

# ANAEROBIC DIGESTION – AN OVERVIEW

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**ABSTRACT:** In the passed five years, anaerobic digestion (AD) has become one of the leading technologies for the production of renewable energies (RE) throughout Europe. More than 60 new biogas plants are built monthly. Both leading countries, Germany and Austria, with high feed-in tariffs have roughly built 4.5 plants per 100'000 inhabitants. Actually, biogas is the only RE that can be used for the production of heat and power, steam and vehicle fuel. Worldwide 6.4 m vehicles drive on natural gas. Sweden and Switzerland are the top countries in biomethane operated vehicles with 10'000 respectively 3'500 gas vehicles; 50% resp. 37% of the gas fuel comes from biogas. AD is more than energy production. It serves timelike to stabilize sewage sludge and MSW, upgrades industrial waste water and improves fertilizer quality of animal waste. Hence it helps fulfilling a number of environmental laws.

**KEY WORDS:** Biogas, production and utilization, overview, municipal solid waste, waste water, energy crop, energy balance.

## 1 HISTORIC BACKGROUND

Biogas is for sure the oldest “modern” RE. Anecdotal evidence indicates that biogas was used for heating bath water in Assyria during the 10<sup>th</sup> century BC and in Persia during the 16<sup>th</sup> century BC [1].

The science of AD is as old as scientific research can be and includes the names of world's most famous searchers: Benjamin Franklin described as early as 1764 that he was able to light a large surface of a shallow muddy lake in New Jersey. This experiment was reported in a letter to Joseph Priestly in England who published in 1790 his own experiences with the inflammable air [2].

Alexander Volta was the first searcher describing scientifically the formation of inflammable gases in (low-temperature) marshes and lake sediments. His letters on the formation of "Aria infiammabile nativa delle Paludi" where published in Italy in 1776. The importance of these findings was fully recognised by the scientific community, which is reflected by the fact, that his letters were translated into German only two years after their appearance [3]. In 1804, Dalton gave the correct chemical formula for methane.

The oldest publication of the temperature influence on methane formation was written by [4]. He found that river sediments could form biogas at temperatures as low as 6°C. With increasing temperature up to 50°C the gas production was stimulated. He also observed that the composition of the gas formed did not change with temperature.

The first digestion plant was built at a leper colony in Bombay, India in 1859 [5]. Gayon, a pupil of Pasteur, recorded a success in his experiments with animal manure in 1883-84 [2]. The volume of gas collected at 35°C was so great that Louis Pasteur concluded anaerobic manure fermentation might supply gas for heating and illumination under special circumstances. But the proposal, made in jest by the newspaper "Le Figaro" to improve the street illumination of Paris by manure fermentation from the numerous horses of the taxis and public works was not executed.

## 2 AD IS MORE THAN CORN TO FUEL

### 2.1 Agricultural Biogas production

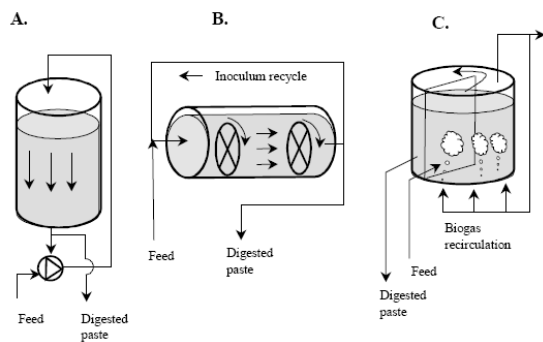
Farm-scale digestion plants treating primarily animal wastes have seen widespread use throughout the world, with plants in developing and technically advanced countries. In rural communities small-scale units are typical; Nepal has some 50,000 digesters and China is estimated to have 14 million small-scale digesters. These plants are generally used for hygienization of the night soil and providing gas for cooking and lighting for a single household.

In more developed countries, farm-scale AD plants are generally larger and the gas is used to generate heat and electricity. These farm-scale digestion plants are simple stirred tank designs that use long retention times to provide the treatment required. Anaerobic digestion of animal manure is perhaps the most common utilisation of AD-technologies. They have primarily two goals, i.e. production of energy and improvement of fertiliser quality: Improve nutrient availability and homogeneity, reduce C/N ratio and odour emission, eliminate plant pathogens and weed seeds and avoid plant burning.

In the seventies and eighties of last century, single site plants were predominant. Today, mostly larger scale plants are operated either by communities or by farmer organizations or companies.

### 2.2 Fertilizer from source separated waste

In total there are 210 plants digesting more than 2'500 tons per year (tpy) of source separated waste [6]. Thereof 140 plants are solely operated on biowaste: 78 plants are so called dry digestion systems (Fig.1), 62 wet systems. 70 plants are digesting the biowaste together with manure as so called co-digestion plants [7]. In total **the 210 plants treat some 8 Mio. tons of organic waste per year.**



**Figure 1:** Dry digestion systems

### 2.3 Upgrading of municipal solid waste (MSW)

The unsegregated (full) waste or the 'gray waste', i.e. after separation of the 'biowaste' can be treated to gain the biogas from the remaining organic fraction and to stabilize it to prevent further emissions in landfills. The latter technologies are called mechanical biological treatment (MBT). The EU has set the goal of reducing the amount of organic waste to landfill by 65% by 2014. Some countries have completely banned the disposal of untreated organic waste.

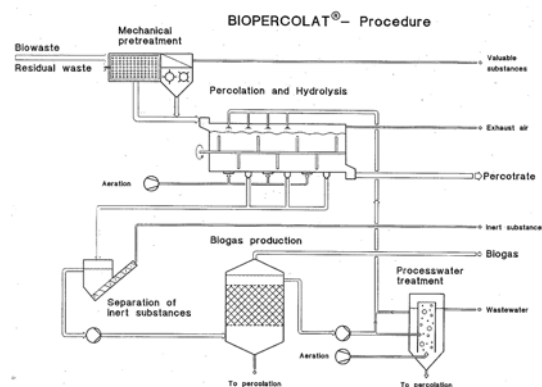
Mechanical-Biological-Treatment (MBT) processes household waste by mechanically separating some parts of the waste and biologically treating others. The M stands for mechanical treatment and refers to sorting, size reduction and sieving technologies achieving separation of potentially useful products and streams for biological treatments. The B stands for biological treatment and refers to aerobic or anaerobic processes which convert the organic fraction into a compost-like material and eventually biogas.

MBT is a well established waste upgrading technology in most parts of Europe. In Italy, Germany and Spain roughly 25% of the population is linked to an MBT. **In total more than 20 Mio. tons of MSW are treated in a MBT**, thereof about 3 to 4 Mio. tons of the biological treatment occurs in an AD process. Again there are wet and dry systems in operation, with a few exceptions equal to the digesters treating source separated waste. There is a new technology that has been brought forward to reduce the organic content of full MSW and grey waste, called percolation system (Figure 2). It is a two-step, two-phase system with an aerobic hydrolysis of the solid material as a first step and an anaerobic digestion of the water which has been flushed through the solid material (percolation) and is loaded with dissolved or suspended organic substrate as a second step [8].

27 companies worldwide are offering MBT systems, 14 thereof with biogas production. Roughly some 120 MBT plants are in operation treating between 12 mio. and 15mio. tons of MSW. With a few exceptions in the USA, Australia and Canada, all of the plants are in Europe.

There are multiple advantages to MBT: 1. It helps to meet the waste diversion targets, 2. It boost the waste recycling targets, 3. It helps to avoid waste incineration, a process which is often heavily defeated by the

population, and 4. It can avoid source separation and decrease processing cost.



**Figure 2:** Percolation system

### 2.4 Industrial waste water (pre-)treatment

The use of AD for sewage sludge stabilisation is well established. In warmer climates (particularly in South America) often waste water treatment consists of a mechanical step followed by an anaerobic treatment in a UASB digester (see below) operated at ambient temperatures.

The use of AD as a (pre-) treatment step for industrial wastewater is increasing rapidly, to the point where there are now **more than 2,500 vendor-supplied systems in operation** or under construction throughout the world. Over 30 types of industry have been identified as having wastewaters amenable to AD treatment, including processors of beverages, chemicals, food, meat, milk, pulp and paper, and pharmaceuticals.

The organic compounds in the waste water are dissolved and therefore easy degradable. Depending on the nature of the compounds, degradation rates are between 80 and 95%. Average concentrations of the waste waters are usually low ranging from 20'000 mg/l COD as low as 1'000 mg/l. The rule of thumb says that below 2'000 mg/l it is advisable to use a aerobic polishing process.

Growth of anaerobic bacteria is slow with doubling times of at least two days. With the fast degradation rates and the large volumes to treat HRT's tend to become low creating the risk that bacteria could be washed out. To counteract wash-out and reduce the solids retention time, dedicated processes have been developed to make the hydraulic retention time independent from the microbial growth. About two thirds of the systems are so called UASB (upflow anaerobic sludge blankets) or EGSB (expanded granular sludge bed) where the bacteria form granules which, thanks to the increased gravity, remain in the digester at low upflow velocities. The rest being either contact processes where part of the sludge is recycled or anaerobic filters where bacteria can attach to plastic filter bodies and stay in the digester even at high flow-through velocities.

### 2.5 Digestion of energy crops

A few years back, farmers started to add substrates from para-agricultural industry to the digester mainly for

two reasons: Fat containing waste gave clearly enhanced gas production and they could even ask for gate fees. However, this didn't last long because it became a buyers market, i.e. gate fees turned into gate costs. Mainly for quality guarantee of the digestate as a fertilizer a new association (Graskraft) started research in the eighties to digest grass and other plant material [9]. As this turned out to be very successful (Table 1), they promoted the idea among farmers. Today, the so called energy crop is the major substrate for agricultural digesters either alone or together with manure. Co-digestion has clear merits like improved nutrient balance or better rheological behaviour [10]. However, it also makes AD systems more complex. Energy crops require pre- and eventually post-treatment. Hence, more technical equipment is needed. Unlike with manure, the loading rate usually is increased and requires intensive monitoring as does the substrate delivery (logistics), prevention of foam and scum formation and removal of sediments from the digester. Process control becomes very important like definition of organic loading rate, gas production, methane and VFA concentration.

**Table 1:** Dry continuous-flow digestion at 37°C

Retention Time (days)		10	15	20	25	Gas yield (=100%)
<b>Fat grass</b>	Fresh 3 cm	70%	83%	92%	97%	<b>700-720 l/kg VS</b>
	Silage 3 cm	77%	92%	97%	99%	
<b>Extenso grass</b>	Fresh 3 cm	67%	82%	90%	91%	<b>540-580 l/kg VS</b>
	Silage 3 cm	65%	78%	86%	90%	
	Hay 3 cm	67%	81%	84%	87%	
	Hay meal	72%	91%	98%	100%	
<b>Solid cattle waste</b>		38%	64%	78%	85%	<b>400-420 l/kg VS</b>

### 3 BIOGAS AS VEHICLE FUEL

Biogas can be upgraded to natural gas quality (Biomethane) and used in the same vehicles that use natural gas (NGVs). Before all, water, CO<sub>2</sub> and hydrogen sulphide have to be removed from the raw biogas [11]. At the end of 2006 there were 6.4 million NGVs in the world thereof 6.2 Mio. cars, 127,000 buses and 113,000 trucks [12]. A number of European cities are exchanging their buses with biomethane driven engines. Six of them teamed in the BiogasMax EC project to share and document their experience.

Most of the gas driven personal cars are converted vehicles that have been retro-fitted with a gas tank in the luggage compartment and a gas supply system in addition to the normal liquid fuel system. Dedicated gas vehicles can be optimised for better efficiency and also allow for more convenient placement of the gas cylinders without losing luggage space. Gas is stored at 200 to 250 bars in pressure vessels made from steel or aluminium composite materials.

Today more than 50 manufacturers worldwide offer a range of 250 models of commuter, light and heavy duty vehicles. Gas vehicles have substantial advantages over vehicles equipped with petrol or diesel engines. Carbon dioxide emission is reduced by more than 95%. Emissions of particles and soot are also drastically reduced, even compared with modern diesel engines equipped with particle filters. The emissions of NO<sub>x</sub> and Non Methane Hydrocarbons (NMHC) are also drastically reduced.

Heavy duty vehicles are normally converted to run on methane gas only but in some cases also dual fuel engines have been used. The dual fuel engine still has the original diesel injection system and gas is ignited by injection of a small amount of diesel oil. The engine normally idles on diesel oil. Dual fuel engines normally require less engine development and maintain the same driveability as a diesel vehicle. However emission values are not as good as for the corresponding dedicated gas vehicle and the engine technology remains a compromise between spark ignition and diesel engine.

Upgraded biogas can be used as a stand alone fuel. There are examples where it is distributed at pumping stations next to the place of production like in Otelfingen, Switzerland. In other cases it is collected and transported by trucks to pumping stations usually in urban areas like in Stockholm. In other places the biogas is transported over a special gas line to the city like in Linköping, Sweden. The predominant part of the biogas for fuel in Switzerland is upgraded and fed into the natural gas grid. The fuelling at the pumping station is virtual, i.e. you usually buy natural gas however, on a data base the provider keeps exactly track on how much biogas is introduced and how much has been used at their pumping stations. The data base which is controlled by a third party. In Switzerland it is the state who does the control because the biogas is tax free.

### 4 ENERGY BALANCE

Why should we drive on biomethane instead of ethanol and biodiesel, the two most renowned biofuels in the world? There are good reasons: 1. Biomethane has the best energy output to input ratio with over 6 (in central Europe!) and is therefore comparable to the actually best BtL which is EtOH from Brazilian sugar cane with a ratio of 8 to 10. 2. Biomethane has by far the best surface specific energy yield in central Europe (Table 2). 3. It needs the least amount of process water for its production, a factor which is at least as important in future as is energy.

**Table 2:** Surface specific net energy production

Technology	Max. yield [GJ/ha*a]	
	Gross	Net
Biogas from maiz	175-300	148-270
Biomethane from maiz	175-300	133-248
EtOH from maiz	73-157	41-100
EtOH from wheat	54	29
SNG from wood	140	125
<b>BTL from wood</b>	<b>135</b>	<b>118</b>

## 5 BIOMASS POTENTIAL

According to two German studies [13, 14], the potential in Germany and in Europe incl. CIS states is large enough to cover substantial amounts of gas as a fuel without touching the surface required for food production. The technical potential in Germany for upgraded fuel gas is 190 PJ corresponding to 6% of the total German natural gas consumption. 44% of the potential is covered by farm waste and 33% by energy crop. Only 13.5% of the agricultural land is needed to produce the energy crop. The potential in Europe28 plus the CIS states is even higher with 17.5 EJ or 37% of the projected natural gas consumption in 2020.

Using consequently the crop species best adapted to the soils and the climate that are available on the market and harvesting at the right period of time can increase surface specific biogas production by 30% and more [15]. On top, during the last two decades the yield of oil and starch producing crops has increased annually by 0.1 t of DM per ha, without using genetical engineering [16].

## 6 REFERENCES

- [1] Ph. Lusk, 1998, Systems and markets overview of anaerobic digestion. IEA Bioenergy, Anaerobic digestion activity. 22 p
- [2] C. Titjen, 1975, From Biodung to Biogas - Historical review of European experience. In: (W.J. Jewell ed.) Energy, agriculture and waste management. Ann Arbor Science. pp. 347-359.
- [3] A. Volta, 1776, Aria infiammabile nativa delle Paludi.
- [4] L. Popoff, 1875, Über die Sumpfgasvergärung. Archiv über die gesamte Physiologie des Menschen und der Tiere von Pflüger, Bd. 10.
- [5] P.J. Meynell, 1976, Methane: Planning a digester. Prism Press, Dorchester. Dorset. p. 3.
- [6] IEA Bioenergy Task 37, 2006, Plant list, [www.iea-biogas.net](http://www.iea-biogas.net)
- [7] R. Braun, 2005, Co-digestion systems, Publications, [www.iea-biogas.net](http://www.iea-biogas.net).
- [8] A. Wellinger and C. Widmer, 1998, Vergärung von Restabfall. In: (K. Wiemer, M. Kern, eds.) Bio- und Restabfallbehandlung II. Fachbuchreihe Abfallwirtschaft des Witzenhausen-Instituts. pp. 437-457.
- [9] U. Baserga and A. Wellinger, 1985, Solid digestion of animal waste and energy crop in an ANACOM digester. Internal research report.
- [10] R. Braun and A. Wellinger, 2005, Potential of co-digestion, IEA Bioenergy Task 37, [www.iea-biogas.net](http://www.iea-biogas.net).
- [11] M. Persson, O. Jönsson and A. Wellinger, 2007, Biogas upgrading to vehicle fuel standard and grid injection, IEA Bioenergy Task 37, [www.iea-biogas.net](http://www.iea-biogas.net).
- [12] P. Boisen, 2007, BiogasMax, Seminar in Lille, April 2007.
- [13] Institut für Energetik und Umwelt, 2006, Einspeisung von Biogas ins Erdgasnetz, FNR Gülzow
- [14] Institut für Energetik und Umwelt, 2007, Möglichkeiten einer europäischen Biogaseinspeisungsstrategie, Teilbericht I, Die Grünen, Fachverband Biogas und STAWAG, not published yet.
- [15] A. Vetter, K. Gödeke, A. Nehring, 2007, Standortangepasste Optimierung des Anbaus von Energiepflanzen für Biogasanlagen. Proc. of the annual conference of the German Biogas Association, Leipzig, January 2007.
- [16] W. Friedt, 2005, Plant Breeding Potential to Improve Energy Crops for the Use in Biogas, IEA Bioenergy Task 37/CROPGEN workshop Wageningen, [www.iea-biogas.net](http://www.iea-biogas.net).