

Anaerobic Digestion: Products

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Draft

Biogas

What is biogas?

Biogas is the mixture of gases produced by the microbial communities within anaerobic digesters, and usually consists of 50-80% methane, 20-50% carbon dioxide, around 1% water vapor, and trace levels of other gases such as hydrogen sulfide, hydrogen, and ammonia. These basic constituents can be found in biogas samples taken from almost any digester.

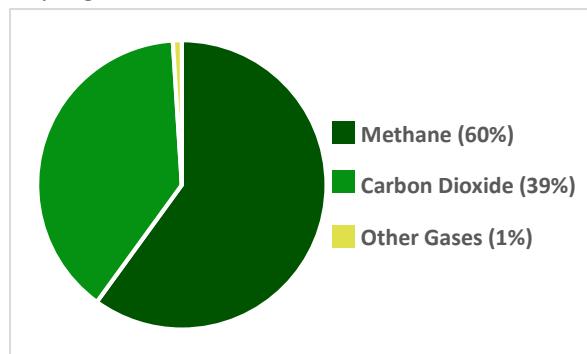


Figure 1. Average biogas composition. (Diagram credit: Cannington Bio Energy)

Because methane – the primary ingredient in natural gas – is the main energy-containing constituent, the energy content of biogas is directly related to the amount of methane it contains¹⁻³. You will often see references indicating a specific energy content for biogas; this is always based on a theoretical methane content (Table 1). In reality, the energy content of biogas will vary according to the proportion of methane it contains, but will

never be greater than 1,000 BTU per cubic foot – the amount of energy contained in one cubic foot of pure methane.

How is it created?

Biogas is produced from the microbial breakdown of organic matter in an oxygen-free environment, but no single type of microbe is solely responsible for the process. Instead, a community of microbial organisms break down the organic material in a cascading food chain known as methane fermentation – one microbe’s waste becoming another’s food source. Ultimately, a group of microbes called methanogens use acetate or hydrogen and carbon dioxide to form methane gas and carbon dioxide – the mixture we term “biogas”⁴.

Depending on the feedstock being added to the digester, additional gases may be generated in proportionally small amounts. These gases are generally harmless, but in some instances they may be problematic (for instance, hydrogen sulfide has been cited as a leading contributor to generator system failures^{5,6}). Because the type of gases being produced is largely dependent on the feedstock being used, care should be taken to investigate and characterize all new materials being fed into a digester.

Predicting Production

Since biogas production results from the microbial degradation of organic matter, tests measuring the concentration of organics in waste streams can be correlated to potential biogas production. The following methods to predict biogas production are mentioned frequently in anaerobic digestion papers and discussions:

Chemical oxygen demand (COD): COD testing relies on harsh chemicals to oxidize waste, providing an indicator of how much oxidizable, or energy-containing, material a waste sample contains⁷. Results are generally given on a weight per volume basis, and this information is used to forecast biogas production. Theoretically, 5.60 cubic feet of methane can be produced from every pound of COD in a waste sample⁸, although actual production will depend on the amount of COD “converted” to biogas during digestion (Table 1).

Volatile Solids (VS): Volatile Solids (VS) testing provides a proxy for the amount of biologically available carbon in organic wastes by measuring the amount of combustible matter present in a given sample. VS tests are conducted by establishing a dry weight for a waste sample – referred to as its total solids (TS) content – and then combusting the sample at high temperatures⁹. The amount of the sample that is burned off represents the volatile solids (VS) content which, in turn, can provide some idea of potential biogas production. Depending on the waste, 12.0 to 18.0 cubic feet of biogas is

typically produced per pound of VS destroyed – or around 7.80 to 11.7 cubic feet of methane per pound VS destroyed¹⁰.

Biomethane potential (BMP): BMP testing is another common method used to test the biogas and methane production capacity of a given waste. Samples of the waste stream are collected, mixed with liquid from an operating digester (termed inoculum), and mixed and heated under ideal conditions for up to thirty days¹². The amount of biogas produced from this test, and the proportion of methane it contains, provides valuable information on the biogas production potential of the waste stream to be digested.

Things to keep in mind: Although COD, VS, and BMP tests all provide useful information, they should be used with care. COD and VS tests are meant to quantify the amount of biodegradable materials potentially available to the microbes in an anaerobic digestion system, but they cannot provide information on the amount of waste that the microbes will actually consume. This information can be gathered with the help of BMP testing. BMP tests, for their part, tend to overestimate the amount of biogas produced by an organic waste, although methane production potential is generally fairly accurate¹².

To calculate Biogas/animal/day in Table 1 Methane/lb COD (ft³) is 6.3 and % Methane is 65 for all animal types.

Table 1. Estimated average biogas production for various livestock. Assuming the following weights Dairy: 1,400 lbs, Beef: 1,000 lbs, Swine: 160 lbs, Poultry 3 lbs. (Credit: NRCS)^{11,32}.

Animal Type	Animal Units (1,000 lb)	COD (lb/AU/day)	VS (lb/AU/day)	% Manure Collected	% COD Conversion	Biogas/animal/day (ft ³)
Dairy	1.4	18.0	17.0	90	30	65.9
Beef	1.0	5.2	32.3	90	30	13.6
Swine	0.16	6.1	0.05	100	60	5.6
Poultry	0.00	13.7	0.693	100	70	0.3

Common Uses

Heating and Steam: This is perhaps one of the simplest uses of biogas. In the absence of any type of upgrading (i.e. removal of carbon dioxide), one cubic foot of biogas can provide enough energy to heat one-half gallon of water. Many farms harness this potential by diverting biogas to boilers, where the resulting hot water and steam are used for sanitary cleaning and heating in milking parlors, farm facilities, or even residence. In addition, biogas-heated water can be used to maintain the operating temperature in the anaerobic digester, keeping the microbial population warm and active^{5,6,13}. The use of traditional boilers or furnaces may require farmers to adapt these systems for use with biogas. Because biogas has a lower energy value than natural gas or propane, burner outlet sizes may need to be increased to accommodate biogas flows.



Figure 3. Biogas flame. (Photo credit: Steven Depolo)

Additionally, biogas may be directly combusted to generate steam, which can be used in adsorption-based refrigeration systems or for electricity generation. The latter is most often used in connection with a combined heat and power (CHP) co-generation system, where exhaust heat is used to boil water to power a steam turbine.

It is important to keep in mind that many farm-related heating requirements may only be needed for part of the year, while biogas is produced year-

round. For that reason, the use of biogas for heating alone should be carefully considered to ensure that it is the best all-around use of the available resource.



Figure 4. A biogas-powered electric/heat co-generator. (Photo credit: Joseph Farms)

Electricity Generation: In the United States, electricity generation is the most common use of biogas produced from farm-based anaerobic digesters¹⁴. In order to generate electricity from biogas, a number of considerations must be made; first and foremost amongst them is cost. The NRCS surveyed thirty-eight dairy farms with an average herd size of 1,284 cows and found that, on average, electricity generation – including all machinery, biogas scrubbing, flares, on-farm wiring, and operation and maintenance – constituted about 36% of total capital costs for the digestion system¹¹. They also found that these costs did not necessarily drop with decreasing farm size or digester complexity. For instance, installing electric generation systems on the least expensive digestion systems – covered lagoons – required more capital as a percentage of the total, indicating relatively fixed costs for generators and maintenance.

A second consideration is the projected value of the electricity that will be produced. Based on data derived from surveys of New York and Wisconsin farms, dairies averaging 1,290 cows and operating solely on cow manure produced 3.12 kWh of

electricity per cow, per day; other reports place the figure between 2 and 5.5 kWh^{6,13,15,16}. These numbers are dependent upon the type of the generator used, the energy content of the waste stream, and the efficiency of the anaerobic digester, amongst others, so the expected production varies. When combined with information on local electric rates and farm usage, it may lend insight into the decision whether or not to generate electricity.

Many farmers opt to purchase combined heat and power (CHP) systems to increase the efficiency of biogas use¹⁷. These systems are designed to generate electricity using biogas and capture the heated exhaust for further use in hot-water heating, digester heating, etc. The use of CHP co-generators can push the biogas-to-energy efficiency as high as 80%^{5,18}.

Engine Fuel: The use of biogas as an engine fuel is most common in Northern Europe and Scandinavia, although some sectors in the United States are beginning to explore this option, as well¹⁷. Using biogas for engine fuel is a cleaner, lower-maintenance alternative to gasoline and diesel, but the biogas cannot be used for this purpose without extensive scrubbing to remove carbon dioxide, hydrogen sulfide, water vapor, siloxanes, and other impurities that would otherwise corrode the engine^{17,19,20}. In a Wisconsin trial creating biogas for vehicle use, biogas was scrubbed to 94-98% methane, 0.5 – 2% carbon dioxide, and undetectable levels of hydrogen sulfide and siloxanes. European standards for biogas fuel use are similar^{17,19}.

Additional equipment and infrastructure requirements for converting biogas to engine fuel on farms include gas conveyance lines, professional-grade gas scrubbers, monitoring ports for periodic gas sampling, and a compressor unit and pressure regulators for gas packaging. Depending on the

purity of the product, a gas-odorizing unit may also be required²¹.



Figure 5. Biogas powered tractor. (Photo credit – AGCO)

Natural Gas: Large-scale anaerobic digestion facilities are increasingly considering the possibility of upgrading their biogas to natural gas pipeline standards for resale to the grid. Purity requirements vary depending on the utility, but in general, biogas is required to be scrubbed to standards equaling or surpassing those required for use as engine fuel – i.e. 95% methane with undetectable levels of impurities. Equipment requirements include gas conveyance lines, professional-grade gas scrubbers, monitoring ports for periodic gas sampling, a compressor unit and pressure regulators for injecting gas into the grid, a flow meter, flow computer, gas quality sensor or specific gravity meter, and an odorizing unit.

Lighting: Although rarely used in the United States and Europe, the direct use of biogas for lighting is a viable possibility, especially for small-scale biogas operations. Gas lamps can be retrofitted or specially purchased to run on biogas, and reports have indicated that 1 m³ of biogas can provide 40-60 W-equivalent light for up to six hours^{22,23}.



Figure 6. Biogas lamp. (Photo credit - Stockholm International Water Institute)

Impurities and Scrubbing

Hydrogen Sulfide (H_2S): During the anaerobic digestion process, sulfur present in the waste stream and in the microbial population can be converted into hydrogen sulfide gas^{17,19}, a poisonous and highly corrosive substance that can wreak havoc on metal components, especially boilers and engines.



Figure 7. Boiler corroded by H_2S . (Photo credit: A.G. Vedenev)

When H_2S is mixed with water vapor and/or combusted, it can form sulfuric acid, a very corrosive chemical to metals. Corrosion of engines and boilers caused by excess hydrogen sulfide in biogas is one of the most commonly cited concern and failure in agricultural anaerobic digestion systems^{5,6}. As a result, hydrogen sulfide scrubbing

is generally recommended for all uses, and regular checks and maintenance of engines – including regular oil changes – should be anticipated²⁴.

There are a number of products that are regularly marketed and used to remove H_2S from biogas, and nearly all rely on one or more of the same basic components: iron oxides (e.g. iron filings), zinc oxides, bacteria, alkaline solids or liquids (e.g. hydrated lime), silicate adsorbents, amine solutions, and water²⁵. These systems vary in their cost and complexity, primarily due to the desired purity of biogas.

Carbon Dioxide (CO_2): Carbon dioxide is the second largest constituent of biogas, but has no useful energetic value to farmers. Especially when attempting to use biogas as a vehicle fuel or when upgrading the gas to sell to natural gas utilities, carbon dioxide must be thoroughly removed to provide a purer methane product. To do this, a number of designs and materials can be used, including water, polyethylene glycol, and a variety of different membranes and pressure differentials²⁰.

Water: Water can constitute between 0.8% and 1.6% of biogas by weight²⁶, depending on its temperature, and creates the risk of corrosion and freeze damage in gas lines and machinery over time. A simple condensation trap, designed to collect water that has condensed in the relatively cool piping leading away from a digester, is often enough to eliminate any problematic issues.

Siloxanes: If considering co-digestion with municipal waste-activated sewage sludge, attention should be paid to the potential presence of silicon-containing compounds often present in the waste in the form of residues from detergents, personal hygiene products, cosmetics, etc. During the digestion process, these compounds can be converted into siloxane – a gaseous compound that is converted into abrasive silica crystals during

combustion and proceeds to wear away, and eventually destroy, engines and machinery²⁷. Most processes used to remove siloxanes from biogas rely on activated carbon to adsorb the chemical²⁷.

To maximize the lifetime of the system and protect the economic investment, biogas should be scrubbed of these impurities before being diverted to an electric generator or combined heat and power system.

Separated Solids and Bedding

In many digestion systems, manure solids are separated post-digestion (to minimize solids settling in lagoons and provide extra nutrients for digestion). Solids separated post-digestion may be composted to create animal bedding material or a soil amendment for crops.



Figure 8. Separated solids for bedding. (Photo credit: Bauer and Fan Separator North America)

Most farms in the United States separate manure solids post-digestion. This material is very often used directly as bedding, especially in thermophilic digestion system (130°F), where pathogen destruction is highest. It should be noted that there are reports of both increased⁶ and decreased⁵ incidences of mastitis on dairy farms using separated solids for bedding, so the decision regarding the end-use of solids should be made after consultation with vets and anaerobic digestion experts.

Nutrients

There is a common misconception that nutrient quantities are reduced during the anaerobic digestion process; they are not. Although some nutrients may settle out with solids eventually all nitrogen and phosphorous that enter an anaerobic digester also exit^{26,28}. Of particular importance is nitrogen, which is converted in large quantities to ammonium, a readily plant-available compound. Ammonium is also highly volatile; meaning that it can transition to ammonia gas and escape with ease, especially given warm temperatures and windy conditions²⁹. Total nitrogen losses from field applied manure via ammonia volatilization are often as high as 70%³⁰. The volatilization of ammonia is significantly reduced in the anaerobic digestion effluent because it is incorporated into the soil quicker³¹.

Most farm operations separate solids from the waste stream leaving their digester, which provides farmers with an easily applied liquid fertilizer. This fertilizer differs from traditional land-applied manure in several ways. Odor is drastically reduced, which many farmers cite as reason enough to install an anaerobic digester and nitrogen, phosphorous, and potassium transition from organic to inorganic forms during digestion^{5,6,13,26,28}.

More Information:

More information can be found by contacting your local agricultural extension agent or by visiting the Cooperative Extension System website at www.extension.umd.org.

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