4: Biology

4.1 Methane— It's a Gas, Man

Many people call the gas which comes out of a generator, "methane gas." It is not. *Methane* is CH_4 and CH_4 is a gas at all normal temperatures and pressures, and whether a particular bit of CH_4 comes from natural gas, from a biogas generator, or from some other source, it is still *methane*.

Biogas, on the other hand, is that gas produced by the anaerobic (airless) biological process, and it's composed of CH_4, CO_2 (carbon dioxide), H_2O (water— as a vapor), and sometimes N_2 (nitrogen gas), H_2S (hydrogen sulfide), H_2 (hydrogen gas) and minute traces of more exotic gases. In literal terms, biogas means "gas produced by life." When we speak of methane in this book, we're talking about CH_4. Biogas will be called *biogas*. Original, eh?

4.2 Anaerobiosis

That big word means "life processes in the absence of free oxygen," and that's number one for biogas. The bacteria which produce biogas, do so only where there is little or no free (gaseous, uncombined) oxygen Thus, they are called anaerobic (*an* means "without" or "no", *aerobic* means "air").

4.3 Digestion and Generation

The process of the anaerobic breakdown of organic materials is *digestion*. The same word is used to describe what happens, and essentially the same process occurs, in our own digestive tract. We eat food, it is digested broken down— and we gain our energy from that process.

Whenever we talk about what happens inside any container built to accomplish this process, then we are talking about *digestion*. If a device, such as a huge municipal sewage plant, is designed primarily to accomplish this decomposition, it is a *digestor*. A *generator*, on the other hand, is designed with the idea of producing (or generating or evolving) biogas. The big difference is how efficient the device is, by design, at producing biogas. Generators are more efficient, and they give us more biogas.

4.4 Culture, Seed, and Inoculation

To "start" a generator, once we've designed, built, and filled it, we need a *culture*, some source of anaerobic bacteria. Cultures can be found in the mud under still water, in fresh manure or excrement, under an old unturned soggy compost pile, or any place organic matter has been sitting, long away from the good fresh air.

If you make yogurt, you've probably familiar with the word *culture*. A yogurt culture will help make milk into yogurt. An anaerobic culture will help us make organic matter into biogas.

When we add our culture to the biogas generator, we *seed* it, and whenever fresh organic material is added to a seed (or visa versa), then the new material is *inoculated*.

In general, these three terms are interchangeable. They all refer to populations of bacteria, and that's the thing to remember.

4.5 Batch vs. Continuous

There are as many kinds of generators as there are generators, since each and every one will be unique in one way or another.

However, there is a distinction that is important in separating one general group of digestors from another. That separation comes about because there are two basic kinds of digestible materials, the "*mix well*" and the "*float much*."

By the way, digestible materials are also known as *substrates*. This word will pop up again and again, so we'll label Table 4.1 by that name.

The mix-wells form a lively *slurry*— the mixture of water and substrate used in filling the generator. They slosh happily around, we can pump them from place to place, and even spray our friends with them, should such a thought occur to us. These materials— and chiefly the fresh manures— can be put into a *continuous feed* generator. We mix up some slurry, pump it into the generator, and it displaces some of the older slurry, which exits gracefully.

Mix-Well	Float-Much
Fresh manures	Dried manures
Fiber-free vegetable pulp	Plant wastes
Sewage	Leaves
Algae	Straw
	Small branches
	Grease (from animal sources)

Table 4.1: Substrates

If your family is large enough to qualify as a city, or if you happen to have three thousand pigs in the back yard, then by all means, build a continuous-feed generator.

If, however, it's just Mom, Pop, and the Kids, and you don't have enough animals kept in barns where the manure is easy to collect, then consider building a *batch-fed* generator. Batch-fed generators, except in special circumstances, are the kind which must be designed for the float-much substrates. You fill them up, they do their stuff, you empty them: a batch at a time.

This can be, and most often is, hard work. Nevertheless, because straw, leaves, and the like behave the way they do, they are hard to pump around, unless fairly finely shredded. Batch generators are usually small; they represent the "low-technology" approach to biogas generation, because they are so simple to build, even if difficult to use. Continuous-feed generators, operating on manure as a substrate, are more often a large-scale, high-technology venture.

We'll discuss this extensively in the section called Design, p. 142, but hang on to this distinction between batch and continuous. *Quite nearly all the research which has been done on anaerobic digestion has been done on city sewage, which is dilute and of small particle size, and generally which digests rather rapidly.* Therefore, these studies were not directed towards the substrates most of us have in relative abundance (leaves, grass clippings, weeds) nor the kind of generator (batch-fed) which these substrates require.

In fact, all the easily available information (see the Bibliography, p. 265) in book form, as of this writing, is directed almost exclusively to the digestion of sewage or manure.

Here is another reason why you won't find an abundance of blueprint drawings of large generators in this book— most of us can't use them since we don't have the required substrates.

4.6 Sludge, Supernatent, Scum, and Sand

For some reason, all these words begin with "s." As you already know, when we mix water with our substrate, we create a *slurry*. When we put the slurry into our generator, and leave it alone, it generally separates into layers, as illustrated in Fig. 4.1.

Below the biogas, *scum* forms. The float-much substrates are mostly scum— that is, whatever floats to the top of the slurry is scum. The scum often forms a dense mat above the slurry, as grease, hair, straw, and assorted undesirable materials float up, stick together, and dry out, forming a hard crust. More about this later.

Below the scum is the *supernatent*. *Super*, meaning above, and *natent*, from *natare*, to swim. So, the supernatent swims above the sludge. Supernatent is the liquidy portion of slurry, left behind when the heavy stuff (sludge) settles out.

Sludge is the goopy or mud-like portion of the whole mess.

Underneath everything is the *sand*. Well… we could call it grit, but that doesn't start with an "s." Basically, the sand layer is made up of all the heavy indigestibles. Depending on how we fill the generator, and with what, there will be a layer of sand which will accumulate, rapidly or slowly, at its bottom.

These layers appear in the slurry when it is not mixed, or only very slowly mixed. When stirred somewhat more rapidly (agitation), the supernatent and sludge recombine, or never separate, and the scum

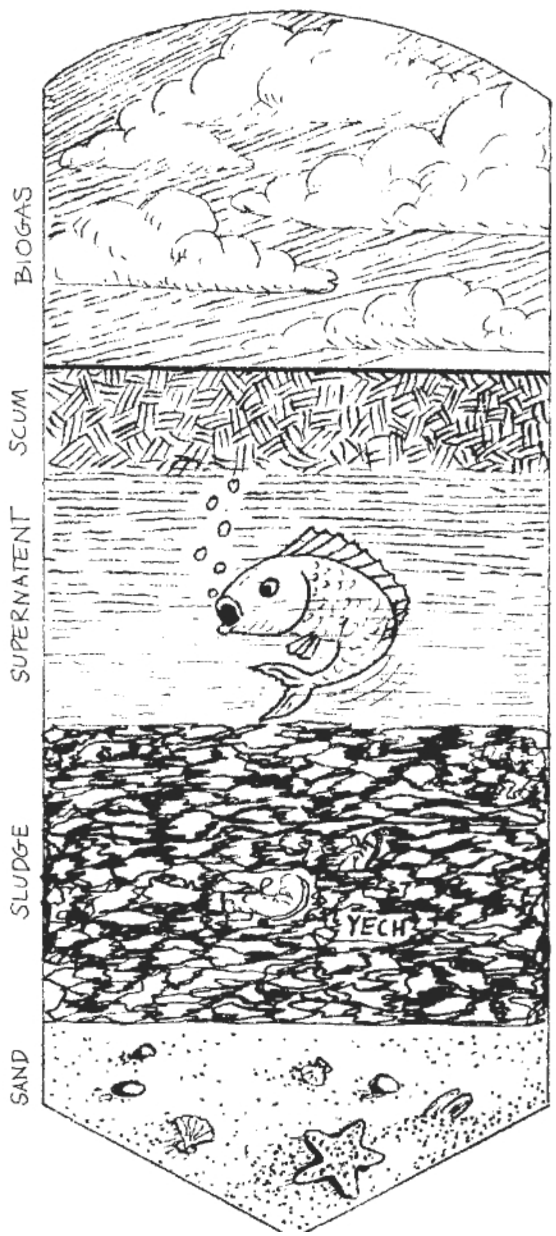

Fig. 4.1: Slurry Layers

(depending on the substrate used) does not form as rapidly, if at all. Very rapid mixing (high-rate mixing) can generally remove the scum, or prevent it from forming, but the sand must still be otherwise dealt with. In some generators, both scum and sand remain and cannot be removed by mixing. More about these difficulties later.

After generation is completed, in other words, when digestion of the slurry is finished, what we have left is *effluent*. In some generators, the used or effluent supernatent is drawn off separately from the effluent sludge and often these are used in different ways, since they can be handled a bit differently if they have separated.

In general, city sewage effluent supernatent is pumped into the nearest innocent waterway or ocean. The sludge effluent is often dried and hauled away by truck.

Most of us, however, will use the whole effluent as it should be used— that is, not simply "disposing" of it, but using it as a fertilizer, to return it to the soil. Thus, when properly digested, whatever substrates we are using will pay us back in both fuel and fertilizer.

Because the process is a natural process, something which goes on in the real world in the absence of government grants or computer programs, we need only understand it well to use it well. This implies no dependence on a military-industrial complex, but rather greater freedom from it.

4.7 Ancient History

For more insight into the biogas process, let's look back in time. According to the best information we have, the earth appears to be about three and one-half billion years old. That's a lot of history, and such history is not written in books or on clay tablets; it's written in the bones of the earth, the rocks and strata.

The primitive atmosphere was composed principally of CO_2 (carbon dioxide), H_2O (water vapor), and CH_4 (methane). There was little or no atmospheric or free oxygen, and thus all life at that time lived and moved in an environment which would not allow us to survive— or only for as long as we can hold our breath. We are *aerobic*, that is, we require free, uncombined, gaseous oxygen for our life processes. Whatever primitive life existed in the dawn of prehistory was anaerobic, that is, it did not need or use free oxygen in its life processes.

An interesting question is— where was all the oxygen? Answer: It was bound up in the iron oxide deposits, bound up in carbon dioxide, bound up in hydrogen oxide (Recognize that one? H_2O), and happily and undiscriminatingly combined with whatever was available. Another interesting question is— why is the air so full of oxygen today? Answer: Green plants. *Photosynthesis* means using light (*photo*), to make the chemicals (*synthesis*) which accompany life. Plants take in CO_2, and they discard O_2 and keep the C. Animals take in O_2, and they discard CO_2. It's a circular process, and very intelligently designed.[1]

But on the very primitive earth, there were no animals, and there was no photosynthesis, and consequently, there was little or no free oxygen, for the only important source of O_2 is the activity of green plants. Protect your local forest! Gradually, however, photosynthetic organisms developed and flourished, though it took a long time for the O_2 to build up to any great degree in the atmosphere.

As conditions changed on the earth, those life forms which once could live in the open "air," could not survive the gradually increasing oxygen concentration, and they were driven into places where the ancient oxygenless, anaerobic conditions still prevailed.

4.8 Today

They are still there, and they earn their keep, for in nature, everything eventually returns or cycles, and these anaerobic organisms help to return organic matter to from whence it came.

Plants come, directly or indirectly, 95% to 98% from the air around us. They take C, O, H and (indirectly) N, from the air, to make their proteins, and carbohydrates. When they die, their remains, made up of these complex molecules, are decomposed by different organisms and returned to the soil and the air. They are, to use a recently popular word, biodegraded. In the anaerobic places (the swamps and bogs, or the lake and slow stream bottoms), the only way these plant (and animal) remains can be biodegraded is by anaerobic bacteria.

Another place where these bacteria help is in the digestive tracts of many creatures. Termites use them to help break down the wood they eat. Ruminants (cloven-hoofed, four-legged cud-chewers) have anaerobic little bitty buddies in their complex digestive tract, which help them break down their food for utilization.

So, the two main places where we find anaerobic life today are under water, and in digestive tracts.

Anaerobic metabolism (the internal life process mechanics of oxygenless bacteria) is not as efficient as aerobic metabolism. Without free oxygen, and the corresponding metabolism designed to use it, anaerobic bacteria cannot derive as much energy from the breakdown of their food molecules as aerobic bacteria derive. One illustration of this is a compost pile.

When compost is made in the open air, rapid breakdown of the organic materials results, and the temperature inside a compost pile is often 70°C (160°F) during its most active period. Similar compost materials, when placed in a biogas generator, in the necessary airless environment, produce no appreciable heat, decompose rather slowly, and leave us most of the energy which was locked up in their molecules (as much as 70%) still locked up, as CH_4, methane.

This difference between aerobic and anaerobic metabolism in regard to their ability to efficiently use (biological) energy also shows up in the fact that the process of biogas generation is easier to upset than the process inside a compost pile. Changes in conditions, compost materials, or levels of toxic (poisonous) substances which would not bother the aerobic compost process, will disrupt or stop the anaerobic process.

Understanding the reason why the process is so delicate requires further understanding of the biology of the process itself.

4.9 Biological Energy

We've been talking about the breakdown of molecules for energy, without really explaining it. Suppose there is a coil spring between your hands. When you force your hands together and lock your fingers, the spring will try to push your hands apart. It took energy to bring your hands together, and now the spring stores that energy, locked between your hands.

In a similar way, two or more atoms are locked together— combined or bonded— and they store energy between them. When they are unlocked or broken down, energy is often released.

When atoms like carbon and oxygen are put together— one carbon atom and two oxygen atoms— we get CO_2. Two hydrogens and one oxygen give us H_2O. These are very simple *molecules*, or combinations of

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1 When this sentence was first written in 1978, it was possible to speak of these things being "intelligently designed" without appearing to engage in political controversy. This is not a scientific statement because it cannot be tested. That does not mean that its not true, but it does mean there's really no reason to argue about it...

atoms, but Mother Nature often puts together hundreds of atoms of many different kinds and comes up with very complex molecules.

If a molecule is unstable, the “locks” in it are not very good, and it may break apart easily. More stable molecules are harder to break apart, just as your pushed together hands would be hard to break apart if you had strong fingers, or if you tied them together with string or rope.

4.10 Chemical Confusion

We’ve thrown a few chemical equations at you without the concept behind them. They are a very simple way of representing what happens when certain molecules get together under certain conditions- a kind of chemist’s shorthand. Notice the conservation of matter in the following equation:

$$CaCO_3 + H_2O \rightarrow Ca(HCO_2)_2$$

Six oxygens on both sides (the bicarbonate ion, (HCO_3^{--}), is doubled, since two of them hang on to the calcium ion, Ca^{++}). Two carbons, one calcium, and two hydrogens are also found on both sides. As should be obvious, the “sub” numbers (“O_2” for example) refer to the numbers of those atoms to which they are appended. Thus, O_3 means a happy group of three oxygen atoms, $(OH)_2$ refers to a gregarious gathering of two OH^- ions.

4.11 Back to Biological Energy

Biologically, in living systems, stable molecules are broken apart (or formed), not by force, but with the help of enzymes. In our spring-hands-fingers model, a bit of grease would act as an enzyme, causing your fingers to slip apart and the stored energy to be released. If your hands were tied together with string, an enzyme would act like a pair of scissors, cutting the string, whereas without the scissors, you would have to break the string with force.

In a biogas generator, complex molecules are broken apart, step by step, into simpler molecules. The process has been compared to an assembly line— except that it’s a disassembly line— where one group of workers works on a complex molecule, derives energy from it and gives the parts (less complex molecules) to another group of workers, who disassemble them further (gaining energy themselves), and so on to the final group of workers, who break the molecules into the very simplest molecules possible under the (anaerobic) circumstances— H_2O, CO_2, and CH_4.

These workers are different kinds of anaerobic bacteria, and many who have studied this process agree that it takes a great many different kinds of bacteria to accomplish the complete disassembly of a very complex molecule into CH_4, CO_2 and the like.

The workers, or bacteria, are of many, many different kinds, and they operate together in ways we might not expect if we studied each one separately.

Here is one of the keys to the complexity of biogas generation— the many varieties of anaerobic bacteria and the many ways they have of operating under different conditions and in different populations.

An operating generator, then, is like a factory, filled with workers, busy manufacturing biogas from the raw materials supplied.

From the foregoing, we can see that inside the factory, things happen in stages:

4.12 Conditions and Stages

Aerobic

Oxygen will inevitably enter with the raw materials put into the generator, and so aerobic bacteria use this oxygen up, meanwhile doing what they can to break the materials down. CO_2 is released, and some heat is generated.

Extracellular enzymes

In this stage, anaerobic bacteria release enzymes that attack large molecules which are still outside their own bodies (extracellular), so these molecules will be broken down into “bite sizes.”

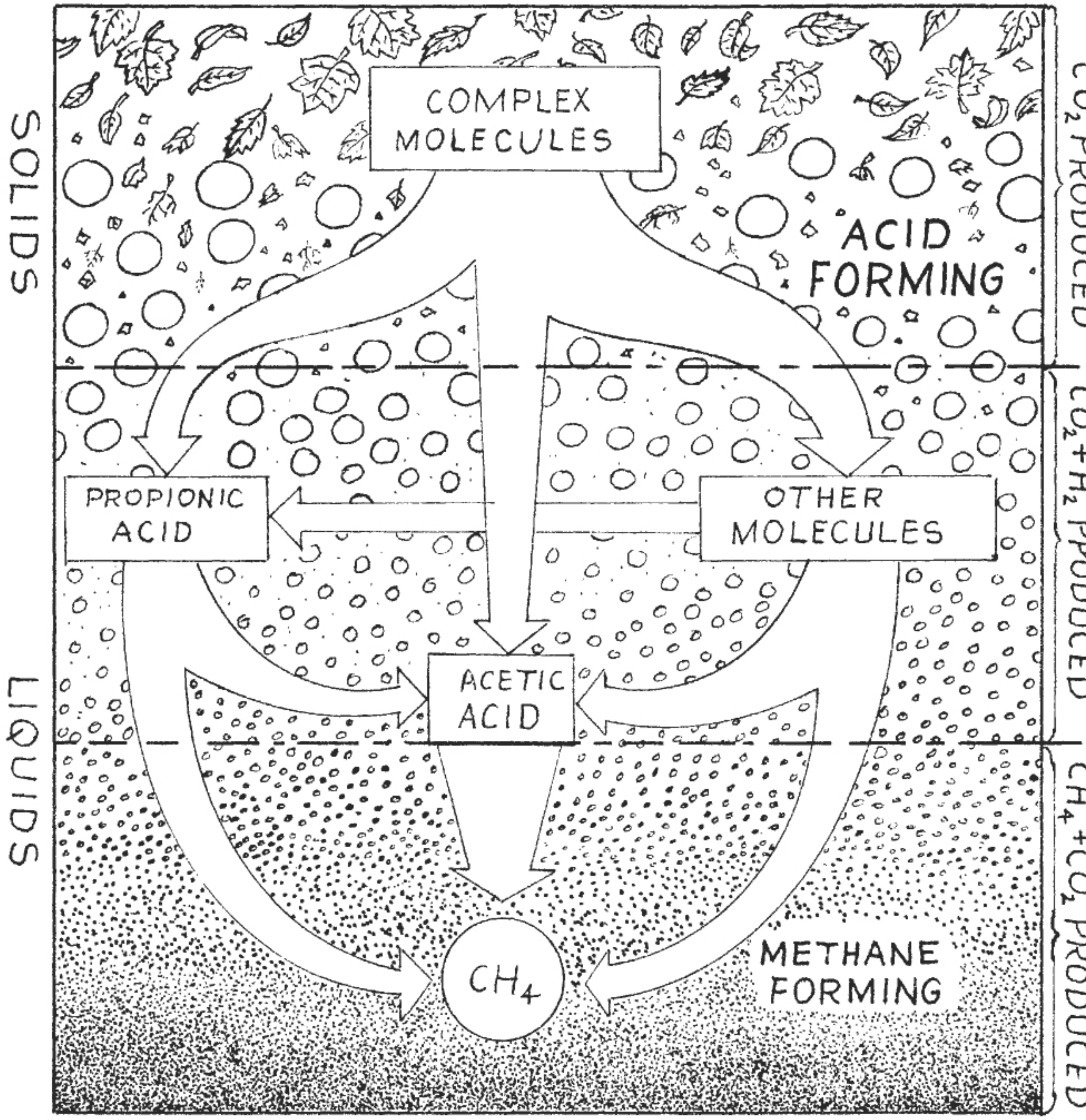

Fig. 4.2: Chemistry of Biogas Production

Acid digestion

The bite size molecules (still fairly large) are absorbed by the bacteria and digested. The main byproducts of this third process are simple molecules such as the short chain fatty acids, H_2 and CO_2. (We'll get into the short chain fatty acids soon.) It's interesting to note that at this stage, hydrogen gas, an excellent fuel, is evolved. Hydrogen does not often show up in the final biogas apparently because it is used by the anaerobic bacteria (in the next stage) in making CH_4, methane.

Gas digestion

Now comes the part we've been waiting for. The fatty acids are now gobbled up by the last group of bacteria, who turn them into H_2O, CO_2, and best of all, CH_4.

For general purposes, we will talk about biogas production as if it had only two stages (*acid digestion* and *gas digestion*), and as if there were only two groups of bacteria involved (*acid forming* and *methane forming*— *AF* and *MF*). The second group is called methane forming even though they also produce other byproducts, because uniquely and alone, these microorganisms produce the methane component of biogas. Recent research indicates that the methane formers are not bacteria, but a whole new kind of creature, as different from bacteria, as plants are from animals. Nevertheless, we'll still call them bacteria for convenience.

The biogas process, unlike many others, leaves no residues which are poisonous to the process itself. As an example of a common biological process which does not follow this pattern, consider alcoholic fermentation. In this process, yeast metabolizes (eats up) sugars and one of the byproducts is alcohol. As the process continues, the percentage of alcohol increases in the sugar-yeast broth, and eventually (at around 17%) kills the yeast.

In the biogas process, however, it cannot be said that any major residual byproduct is poisonous to the bacteria. Sunlight, even in the absence of oxygen, can damage or kill the bacteria.

4.13 Peer Amid the Pyramids

One last point, previously referred to briefly, can now be more fully explained. When we were discussing the easily upset process of biogas generation, and the low efficiency of anaerobic metabolism, another factor, it was stated, contributes to this delicate character. It has to do with pyramids. Whenever the soil is unhealthy, plants grown in that soil will be unhealthy. Animals eating the plants will be unhealthy, and people eating the plants, animal products, and animals will be unhealthy. This is the food pyramid, sometimes called the food chain, greatly simplified.

At the bottom is the soil; standing on that are the plants, above that, the animals, and at the top is man. The only reason we're on top is that we're standing on everybody else. If anyone below us slips, we slip too. The snail darter may be more important than we realize.

There are a lot of pyramids which we can find around us. For example, our society rests on our economy, and our economy rests on our agriculture, and everything is balanced on the natural world and the things we are given freely each day. Sunlight. Oxygen. Water. Change the weather a little, agriculture suffers, the economy self-destructs, and the social animal turns savage. The point here however, is not social, but biological.

The biogas bacteria are at the top of their little pyramid as well. If anything goes wrong somewhere else, it affects them, and biogas production slows down or stops. Anybody else's trouble automatically becomes their trouble. So, we have to remember not to rock the boat. Gradual changes can be more easily tolerated by the ecosystem in the biogas generator than can rapid changes in temperature, pH, and so on. Next up, more on these conditions.

Terms

Acid digestion: The "first part" of biogas generation, where complex molecules are broken down into simpler molecules, such as the fatty acids, CO_2 and H_2.

Aerobic: Needing free gaseous oxygen to survive, or being able to tolerate it.

AF: Acid forming.

Agitation: Mixing.

AKA: Also known as (alias).

Anaerobic: Requiring an oxygenless atmosphere. Poisoned by oxygen.

Anaerobiosis: Life processes carried on in the absence of free oxygen.

Batch feed: A load, generate, clean out type of generator.

Biogas: That combination of gases which is produced by anaerobic decomposition.

Biological energy: Energy available to life, most generally gained from, or with the assistance of, other life forms.

CH4: Methane.

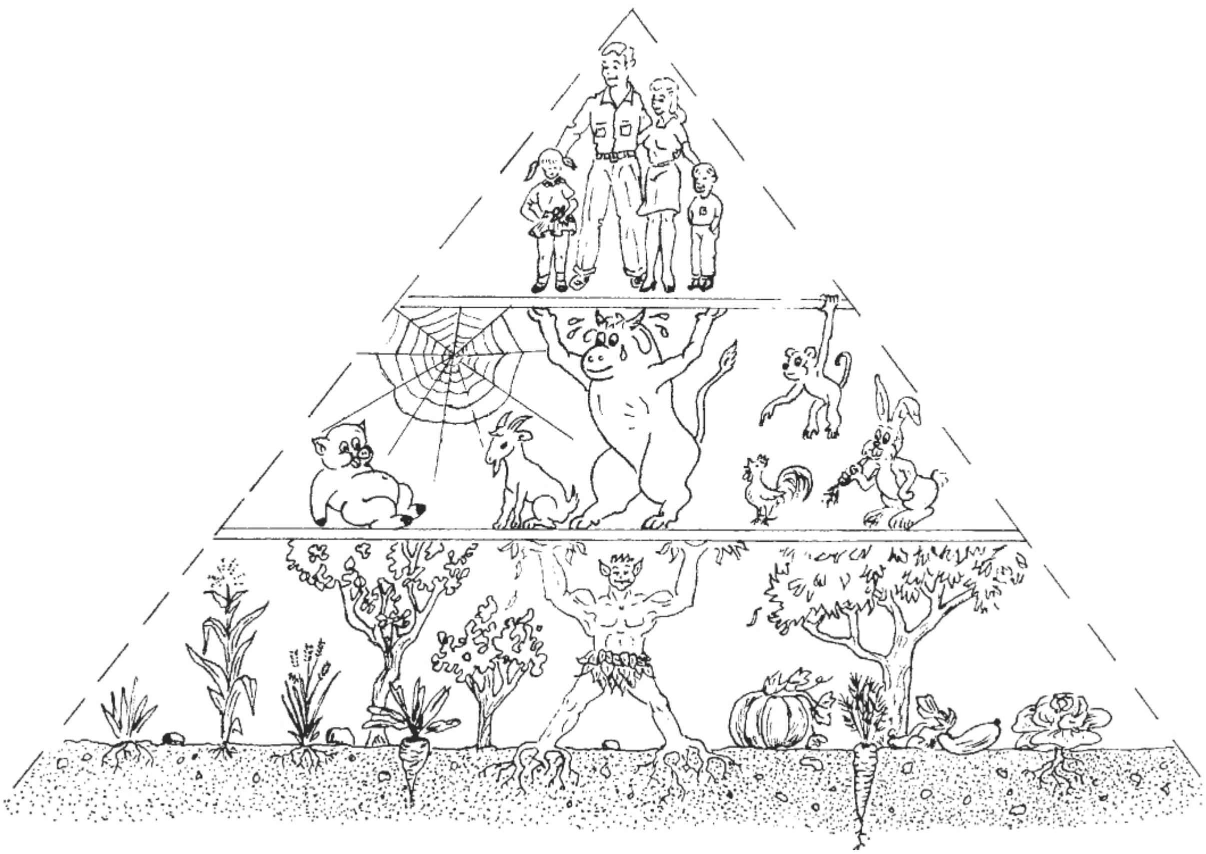

Fig. 4.3: Food Pyramid

Continuous feed: Generators into which slurries are daily or more constantly put.

Culture: Populations of anaerobic bacteria. Digestion: The biological breakdown of organic materials.

Digestor: A device designed to break down organic materials.

Ecosystem: The interactive web of life which covers the whole planet.

Effluent: The used slurry, sludge, supernatent or scum.

Enzymes: Chemicals which help form and break down molecules.

Extracellular enzymes: Enzymes which operate outside the bitty bodies of biogas buddies.

Fatty acids: More about this is found later. We'll come to it.

Gas digestion: The "second stage" of biogas generation, during which the CH_4 of the biogas is produced.

Generation: Here, the production of biogas.

Generator. A device designed to produce biogas.

Food pyramid: The food chain, another reason to believe that all flesh is grass.

Float much: Those substrates which refuse to make easily pumpable slurries.

Inoculation: Populations of anaerobic bacteria.

Low Technology (or *low tech*): A technology available to mom, pop, and the kids. AKA "kitchen sink technology".

Metabolism: The cellular mechanics of life; the process of using biological energy.

Methane: CH_4.

ME: Methane forming.

Mix well: Those substrates which make pumpable slurries.

Molecules: CH_4, CO_2, H_2O and their brethren and sisteren.

Parameters: conditions or factors.

Photosynthesis: Another miracle.

Ruminants: Cud-chewing, four-legged, cloven-hooved animals.

Sand or grit: Sand or grit.

Scum: The floating mass of material above the supernatent.

Seed: Populations of anaerobic bacteria.

Sludge: The settled portion of the slurry; a mud-like, semi-solid mass.

Slurry: The mixture of a substrate and water which sits in the biogas generator.

Substrates: Those materials, once alive, that are mixed with water to form slurry and fed to the generator to produce biogas.

Supernatent: The liquid portion of the slurry which "floats" above the sludge.

Questions

1. Where did all the O_2 in the air come from?
2. Did you ever notice that science is good at the "how" of things, and very poor with the "why" of things?
3. When something goes wrong with our generator, we should change it as fast as possible, right?

Problems (none)