Living Web Farms

# Small Scale Biogas Digesters

### What this workshop is about

• Using kitchen and garden wastes and manures to produce a burnable gas and a liquid fertilizer

• Understanding the process of anaerobic digestion and how anaerobic bacteria work

• Examining best practices in the production and use of home-generated biogas

• Evaluating appropriate materials for building an anaerobic digester

• Understanding the expectations and limitations of small scale biogas digesters

### What is anaerobic digestion?

The natural decomposition of organic material in the absence of oxygen, abbreviated as AD

The process occurs in Four stages:

1. Hydrolysis—breaks down complex matter, such as carbohydrates and proteins, into sugars and amino acids. The long-chain chemical compounds are reduced to single molecules

2. Acidogenesis—breaks down single molecules of sugar and amino acids into ethanol and fatty acids, while producing carbon dioxide and hydrogen sulfide as by-products

3. Acetogenesis--ethanol and fatty acids are converted into hydrogen, carbon dioxide, and acetic acid

4. Methanogenesis—the microorganisms convert the remaining hydrogen and acetic acid into methane and more carbon dioxide

Composition of the gas varies from 55-65 percent methane; 30-45 percent $CO_2$; with traces hydrogen sulfide, nitrogen, hydrogen, and water vapor

### What benefits exist in processing waste like this?

• Carbon accumulation and leaching of nitrogen and phosphorous in conventional manure has negative environmental impacts. Extracting methane from the waste and using it to produce heat and electricity means that the waste does not degrade in the environment and cause direct methane atmospheric emissions.

• After enteric methane ($CH_4$) --which is produced in rumens by microbial fermentation-- manure represents the second largest source of greenhouse gas emissions in intensive dairy cattle and buffalo farms. Methane is 30 times more potent as a heat-trapping gas than $CO_2$ is.

• Volatilized ammonia from manure can remain residual in water and land ecosystems or be converted into nitrous oxide emissions, contributing to both water eutrophication and climate change.

• The energy provided by the biogas can replace its share of fossil fuel which is the main contributor to greenhouse gas emissions. In addition, anerobic digestion may be a supplementary source of income for farmers through renewable energy production and the residual liquid fertilizer. Biogas energy is considered carbon neutral, since carbon emitted by its combustion comes from carbon fixed by plants in the natural carbon cycle.

**How much energy is in biogas?**

• The major component of biogas is methane, up to 65 percent. Natural gas has a methane content of about 90 percent, so biogas contains 25 percent less energy but it is renewable.

• There are 600 Btu's in each cubic foot of biogas. Each cubic meter (35 cu. Ft.) of biogas contains the equivalent of 6 kWh of heat energy or 21,000 Btu's

• 2 kWh is enough energy to power a 100 Watt light bulb for 20 hours or a 2000 Watt hair dryer for 1 hour

• Cookstove burners use about 5-15 cu.ft. per hour depending on size. Gas lamps will burn about 4 cu.ft. per hour.

• Biogas can be used as cooking fuel, and for lighting, space and water heating, crop drying, refrigeration, and generation of electricity, depend on the scale of digester.

**What happens to the waste after digestion?**

• The amount of waste going into the digester is almost equal to the amount coming out. But the quality of the waste is improved with less odor and a higher quality fertilizer because the nitrogen in the effluent is more readily absorbed by plants than the nitrogen in raw manure.

• Waste from the digester can be separated between solids and liquid. The solid part can be composted and the liquid part can be used as liquid fertilizer.

• The nutrient component of what goes into the digester remains almost complete in the effluent

• Most disease vectors are destroyed in the completed anaerobic digestion process

• Digesting manures provides odor and insect control

**What conditions affect anaerobic digestion?**

- Heat
- pH balance
- Carbon to Nitrogen ratio of feedstock input
- Anaerobic digestion can be carried out under mesophilic (about 95 F), thermophilic (about 130 F) or even psychrophilic (below 68 F) conditions in engineered systems. The reaction temperature affects biogas production and the overall efficiency. The duration of the process, in retention time, is 15–50 days in mesophilic conditions, 14–16 days in thermophilic conditions. The mesophilic process is the simplest to control, and ideal temperature is about 95 to 98 F.
- Desirable pH values are above 6.6 and ideally 7.0 to 7.5. Digestion problems usually result in a drop in pH where the system goes "sour" or acetic. Corrections can be made with sodium bicarbonate (baking soda) or sodium carbonate (washing soda). Lowering pH if needed can be accomplished with lactic or citric acid.
- As the C/N ratio is increased, methane potential will initially increase and then decline. C/N ratios between 25:1 and 30:1 have the best digestion performance, with a stable pH and low concentrations of total ammonium nitrogen and free ammonia.
- Retention time, system pressure, and feedstock loading rates also affect the digestion process.

**What are suitable feedstock materials for a biogas generator?**

- Suitability of a substrate or feedstock for anerobic digestion depends on the levels of total solids (TS) and volatile solids (VS), the carbon to nitrogen ratio (C/N) and pH value. Livestock manure is usually in a liquid form with a dry matter content (DM) of less than 10%.
- Too much dilution of manure reduces the systems feasibility in a farm setting, and too high a DM will cause operating problems. Co-digestion with other solid organic feedstocks can reduce DM levels.
- Animal manure biogas yields, greatest to lowest:

1. Poultry (limited)
2. Swine
3. Cow
4. Horse
5. Rabbit
6. Goat
7. Buffalo
8. Sheep

- Our small 300-gallon system can take up to 2 gallons of food waste and 4-5 gallons of manure per day, mixed thoroughly with water in a 50/50 slurry.

- Food waste and garden culls including vegetables, dairy products, meats, fats, bones, seeds and egg shells. Molded and rotten foods will not affect the digestion process.

• Animal manures, especially from ruminants such as cows, buffalo, goats, and sheep, are fine. It should be free of stones, straw, and soil, which will not break down in the digester. Clean dog or cat waste  can be used as well.

• What to avoid:

Excessive quantities of citrus fruit (orange, grapefruit, lemon) peels; they contain anti-bacterial oil.

Cardboard, sheet paper, feathers, fur, coffee grounds, bleach, clippings, sawdust,  wood chips, straw, hair, soil, sand, digestible biobags, and shells.

• What to limit:

Chicken droppings, which contain a high level of ammonia and alter the pH balance. 25% to 50% at most

Fats, oils, and cooking grease, up to 25-30%
Citrus fruit and no more than 2 citrus fruit peels a day
Roots and stalks
Toilet and tissue papers

• How quickly food products break down and convert into biogas depends on factors such as the waste profile and ambient temperatures. Different foods have different amounts of energy that become available when the food is digested either by your body or within a biodigester.

• Food waste has a higher energy potential because it has not yet been digested by the stomach of an animal. For food waste, fats, oils, and greases are especially productive, though not in large quantities. A feedstock high in calories, fat, starch, and sugar usually produces more biogas than other foods.

• High biogas yields include bread, corn, tomatoes, and peas

• Lower biogas yields include fish, poultry, and spinach

**Maintaining a balance in the system**

Just as in composting, it's important to maintain a good Carbon/Nitrogen (C/N) ratio in the slurry. This is the balance between carbonaceous materials and nitrogen-rich materials used to feed the digester.

Calculating the C/N ratio

Though the biogas digestion process relies on a balance of carbon to nitrogen in the substrate, manures for the most part are already in the desirable range and you'll only be adding supplemental food and garden wastes (along with manure) to maintain gas production.

The 300 gallon digester can take up to 2 gallons of suitable food waste per day and up to 5 gallons of manure slurry. But additional materials such as vegetable stalks, straw and sawdust that may be mixed in with manure, leaf residue, shells, tissue, and other items that find their way into the slurry will affect the C/N ratio.

If you want to do rough calculations, refer to the C/N Ratio chart to find the approximate value of each feedstock component and then go through the four steps below. This is especially helpful if you have fairly a consistent food input supply.

*Step One:* Weigh each material; the input is measured by weight, not volume
*Step Two:* Calculate the total carbon value by multiplying the percent of carbon in each ingredient by its weight value. Add up the carbon totals for all the ingredients
*Step Three:* Calculate the total nitrogen vale by multiplying the percent of nitrogen in each ingredient by its weight value. Add up the nitrogen totals for all the ingredients.
*Step Four:* Determine the C/N ratio by dividing the carbon total by the nitrogen total. The result should be between 25:1 and 30:1. If the ratio is higher or lower than that, you can adjust the proportions of ingredients to bring it into the correct range.

For example, we'll use 1 lb. of horse manure, 1/2 lb. of kitchen waste, and 1/2 lb. of fruit waste:
<u>Carbon values</u>
1 lb. of horse manure at 25% C = 0.25 lbs. C
1/2 lb of kitchen waste at 15% C = 0.075 lbs. C
1/2 lb. of fruit waste at 40% C = 0.20 lb. C
Total carbon = 0.525 lb.
<u>Nitrogen values</u>
1 lb. of horse manure at 1% N = 0.01 lbs. N
1/2 lb of kitchen waste at 1% N = 0.005 lbs. N
1/2 lb. of fruit waste at 1% N = 0.005 lb. N
Total nitrogen = 0.02 lb.

So 0.525 divided by 0.02 = 26.25 parts carbon to 1 part nitrogen

**C/N Ratio for range of food, manures, and yard materials (calculated by percentage)**

| Material | C/N |
|---|---|
| Fish scraps | 5:1 |
| Horse manure | 25:1 |
| Pig manure | 6:1 |
| Chicken manure (laying hens) | 6:1 |
| Chicken manure (aged) | 7:1 |
| Cow manure | 20:1 |
| Poultry manure | 10:1 |
| Sheep manure | 20:1 |
| Horse manure with straw | 60:1 |
| Llama manure | 20:1 |
| Seaweed | 19:1 |
| Vegetable trimmings | 12-25:1 |
| Food scraps | 17:1 |
| Kitchen Waste | 15:1 |
| Hair/fur | 10:1 |
| Fresh grass | 17:1 |
| Coffee grounds | 20-25:1 |
| Alfalfa | 12:1 |
| Fruit Waste | 25-40 :1 |
| Fresh weeds | 20:1 |
| General Garden Waste | 30-40:1 |
| Clover | 23:1 |
| Ugandian Banana skins) | 30:1 |
| Sawdust | 500:1 |
| Straw | 90:1 |
| Tissue paper | 70:1 |
| Corn stalk | 60:1 |
| Cardboard | 378:1 |
| Nut Shells | 35:1 |
| Fresh Leaves | 37:1 |
| Mushroom Compost | 40:1 |
| Newspaper | 50-200:1, 54:1 |

**Biogas storage and burner hardware**

• Biogas is difficult to store, compress, or liquefy, especially on a small scale. To be liquefied, methane requires a temperature of −117°F at a pressure of 5,000 psi. On the scale we can work with, storage is accomplished in rubber or PVC bladders, or in plastic or mild steel tanks at very low pressure

• Burners and Lighting: Cooktop gas burners and propane gas lamps can be converted to use biogas. Depending on the hardware, pressure regulators can be removed from burners or gas orifices increased by 35% total area to use biogas. The single burner used here is rated at 6000 Btu/hr.

• Internal combustion engines: If biogas is used to fuel an engine, it should be stationary, close to the digester, and operating regularly. The engine's cooling water can be used to heat the digester to increase the system's efficiency. A gaseous-fuel delivery system must be installed to make the conversion, as in LP-powered vehicles. The energy in 200 cubic feet of biogas equals the energy in 1 gallon of gasoline.

• The pressure within the system is 4 inches water column or 0.15 psi; The system will operate below 3 inches wc but pressure above 6 wc slows bacteria activity. One psi equals 28 inches water column.

• Hydrogen sulfide and moisture: Techniques for removing H2S include the use of activated carbon, alkaline solution, or the use of zinc or ferrous oxides. Iron oxide pellets or iron filings will remove H2S and silica beads will remove water vapor. Carbon dioxide can be reduced in the gas by passing it through caustic soda.

• High water content (low solids) in the digester can help increase CH4 content.

**Design and building**

• Masonry block, brick, concrete: Masonry and concrete construction is the traditional method, especially in below-ground builds. The inner walls can be sealed with a surface bond or sealer to maintain water retention

• Tanks: ABS plastic, fiberglass, mild steel, and tote-style storage tanks have all been used in small scale systems. Steel will corrode over time due to the presence of hydrogen sulfide in the biogas

• Bladder material: PVC/TPU coated fabric, thickness range 0.80mm-1.80mm
EPDM Rubber sheet 2.0mm

• In self-built systems, it’s important that inlets and outlets are water-sealed and there is a provision for solids cleanout. Some method for collection of gas and pressure control has to be included. Larger system may need agitation.

• Tanks and chambers can be vertical or horizontal and do not have to be in-ground. Insulation is critical above ground in almost all climates to reduce the amount of heat input needed.

**The Seven S's of Digester Design**

From Micro-Scale Biogas Production, NSAIS

1. Substrate: The organic material that you will be feeding your digester. This can be manure, plant waste, pulp, or other biodegradable material.

2. Slurry: The slurry is the homogeneous mush that you will be passing through the digester. In order for efficient digestion to take place, the substrate material should be mashed or ground and mixed with water to make a uniform substance with 15–40% solids, depending on your digester design.

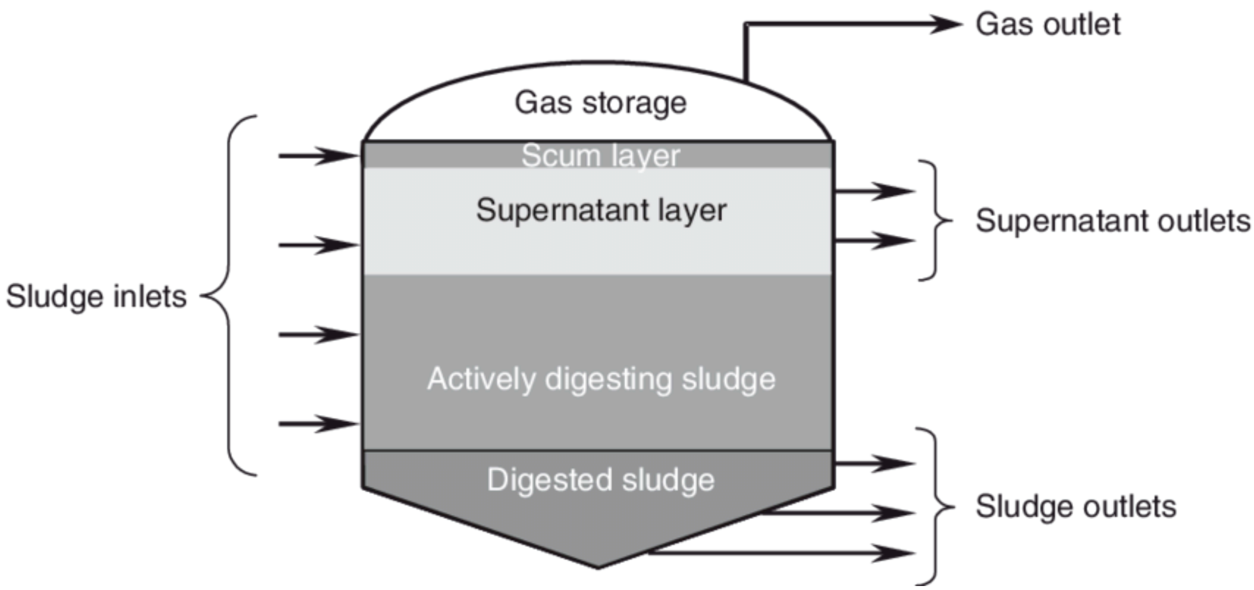
3. Stratification: As your slurry breaks down in the digester, it will separate into layers. These layers—or "strata"—are biogas, scum, supernatant, sludge and solids. Mixing of the slurry prevents excessive stratification, but some stratification will always occur, especially in "batch" digesters (Micro-digester Designs: Global D.I.Y. Technology).

4. Scum: The scum layer floats on the top of the material in the digester, just below the gas level. The scum level is formed by hard-to-digest material like coarse straw and grease.

5. Supernatant: The spent liquid of the slurry. The Supernatant has a high content of solids, making it of high value as fertilizer, similar to "compost tea."(Diver, 2002)

6. Sludge: Below the liquid supernatant is the sludge layer. The sludge is the digested and semi-digested organic solids. This sludge can provide excellent composted fertilizer, but depending on the feedstock, it may need to be dried in the sun to kill any surviving pathogens. This is more of an issue with manure-based systems.

7. (Inorganic) Solids or Sand: The bottom layer consists of those non-digestible solids that find their way into the digester. These could include dirt, sand, small rocks, plastic or metal—any inorganic solid that may inadvertently be introduced into the system.



**Understanding output: Btu's, cubic feet, and more**

• Every kilogram (2.2 lbs.) of food waste produces approximately 7 cubic feet (200 liters) of gas which is equivalent to 1 hour of cooking on a high flame. Stove cooking time may be up to 2 hours per day with the storage provided in this system

• Daily gas / energy output:
700 Liters of gas = 3850 calories = 4.4 kwh = 15.4 mega-joules or 14,600 Btu
• Lamps require 4-5 cu.ft. per hour to burn. Burners require 5-15 cu.ft. per hour to burn

• A well designed system can produce 1 cu.ft. per day of gas per 1 cu.ft. of volume in the digester.

• 700 liters of biogas is about 24 cubic feet in the storage bag of this system

• There are 600 Btu's per cubic foot of biogas

• The aquarium heater used in the colder season consumes 300 watts, or 1,024 Btu/hr. It takes about 46 hours to raise the temperature of the digester tank from 65 F to 80 F. The greenhouse enclosure and insulated floor are key to maintaining heat.

**Important safety considerations**

• Methane content of the biogas will fluctuate according to digester conditions. Biogas contains traces of hydrogen sulfide which is highly corrosive, but can be removed by filtering the gas through steel wool or iron filings.

• Condensation traps in the gas lines are necessary to prevent water from blocking the low points in the lines, especially in cold climates.

• Methane is odorless, colorless, and lighter than air so it is difficult to detect

• Methane is flammable and is an asphyxiant, and can explode at higher concentrations, similar to natural gas or propane

**Resources**

Recent Updates on the Use of Agro-Food Wastes for Biogas Production

https://www.mdpi.com/2076-3417/9/6/1217/pdf

Biogas From Manure

https://extension.psu.edu/biogas-from-manure

Micro-Scale Biogas Production: A beginner's guide; National Sustainable Agriculture Information Service

https://www.build-a-biogas-plant.com/PDF/Micro-Scale%20Biogas%20Production.pdf

The Complete Biogas Handbook by David William House; House Press 2006; ISBN: 978-0915238477

The Biogas Handbook: Science, Production and Applications

Edited by Arthur Wellinger, Jerry D. Murphy and David Baxter; Woodhead Publishing 2013; ASIN: B00H1YWKBK

Three Cubic Meter Biogas Plant: A Construction Manual; A VITA Publication ISBN 0-86619-069-4

https://www.builditsolar.com/Projects/BioFuel/VITABIOGAS3M.HTM

HomeBiogas

homebiogas.com

Dragon Husbandry for Regenerative Agriculture (Bob Hamburg)

dragonhusbandry.com

The Biogas/Biofertilizer Business Handbook by Michael Arnott; Peace Corps Information Collection and Exchange

https://www.build-a-biogas-plant.com/PDF/PeaceCorpsBiogas.pdf