18: On Growing Substrates

The biogas process is essentially a means of collecting secondhand solar energy. The sun shines, plants grow, we make the plant matter into biogas. This being the case, the question naturally arises: Can we make use of this process to grow energy? Can we, in other words, turn a certain area into a biological solar collector?

As with any process where energy is transferred or transformed, a certain amount of energy is lost during each step. In the sun-plant-biogas process, it might look like this:

1. Sun to plant conversion efficiency: 2% maximum
2. Plant to biogas conversion efficiency: 65% average

Let's look at each step in this energy accounting.

Sun to plant conversion efficiency depends on a number of things. Incoming radiant solar energy is only about 43% visible light. The rest is heat (infrared radiation) and other kinds of radiation. Plants use only the visible portion of the spectrum for photosynthesis. Here, then is the first limitation. Plants— at 100% conversion efficiency of the visible light— could only make 43% of the sun's radiation into the stored energy of plant matter.

However, plants do not make 100% of the sunlight into plant matter. Some of the energy is used to support the life processes of the plant, some is not even gathered. The upshot is that only a very small portion (1% to 5% under ordinary conditions) of the visible light is converted into plant matter. All told, this means that only (0.43 x 0.05) 2.15% of the incoming solar radiation maximum is converted into plant matter under ordinary conditions. (Plant matter is also known as biomass.)

From this, we must subtract further energy. The energy required to make the necessary farming equipment (which may not even resemble a tractor); the energy used to manufacture, transport and apply the herbicides, pesticides and fertilizers; the energy required for irrigation; the energy we must invest in planting, cultivation, harvesting, storing and— perhaps most important— transporting our substrate plants to the generator; as well as the energy consumed in building, maintaining and heating the biogas generator; must all be subtracted from the only energy we care about: the energy stored in the bonds of the CH_4 molecules in the biogas.

Many authors seem to concentrate on the growth and utilization of algae as *the* plant for conversion into biogas. Indeed, algae has shown the advantages, in small-scale studies, of having excellent conversion efficiencies (from 2% to 18%) of the incoming light into the potential energy of plant mass, and of having high yields of 100 to 160 pounds per acre (160 pounds per acre is about 12.5 grams per square meter) per day.

Algae, however, have not been grown on a very large scale. The facilities for large-scale algae growth will be very expensive, and the energy involved in harvest and processing will be high. Algae do not digest well at ordinary mesophilic temperatures, primarily because the conditions in a mesophilic generator do not kill the cells— which therefore remain intact and unavailable for digestion. Thermophilic digestion is required for intact algae, and this requires higher generator temperatures, and therefore more total energy and/or a higher cost in insulation. Killing the algae cells before use, by heat, ultrasonics, microwaves, fungi or drying would make mesophilic digestion feasible, but these processes must be energy efficient to be competitive with thermophilic digestion.

Because of the high protein content of algae, it produces a very colloidal, jello-like, slimy effluent which is hard to dry. This need not be a drawback where all the effluent is recycled into ponds used for growing algae, but the higher water content of such an effluent makes any use that requires dewatering or transport more expensive. A possible use for an algae effluent is dilution and direct irrigation, but this has not been investigated.

Algae cultures (in ponds) must also be cooled in any situation where intense sunlight is available. Photosynthetic green plants do not make use of the sun's heat, yet where sunlight is strong, heat is usually also intense. The algae pond, filled with water, has a high capacity for heat, and avidly collects it. As temperatures climb above 27°C (80°F), the growth of algae suffers. Either this water must be cooled, or the heat must be extracted before it arrives at the pond surface. Both options require further equipment and therefore more money and energy. The use of a "filter" made of a solution of water and alum (potassium aluminum sulfate: $KAl(SO_4)_2 \times 12\ H_2O$) will allow visible light to pass, yet stop the infrared (heat) radiation, but a simple, inexpensive and foolproof method of using this information has not been devised. So growing algae is probably going to be complex and expensive.

Species or Plant	Location	Annual yield Tons/acre	Annual yield Tonnes/hectare
Jerusalem artichoke	*Russia*	13.5	30.3
Exotic forage sorghum	*Puerto Rico*	30.6	68.6
Forage sorghum (irrigated)	*Kansas*	12	26.9
Kenaf	*Florida*	20	44.8
Water hyacinth	*Florida*	16	35.9
Sugarcane	*Mississippi*	20	44.8
Sugarcane (state average)	*Florida*	17.5	39.2
Sugarcane (best case)	*Texas (south)*	50	112
Sudan grass	*California*	15-16	33.6-35.9
Bamboo (4 yr. stand)	*Alabama*	7	15.7
Algae (fresh water pond)	*California*	8-39	17.9-87.4
Tropical rainforest (average)		18.3	41
World's oceans (primary productivity)		6	13.5
Sugar beet (best growth)	*England*	24	53.8
Potatoes (experimental hydroponic)	*US*	60	134.5

The hydrophonic growth of potatoes is of course an extremely energy inefficient process; it is included here in Table 18.1 to indicate that the yield of the higher plants can equal or exceed anything reported for algae, under similar highly controlled laboratory conditions.

Table 18.1: Biomass Yield

For these reasons, a low-technology approach to growing biomass for biogas will for the time being probably have to be based on the higher plants. The disadvantages of algae do not put it out of the running, but they tend to legislate against its use in small-scale situations.

In Table 18.1, we give some figures on plant yield per acre per year. However, in agriculture, climate is all important. Some crops suitable in one climate will not grow in another. Notice that the tropical climate crops outperform the temperate crops. This is at least partly because yields fluctuate in temperate climates from summer to winter, but yields in tropical crops are more or less constant, with several cycles of plant-and-harvest each year.

Remember as well that these figures represent a broad spectrum of farming practices and that each plant has a different suitability to the biogas process as well as different final biogas heat value yield per unit weight. Much more experimentation is needed in this area, for biogas is such a lovely fuel, so well suited to many different uses, and yet the production of the substrate can be very "low technology" if necessary. This makes biogas production suitable to many more primitive situations where energy is otherwise scarce, and the local technology is undeveloped.

For those interested in any case in experimenting with algae, some points of information will prove helpful.

18.1 Algae

Whenever effluent is used for the nutrient base in the pond, the algae will grow best in association (symbiosis) with certain kinds of bacteria. These bacteria break down more complex nutrients into the simple molecules which provide food for the fastest algal growth rate. Once the algal pond is established, only a small percentage of the total nutrients need to be imported in the form of manure, sewage or other materials. The rest can come from the effluent of the algae fed generator. As more of the algae goes to other purposes— such as animal feed— more nutrient imports will need to be made.

All the available byproducts from associated processes should, where possible, be returned to the algal pond. If the algae is used for feedstuff, the animal manures should be returned. If the algae is used for fertilizer, the crop wastes should be returned. As well, the gases "scrubbed" from the biogas, and whenever possible, the combustion byproducts of the burning of biogas should be returned to the algal pond—particularly CO_2.

CO_2 is important to the algae because the growth rate depends— among other factors— on what is known as the "limiting nutrient". Photosynthetic plants, as you may know, require a great many nutrients, the main ones being carbon (C), oxygen (O), hydrogen (H), nitrogen (N), phosphorus (P) and potassium (K). Any plant, other conditions being favorable, will grow as well and as fast as it can as long as the necessary nutrients are available. Ideally, growth continues until one of them is used up. This nutrient is the *limiting nutrient* because the amount of this one (relative to the plant's needs) is less than any other. Plants need CO_2, much as we need oxygen. However, the air contains only 0.03% CO_2, global warming notwithstanding. In an algal pond, CO_2 is often the limiting nutrient. Returning this CO_2 to the algal pond may stimulate the growth of algae.

CO_2 concentrations of 0.1% to 5% (by volume) in air, when bubbled through the culture water, will markedly increase the growth rate. At the higher concentration, 6.25 milliliters of the gas mixture per liter of culture per minute has, in one experiment (Geoghezon, 1953), proven sufficient.

When using organic substrates such as the recycled algae effluent or sewage, CO_2 is produced when aerobic bacteria break down these substrates, supplying to some degree the need for CO_2 in the culture water. Aerobic compost also produces abundant CO_2— but capturing it may be difficult.

As has been mentioned, the temperature of the pond is important. Temperatures in excess of 27°C (80°F) are inadvisable. Cooling can be accomplished by evaporation in a cooling tower, where the pond water is pumped up to a height and allowed to drain down surfaces while exposed to air. Water lost to evaporation needs to be replaced. (It seems a shame, however, to waste all that lovely heat.)

Another solution to the problem of high pond temperatures is to grow temperature-tolerant species, but this is a high technology approach since the cultures may need to be kept pure (only one species of algae) by the use of chemicals or sterile equipment.

Algae grows best if the temperature is varied from day to night. In fact, high temperatures which might otherwise depress the growth of algae (30°C, 86°F) can prove a stimulant to growth if the temperature is also lowered during the night (20°C, 68°F). Sometimes temperatures as high as 45°C (113°F) are used to control pest microorganisms such as rotifers, but these temperatures will also damage algae, and even if they are not killed, growth will be hampered for days. The temperature limits and optimums depend on the species involved.

The full intensity of sunlight is more than algae can efficiently handle. All the studies showing very high efficiencies were the result of experiments using low intensity light or intermittent light. A young culture can even be killed by full sunlight, and so it is good practice to give an algae culture partial shade when it is becoming established.

Turbulence in the culture water will, at sufficient concentrations of algae cells, cause the individual cells to experience varied light intensities and the distribution of light energy input will be more even among all the cells in the culture.

In cultures which are nourished by organic substrates, continued stirring or turbulence is not beneficial, since the particles of substrate and the aerobic bacteria will disperse throughout the culture water and absorb too much light. When stirring ceases, these particles settle and most of the algae continues to float. According to experiments done by Oswald and Golueke (1960) using an algae pond such as is described below (p. 84), mixing during the day lowers the pH, which later rises as the algae use up nutrients in the pond water. This is probably a result of the changing concentrations of CO_2 that such mixing might cause. (A lower pH would result from an increased concentration of CO_2.) Mixing during the night allows the settled bacteria and substrate to become reoxygenated and does not interfere with photosynthesis. Unless mixing occurs at least once in 12 hours, the settled bacteria will use up the oxygen available in the pond bottom, which will gradually become anaerobic. For these reasons, mixing for a half hour around 1:00 PM, and for 2 to 4 hours starting at midnight was recommended by and proven satisfactory for these researchers.

For a great many chemical and biochemical reasons, a pH range of 6.0 to 6.5 is best. When the nutrients in the culture come from organic sources, the pH generally remains more stable, but it may need to be manipulated to bring it into this range, either by mixing or by chemical means.

Young cells have a higher protein content and more vitamin B_1, and older cells (14 to 28 days) tend to have more fats. If the nitrogen content of the culture water is restricted, the fat content of the algae cells increases, but total biomass production is lower. Whenever cell division ceases, while cell growth continues, fats increase. These facts may hold promise for biogas production, as fats produce a better quality and greater quantity of biogas than protein. As was mentioned before, the high protein content of algae produces a very colloidal effluent. A higher fat content algae therefore may also produce an effluent which can be more easily dewatered.

Maximum biomass yields per unit area per unit time occur in 2 to 5 days, but if the fat content of the cells markedly affects biogas production, the maximum biogas or methane production per unit area per unit time may take longer to develop.

It appears that the simplest low technology method of growing algae is a pond, with curbs or dikes in it so that the water, pumped from one end causes a flow along the whole length of the pond. See Figure 18.1 for a schematic drawing of such a pond viewed from directly overhead. If water is pumped from A, the outlet, B would be the inlet end.

This pond design is essentially the same as that proposed and used by Oswald and Golueke (1960). The reason for using such a design is primarily that it is easier to mix the pond culture for aeration in this design versus a pond without channels and dikes. A flow velocity of 30 centimeters (one foot) per second, or more, will mix the substrate and the pond water sufficiently to produce aeration. (This velocity is the minimum required to stir up the organic matter, causing it to mix with the algae and become reoxygenated; lower velocities may lengthen the maximum time required between mixings by causing some oxygen to infiltrate the organic material on the pond bottom, without stirring it up so much that it blocks the light.)

The pond should be 20 to 30 centimeters (8 to 12 inches) in depth, and have a channel length, width, and bottom smoothness such that the energy needed to drive the pumps to cause that flow will be at a minimum. Specific mathematical information is available from Oswald and Golueke (1960), and in publications on hydraulic flow

Harvesting the algae provides another problem. Filtering, according to Oswald and Golueke, is too difficult, and centrifuging is too costly. Chemical coagulation is feasible with the use of lime, adding that until the pH rises to 11.3, rapidly mixing the culture for a brief period, then 3 to 5 minutes of gentle stirring to encourage the formation of coagulated groups of algae cells, known as *floc particles*. The process, of course, is then *flocculation*.

Draining off the top liquor before dawn will help, as the algae tend to settle at night. But a natural flocculation process was observed in the Richmond, California algae pond. During the afternoon of sunny days, when the temperature of the pond had increased several degrees above the morning level and the pH had increased to 10 or 11 (as a consequence of the changing CO_2 concentration, as noted earlier), the algae clumped together and settled to the bottom. It was recommended that special ponds 7.6 to 15 centimeters (3 to 6 inches) deep be constructed to take advantage of this natural process. The culture water should be pumped into the flocculation pond early in the morning, and after the algae have settled, the supernatent liquid should be returned to the culture pond, and the concentrated algae transferred to another pond for further concentration, or to a sand drying bed. Natural flocculation does not occur in ponds of greater than 60 cm (2 feet) depth.

As mentioned, algal slurries should be digested thermophilically unless the algae are first killed. Hydraulic retention times of 11 to 20 days can be used. Experiments have shown that from 150 to 225 cubic centimeters of combustible gas (CH_4 + H_2) is produced from each TS gram of algae introduced into the generator (2.4 to 3.5 cubic feet per pound). Loading rates of 1.2 to 2.3 grams VS per liter (0.09 to 0. 18 pounds VS per cubic foot) have been tried and do not overload the generator. On a dry weight basis, algae is 85% to 90% VS when it is grown chemically. Effluent-grown algae has a lower VS content of 80% to 85%. Generator sizes of 9.1 liters per square meter of pond (0.27 cubic feet per square yard, 1,300 cubic feet per acre) should prove adequate. Further information can be found in the Bibliography (p. 265).

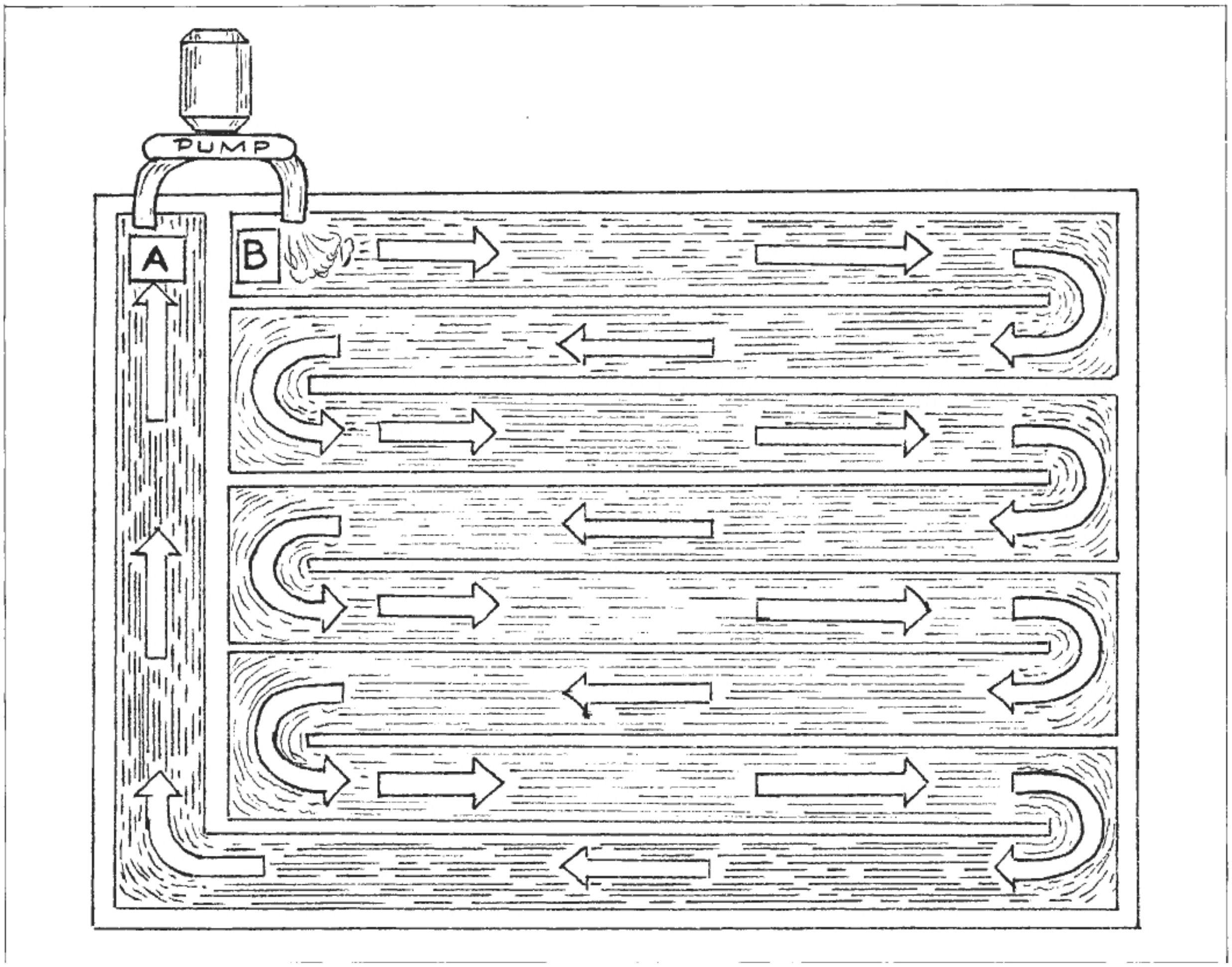

Fig. 18.1: Algae Pond Design

Terms

Flocculation: The process of natural coagulation.

Questions, Problems (none)