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Biogas production from gut contents and low value offal

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Abstract

Biogas is a regenerative energy source produced from organic material under anaerobic conditions. A biogas plant is a valuable addition to a slaughterhouse because it solves the problem of the disposal of slaughterhouse by-products like gut contents, low value offal and other material. These materials have a worthwhile biogas yield as one cubic meter of typical waste from the slaughterhouse could substitute about 80 litres of mineral oil. Currently there are no known biogas plants that exclusively digest slaughterhouse waste on a large scale. However, there is no biological or technical impediment against the development of such a plant.

Introduction

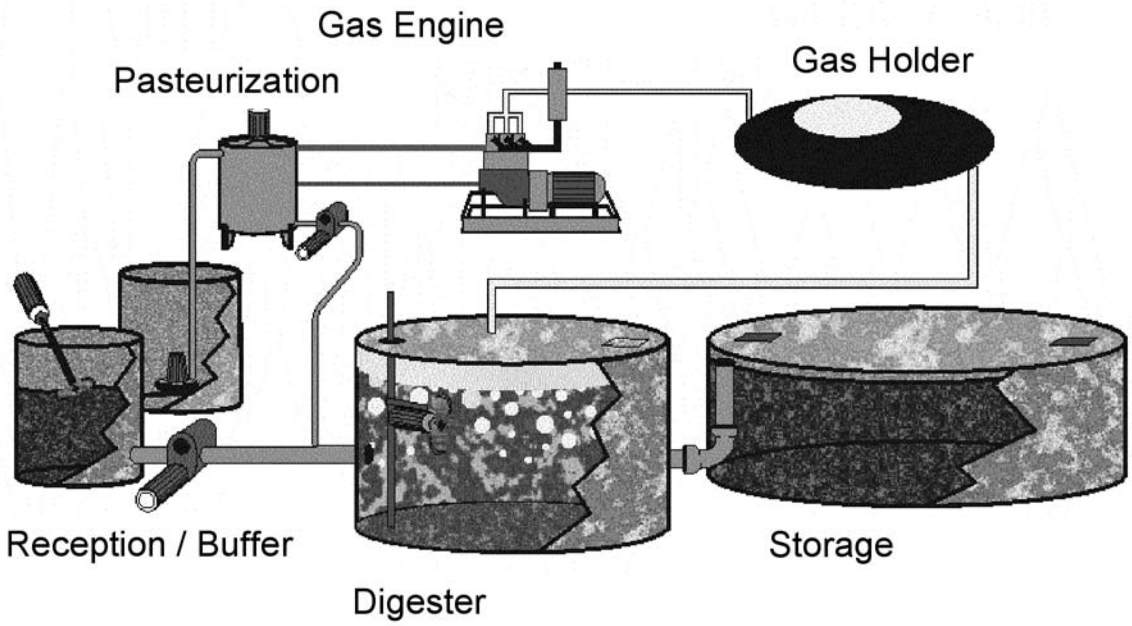
Other than a short increase in activity just after World War II, the first biogas plants for the digestion of animal manure were constructed in Europe in the mid-1980s. Denmark with its big farms focused on centralised large biogas plants; whereas in West Germany mainly independent farm-scale biogas plants were constructed. In the 1980s the circumstances were very difficult with no funding and no external payment for the energy produced. As a result, only a few dozen plants were established. From this slow start in the 1980s, the biogas business gradually began to grow. In the 1990s the implementation of two very important regulations in Germany favoured the economic and technical development of renewable energy in general and biogas plants in particular. In the past 20 years German engineers have gained a great deal of experience in the planning and construction of biogas facilities. Currently (2006) there are approximately 3,500 biogas plants in Germany producing more than 5 million MWh of electricity (Fachverband Biogas e.V.). This represents about 0.9% of the total electricity demand in Germany. In total about 11.8% of electricity was provided by renewable energy sources in 2006 (BMU 2007).

Krieg & Fischer Ingenieure GmbH was founded in 1999 by Andreas Krieg and Torsten Fischer as an engineering office with long experience in biogas plant engineering and construction. Due to the fact that A. Krieg and T. Fischer used to work for several companies in the field of biogas production before they founded Krieg & Fischer, the company can draw upon more than 20 years of experience. During this period, they have generated about 120 references. Their experience covers mesophilic, thermophilic, one- and two-stage, wet and dry fermentation biogas plants, agricultural, municipal and industrial applications. The digester volume ranges from 50 m³ to 12,500 m³, and the cogeneration units ranges from 27 kW to 8.4 MW electrical power. Krieg & Fischer biogas plants process a wide range of input substrates including all kinds of manure, kitchen waste, organic sludges from industry, fats, potato pulp, brewery waste and vine residues, domestic and commercial bio-waste from source separated collections, energy crops like maize silage, grass silage, etc. Most of the plants are located in Germany but there are references in Japan, Canada, USA, Austria, Switzerland, Lithuania, Slovakia, USA, Italy, Ireland, Spain and in the Netherlands.

Description of a biogas plant

Biogas is produced through the anaerobic digestion of organic matter. During this process, organic components are broken down in several steps by micro-organisms with methane being one of the final products. The input material can come from agricultural waste, commercial waste or specially grown energy crops such as maize or corn. Biogas is mainly composed of methane and carbon dioxide. It can be used for

Fig. 1: General layout of a biogas plant.



energy production (electricity and heat), as fuel for transportation (vehicle fuel), for cooking and heating like any other usage of natural gas. It is also possible to operate a steam generator from biogas. The heat energy is used to heat the digester, the buildings, for hot water supply and for pasteurization as necessary.

In summary, a biogas plant consists of the following components: a reception tank, a digester, a gas holder, a gas engine, pipe work, mixers, and a storage tank (Fig. 1).

The delivered substrates are buffered in a reception tank to assure a continuous supply of substrate into the digester. From the reception tank the substrates are transferred to the digester, the most important component of a biogas plant. In the case of slaughterhouse waste, pasteurization may be necessary depending on what type of waste is being processed. The digester is a sealed tank made of concrete or steel. There are three possible types of digesters:

The horizontal 'plug-flow' digester is often used in small or medium-sized biogas plants. They are made of steel or concrete and have a volume up to 2.000 m³. This type of tank is well-suited for treatment of dung and poultry manure as there are very good mixing conditions even for solids. Grit removal is easy to accomplish.

The more common types of digesters include the upright standard agriculture digester and the upright large scale digester:

The standard digester in German biogas industry is the upright, cast in place concrete digester where the diameter is typically greater than the height (Fig. 2). The standard size of these units is between 1,000 and 2,000 m³. The height is often 6 m with a diameter between 10 and 20 m. The tanks are equipped with a heating system which circulates hot water through tubes inside the tank. The mixer is either completely submerged or equipped with a motor located outside the tank as shown in Figure 2. Larger diameter tanks are equipped with two or more mixers. Proper insulation is achieved with a layer of mineral wool held in place by an external envelope of aluminium cladding.

The top of the digester is fitted with a single or double membrane gas holder roof. The inner membrane of a double membrane gas holder roof provides the gas holding buffer while the outer membrane provides weather protection. The inner membrane is flexible in height to allow variable gas outputs, while the outer membrane is always inflated into a dome. This is achieved with a blower that maintains a constant slight positive air pressure in the space between the two membranes in a manner similar to that used to support air structures. This type of tank is well-suited for

Fig. 2: Standard digester of biogas plants used in agriculture (Volume up to 2,000 m³).

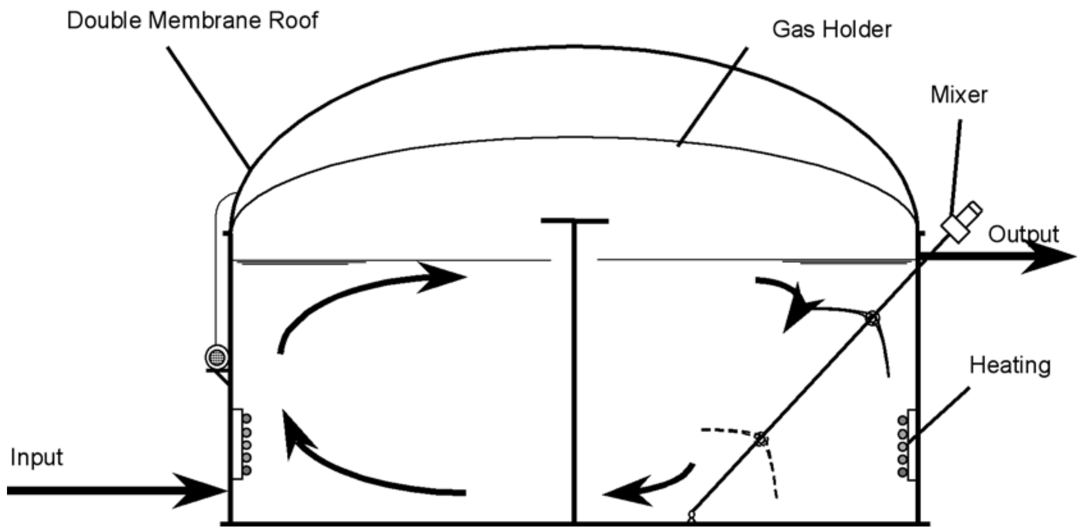
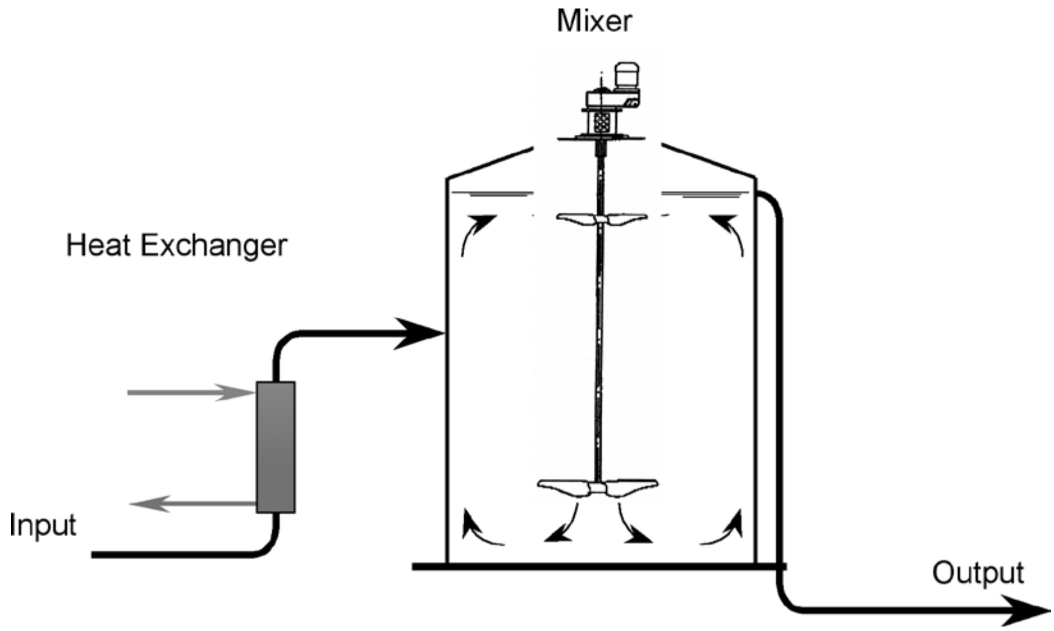


Fig. 3: Upright large digester of biogas plants for industrial use (volume up to 5,000 m³).



every kind of input substrate as long as the flow rate is low enough. The hydraulic retention time is typically between 30 and 80 days depending on the input substrate type.

For large quantities of input substrate, large upright digesters are most commonly employed. In most cases the tanks are made of glass-coated prefabricated steel plates, or less commonly concrete is used. The standard size is between 1,000 and 5,000 m³. The diameter height ration is normally 1:1. The height is often between 15 and 20 m; the diameter varies between 10 and 18 m. Mixing is achieved using a mixer centrally located on the roof, which is in continuous operation (Fig. 3). The substrate is heated by an external heat exchanger. The hydraulic retention time is generally 20 days for pure manure with longer retention times applied to most other kinds of input substrate. The digester temperature can be either mesophilic or thermophilic. Large centralized digestion plants often have two or more such tanks.

In order to increase the degradation rate, a secondary digester is often connected to the main digester in series. This can apply to all digester types. The secondary digester is usually made of concrete and has two submerged mixers. Biogas is produced in both digesters and is collected in a gas holder which can be located on top of the main digester or on top of the second digester or both.

Other than a methane content of 50 to 75%, biogas is also characterised by a moderate concentration of carbon dioxide (25 to 50%). Other gases that arise include hydrogen sulphide, molecular nitrogen, water vapour and oxygen (in total less than 2%). Depending mainly on the amount of proteins in the input substrate, hydrogen sulphide occurs in various concentrations. As hydrogen sulphide is a primary cause of corrosion in the gas engine, desulphurization is recommended. This is typically achieved by pumping small amounts of air into the gas holder. The oxygen in the air reacts with hydrogen sulphide in the biogas via a microbiological pathway resulting in the generation of benign particulate elementary sulphur that is retained in the digester. Prior to combustion of the biogas in the engine, the biogas must also be cooled to reduce its moisture content through condensation.

The engine produces both electrical and heat energy. The generated electrical power can be used locally or fed into the electricity grid. The heat can also be used locally in the slaughterhouse or other facilities. There are also gas engines available which produce steam that can be used directly in the slaughterhouse. Usually the minimum size for these engines is 1 $MW_{electric}$.

It is also possible to feed biogas to the natural gas grid if sufficiently purification of the gas can be achieved i.e. removal of carbon dioxide, water, hydrogen sulphide and others. Once this is achieved the cleaned biogas has the same fundamental characteristics of natural gas.

During the fermentation process, all nutrients are effectively conserved. The main losses are attributable to carbon metabolism to methane and carbon dioxide. This can result in a wet volume reduction of between 5 and 30%. In addition, the resultant digestate has a lower solid content and is consequently less viscous than the original material.

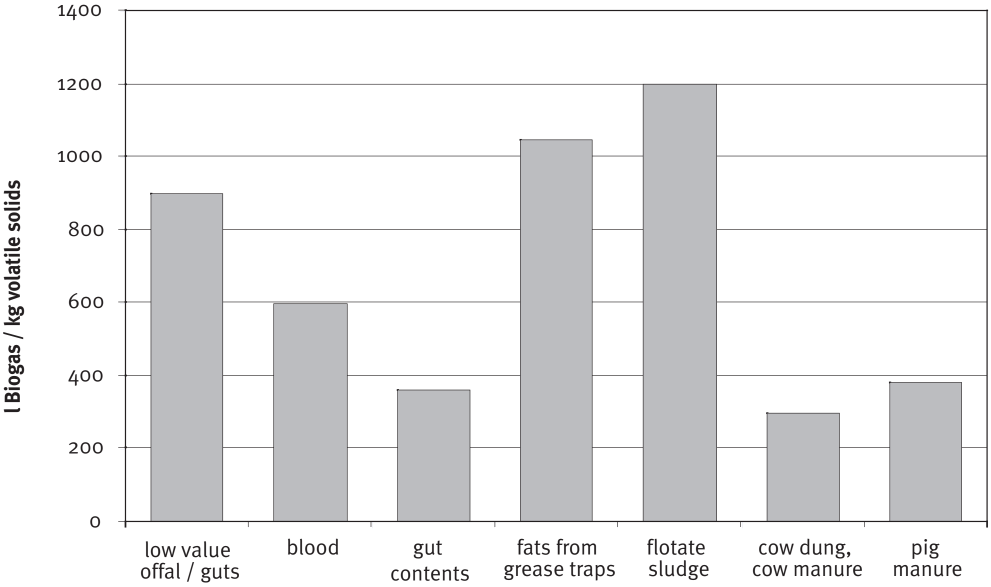
The digested substrate that consists of highly degraded organic material is collected in a storage tank. In Western Europe, a storage capacity of 6 months is usually obligatory to preclude nitrate contamination of groundwater during winter spreading. However during the growing season, field spreading of digestate is beneficial due to the high content of mineralised nutrient elements like nitrogen, phosphorus, potassium and trace elements. The digestate can be spread on land with common agricultural equipment used for manure spreading. The advantages of digestate use in agriculture include the reduction of organic matter during fermentation, high availability of nutrients and the increase in soil humus attributable to the remaining persistent fibres in the digestate. In contrast to the use of raw manure, digestate is considerable less malodorous, more homogeneous and consequently easier to spread. Specifically, nutrient recycling is assured with the consequential potential to displace mineral fertilizers.

Slaughterhouse substrate

Most organic material with an adequate water content can be fermented in a biogas plant. The exceptions are persistent materials such as lignin, chitin or keratin. The most common substrates for biogas plants are pig and cattle manure. In Germany most farm scale biogas plants use manure and silage derived from maize and corn or grass. To increase the energy yield co-ferments are added. Typical co-ferments include kitchen waste, market waste, waste fats, fats from grease traps, spice residues, residues from food industry and many similar substances. The operator of the co-fermentation biogas plant increases his income in two ways: firstly though the potential revenues derived from tip fees for the co-ferments and secondly through higher biogas production.

Slaughterhouses generate a wide range of organic residues that vary in their suitability for use as inputs to a biogas plant. Some products such as brain, eyes or spinal cords or carcasses from infected animals are categorised as high risk material. This material must be treated separately. According to European law (EU-regulation 1774 of the year 2002), this material is defined as category 1 material that has a high probability of being infected with BSE prions or other pathogens

Fig. 4: Biogas yields of different substrates (Arbi-Probag 1993, Baserga 2000, Eder and Schulze 2006, Krieg 1993)



and can only be disposed of through controlled incineration. Category 2 includes materials such as floatation sludge, fats from grease traps and also manure and gut contents. This material can be used in a biogas plant. This material must however be initially autoclaved at a particle size < 50 mm with temperatures more than 133° C and pressures > 3 bar for a period of more than 20 minutes. The principal exception to this requirement is manure and gut contents. European competent authorities have been allowed to permit the use of manure and gut contents in biogas plants without autoclaving or pasteurization.

Category 3 materials comprise parts of slaughtered animals which are fit for human consumption, domestic and commercial catering waste in addition to hides and skins, hooves and horns, pig bristles, feathers and blood. Under the 1774 regulation, category 3 materials must be reduced in size to less than 12 mm and must then be pasteurized at a temperature > 70° C for > one hour. The outputs from this process are suitable for processing in a biogas plant.

Clearly, material such as bones, bristles, feathers or hooves are only poorly degradable in a digester if at all. In contrast, other 'soft' slaughterhouse products like gut contents and low value offal are readily degradable in a digester and can generate a high biogas yield.

As to be seen in figure 4 cow manure delivers a relatively low yield of biogas of about 300 m³ per tonne of volatile solids. The biogas yield of pig manure and gut contents is somewhat higher. The highest biogas yield is achieved by all kinds of fat (Schulze and Eder 2006). The use of gut contents, guts, blood and fats as a substrate mixture was investigated in laboratory experiments (Wellinger et al. 1998). This showed that these substrates are readily fermentable. In batch experiments, a very good yield of 710 litres biogas kg^{-1} volatile solids was recorded. The methane content was 420 litres CH_4 kg^{-1} volatile solids. A cubic meter of these mixed substrates was found to generate approximately 80 m³ of methane, which is equivalent to 80 litres of mineral oil. In this study, Wellinger et al. (1998) listed the following basic conditions for the fermentation of slaughterhouse substrates:

Organic loading rate	≤ 3.2 kg VS m^{-3} d^{-1}
Retention time	≥ 15 days
Ammonium concentration	≤ 3.0 kg m^{-3}
Methane concentration	approx. 65%

The organic loading rate of a biogas plant is defined as the daily input of substrate (volatile solids) per digester volume. If the organic loading rate is too high, there is a great risk of a process breakdown due to overloading. The retention time is also an important variable and this gives a mean value for the duration that a particle stays in the digester prior to discharge. Ammonia toxicity is also a factor to be considered. Ammonium is a degradation product of proteins and dissociates to unionised ammonia which is toxic in higher concentrations. If the ammonia concentration is too high, substrates with a higher C/N ratio (lower nitrogen content) should be added to dilute the concentration. The methane concentration in the biogas depends on the characteristics of the input materials and the fermentation quality.

A mono-fermentation of gut contents and low value offal is possible. Other substrates may be added to increase the yield of the biogas plant. This could be manure, but other waste products from the slaughterhouse like fats, blood or floatation sludge from waste water can also be added. Currently there are no biogas plants exclusively digesting slaughterhouse waste. Slaughterhouse waste and similar substrates are however currently used as co-ferments together with manure at a number of facilities. Specifically, there is no fundamental biological or technical impediment against mono-fermentation in principle. Substrates should be trialled in a continuous laboratory test in advance to determine digestibility, biogas production and to identify whether the substrate causes an inhibition of the biological process.

Examples of two different biogas plants using substrates similar to slaughterhouse waste

In the absence of biogas plants that exclusively process slaughterhouse waste, two biogas plants developed by Krieg and Fischer that use slaughterhouse products as co-ferments or substrates similar to slaughterhouse waste are described.

The im Brahm biogas plant is located in Essen, a densely populated area in the West of Germany. It is a medium size biogas plant with an electric capacity of 380 kW. The digester is an upright standard digester constructed from concrete with side mounted mixers. The digester, on the right (Fig. 5) is followed by a second digester (left) and two storage tanks. The input substrates are manure, kitchen waste and fats from grease traps. The kitchen waste and the fats are treated in a pasteurization tank in the reception hall.

Fig. 5: The Im Brahm Biogas plant

The second biogas plant is Werlte located near Hamburg. This biogas plant is an industrial size facility with an electrical capacity of 2.6 MW (Fig 6). The two digesters are upright large steel digesters. The digesters are followed by two second digesters and two storage tanks. Two pasteurization tanks are in alternate use to pasteurize the input substrates which include manure, fats and residues from rendering plants.

A comparison of both biogas plants is shown in Tab. 1.

Fig. 6: Biogas plant Werlte as a big centralized biogas plant

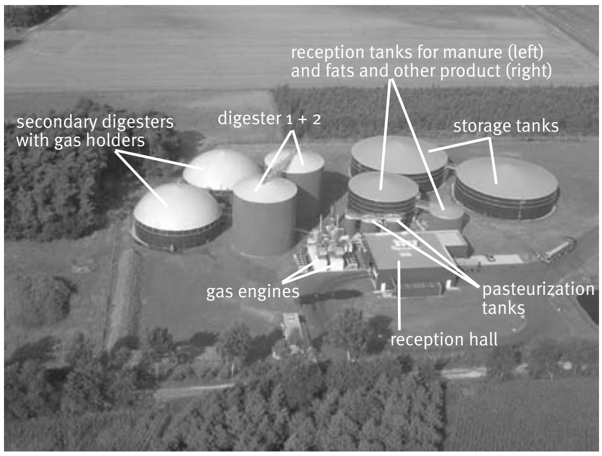


Table 1. Comparison of two biogas plants

	Biogas plant IM BRAHM	Biogas plant WERLTE
Location	Essen, Germany 150 m distance to a residential area and adjacent to a water protection area (WSG II)	Werlte, Germany in a water protection area (WSG III)
Construction period	2005	2002/2003
Planned input	6,250 t/a	110,000 t/a
Input material	manure (2,555 t/a) horse dung (2,750 t/a) kitchen waste, fats (8,395 t/a) total: 13,700 t/a	manure (41,000 t/a) cosubstrates (33,000 t/a) as: fats, kitchen waste, gastrointestinal-tracts and content and blood total: 74,000 t/a
Co-Generator	gas engine (2 x 190 kW) containerized	gas engine (2 x 1,262 kW) containerized
Heat usage	pasteurization, farm buildings	pasteurization
Temperature	mesophilic	mesophilic
Digester heating mixing operation	1 concrete tank (1,205 m³) internal pipe heating system side mounted agitator unit (2 x 11 kW) 2-stage digestion	2 steel tanks (2 x 3,200 m³) external heat exchanger top-mounted mixer (2 x 11 kW) 1-stage digestion
Investment	Euro 1 Million	Euro 6 Million
Delivery	reception hall with biofilter	reception hall with biofilter
Pre-treatment	grinding and full stream pasteurization (70° C, 1 h)	grinding and full stream pasteurization (70° C, 1 h)
Solid input device	for horse dung	-
receipts	50 Euro/t (average)	5 Euro/t
Necessary expert's reports	odor emissions noise	odor emissions noise

Summary

Slaughterhouse waste can be readily digested in a biogas plant as a co-ferment. In the case of mono-fermentation, specific substrates should be tested in continuous laboratory trials in advance. In summary, a biogas plant is an efficient solution for the processing of slaughterhouse waste given the hygienic degradation of the waste in the digester. Moreover, compared with other disposal methods like burning or composting, biogas has the added benefit of generating excess energy from the process.

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