

BIO GAS



BASIC DATA ON BIOGAS - SWEDEN

2007

PRODUCTION OF BIOGAS

1.3 TWh of biogas is produced annually in Sweden at more than 230 facilities. Sewage treatment plants contribute most to this production. Most of the newer plants are designed to co-digest waste materials including, for example, organic household wastes, food industry wastes, manures and ley crops.

Biogas plants	Number	Energy in biogas (TWh/year)
Municipal sewage treatment plants	139	0.56
Landfills	70	0.46
Industrial wastewater	4	0.09
Co-digestion plants	13	0.16
Farm plants	7	0.01
Sum	**233**	**1.3 TWh**

Source: Swedish Energy Agency, Produktion och användning av biogas år 2005 (Production and use of biogas in 2005); ER 2007:05.

POTENTIAL BIOGAS PRODUCTION

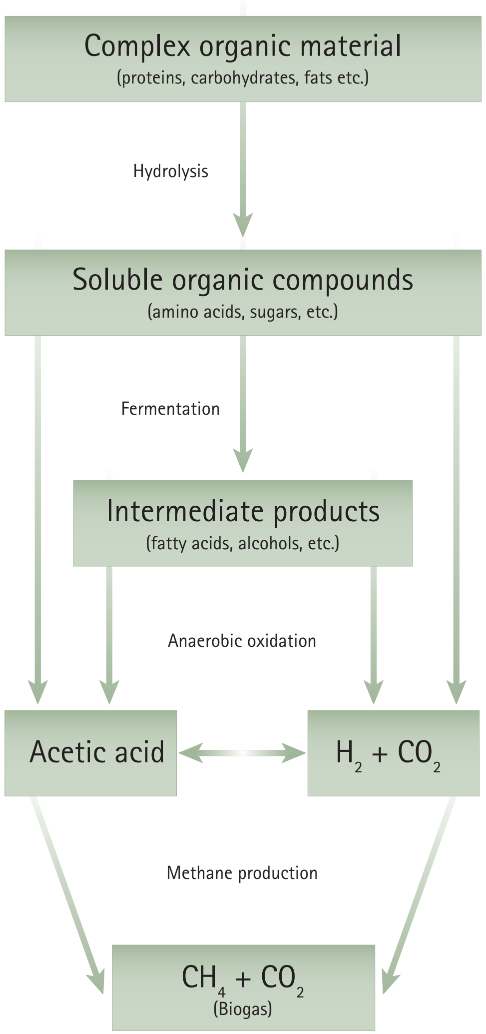
Agriculture represents the greatest potential resource to increase production of biogas in Sweden. This is especially the case for cultivated crops, but also for waste products such as manure and tops. More food waste could also be used to produce biogas. The theoretical potential biogas production in Sweden has been estimated at 14 TWh/year, that is ca. ten times greater than the current value. This estimate assumes that 10 % of the agricultural land can be used to grow crops to produce biogas. The potential production would increase to 21 TWh if 20 % of the agricultural land is set aside for this purpose.

Substrate	Potential biogas production (TWh/year)
Cultivated crops	7.2
Manure	2.6
Tops, rejected potatoes	0.92
Chaff, husks	0.06
Food wastes from households, restaurants and shops	0.94
Garden wastes	0.23
Park wastes	0.24
Sludge from sewage treatment plants	0.97
Sludge from septic tanks	0.03
Pulp and paper industry	0.09
Other industries	0.82
Sum	**14 TWh**

Source: M. Linné, O. Jönsson, Sammanställning och analys av potentialen för produktion av förnyelsebar metan (biogas och SNG) i Sverige (Summary and analysis of the potential production of renewable methane (biogas and SNG)) BioMil, Swedish Gas Centre, 2004.

THE BIOGAS PROCESS

Under anaerobic conditions, organic material is decomposed by microorganisms in a number of steps to the final products methane and carbon dioxide.



Source: Å. Jarvis, Biogas – renewable energy from organic waste, November 2004, Swedish Biogas Association.

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. A special feature of gas produced at landfills is that it includes nitrogen. The table below lists the typical properties of biogas from landfills, digesters and a comparison with average values for Danish natural gas for 2005.

		Landfill gas	Biogas from AD	Natural gas
Calorific value, lower	MJ/Nm^3	16	23	40
	kWh/Nm^3	4.4	6.5	11
	MJ/kg	12.3	20.2	48
Density	kg/Nm^3	1.3	1.2	0.83
Wobbe index, upper	MJ/Nm^3	18	27	55
Methane number		> 130	>135	72
Methane	vol-%	45	65	89
Methane, range	vol-%	35-65	60-70	–
Long-chain hydrocarbons	vol-%	0	0	10
Hydrogen	vol-%	0-3	0	0
Carbon monoxide	vol-%	0	0	0
Carbon dioxide	vol-%	40	35	0.9
Carbon dioxide, range	vol-%	15-50	30-40	–
Nitrogen	vol-%	15	0.2	0.3
Nitrogen, range	vol-%	5-40	–	–
Oxygen	vol-%	1	0	0
Oxygen, range	vol-%	0-5	–	–
Hydrogen sulphide	ppm	< 100	< 500	3
Hydrogen sulphide, range	ppm	0-100	0-4000	1-8
Ammonia	ppm	5	100	0
Total chlorine as Cl^-	mg/Nm^3	20-200	0-5	0

Source: Energigaser och miljö (Energy gases and the environment) Swedish Gas Centre, 2005; Gaskvalitet årsgennemsnit (Gas quality, annual averages) 2005, www.energinet.dk.

WHAT IS THE ENERGY CONTENT OF BIOGAS?

A typical normal cubic metre of methane has a calorific value of ca. 10 kWh, while carbon dioxide has none at all. The energy content of biogas is therefore directly related to the methane content. Thus, if biogas comprises 60 % methane, the energy content is ca. 6.0 kWh per cubic metre.

The energy content of different fuels:
1 Nm^3 biogas (97 % methane) = 9.67 kWh
1 Nm^3 natural gas = 11.0 kWh
1 litre petrol = 9.06 kWh
1 litre diesel = 9.8 kWh
1 litre E85 = 6.6 kWh
1 Nm^3 biogas is equivalent to ca. 1.1 litres of petrol.
1 Nm^3 natural gas is equivalent to ca. 1.2 litres petrol.

Source: www.preem.se (petrol, diesel, E85)
www.swedegas.se (natural gas)

BIOGAS PRODUCTION FROM CROPS

Biogas production in Sweden could be greatly increased by using crops. Important factors that influence the selection of crops to produce biogas include crop yield and gas yields (see table for approximate figures). Biogas production has become a major feature of German agriculture, with maize as a typical energy crop.

		Ley	Maize	Cereals	Sugar beet	
		grass/ clover	whole plant	grain	beets	tops
Average yield	(tonnes fresh weight/ha and year)	22	43	5.2	34	20
Methane production	(m^3 CH_4/tonne fresh weight)	95	95	334	94	33
	(m^3 CH_4/tonne DW)	271	317	388	392	235
	(MWh/tonne fresh weight)	0.93	0.93	3.3	0.92	0.32
Land requirements	(ha/GWh)	50	25	58	32	27*
Methane yield	(l/kg VS)	300	350	400	424	297
Dry weight	(% of fresh weight)	35	30	86	24	14

*beets and tops
Source: Åke Nordberg, Biogas from crops, JTI. Presentation at "10th year Anniversary for Biogas in Trollhättan" May 31st 2006. Methane production from cereals is re-calculated assuming 400 l/kg VS, DW-86 %, VS-97%.

It is important to consider the net energy yield when agricultural land is used to produce fuel (i.e. how much energy is gained after subtracting the amount used in its production). As the comparison in the table below shows, agricultural land is used most efficiently when biogas is produced from wheat. This gives ca. three times more energy than growing wheat to produce ethanol.

Fuel chain	Energy supplied (GJ/ha and year)	Energy yield (gross) (GJ fuel/ ha and year)	Net energy yield (GJ fuel/ha and year)
Lay → biogas	33	69	36
Wheat → biogas Straw → biogas	34 7	81 15	55
Wheat → ethanol Stillage → feed Straw → ploughed down	49	65	16 (23)*
Wheat → ethanol Stillage → biogas Straw →biogas	38 8 7	65 24 15	51

*assuming that 30 % of the yield becomes feed (stillage), i.e. ethanol production utilizes only 0.7 hectares if the alternative use of the agricultural land is assumed to be feed production.

Source: Pål Börjesson, Energianalys av drivmedel från spannmål och vall (Energy analysis of fuels from cereals and ley crops) Dept. of Environmental and Energy Systems, Lund University, 2004.

GAS YIELDS FROM DIFFERENT SUBSTRATES

The table below shows approximate figures for the amount of biogas that can be produced from different substrates.

Raw material		Dry weight	Methane production		Methane content
		(%)	(m^3/ton DW)	(m^3/ton fresh weight)	(%)
Liquid manure (cows)		9	156	14	60-65
Liquid manure (pigs)		8	225	18	62-67
Slaughterhouse waste	Stomach contents	15	300	45	60-65
	Sludge from slaughterhouse waste treatment plants	16	338	54	60-65
	Soft parts	30	633	190	65-70
Source-sorted food waste	Households	30	433	130	60-65
	Restaurants	25	440	110	63-68
	Wholesale/retail	15	427	64	57-62

Source: Ulf Nordberg, JTI, Biogas – Nuläge och framtida potential (Biogas - current situation and future potential) Report 993, Värmeforsk, 2007.

ONE GAS, MANY APPLICATIONS

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

- **Heat** – The gas is combusted in a boiler. The heat generated warms up water which is then used to heat nearby buildings or is 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 or gas turbines, typically Otto or diesel engines. About a third of the energy in the fuel is used to produce electricity and two-thirds becomes heat.
- **Vehicle fuel** – Biogas can be used as a vehicle fuel for cars, buses and trucks, providing it is upgraded by removing hydrogen sulphide, water and carbon dioxide. Water scrubbing, chemical absorption and PSA (Pressure Swing Adsorption) are the most widely used techniques for upgrading biogas to vehicle fuel quality. The gas must also be odorised and pressurized to ca. 200 bars before it can be used.

Biogas can also be introduced into the national gas grid, which will stimulate the development of new markets and uses. One advantage with distributing biogas through the national gas grid is that all the gas that is produced can be used.

Foto: Ole Jais, källa NSR

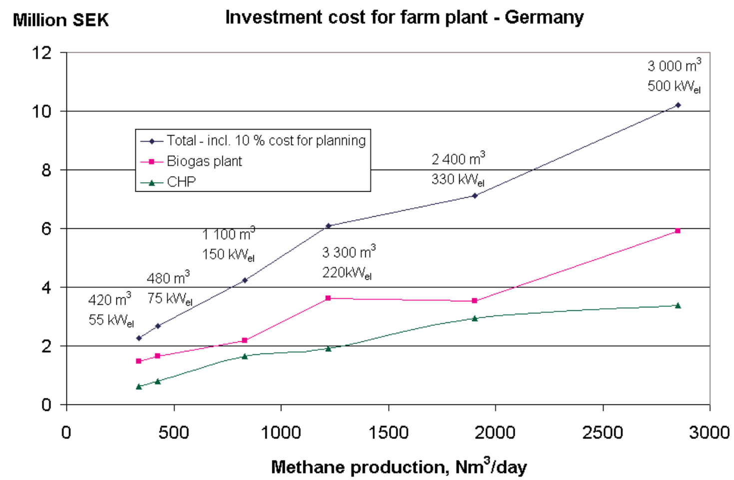
INVESTMENT COSTS

Farm-scale plants with combined heat and power production

In 2006, there were about ten biogas digesters located at farms or agricultural schools in Sweden. This can be compared with Germany, where the number of on-farm biogas digesters has increased tremendously. The number reached ca. 2400 in 2004, and has now further increased.

Data on investment costs for six different types of digesters are shown in the figure below, taken from a German handbook on farm-based biogas production and use. These reactors are designed to co-digest mainly manure and energy crops such as maize and leys. Food wastes and sludge from grease separators are also included in the substrate mixture for the digester with the largest production. Dual-fuel engines are used to produce heat and power in the plants with smaller capacity and Otto engines in the two largest. The figure shows the total investment costs for both the biogas digester and the plant for combined heat and power production, and the costs divided between the digester (including pre-treatment, reactor, torch and residue storage) and the combined heat and power plant.

The investment cost is specified in relation to the daily methane production. The digester volume (m^3) and installed power (kW_{el}) of the combined heat and power plant are also given.



Source: Handreichung Biogasgewinnung und – nutzung, Institut für Energetik und Umwelt gGmbH, Fachagentur Nachwachsende Rohstoffe e.V., 2004.

INVESTMENT COSTS
Co-digestion plants

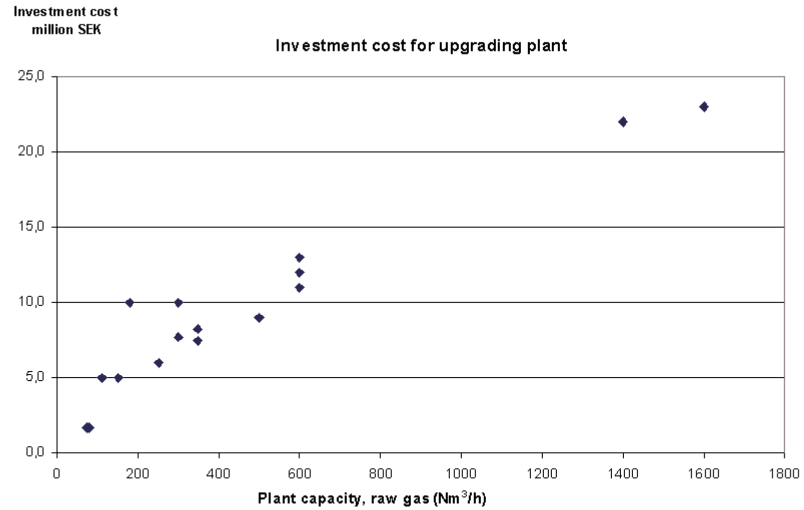
In 2006, there were fifteen plants in Sweden that co-digest different substrates. A large proportion of the wastes that these plants normally digest comes from the food industry, slaughterhouses and households. An evaluation of these plants gave the following total investment costs per tonne of waste per year for pre-treatment, digestion and storage. Plants that mainly handle household wastes and other semi-solid wastes have much higher investment costs than those that only accept liquid wastes that can be pumped.

	Investment (SEK/tonne)	Investment (SEK/tonne DW)
Liquid wastes that can be pumped[1]	850 -1600	5 900 – 23 000
Household wastes and other semi-solid wastes[2]	2200 – 8600	8 000 – 30 700

[1] Based on data from four existing plants.
[2] Based on data from one existing and five planned plants.
Source: Utvärdering av storskaliga system för kompostering och rötning av källsorterat bioavfall (Evaluation of large-scale compost and digester systems treating source-sorted biological waste) RVF Utveckling 2005:06.

INVESTMENT COSTS
Upgrading plants

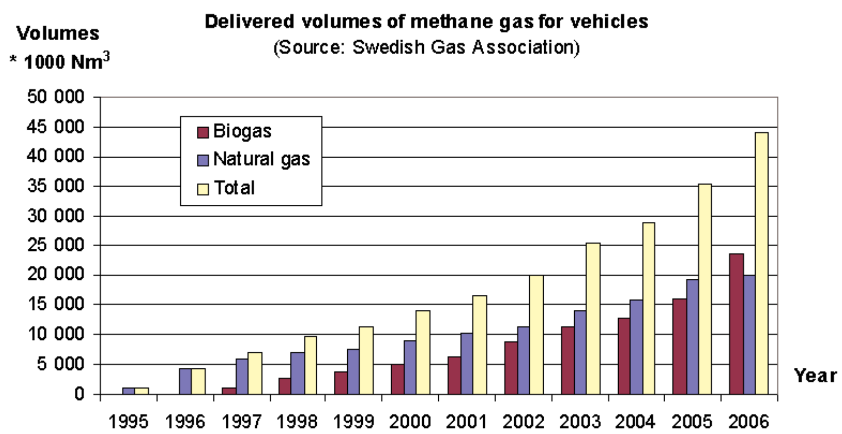
Biogas must be treated in an upgrading plant if it is to be used as a vehicle fuel or introduced into the gas grid. The figure below shows investment costs for these upgrading plants, based on data from 16 plants in Sweden. These costs include neither the equipment needed to pressurize the gas to 200 bars nor, in most cases, the cost for buildings. The investments were carried out between 1996 and 2006 and the figures have not been adjusted for this.



Source: M Persson, Utvärdering av uppgraderingstekniker för biogas (Evaluation of upgrading techniques for biogas) SGC report 142, 2003. Complemented with information from five other plants.

BIOGAS AS VEHICLE FUEL

During 2006, almost 24 million normal cubic metres of biogas were used as vehicle fuel in Sweden, which is equivalent to 26 million litres of petrol. 2006 was the first year in Sweden when more biogas was sold as vehicle fuel than natural gas (biogas comprised 54% of the total volume).



Source: Swedish Gas Association, 2007.

REQUIREMENTS FOR BIOGAS AS A VEHICLE FUEL

Biogas used as vehicle fuel must follow the Swedish standard, SS 15 54 38, Motorbränslen – Biogas som bränsle till snabbgående ottomotorer (Motor fuels – biogas as a fuel for high-speed Otto engines). 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 stochiometric combustion, for example in private cars. Nowadays, most heavy vehicles also have lambda regulation.

Details of the Swedish standard for biogas as vehicle fuel, SS 15 54 38

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 (t = lowest average daily temperature on a monthly basis)	°C	t - 5	t - 5
Water content, maximum	mg/Nm^3	32	32
Maximum carbon dioxide + oxygen + nitrogen gas content, of which oxygen, maximum	vol-% vol-%	4.0 1.0	5.0 1.0
Total sulphur content, maximum	mg/Nm^3	23	23
Total content of nitrogen compounds (excluding N_2) counted as NH_3, max.	mg/Nm^3	20	20
Maximum size of particles	µm	1	1

* at 273.15 K and 101.325 kPa

ELECTRICITY CERTIFICATES

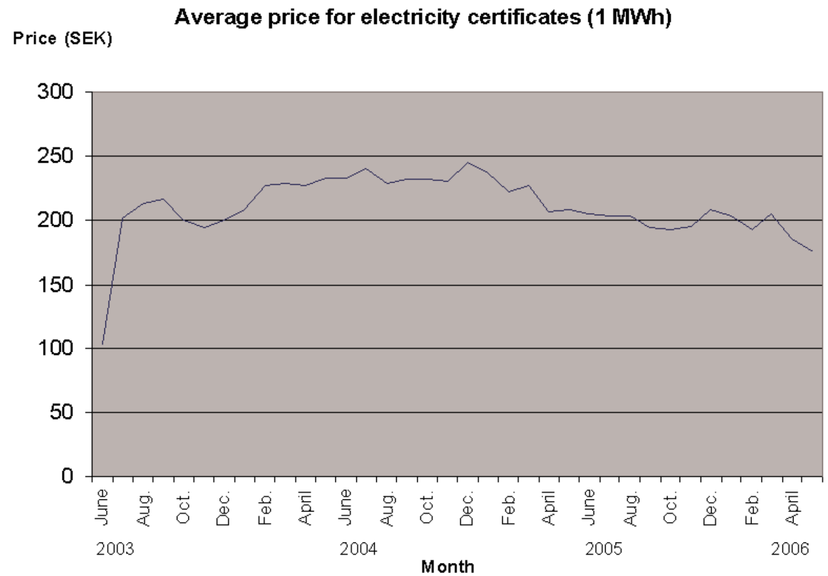
A support system based on electricity certificates for electricity production from renewable energy sources was introduced in Sweden in May 2003. Producers are given one certificate for every megawatt hour of electricity produced from renewable energy sources such as biogas. Producers then receive income from the sale of certificates. Producers can, of course, sell electricity as usual. The average price of a certificate from May 2003 to June 2006 was 216 SEK, or 0.22 SEK per kWh electricity. The price of electricity at Nordpool fluctuates continuously, but in October 2006 it was ca. 0.52 SEK/kWh.

The cost of the electricity certificate is borne by the consumer. Obligatory quotas have been introduced, which means that electricity consumers must buy certificates in relation to their total use. The supplier is responsible for ensuring that the quota requirements are fulfilled. The quota for 2007 is 15.1 %. The system of electricity certificates has been extended until 2030. The quota will increase to 2010, and thereafter decrease to reach 4.2 % by 2030.

Obligatory quotas for 2003 – 2017:

Calculation year	Quota (%)	Calculation year	Quota (%)
2003	7.4 %	2011	17.9 %
2004	8.1 %	2012	17.9 %
2005	10.4 %	2013	8.9 %
2006	12.6 %	2014	9.4 %
2007	15.1 %	2015	9.7 %
2008	16.3 %	2016	11.1 %
2009	17.0 %	2017	11.1 %
2010	17.9 %		

Source: www.stem.se



Source: www.stem.se

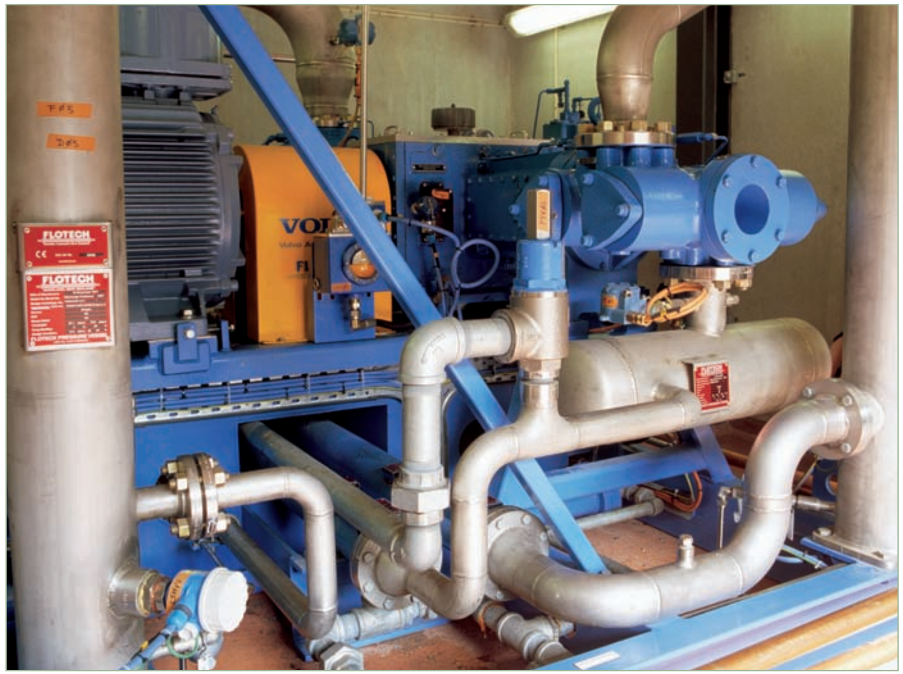


Photo: Ole Jais, källa NSR

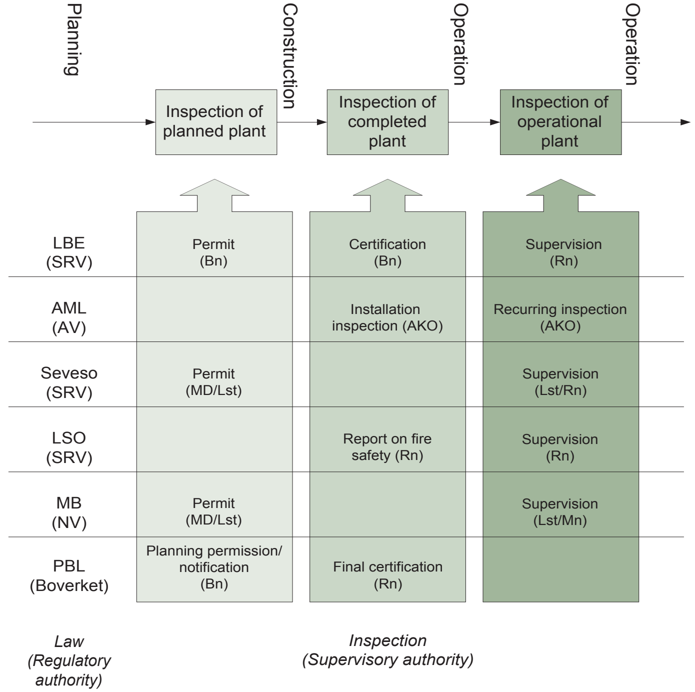
SAFETY

Biogas is combustible in mixture with air. The flammability limits of biogas in air depend on the methane content in the gas. The flammability limits are also called lower (LEL) and upper explosion limits (UEL). The flammability limit of biogas containing 60 % methane is between 7 and 28 vol-% concentration of gas in air. Pure methane has a flammability limit between 4 and 17 vol-% in air.

Biogas is lighter than air, so that any gas leaking will rise upwards. Biogas also has a higher temperature of ignition than either petrol or diesel. This means that the risk of fire or explosion in traffic accidents is smaller for biogas than for petrol or diesel.

PERMITS AND INSPECTIONS

Planning permission and permits are required in Sweden to build and operate biogas plants 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 the Swedish Gas Association (BGA 05). Various inspections may also be necessary. Information on permits and inspections can be summarized as follows:



Source: Swedish Gas Association, Anvisningar för utförande av biogasanläggningar (Guidelines for design of biogas plants), BGA 05.

AKO	Accredited organisation for inspection
AML	Health and Safety at work legislation
AV	Swedish Work Environment Authority
Boverket	The National Board of Housing, Building and Planning
Bn	Office for planning permission and regulations at the local authority
LBE	Law on flammables and explosives
LSO	Law on protection against accidents
Lst	County Council
MB	Environmental legislation

MD	Environmental court
Mn	Office for environmental regulations at the local authority
NV	The Swedish Environmental Protection Agency
PBL	Legislation on planning and construction works
Rn	Office for rescue services at the local authority
SRV	Swedish Rescue Services Agency

CONCEPTS AND UNITS

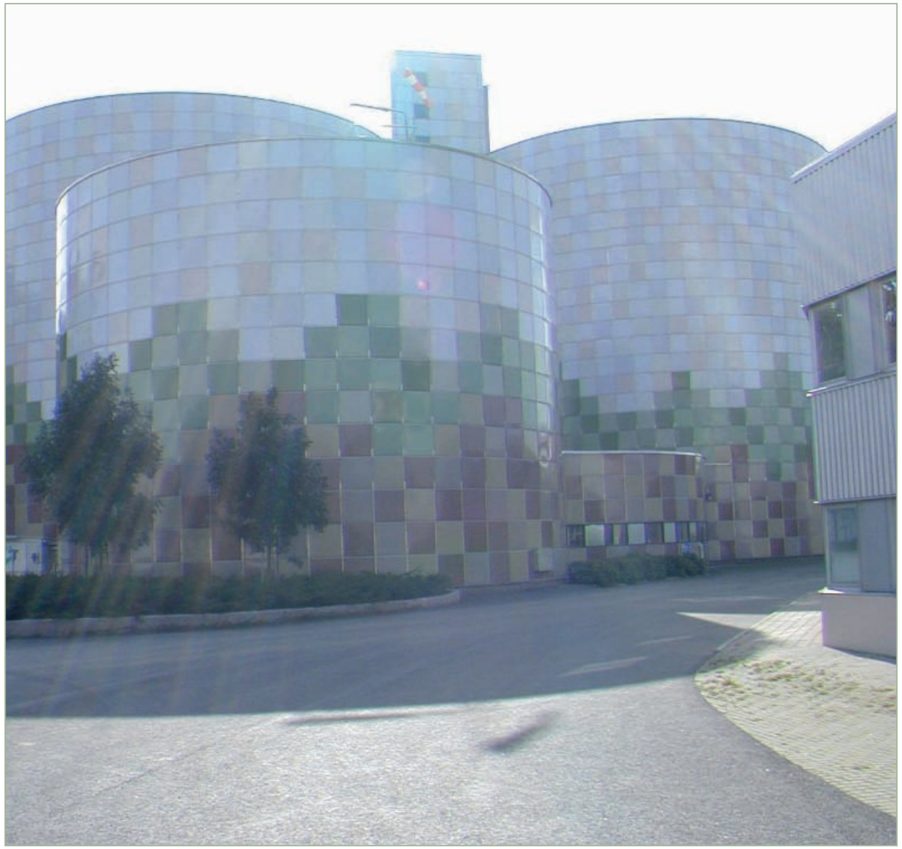
Anaerobic	Oxygen free.
Calorific value, H	Energy released during combustion. Lower and upper calorific values can be defined. The lower calorific value (used mostly in Sweden) gives the energy released when the water vapour generated during combustion is still in the gas phase. The upper calorific value includes the energy released when water vapour condenses.
Degradation efficiency	The percentage of the organic material that is decomposed and converted to biogas during a given time period.
DW	Dry weight. The mass remaining when water is removed from a material. Often specified as percent of fresh weight.
Gas yield	The amount of biogas in Nm^3 produced per unit mass of organic material.
LEL	Lower explosion limit. The lower limit of combustibility for a gas in air.
Methane number	Describes the gas resistance of knocking in a combustion engine. By definition, methane has a methane number of 100 while carbon dioxide increases this value.
Nm^3	Normal cubic metre. Volume under normal conditions, that is 273.15 K (0 °C) and 1.01325 bar (atmospheric pressure).
Organic loading rate	The amount of organic material added to the digester each day.
Pressurized water dew point	The temperature at a given pressure at which water vapour in the gas condenses.
Relative density	The density of the gas divided by the density of air.
Retention time	The time that a substrate resides in the digester.
UEL	Upper explosion limit. The upper limit of combustibility for a gas in air.
Vehicle gas	Upgraded biogas or natural gas used as vehicle fuel.
VS	Volatile solids. Organic content, i.e. dry weight minus ash. Usually given as a percentage of DW.
Wobbe index, W	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 ENERGY UNITS

Energy	kWh	MJ
1 kWh	1	3.6
1 MJ	0.278	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



This brochure is based on a Swedish publication from 2006. In connection with this English translation, the text has been updated in some places.

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