Literature study

Summary and analysis of the potential for production of renewable methane (biogas and SNG) in Sweden.

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Section 1 – Renewable methane in the Swedish energy system

General

This report summarizes the potential concerning methane gas derived from biomass. Renewable methane is here treated as produced in two different ways:

- Anaerobic digestion of organic substances for production of biogas
- Thermal gasification of organic matter with subsequent methanisation into synthetic natural gas (SNG)

Biogas and the Swedish environmental targets

The production of biogas has a positive influence on Swedish environmental targets. The following influences on the environmental targets are those most worthy of highlighting:

- *Reduced environmental impact,* since gasoline and diesel are replaced by renewable biogas, and due to a reduction of the emissions of methane and laughing gas caused by the storing and spreading of manure, or by the depositing of organic waste in landfills.
- *Clean air,* since gas driven vehicles emit less nitrogen oxides, particulates and hydrocarbons than other vehicles, and since odour inconveniences from the spreading of biogas digestate is far less than when spreading untreated manure.
- *Reduced eutrophication,* since the fertilizer resulting from the biogas process contains a larger share of easily accessible nitrogen which reduces the risk for leakage of nitrogen compounds and emissions of ammonia from stored manure. Nitrogen leakages occurring when growing energy crops can be reduced via the choice of crops with a long vegetation period, and with a strong ability to absorb nitrogen.

Methane as a vehicle fuel

As a vehicle fuel methane gas offers several advantages. Methane has a high octane rating which means a possibility for high efficiency when used in an otto engine. In addition methane offers cleaner combustion than what is possible with liquid fuels, and thus also lower emissions. The great advantage, however, is that it is an already established fuel used for a variety of different applications within industry, electricity production and heating. The market for the gaseous fuel is thus already established. The limitations for methane used as a vehicle fuel is the fact that it is a gaseous fuel which must be compressed to a high pressure in order to provide the vehicles with a sufficient operating range. This means an additional vehicle cost in comparison with vehicles using liquid fuels. By condensing methane (LNG), which occurs at approximately –160 °C, the volume is reduced by a factor of 600 approximately. This technique is being used for some applications.

Globally there are substantial investments in gas driven vehicles (NGV) with natural gas as the most important fuel. Internationally there is a well developed infra structure for the distribution of natural gas which also facilitates the use of biogas. Natural gas mainly consists of methane gas which means that the NGVs (natural gas vehicles) can be run on biogas as well as natural gas.

An investment in methane as an energy carrier also means an investment in a possible future system for distribution of hydrogen gas. Several projects within the 6th EU framework programme aim to use the existing natural gas pipeline grid as the base for the introduction of hydrogen as an energy carrier. If Sweden shall have a share of this energy potential it is important to view an extension of the Swedish gas grid as an infra structure for methane gas which could have different origins. More favourable rules for the distribution of biogas via the natural gas grid is something which could favour a future introduction of hydrogen gas.

The EU Bio-Fuels Directive aims to increase the security of supply, and to reduce global environmental impact. These arguments were also important corner stones in the EU argumentation for an alternative fuels market in the year 2020 based on 10 % natural gas, 8 % bio-fuels, and 5 % hydrogen. In order to increase the security of supply a domestic fuel offers advantages over a fuel imported from other parts of the world. From an energy and environmental point-of-view long distance transports should, if possible, be avoided in order to secure a sustainable system.

Large natural gas investments are made within Europe in order to fulfil the political ambitions. This means an expansion of the refuelling infra structure, and also that more and more vehicle manufacturers are able to offer gas driven vehicles. There is also in Sweden development and manufacturing of gas driven vehicles which, of course, is supported by the investments in gas used as a vehicle fuel.

Infra structure and synergies with natural gas

The infra structure available for natural gas offers synergies concerning the distribution of biogas as a vehicle fuel. The biogas can be distributed using the existing gas grid, thus assuring use of the complete available production capacity. The combination of biogas refuelling stations and natural gas refuelling stations also means that the refuelling opportunities are expanding at a faster rate than if the biogas alternative on its own should be responsible for the expansion. The interaction between the products also means an increased assurance of continuous deliveries.

In addition to the annual biogas potential of 3,6 TWh in the year 2020 we must add another 7,6 TWh (10 % of the current annual vehicle fuel consumption of 76 TWh) from natural gas to fulfil the EU targets. The total annual potential for methane as a vehicle fuel in 2020 is thus 11,2 TWh. Biogas could be considered as fuel blended into natural gas in the same manner as ethanol blended into gasoline.

Carbon dioxide advantages

Until 2010 the volume of biogas used as a vehicle fuel is estimated to grow from 126 GWh (2004) to 1040 GWh. In 2010 about one third of the biogas production will be derived from sewage sludge. The other part will come from cogeneration plants using a combination of different substrates. The share based on specially grown crops is for 2010 estimated to be some 250 GWh.

Production of biogas from sewage sludge is already in existence and is most often used for heating purposes. For these purposes there are, however, other lower grade energy sources (miscellaneous biomass, excess heat etc) which could be used, thus freeing up biogas for use as a high grade vehicle fuel.

800 GWh is derived from other substrates than sewage sludge. The carbon dioxide effect amounts to some 65-85 % depending upon the substrate[1]. In addition biogas production based upon manure means that the leakages of methane and laughing gas from the manure pits are reduced, which further reduces the greenhouse gas emissions. This indirect effect can mean a doubling of the green house gas effect[2].

[1] Miljöanalys av biogassystem, P. Börjesson och M. Berglund, Avd för miljö- och energisystem Lunds Tekniska Högskola, May 2003

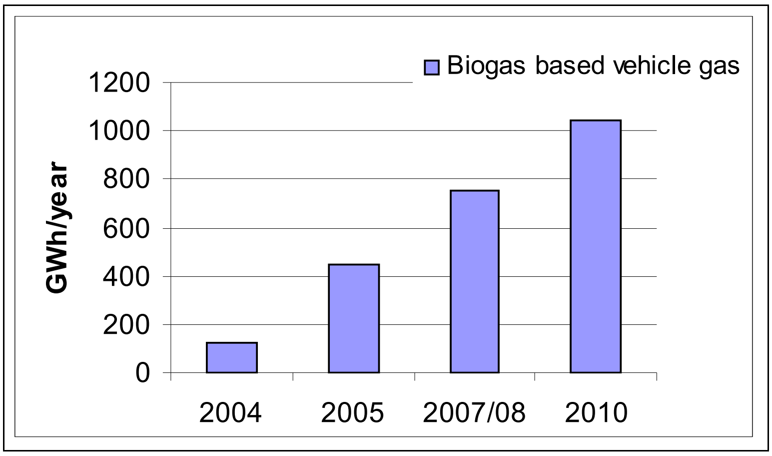
[2] Energianalys av drivmedel från spannmål och vall, Börjesson, P., Avd för miljö- och energisystem, Lunds Tekniska Högskola, March 2004

Section 2 – Biogas from anaerobic digestion

Production potential for upgraded biogas – vehicle fuel quality

Estimates of vehicle gas potentials until 2010 are based on information from biogas plant operators, municipalities and provincial governments. The production capacity shown for 2005 is already existent, or alternatively based on already made decisions concerning new upgrading facilities. For some plants the upgrading is part of 'KLIMP' applications this year. The figures for 2007/2008 and 2010 are based on now planned facilities.

The vehicle gas potential for the years 2005, 2007/2008 and 2010 are shown in appendix 1-3. The quantity of produced vehicle gas is estimated to increase from today's 126 GWh to 1040 GWh in 2010, see chart 2.1.



In 2010 about one third of the vehicle gas production will come from sewage sludge.
The remaining production is derived from cogeneration plants using a combination of different substrates. The share sourced from manure and crops is in 2010 estimated to be some 250 GWh.

Chart 2.1 Planned expansion of the annual production of biogas based vehicle gas in GWh.

Chart 2.2 shows a forecast of renewable methane gas used as a vehicle gas in 2010/20/50 (dotted area). The diagram also shows the total biogas potential in 2050. The extent to which the potential will in fact be used for production of vehicle gas will, of course, depend on the economic conditions within each sector (electricity, vehicle fuels), political measures, EU agricultural policies etc.

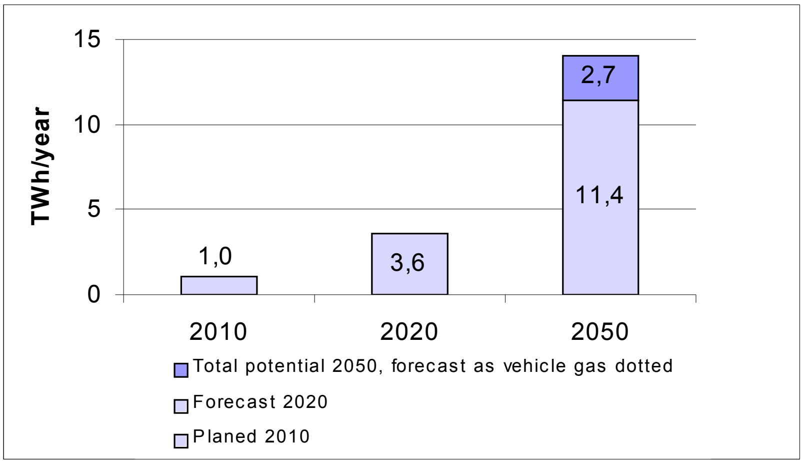


Chart 2.2. Projection of the potential for methane as a vehicle fuel until 2050

2004 Deliveries of methane used as a vehicle fuel

The 2004 deliveries of vehicle gas, split between biogas and natural gas, are shown in table 2.1. The information has been provided by the distributors of vehicle gas, and has been compiled by the Swedish Gas Association. The total biogas deliveries amounted to 126 GWh in 2004. The number of public refuelling sites at the end of the year was 47 stations.

Table 2.1 Delivered quantities of vehicle gas in 2004.

Supplier	Biogas (GWh)	Natural gas(GWh)	Public filling stations
Borås	3		1
Eskilstuna	3,8		1
Eslöv	2,8		1
Falkenberg		0,3	1
Gislaved		0,3	1
Gnosjö		0	1
Göteborg	20,6	58,5	6
Halmstad		1	1
Helsingborg	3,2	1	2
Jönköping	1,9		1
Kalmar	0,6		1
Katrineholm	0,7		1
Kristianstad	10,6		2
Laholm		0,5	1
Lerum		1,5	1
Lilla Edet			
Linköping	42,2		4
Lund		16,8	2
Malmö		94,4	4
Mölndal		3	1
Norrköping	4,9		2
Nyköping	0		1
Partille		2	1
Skövde	1		1
Stockholm	10,6		4
Trollhättan	8,2		1
Ulricehamn	0,1		
Uppsala	11		
Västerås	0,7		1
Ängelholm		0	1
Åstorp		0	1
Sum	**125,9**	**179,3**	**47**

Potential for biogas production

The most complete study made in recent years concerning the potential for biogas production is the study made by 'Jordbrukstekniska Institutet' (JTI) in 1997-1998[3]. The total Swedish biogas potential was in this study estimated as 17.4 TWh annually (see table 2.2). The agricultural sector accounted for the major part of the feed stock potential.

In order to estimate future biogas potentials a new estimate has been made for different substrate categories, which is compared with the JTI report. The results are shown in table 2.2. (adjusted biogas potential). The estimates used as a basis for a revision are discussed on the pages 6-9. In cases where no new information is available the original JTI data are used.

The main differences between the estimates concerning the biogas potentials is that straw has been excluded, and that the acreage with specially grown crops has been increased from 6 to10 %. Furthermore the yield from the crops has been increased as a result of the inclusion of sugar-beet and maize in the mix of crops grown. The total biogas potential is now estimated as 14 TWh annually.

Table 2.2 Biogas potential, GWh/year

Substrate	**Biogas potential within 10 years (GWh/year)**	**Adjusted biogas potential (GWh/year)**	**Comments**
Specially grown crops	3250	7190	10 % of agricultural land, mix of crops
Manure	2940	2560	Reduced live stock
Straw	7140	0	
Tops and potato refuse	920	920	
Chaff	60	60	
Organic household waste	600	940	
Garden waste	230	230	
Organic waste from restaurants and food industry	60	0	Now included in the household waste
Park waste	240	240	
Municipal sewage sludge	970	970	
Private sludge	30	30	
Paper and paper pulp industry	110	90	Two plants have been converted to aerobic treatment process
Other industry	820	820	
Total	**17370**	**14050**	

[3] Biogaspotential och framtida anläggningar i Sverige, Nordberg, Å., Lindberg, A., Gruvberger, C., Lilja, T., Edström, M., JTI-rapport, Kretslopp&avfall nr 17, 1998

Straw

The JTI report shows a straw potential of 7 TWh annually. The inclusion of straw in the potential is a point for debate, but it is feasible to use straw for biogas production. The yield is relatively low compared to other substrates, due to its lignocellulosic contents, and comparatively long time for digestion. Pre-treatment, e.g. via hydrolysis or grinding, could lead to an increased yield or a reduced time for digestion. When estimating the potentials we have, however, chosen not to include the straw. Should the straw, however, be included in potential estimates concerning ethanol production, it is, of course, possible to also include it as a potential for biogas production.

Manure

The number of live stock in the country has fallen since the date of the JTI study. The JTI estimates were based on data from the SCB agricultural register for the year 1990. Compared to 1990[4] the stock of cattle had been reduced by 6 % in June 2003[5]. The number of pigs and chicken had over the same time period been reduced by 16 % and 47 % respectively. With a biogas production of 190 m3 CH4 per tonne dry substance for cattle manure, 210 m^3 CH_4 per tonne dry substance for pig manure, and 240 m^3 CH_4 per tonne dry matter chicken manure, and with the over all assumption that one cow, ten pigs or one hundred chicken equal one animal unit, the biogas potential can with the present number of animals be estimated to have been reduced by 13 % in comparison with the potential in 1990. The sizes of the herds of pigs and cattle have, on the other hand, increased substantially since 1990, which ought to favour a rational collection of manure for treatment at central plants, or alternatively at farm scale units.

Specially grown crops

The farming acreage available for the production of energy crops largely depends on agricultural policies within the EU. Identical assumptions on available land should, of course, be made in a comparison of different crop based fuel alternatives, with similar assumptions concerning crop rotation, soil humus contents, nitrogen fixture, nitrogen leakage etc.

The agricultural area in Sweden is now estimated as 2 626 000 hectares[6]. For 2004 the demand concerning so called set-aside-land was reduced to 5 % of the total acreage as a result of the draught in Europe last year. The share of set-aside-land has varied between 5 and 10 % during the last few years. Set-aside-land may be used for production of energy crops. Starting from 2004 there are also possibilities to grow energy crops on other than ‘set-aside-land’. Sugar beets may be grown as an industrial or energy crop on set-aside-land, but without any acreage compensation.

The use of agricultural land for production of crops to be used in biogas production has several advantages:

- Several different types of crops can be grown which means rotational advantages and a reduced need for pesticides.
- In areas continuously used for grain production the rotational sowing of grass can improve the soil structure and over time increase the yields. A continuously increased production of grain would, on the other hand, definitely reduce the yields[7].
- Sugar beets and maize react very little on nitrogen fertilizers, straw seeds considerably more. This situation is caused by the different vegetation periods. Sugar beets and maize have a maximal nitrogen demand when the mineralization in the soil is at its maximum, and they are thus not very dependant on fertilizers, but can absorb the nutrients out of

[4] www.scb.se, Antal husdjur av olika slag, 1990
[5] Husdjur juni 2003, JO 20 SM 0401, Statistiska meddelanden, Jordbruksverket
[6] www.jordbruksverket.se
[7] Lantbrukets produktionsekonomi vid anslutning till biogasanläggning, D Hallén, LRF konsult Karlstad, December 2003

the soil. Straw seeds, on the other hand, demand fertilizers already when it is still cold, and before the mineralization has really started[8].

The interest in growing energy crops for biogas production has increased substantially in some European countries, e.g. Germany and Austria. At a conference in Austria in March 2004[9] the methane yields per hectare from different crops were presented. The yields varied substantially, from 20 MWh/ha for ray grass up to 140 MWh/ha for sugar beet and maize.

Swedish conditions allow the growth of sugar beets in Skåne, Halland, Blekinge, Kalmar and Gotlands län. Maize is grown in Skåne, southern Halland, Blekinge, southern Kalmar and also, on an experimental basis, in Östergötlands län[10]. The work on plant improvement means that earlier and more cold resistant species are developed, gradually moving the boundaries in a northerly direction. Grass and grain can be grown in the entire country, however, with different yields.

For estimations of the biogas potential it is assumed that 10 % of the agricultural land is used for the growing of various types of energy crops as shown in table 2.3. The harvesting levels shown represent an average of today's yields, i.e. no anticipation of future yield improvements. The reason for this assumption is that a too intensive farming practise, with large fertilizer additions, does not comply with the Swedish environmental ambitions concerning reduced leakage of nitrogen from the agricultural sector. Nevertheless there are opportunities to raise the agricultural yields due to improved crop rotation with perennial energy crops, and with continued plant improvements.

Table 2.3 Biogas potential from crops if 10 % of the total Swedish acreage is used for biogas production.

	Share of the acreage for energy crops	Average harvest[11] (kg dry matter per ha/year)	Methane yield [12] l CH_4/kg dry matter)	Energy yield (MWh/ha)	Biogas potential (GWh)
Grain	30	6000	340	20	1610
Grass	40	7500	300	23	2360
Maize	20	10000	360	36	1900
Sugar beet incl. tops	10	14600*	340	50	1320
Sum					7190

* 11000 tonne dm/ha for sugar beets and 30 tonne per ha for tops with a dm content of 12 %

When using grain for ethanol production a by-product, draff, is formed. This draff can be used for biogas production. For every litre of ethanol produced some 0.85 kg dm draff[13] is also produced. The biogas yield from draff is some 270 Nm^3/tonne VS according to trials conducted by Svensk Biogas. With a VS content of 90 % this means that for every litre of ethanol (with an energy content of 5.9 kWh) produced, another 2.1 kWh can be produced when using the draff for biogas production.

[8] www.greppa.nu
[9] Nachwachende Rohstoffe als Biogaslieferanten, K. Mayer, Konferens Steirische Biogastagung, March 31,2004
[10] Private correspondence with Gunnar Svensson, SLU at Alnarp
[11] Estimated average based on SCB data on typical harvests for grain and sugar beets, maize crops according to Torsten Hörndahl SLU-Alnarp, grass harvests in line with 'Energianalys av drivmedel', P.Börjesson, Rapport 54, March 2004
[12] Methane yields for grain: Svensk Biogas AB, for grass: norm values from different JTI reports, for maize: ref 8, for sugar beets: 90 % of calculated value based on the composition, for sugar beet tops: fermentation trials by BioMil AB.
[13] www.agroetanol.se

Organic household waste

One of the targets in the national objective '*Good populated environment'* is that at least 35 per cent of all food waste from households, restaurants, kitchens and shops by 2010 should be recovered via biological treatment. The target includes sorted food waste both for home composting and central treatment.

The quantity of organic household waste, including waste from restaurants and shops, is 975 000 ton. Table 2.4 includes an estimate of the future development of biogas production based on organic household waste. This estimate has been made in cooperation with RVF (the Swedish Waste Treatment Association).

Table 2.4 **Biogas production from organic household waste**

	2005	**2010**	**2020**	**2030-50**
Treated volumes (%)	15	35	55	70-80
Biogas potential* (GWh/year)	170	410	650	820-940

* For calculation of biogas potentials 10 % losses, 35 % dry matter, 85 % VS of TS, 450 m^3 CH_4/ton VS have been assumed.

Energy analysis of biogas and ethanol

When using agricultural land as a base for the production of vehicle fuels the energy yield per hectare is an important parameter. Since the available land is a limited resource it should be used in as optimal a manner as possible. One method of measuring and comparing the resource usage efficiency for different fuel pathways is to analyse their energy efficiency, i.e. how much energy is required in order to produce one energy unit of vehicle fuel. The energy efficiency for biogas and ethanol respectively is shown in table 2.5[14]. Grass as feedstock for production of biogas and wheat as feedstock both for ethanol and biogas have been studied, and, in addition the consequence of the by-products straw and draff, for biogas production.

The table shows that the agricultural land is most efficiently used when dedicated to production of wheat for biogas production. The production of ethanol from wheat, on the other hand, gives the lowest yield per hectare, even if the draff is used as fodder. If the draff is used for biogas production the yield is improved to a level where it beats grass used for biogas production, but it is still lower than if the wheta had been used directly for biogas production.

An energy analysis concerning ethanol based on surplus wine from southern Europe shows that 1.6 MJ of energy is required to produce 1 MJ fuel[15]. The energy analysis then comprises the total life cycle, i.e. the energy required for the growing, production and distribution of the wine. If only the production and the distribution of the wine ethanol is considered, i.e. if the wine is seen as a surplus feedstock, and the wine production is not included in the energy consumption, 1.1 MJ of energy is required to produce 1 MJ of ethanol. The energy balance is in both cases negative, more energy is used than what is made available as a vehicle fuel, hardly what we call 'sustainable development'.

[14] Energianalys av drivmedel från spannmål och vall, Börjesson, P., Avd för miljö- och energisystem, Lunds Tekniska Högskola, mars 2004
[15] Miljöfaktabok för bränslen, Uppenberg, S. et al., IVL, 2001

Table 2.5 Efficiency in the use of agricultural land for different vehicle fuel pathways.

Pathway	**Energy use** (GJ/ha/year)	**Energy yield (gross)** (GJ fuel/ha/year)	**Net fuel yield** (GJ fuel/ha/year)	**Energy balance** (fuel yield/ energy input)
1. Grass→biogas	33	69	36	2,12
2a. Wheat→biogas Straw →ploughed down	34	81	47	2,38
2b. Wheat→biogas Straw→biogas	34 7	81 15	55	2,33
3a. Wheat→ethanol Draff→fodder Straw→ploughed down	49	65	16 (23)[1]	1,31
3b. Wheat→ethanol Draff→biogas Straw→ploughed down	38 8	65 24	43	1,97
3c. Wheat→ethanol Draff→biogas Straw→biogas	38 8 7	65 24 15	51	2,05

1/ Includes consideration that 30 % of the harvest results in draff which could be used as fodder, i.e. the ethanol production only uses 0.7 hectares if the alternative use of the land is considered as being used for production of fodder.

Economy

Table 2.6 shows the costs for production of biogas for vehicle use (upgraded and pressurized). The costs, excl. vat, are estimated as 2.3-5.0 SEK per litre gasoline equivalent. The costs for the refuelling station, which may vary depending upon execution, location, public/non public, amortization plan etc, are additional.

Table 2.6 Summary of costs (SEK) for the production of biogas used as a vehicle fuel.

Gas price excl. vat	Biogas(sewage sludge)	Biogas(organic waste)
Production	0-1,5	1,5-2,5
Upgrading	1-2	1-2
Compression	1	1
Sum SEK/Nm^3	2,0-4,5	3,0-5,5
Sum SEK/litre gasoline equivalent	2,3-4,1	2,7-5,0

Svensk Biogas AB estimates a cost range for the production of biogas used in vehicles, reflecting different production conditions, in the order of 3.50 – 4.50 SEK/Nm^3. This range also includes crop based biogas. The higher feedstock cost when using crops is partially compensated for by lower treatment costs in the biogas plant, e.g. no need for hygienisation.

The range of 3.50-4.50 SEK/Nm^3 is considered to be sufficient to guarantee a price for the end customer that does not exceed the price of taxed gasoline. Today's market price for biogas used as a vehicle fuel is about 70 % of the price of gasoline (including tax).

Section 3 – SNG from thermal gasification

Bio-fuel potential in Sweden

The present use of bio-fuels in Sweden amounts to some 90 TWh (including lye, wood used as fuel, organic waste, and peat). It is assumed that an increase of the use of bio-fuels mainly would be based on increased used of biomass from wood (currently 38 TWh) and via increased supply of energy crops (currently 0.2 TWh). The Swedish availability of biomass has for years been the subject of a large number of investigations, and these investigations in summary show very diverging results. This is only natural since the investigations have been made using quite different conditions, and with different sponsors.

The results of the investigations concerning the wood resources have a span between 30 and 135 TWh annually (table 3.1). The truth may lie somewhere between these numbers, and depends on how the wood should be collected, and the conditions which will apply. The use of the wood resources can with different means be steered into paper pulp production, use in the wood industry, generation of remote heat and electricity, or production of fuels. The deliveries of bio-fuels are a function of supply and demand. Presently there is no supply of wood for energy production due to the pricing within the energy sector. SLU (the Swedish Agricultural University) has estimated that an additional 30 TWh of wood for fuelling purposes could be supplied at roughly the same prices which apply today. For increased use it is estimated that the prices would escalate drastically, but it is not today possible to forecast to what level.

The potential supply of bio-fuels (including the present use of bio-fuels) is shown in chart 3.1. This table is based on more conservative estimates than what has been published in various articles and publications from the Swedish Energy Board, SLU, the 'Nordleden project' etc.

Table 3.1 Supply potential divided into different categories.

	lyes	wood	peat	crops	waste	other	sum TWh
2003 (STEM)	35,3	38,2	3,6	0,5	6,9	5,7	**89,7**
2005 (Nordleden-projektet)	35	45	3	0	5	4	**92**
2010 (2003 +30 %)	35	63	5	1	9	4	**117**
2020 (Nordleden plus estimate)	35	86	5	10	10	4	**150**
2050 (Nordleden reduced)	35	134	12	20	15	4	**220**

The table shows a biomass based potential already in 2010 of some 27 TWh available for the production of vehicle fuels (in addition to present use of bio-fuels).The supply would then successively increase to 220 TWh in 2050. This would mainly result from increased use of wood, but also via a threefold use of waste, and additional crops to a level of some 20 TWh annually[16]. Such a strong increase of the use of bio-fuels in Sweden is probably not realistic as it would demand enormous investments in the whole chain from forests to the distribution of bio-fuels. In the continued discussion we have thus assumed that biomass enabling a production of bio-fuels in the order of 27 TWh per annum could be available by 2010. A doubling of the supply to 60 TWh for vehicle fuel production until 2050 could be considered as reasonable, if suitable incentives are introduced in the national policies.

[16] Nordleden 2003

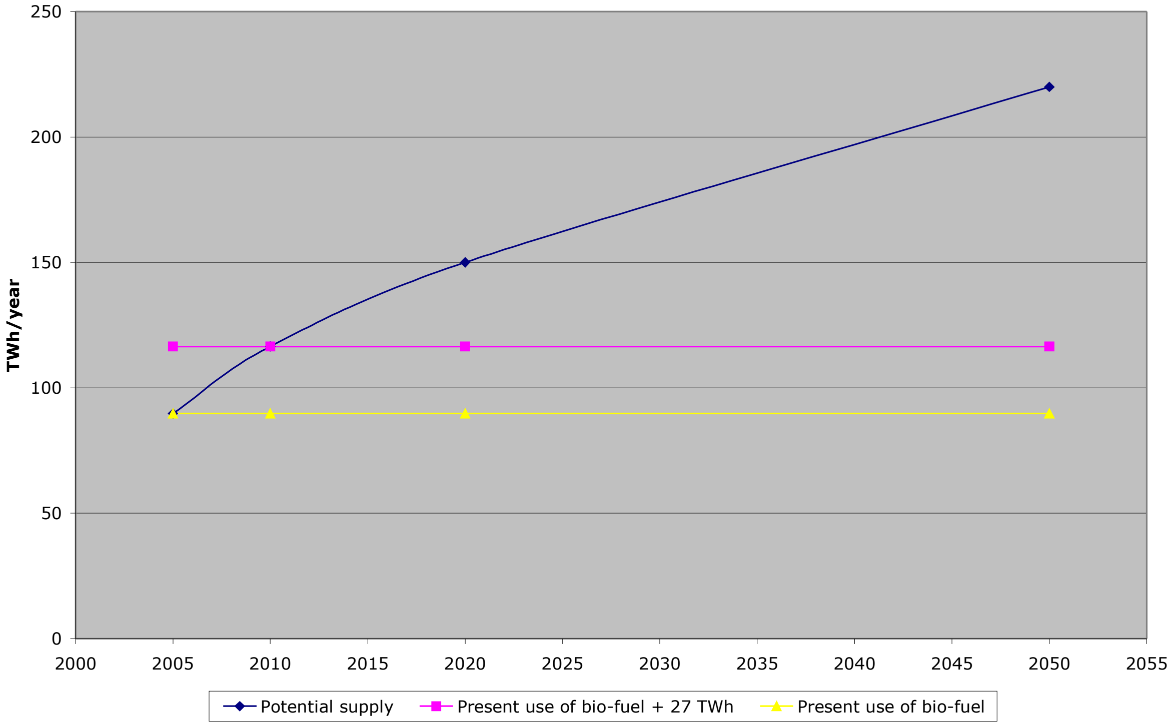


Chart 3.3 Bio-fuel potential available for production of vehicle fuels

From biomass to bio-methane

In any conversion of biomass to a vehicle fuel some of the energy is lost in the transformation process. The amount of energy which is lost depends on the efficiency level in the conversion process, and the possibilities to harness waste energy (usually low grade heat transferred to remote heat systems). The efficiency for thermal conversion of biomass into methane gas has not yet been demonstrated on a commercial scale, but diverse literature studies indicate values in the region between 55 and 67 %. It must, however, be emphasized that there is no commercial technology available for the production of methane via gasification of biomass. This technology must first be demonstrated on a pilot or demonstration scale.

It is not realistic to assume that any significant SNG production could be established in Sweden already in 2010. Possibly a pilot plant could be established (compare the CHRISGAS project). The production in this plant (the Värnamo gasification plant) could reach some 50 GWh annually by 2010. If the CHRISGAS project should demonstrate good results, a full scale production plant could be in operation in 2015 approximately (with an estimated annual production capacity of 0.2 TWh).

Assuming the availability,on reasonable economic terms, of 60 TWh biomass (about 50 % of the unused potential of 135 TWh) by 2050, the methane production could reach over 30 TWh. To secure a reasonable security of supply in a system with such high gas volumes, it is essential that production units and users are tied together via a pipeline distribution network.

For a 100 MW SNG plant with a 55 % efficiency factor an SNG price of some 8€/GJ = 260 SEK/MWh has been predicted, assuming biomass prices of 2.5 €/GJ (=82 SEK/MWh)[17]. With Swedish biomass prices one might instead expect an SNG price of some 300 SEK/MWh.

[17] M Mozaffarian, R W R Zwart, Feasibility of biomass/ Waste related SNG production technologies, ECN-C-03-066, July 2003

Section 3 – Conclusions

In 2004 126 GWh of biogas was delivered as a vehicle fuel. Based on present plans the production of biogas as a vehicle fuel is estimated to reach 1040 GWh in 2010. The present plans concerning new biogas plants and upgrading units are based on today's conditions. This means that changes of the gasoline price, agricultural support, alternative costs for disposal of organic waste etc could result in a faster expansion rate. The total biogas potential by 2050 is estimated as 14 TWh (including crops grown on 10 % of the Swedish agricultural land, but excluding the use of straw). The potential for biogas as a vehicle fuel in 2020 is estimated as 3.6 TWh annually. In addition to the vehicle fuel potential offered via biogas we must include another annual contribution of 7.6 TWh from natural gas, if the EU targets concerning 10 % natural gas should be fulfilled. The total annual potential in 2020 for methane gas used as a vehicle fuel is thus 11.2 TWh.

An energy analysis shows that agricultural land is used in the most efficiently used when producing wheat for production of biogas. Production of ethanol from wheat, on the other hand, gives a lower energy yield, even if the draff is used as fodder. If the draff instead is used for biogas production, the yield is improved, and is better than for biogas produced from grass, but lower than if the wheat had instead been used directly for biogas production.

The costs for production of biogas intended for use in vehicles (upgraded and pressurized) is estimated between 2.70 and 5.00 SEK per litre gasoline equivalent. Today's market price corresponds with 70 % of the current price of gasoline (including taxes).

The carbon dioxide advantage, seen from a life cycle perspective, is 65-85 %, depending on the choice of biogas production feedstock. An increased use of biogas well agrees with several of the national environmental targets, in particular *Limited climate impact, Clean air, and No eutrophication.*

An expansion of the Swedish capacity for production of synthesis gas could be used to produce SNG (synthetic natural gas). Until 2010 it is probably only the Värnamo gasification plant which could be used for production of methane via gasification. This could provide an annual addition of some 50 GWh in 2010. By 2015 the annual production could be increased to 0.2 TWh, provided that the CHRISGAS project succeeds, and that suitable investors are linked to the project. The production of methane will in the period up to 2020 not be limited by insufficient supply of feedstock, but instead by the lack of proven reliable technology and the availability of risk capital for investment into the erection of production facilities. By 2050 an SNG venture could result in an annual production of more than 30 TWh.

An expansion of the use of methane (in the extension also hydrogen) as a vehicle fuel would be facilitated by a simultaneous expansion of the natural gas grid in Sweden. The infra structure already in place, possibly extended to allow increased use of natural gas, could also be used for biogas and methane from gasification plants. This would mean a faster expansion of the number of refuelling outlets, and also that all biogas could be put to valuable use (no flaring). A back-up would also be available in the event of any disruptions in the production at the biogas plants. Natural gas could also be used as a feedstock for production of synthesis gas (if a gasification plant should experience production disturbances). This also means that biogas could be seen as a natural gas blending fuel in the same manner as with ethanol blended into gasoline.

Annex 1 – 2005 Potential for biogas used as a vehicle fuel

Plant	sludge	meat prod.	waste from industry	house-hold waste*	manure	crops	vehicle gas GWh/year
Ryaverket	X						60
Trollhättan/TRAAB	X		X	X			20
Borås	X	X	X	X			20
Skövde	X	X					15
Ulricehamn	X						2
Lilla Edet	X						1
Linköping Åby		X		X	X	X	45
Linköping Nykvarn	X						19
Norrköping	X						10
Norrköping Händelö			X			X	24
Skellefteå	X	X	X	X			20
Boden	X			X			7
Östersund	X						5
Uppsala	X				X		12
Västerås	X			X		X	23
Stockholm Vatten	X						65
Växjö	X						1
Helsingborg, NSR		X	X				18
Jönköping	X						5
Kalmar	X	X					5
Kristianstad	X	X	X	X	X		16
Laholm		X	X		X		25
Ystad	X						3
Malmö	X						20
Eslöv	X		X				10
Sum							451

* including waste from restaurants and industrial kitchens

Annex 2 – 2007/2008 Potential for biogas used as a vehicle fuel

Plant	sludge	meat prod.	waste from industry	house-hold waste*	manure	crops	vehicle gas GWh/year
Ryaverket	X						90
Trollhättan/TRAAB	X		X	X			20
Borås	X	X	X	X			20
Skövde	X	X					15
Ulricehamn	X						3
Lilla Edet	X					X	3
Vänersborg	X						5
Lidköping			X				20
Alingsås	X						5
Uddevalla	X						4
Linköping Åby		X		X	X	X	45
Linköping Nykvarn	X						19
Norrköping	X						10
Norrköping Händelö			X			X	24
Gröngas 1			X			X	39
Motala	X			X			6
Åtvidaberg	X			X	X	X	5
Skellefteå	X	X	X	X			20
Boden	X			X			7
Östersund	X						5
Uppsala	X				X		14
Västerås	X			X		X	23
Örebro	X						15
Käppalaförbundet	X						45
Stockholm Vatten	X						65
Växjö	X						1
Helsingborg	X						10
Helsingborg, NSR		X	X				36
Jönköping	X						30
Kalmar	X	X					5
Kristianstad	X	X	X	X	X		30
Falkenberg		X	X		X		47
Laholm		X	X		X		25
Ystad	X	X	X		X	X	8
Malmö	X						20
Eslöv	X		X	X			15
Sum							754

*including waste from restaurants and industrial kitchens

Annex 3 – 2010 Potential for biogas used as a vehicle fuel

Plant	**sludge**	**meat prod.**	**waste from industry**	**house-hold waste***	**manure**	**crops**	**vehicle gas GWh/year**
Ryaverket	X						90
Trollhättan/TRAAB	X		X	X			20
Borås	X	X	X	X			20
Skövde	X	X					15
Ulricehamn	X						3
Lilla Edet	X					X	3
Vänersborg	X						5
Lidköping			X				20
Alingsås	X						5
Uddevalla	X						4
Brålanda		X				X	3
Skara		X	X				20
Falköping				X		X	20
Grästorp						X	5
Linköping Åby		X		X	X	X	45
Linköping Nykvarn	X						19
Norrköping	X						10
Norrköping Händelö			X			X	24
Gröngas 1			X			X	39
Motala	X			X			6
Åtvidaberg	X			X	X	X	5
Gröngas 2			X			X	39
Gröngas 3			X			X	39
Skellefteå	X	X	X	X			20
Boden	X			X			7
Örnsköldsvik/Domsjö			X				88
Borlänge				X			12
Östersund	X						5
Uppsala	X				X		18
Västerås	X			X		X	23
Örebro	X		X		X		35
Käppalaförbundet	X						45
Stockholm Vatten	X						65
Växjö	X						1
Helsingborg	X						10
Helsingborg, NSR		X	X				36
Jönköping	X		X	X			40
Kalmar	X	X					13
Kristianstad	X	X	X	X	X		47
Falkenberg		X	X		X		47
Laholm		X	X		X		25
Ystad	X	X	X		X	X	10
Malmö	X						20
Eslöv	X		X	X			15
Sum							**1041**

*including waste from restaurants and industrial kitchens