

Car modell	Valuation of CO_2, SEK/kg	Benefit-cost ratio
Opel Astra automatic gear-box	Reference car	Reference car
Opel Astra manual gear-box	-5.11	"win-win"*
BMW 316g Compact 100% biogas	0.62	1.26
BMW 316g Compact 70% gasoline	1.47	0.55
Volvo V70 Bi-fuel 100% biogas	6.45	0.13
Volvo V70 Bi-fuel 70% gasoline	29.63	0.03
Volvo V70 Bi-fuel 100% natural gas	20.25	0.05
Ford Taurus FFV (100% E85)	17.17	0.05
Renault Clio 1.4	Reference car	Reference car
Clio Electric #	4.35	0.25
Volvo V 70 (100% gasoline)	Reference car	Reference car
Volvo V70 bi-fuel 100% biogas	1.78	0.23
Volvo V70 bi-fuel 100% natural gas	4.40	0.11
”Eco-driving”, employee with 15 000 km/y	-0.26	1.43
”Eco-driving”, employee with 5 000 km/y	4.72	0.48

* Reductions in costs and emissions

Based on the average annual supply of electricity.

Exchange rates (6 July 1999): USD = SEK 8.50, Euro = SEK 8.70

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