BASIC DATA ON BIOGAS

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Preface

Renewable gases such as biogas and biomethane are considered as key energy carrier when the society is replacing fossil fuels with renewable alternatives. In Sweden, almost 80 % of the fossil fuels are used in the transport sector. Therefore, the focus in Sweden has been to use the produced biogas in this sector as vehicle gas.

Basic Data on Biogas contains an overview of production, utilisation, climate effects etc. of biogas from a Swedish perspective. The purpose is to give an easy overview of the current situation in Sweden for politicians, decision makers and interested public. Swedish Gas Technology Center Ltd (SGC) has been responsible for the writing with financial support from Avfall Sverige, Energigas Sverige, E.ON Gas Sverige AB, Greenlane Biogas AB, Göteborg Energi AB, LRF, Lunds Energikoncernen AB, Läckeby Water AB, Malmberg Water AB, NSR AB, Processum Biorefinery Initiative AB, Stockholm Gas AB, Svensk Biogas i Linköping AB, Svenskt Vatten and Swedish Energy Agency. The translation has also been supported by EU through Biomethane Regions and Intelligent Energy Europe.

The assignment of SGC is to co-ordinate the Swedish industrial interest in R&D focused on gas fuel technology. This is performed on a non profit base. The Swedish government represented by the Swedish Energy Agency participates in financing the R&D-program. SGC was established in 1990. For more information, please visit, www.sgc.se.

This publication is an updated version of *Basic Data on Biogas*, that was published for the first time in 2007.

Production of biogas

1.4 TWh of biogas is produced annually in Sweden at approximately 230 facilities. The 135 wastewater treatment plants that produce biogas contribute with around half of the production. In order to reduce the sludge volume, biogas has been produced at wastewater treatment plants for decades. New biogas plants are mainly co-digestion plants and farm plants. The landfilling of organic waste has been banned since 2005, thus the biogas produced in landfills is decreasing.

Biogas plants	**Number**	**Energy in biogas [GWh/year]**
Wastewater treatment plants	135	614
Co-digeston plants	18	344
Farm plants	14	16
Industrial wastewater	5	114
Landfills	57	298
Sum	**229**	**1 387**

Source: Swedish Energy Agency, Produktion och användning av biogas år 2010; ES2011:07

Potential biogas production

There is a large potential to increase the Swedish biogas production as biogas can be produced from various types of substrates that are currently treated as residues or waste. Agricultural residues represent the greatest potential resource. The theoretical potential biogas production in Sweden has been estimated to be more than 15 TWh/year, which is around ten times more than the current production.

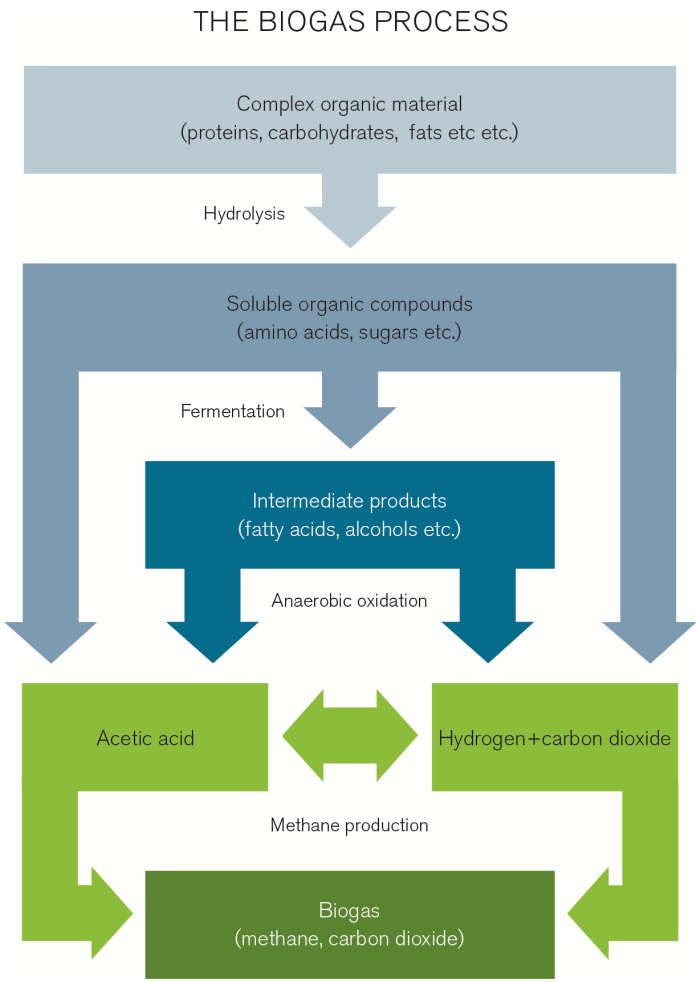
Substrate	**Potential biogas production with limitations* [TWh]**	**Total biogas potential [TWh]**
Food wastes	0.76	1.35
Wastes from parks and gardens	0	0.40
Industrial waste and residues (including food industry)	1.06	1.96
Sludge from wastewater treatment plants	0.70	0.73
Agricultural residues and manure **	8.10	10.78
Totalt	**10.62**	**15.22**

*Taking into account limitations in todays technical and economical situation.
** 5.8 TWh of this potential origins from straw which requires pretreatment before digestion.
Source: Den svenska biogaspotentialen från inhemska restprodukter, 2008.

Biogas can also be produced from crops. This potential is difficult to estimate and depends entirely on which assumptions are made regarding land use, crop and yield. If 10 % of the agricultural land in Sweden is used, approximately 7 TWh of biogas could be produced annually.
(Source: Biogaspotential och framtida anläggningar i Sverige, 1998)

The biogas process

Biogas, which is mainly composed of methane and carbon dioxide, is produced during the decomposition of organic matter in anaerobic conditions. The organic matter is decomposed in a number of steps in a collaboration between several different types of microorganisms. The efficiency of the biogas production depends on how suitable the conditions are for the microorganisms. To initiate a biogas process, sludge containing the bacteria for starting the process is inoculated from an existing biogas plant.



The biogas process divided into a number of stages that take place during digestion. (**Illustration:** Energigas Sverige)

Parameters for the biogas process

Loading rate	Amount of substrate added to the digester. Expressed *e.g.* as kg VS per m^3 digester and day.
Biogas production	Amount of produced biogas expressed *e.g.* Nm^3 per ton TS.
C/N-quota	Relation between carbon and nitrogen content in the substrate.
Pretreatment	Prior to digestion, many substrates needs to be pretreated. This pretreatment can be pasteurisation, thickening or disintegration.
Volatile Solids – VS	Weight of organic matter in the substrate. Normally expressed as percentage of TS.
Mesophilic Digestion	Digestion at 25–40 °C. Usually around 35–37 °C.
Methane concentration	Amount of methane in the biogas. Normally expressed as percentage by volume.
Methane yield	Amount of produced methane expressed *e.g.* Nm^3 per ton TS.
Thermophilic Digestion	Digestion at 50–60 °C. Usually around 50–55 °C.
Total Solids – TS	The weight of the substrate after drying. Normally expressed as percentage of wet weight. Also called dry matter (DM)
Dry Digestion	Digestion of substrate with TS around 15–35 %.
Hydraulic retention time	The average time that the substrate is inside the digester.
Degradation of VS	Describes how much of the substrate that is degraded in the digester. Usually expressed as percentage of VS.
Wet digestion	Digestion of substrate with TS around 2–15 %.
Wet weight	The weight of the substrate including water.

Biogas production for different substrates

The biogas production varies between different substrates depending on the composition of the substrate. The biogas production figures in the table below are determined in laboratory scale and therefore higher than expected during continuous operations in full scale.

Substrate	TS	Biogas production		Methane concentration
	[%]	[m^3/ton TS]	[m^3/ton wet weight]	[%]
Sludge from waste-water treatment plants	5	300	15	65
Fish waste	42	1 279	537	71
Straw	78	265	207	70
Sorted food waste	33	618	204	63
Liquid cattle manure	9	244	22	65
Potato haulm	15	453	68	56
Slaughter house waste	16	575	92	63
Liquid pig slurry	8	325	26	65

Sources: Substrathandbok för biogasproduktion, SGC 2009
Den svenska biogaspotentialen från inhemska restprodukter, 2008
Ökad biogasproduktion vid Henriksdals reningsverk, 2009

Biogas production from crops

Biogas production in Sweden could be greatly increased by using crops. Examples are given in the table below.

Substrate	Harvest[1)]	TS	Methane yield	Substrate need	Land requirement
	[ton/ha and year]	[% of wet weight]	[Nm^3 methane/ ton wet weight]	[ton/GWh]	[ha/GWh]
Jerusalem artichoke[2)]	60	22	48	1500	25
Maize	43	30	95	1070	25
Potato	26	25	100	1020	39
Sugar beet[3)]	50	24	94	1090	22
Grass	22	35	95	1100	50
Wheat grain	5.2	86	370	300	58

1) Harvest quantities are valid in the area of Mälardalen.
2) Data is valid for harvest of stem.
3) Harvest quantities are valid in the area of Skåne.
Source: http://www.bioenergiportalen.se, 2011-02-15

Composition of biogas

The composition of biogas depends on a number of factors such as the process design and the nature of the substrate that is digested. The main components are methane and carbon dioxide, but several other components also exist in the biogas. The table below lists the typical properties of biogas from landfills and digesters as well as a comparison with Danish natural gas.

		Landfill gas	Biogas from AD	Natural gas
Lower calorific value	MJ/Nm^3	16	23	39
	kWh/Nm^3	4.4	6.5	11.0
	MJ/kg	12.3	20	48
Density	kg/Nm^3	1.3	1.1	0.82
Relative density	-	1.1	0.9	0.63
Wobbe index, upper	MJ/Nm^3	18	27	55
Methane number		>130	>135	73
Methane	Vol-%	45	65	90
Methane, range	Vol-%	35–65	60–70	85–92
Heavy hydrocarbons	Vol-%	0	0	9
Hydrogen	Vol-%	0-3	0	—
Carbon dioxide	Vol-%	40	35	0.7
Carbon dioxide, range	Vol-%	15–40	30–40	0.2–1.5
Nitrogen	Vol-%	15	0.2	0.3
Nitrogen, range	Vol-%	5–40	—	0.3–1.0
Oxygen	Vol-%	1	0	—
Oxygen, range	Vol-%	0–5	—	—
Hydrogen sulphide	ppm	<100	<500	3.1
Hydrogen sulphide, range	ppm	0–100	0–4000	1.1–5.9
Ammonia	ppm	5	100	—
Total chlorine as Cl^-	mg/Nm^3	20–200	0–5	—

Sources: *Energigaser och miljö*, SGC 2006.
Energinet.dk, www.energinet.dk, 2011-02-15

Upgrading of biogas

To increase the energy density of the biogas, it is possible to upgrade it with different technologies. In practice, this is performed by removing the majority of the carbon dioxide. Examples of techniques are given in the table below.

Technique	Function	Regeneration
Pressure Swing Adsorption (PSA)	Adsorption of carbon dioxide on e.g. activated carbon.	Depressurisation
Water scrubber	Absorption of carbon dioxide in water.	Depressurisation and counter flow of air.
Chemical absorption	Chemical reaction between carbon dioxide and amine – based solvents.	Heating
Membrane	Separation through a membrane that is permeable for carbon dioxide.	—
Cryogenic separation	Cooling until condensation or sublimation of the carbon dioxide	—

To increase the energy density even further, it is possible to condense the biogas by cryogenic cooling. Liquified biogas is normally abbreviated LBG.

Energy content of biogas

A typical normal cubic meter of methane has a calorific value of around 10 kWh, while carbon dioxide has zero. The energy content of biogas is therefore directly related to the methane concentration. In other words, assuming a biogas composition with 60% methane, then, the energy content would in this case be around 6.0 kWh per normal cubic meter.

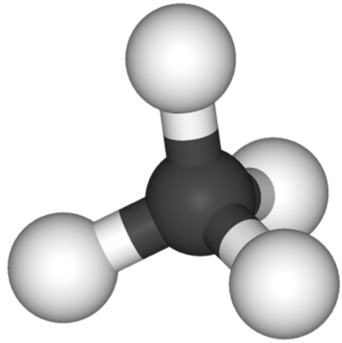
Vehicle fuel	Energy content [kWh]
1 Nm^3 upgraded biogas (97 % methane)	9.67
1 Nm^3 natural gas	11.0
1 litre petrol	9.06
1 litre diesel	9.8
1 litre E85 (vehicle fuel with 85% ethanol and 15% gasoline)	6.37 (summer, 85% ethanol) 6.59 (winter, 79.5% ethanol)

Sources: Energinet.dk, www.energinet.dk, 2011-02-15
Preem, www.preem.se, 2011-02-15

This in turn implies that the energy content in 1 Nm^3 biogas corresponds to around 1.1 litre petrol and the energy content in 1 Nm^3 natural gas corresponds to around 1.2 litre petrol.

In the figure below, the volumes of compressed (200 bar) and liquefied biogas with the same energy content as 1 liter petrol are shown.

Methane



Methane is the simplest alkane and consists of one carbon atom and four hydrogen atoms and is probably the most abundant organic molecule on earth.

Property	Unit	Value
Density, gas	kg/m^3	0.72
Relative density		0.56
Density, liquide	kg/m^3	423
Upper calorific value	kWh/Nm^3	11.0
Lower calorific value	kWh/Nm^3	9.97
Wobbe index, upper	kWh/Nm^3	14.8
Wobbe index , lower	kWh/Nm^3	13.3
Flammable range	%	4.4–16.5
Boiling point	°C	–161.5

Source: Encycopedie des Gaz, L'air Liquide

Safety

There exists several safety aspects that need to be considered during production and handling of biogas. It is very important to be aware of the risks and to minimise these. The most common risks are:

- Flammability
- Poisoning (mainly H_2S)
- Suffocation
- Risks caused by high pressures
- Thermal injuries

As the density of upgraded biogas is lower than air, any gas leaking will rise upward. In addition, upgraded biogas has a higher temperature of ignition than both petrol and diesel. This means in turn that the risk of fire or explosion in traffic accidents is smaller for upgraded biogas than for petrol or diesel.

Utilisation of biogas

The annual energy use in Sweden is around 600 TWh and it origins mainly from four energy carriers: oil (187 TWh), nuclear power (166 TWh), biofuels (141 TWh) and hydro power (67 TWh). The annual energy use, without conversion losses, is estimated to around 400 TWh.

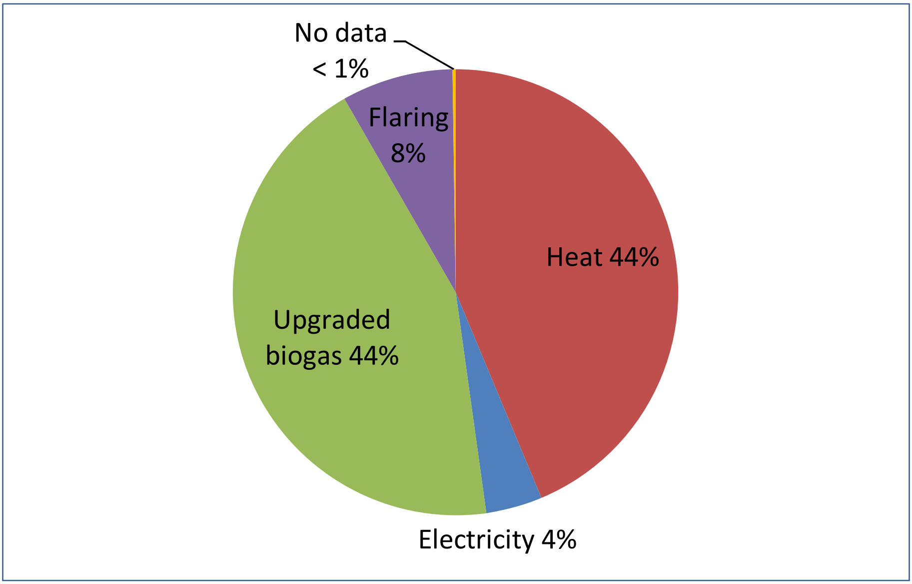
Out of the 117 TWh oil (without conversion losses) that is used annually in Sweden, almost 80% is used in the transport sector, which makes this sector the most fossil fuel depending sector. Electricity and heat production is mainly produced from non-fossil energy carriers. This makes the utilisation of biogas as a vehicle fuel the best way to decrease the fossil fuel dependency in Sweden.

Biogas can be used in many ways. Typical applications in Sweden include:

Heat	The gas is combusted in a boiler. The heat generated warms up water which can be used to heat the digester and nearby buildings or be exchanged on a local district heating network. A gas boiler works like a boiler for solid and liquid fuels, but with the difference that the boiler is specially modified to combust gas.
Heat/Power	Biogas can be used as a fuel in stationary engines, typically Otto or diesel engines, or gas turbines. About 30-40% of the energy in the fuel is used to produce electricity while the remaining energy becomes heat.
Vehicle fuel	Biogas can be used as a vehicle fuel for cars, buses and trucks, providing it is upgraded by removing carbon dioxide, water and hydrogen sulphide. Water scrubbing, chemical scrubbing and PSA are the most widely used techniques for upgrading biogas to vehicle fuel quality. The gas must also be odourised and pressurised to around 200 bar before it can be used as vehicle fuel.

Upgraded biogas can also be introduced into the national gas grid, which will stimulate the development of new markets and applications.

In 2010, the utilisation of biogas was divided according to the diagram below:

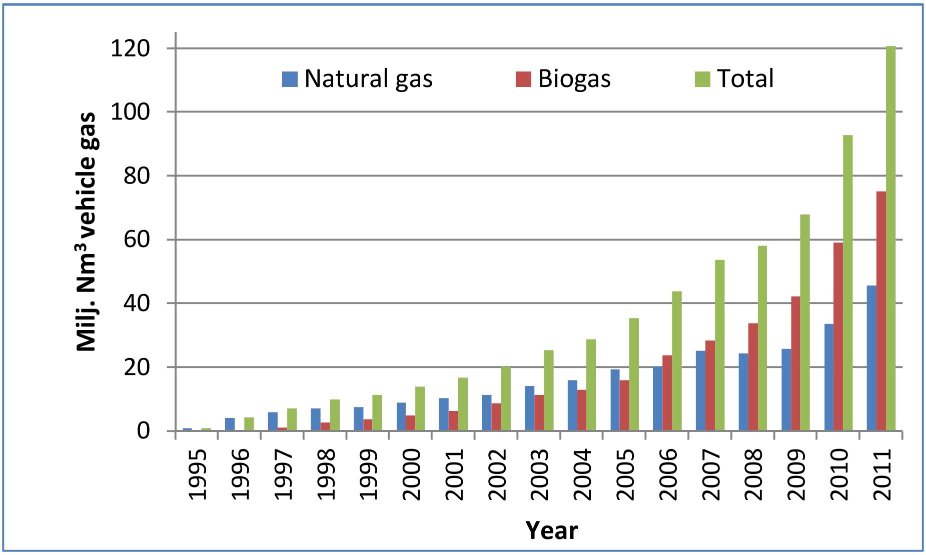


Source: Produktion och användning av biogas år 2010; ES2011:07.

Biogas as vehicle fuel

Due to the dependency of fossil fuels in the Swedish transport sector, utilisation of biogas as vehicle fuel has gained large interest during the last few years. Today, it is a mixture of natural gas and biogas that is sold as vehicle fuel of which biogas comprised 62% by volume in 2011. Both the biogas volume used for vehicle fuel as well as the number of vehicles that are able to use biogas as a vehicle fuel has increased during the last few years.

Except for in the Otto engines, biogas can also be used in Dual-Fuel engines. In Dual-Fuel engines, the biogas can be used in combination with diesel as a vehicle fuel and maintain the high efficiency of the diesel engine. The percentage of biogas can be as high as 90% .



Sold volume of natural gas and biogas as vehicle fuel , 1995–2011
Source: http://www.gasbilen.se, http://www.scb.se, 2012-03-12

Requirements for biogas as a vehicle fuel

The biogas used as vehicle fuel must obey the Swedish standard, SS 15 54 38. The table below shows some details of this standard. Biogas type A concerns biogas for engines without lambda regulation, that is ´lean-burn´ engines used in heavy vehicles such as trucks and buses. Type B concerns biogas for engines with lambda regulation used in stoichiometric combustion, for example private cars. Nowadays, the majority of the heavy vehicles also have lambda regulation.

Property	**Unit**	**Biogas, type A**	**Biogas, type B**
Wobbe index	MJ/Nm^3	44.7-46.4	43.9-47.3
Methane content	vol-%*	97±1	97±2
Water dew point at the highest storage pressure.	°C	T–5**	T–5**
Water content, maximum	mg/m^3	32	32
Carbon dioxide + oxygen + nitrogen, maximum	vol-%	4.0	5.0
Of which oxygen, maximum	vol-%	1.0	1.0
Total sulphur content, maximum	mg/m^3	23	23
Total content of nitrogen compounds (excluding N_2) counted as NH_3, maximum	mg/m^3	20	20
Maximum size of particles	µm	1	1

* at 273.15 K and 101.325 kPa

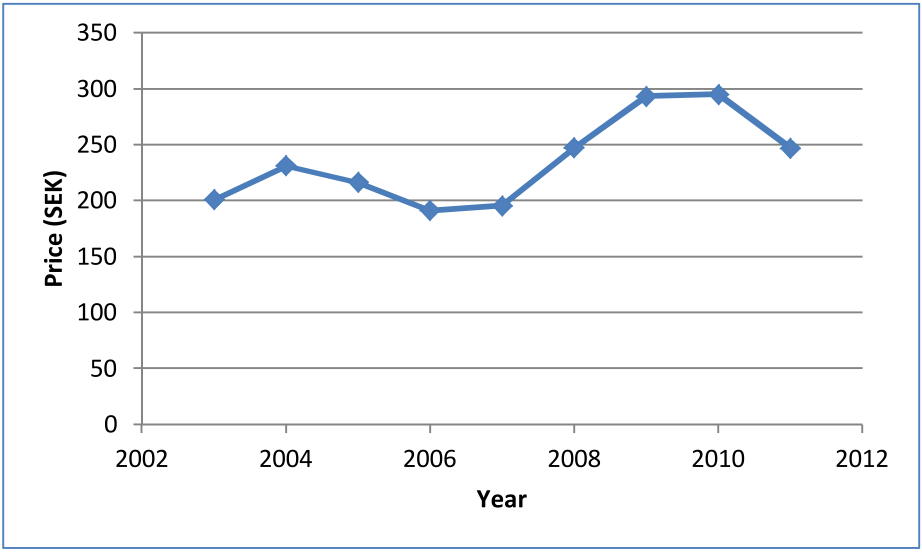
** T = lowest average daily temperature on a monthly basis

Electricity production

Electricity is produced from biogas through combustion in a gas engine or in a turbine. Both Otto and diesel engines are used. About a third of the energy in the fuel is used to produce electricity and two-thirds becomes heat. The producers of the renewable electricity also receive electricity certificates to improve their profitability .

Electricity certificates

In 2003, a support system based on electricity certificates was introduced in order to stimulate the production of renewable electricity. With this system, the producers are given one certificate for every MWh electricity produced from renewable resources. Obligatory quotas have been introduced, which means that the electricity consumers must buy certificates in relation to their total use although, in practice, each supplier is responsible for the quota requirements being fulfilled. For every year until 2035, the quota is determined.



Average price for electricity certificates (1 MWh).
Source: http://elcertifikat.svk.se, 2012-03-22

Digestate

Both biogas and digestate are produced during anaerobic digestion. The digestate contains most of the nutrients originating from the substrate. In order to reach maximum recovery, these nutrients should be used as fertilizer for the production of new biomass.

Depending on the substrate, the digestate has different properties. In Sweden, the main substrates are sludge from wastewater treatment plants and various food and industrial wastes such as food waste and slaughter house waste.

REVAQ is a certification system for digestate from wastewater treatment plants that are spread on arable land. The certification include an active upstream work and continued improvements on the wastewater treatment plant. Furthermore, the producer of the digestate has to be open with all information and has a developed traceability for the produced digestate. In the beginning of 2012, 45% of digestate from wastewater treatment plants were certified according to REVAQ.

The certification system “Certifierad återvinning” was initiated in 1999. The certification is voluntary and is based on open communication between the producer and the consumer of the digestate through documentation and free insight on the quality of the product. The entire chain from substrate to end product is adapted to environmental and user needs. The certification of digestate from waste is described in SPCR120. Of the certified digestate according to SPCR120, 92% was spread on arable land in 2010.

Certification symbols for ”Certifierad Återvinning” and REVAQ.

Environmental benefits

The actual gain in green house gas emissions when replacing fossil fuels with biogas depends on the substrate used. It is possible to reduce the greenhouse gas emission by more than 100% by including for example the decreased need of fertilizer. The large environmental benefit for biogas produced from manure depends on the decreased leakage of methane and nitrous oxides compared to the traditional manure storage systems.

Substrate	**[%]***
Grass	86
Sugar beet (incl. tops)	85
Maize	75
Manure	148
Waste from the food industry	119
Organic household waste	103

*Reduction of greenhouse gas emissions compared to fossil fuels.
Source: Livscykelanalys av svenska biodrivmedel, SGC, 2010.

Sustainability criteria

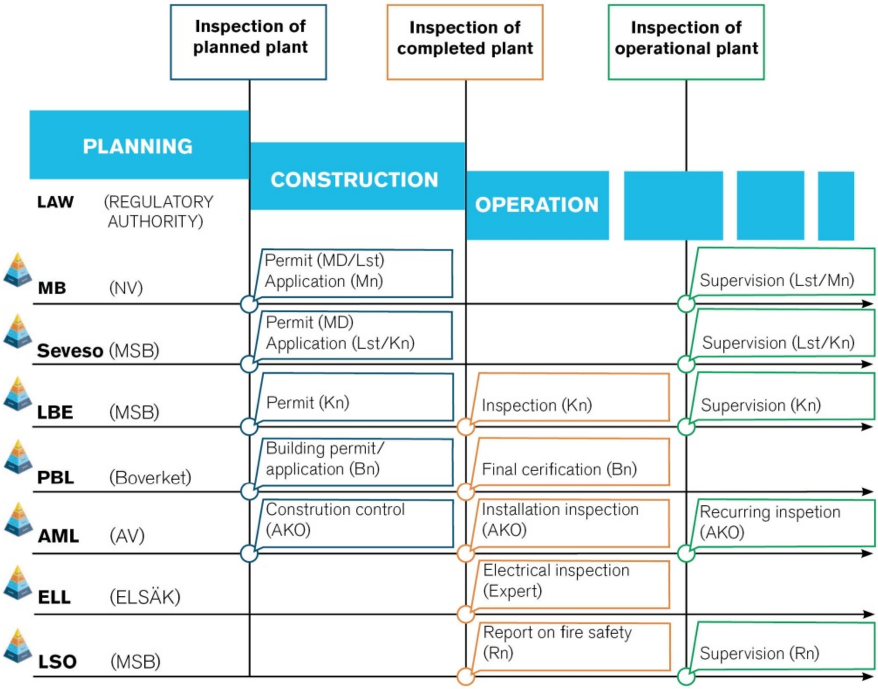
On April 23rd 2009 the EU directive (2009/28/EG) on the promotion of renewable energy, was adopted. The Directive define binding national targets for each member state in order to increase the use of energy from renewable sources. By 2020, 49 percent of the Swedish energy use should be met by renewable energy. For the transport sector, the corresponding number is 10 percent.

To consider a vehicle fuel as sustainable, a number of sustainability criteria should be met along the entire production chain, from primary production to final use. To be termed sustainable, they may not have destroyed areas of high biological value, or given rise to excessive emissions of greenhouse gases.

To ensure that the biofuels lead to decreased greenhouse gas emissions, the sustainability criteria require that GHG emissions from the fuel's life cycle must be at least 35 percent lower compared to fossil fuels. The greenhouse gases included are carbon dioxide, methane and nitrous oxide. The requirement for greenhouse gas reductions is increased in 2017.

Permits and inspections

Prior to building and operating a biogas plant in Sweden, special planning permissions and permits are required according to planning and environmental legislation and laws related to inflammable and explosive goods. More information on legislation related to biogas plants can be found in the guidelines for operation of biogas plants published by Energigas Sverige (BGA 2012). An overview of the permits and inspections required are shown in the figure.



Abreviations : MB: Miljöbalken, LBE: Lagen om brandfarliga och explosiva varor, PBL: Plan- och bygglagen, AML: Arbetsmiljölagen, ELL: Ellagen, LSO: Lagen om skydd mot olyckor. NV: Naturvårdsverket, MSB: Myndigheten för samhällsskydd och beredskap, AV: Arbets-miljöverket, ELSÄK: Elsäkerhetsverket, MD: Miljödomstol, Lst: Länstyrelsen, Mn: Miljö-nämnden, Kn: Kommunal nämnd, Bn: Byggnadsnämnden, AKO: Ackrediterat kontrollorgan, Rn: Räddningsnämnden
Illustration: Energigas Sverige

Terms and units

Anaerobic	Oxygen free
Calorific value	Energy released during combustion. Lower and upper calorific values can be defined. The lower calorific value (used mostly in Sweden) gives the energy released when the water vapour generated during combustion is still in the gas phase. The upper calorific value includes the energy released when water vapour condensates.
CBG	Compressed biogas
LBG	Liquefied Biogas
LEL	Lower Explosion Limit
Methane number	Describes the gas resistance to knocking in a combustion engine. By definition, methane has a methane number of 100 and carbon dioxide increases the number.
Nm^3	Normal cubic meter. Volume at normal conditions, 273.15 K (0°C) and 1.013 bar (atmospheric pressure).
Pressurised water dew point	The temperature at a given pressure at which water vapour in the gas condenses.
Relative density	Density of the gas divided by the density of air.
UEL	Upper Explosion Limit.
Wobbe index	Defined as the calorific value divided by the square root of the relative density. As with the calorific value, there is an upper and lower Wobbe index.

Conversion between different units

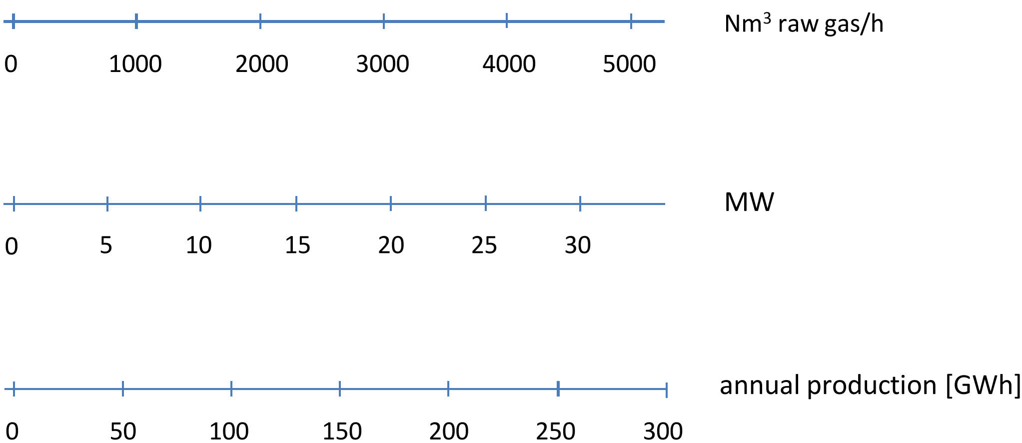
Conversion between units:

Energy	kWh	MJ	Btu
1 kWh	1	3.6	3412
1 MJ	0.278	1	947.8
100000 Btu	29.3	105.5	1

Prefix:

k	kilo	10^3	1 000
M	Mega	10^6	1 000 000
G	Giga	10^9	1 000 000 000
T	Tera	10^{12}	1 000 000 000 000
P	Peta	10^{15}	1 000 000 000 000 000

Conversion between different units that are used to evaluate the biogas process. The values are calculated for dried raw gas with 65% methane.



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