The Unexplored Promise of Biogas

The Domestication of Dragons

Bob Hamburg

AFTER FOUR DECADES THRASHING at the end of life's anaerobic digestion thread, I suggest that the easiest way to get a personal understanding of biogas systems is to consider "lighting farts." Google offers thousands of experiences; and you can even check on Wikipedia. The digestion process that occurs within the intestines of all animals results in the production and release of a mixture of gases that are often combustible—hence, I think of biogas systems as dragon husbandry. This intestinal activity is largely accomplished by trillions of anaerobic microbes which symbiotically inhabit our guts. It is "they"—these lifeforms from another biological kingdom (Archaea, Earth's oldest)—that digest what we eat. It is they that make the embodied energy and nutrients available for "us" to be.

This mutually supportive arrangement has evolved over more than 2 billion years. As earth's oldest lifeforms, the microbial Archaea developed 3-4 billion years ago in an environment devoid of chemically unbonded oxygen. When cyanobacteria and photosynthetic eukaryotes began to proliferate about 2.3 billion years ago, they released huge amounts of O_2, which is poisonous to most Archaea. (See the "Great Oxygenation Event".) In an effort to survive as widely as possible, some anaerobes struck a deal with multicellular organisms (the Eukaryotes): If the larger organisms would protect them with an internal home purged of poisonous O_2, the Archaea would decompose the complex compounds in the larger organism's food and make the embodied energy and nutrients available to sustain the larger organism's existence. This deal has served both biological kingdoms quite well over the last couple eons—a great example of permaculture, if there ever was one.

Thus, from its evolutionary beginnings, our species has had a very intimate symbiotic relationship with anaerobic microbes. We provide them a home in our guts, and they digest our food. Without them, our bodies would not be able to make use of the nutrients we consume. There also appears to be a quickly growing understanding that these beasties have much broader impacts on our physiology, health, mental processes, and behaviors—but that's another story…

In a "sausage design," sequential batches of feedstock are digested in a process that mimics intestinal digestion. Photos provided by Alex Eaton, Sistema Biobulsa (www.sistemabiobolsa.com).

Biogas systems may be recognized as externalizing the anaerobic digestion process so as to expand upon the 2-billion-year-old symbiotic deal struck by Archaea and Eukaryotes. This symbiotic expansion can increasingly help in creating greater regenerative energetic and material flows from resources coopted by human activity. Technology applied to the biological semi-cycle of return—in the service of diversity and regeneration.

Biogas is a groovy byproduct. Nutrient conservation is the thing.

Two recycling pathways

Nature has provided two bacteriological pathways for recycling organic materials: aerobic (composting) and anaerobic (digestion). In nature, they have much in common, and there is much collaboration.

Both pathways begin with photosynthetically created organic materials (solar energy-animated earthly stuff). Both do best with a feed material carbon:nitrogen ratio of around 20-30:1. Both pathways are greatly facilitated by grinding the feedstock so that bacteria have easier access (think: chewing our food). In our digestive system, aerobic microbes dominate the early phases of the process, while anaerobic microbes take over in the intestines.

Aerobic decomposition requires large amounts of oxygen (O_2) to sustain the processes. Thanks to a couple billion years of green life's photosynthetic O_2 production, the current atmosphere allows this to happen naturally over most of the earth's surface. To increase the speed or concentration of the process generally requires significant energy inputs for collection, operation of aeration pumps, and/or turning piles. The process works best at moisture levels of 40-60% (damp, but not sopping wet). When conditions are optimal, the composting microbes transform the stored photosynthetic energy into the

Biochar and recycling woody, lignin-rich organic materials—Enter the Fungi!

Both aerobic and anaerobic recycling pathways rely on bacterial activity. Composting woody materials in a timely fashion requires considerable energy inputs for size-minimization and aeration. Without even more significant pretreatments, the anaerobic pathway cannot decompose woody materials—at least not in an economical or timely fashion.

Fortunately, an entire kingdom of life has evolved to more rapidly re-utilize the energetic and material resources available in woody materials: the Fungi! And don't forget that even the humble fungus is decomposed after life by the two bacterial pathways.

Hügelkultur offers wonderful possibilities for multi-purposed recycling of woody materials (see PcD #101, "Raised beds—permaculture style: Hügelkultur 101" by Diana Sette).

And now there is biochar: a thermochemical, rather than bacteriological recycling pathway (see PcD #92, "A Great Chain of Benefits: 55 Uses for Biochar" by Kelpie Wilson and Hans-Peter Schmidt).

Biochar certainly returns some long-lasting carbon to the soil, and it does handle woody materials. But the process releases huge quantities of solar energy as heat, and many other soil nutrients are volatilized in the process, and these losses are greater in poorly designed systems. Energy-wise, biochar systems might do well to include utilization of all that wasted heat. In temperate climates, there might be a "biochar season" in colder months, and the heat could be usefully directed. Nutrient-wise, biochar is said to greatly increase the nutrient and water storage capacity of soils. So a biochar saturated with compost tea, vermiculture liquids, or digester effluents would greatly kick-start the benefits. It's largely a matter of trying to understand and manifest the potential long-term symbioses. Δ

heat necessary to maintain their metabolic processes.

In contrast, anaerobic digestion systems require the exclusion of oxygen (O_2). Therefore, the most important consideration is some sort of gas-tight containment vessel. Water saturation is almost always chosen as the means to exclude O_2 from the process, although there are exceptions. Since digester feed slurries may vary from <1 to >15% solids, the vessel or lair must also be robust enough to contain the hydraulic pressure. The second major consideration for anaerobic digestion systems is temperature. Anaerobic digestion produces insignificant heat. The photosynthetic energy in the organic feedstock is transformed into the energy in the chemical bonds of methane (CH_4) which is released upon combustion.

So as a series of biological processes, digester activity is highly dependent on temperature. Over the last couple of eons, millions of species of anaerobes have evolved to exploit the earth's oxygen-free ecosystems, both internal and external. The activities of hundreds of thousands of anaerobic species are generalized to suggest these nice, smooth ideals. All these anaerobes do have their favorite conditions, but most can and do adapt to gradual, moderate temperature changes. For most biogas systems (aka, domestication of dragons), a mesophilic temperature seems most appropriate (35°C or 95°F). The following graph describes the effect of differing temperature on mesophilic digester activity. At 95°F, reasonably complete digestion occurs in about 19 days. At 75°F, it takes >30 days for the same level of decomposition, and at 55°F, it takes about two months. At lower temperatures, some activity does continue, but the beast may be considered to be hibernating. Even if frozen, digesters tend to return to (vigorous) activity as they warm (with implications for permafrost).

Creating symbiotic inter-relationships with digesters is far simpler in tropical climates, where ambient air and earth temperatures are more supportive of reasonably active systems throughout the year. But food scraps and other discarded organic materials tend to occur in temperate climates as well. If we have to deal with this surplus organic stuff, why don't we investigate a biological means to both make use of the huge residual of solar energy and conserve all plant nutrients for the next cycle of growth at the same time? The trick is to somehow keep digesters warm during temperate winters. And NO…. the biogas produced will not be sufficient, but there are other alternatives…. of design, etc.

Energetic differences between aerobic and anaerobic digestion translate into heat losses. Aerobic composting releases most of the organic materials' embodied solar energy as heat. Certainly, there are many ways to make further use of this heat, rather than cavalier release to the atmosphere, but most often this heat is indeed wasted. Anaerobic digestion produces little to no heat, but releases the photosynthetically ensnared energy as natural, renewable, combustible methane gas.

Material differences are also important considerations. Both pathways prepare the organic material's carbohydrates for long-term incorporation into the soil. Through composting, many embodied organic nutrients may be lost through volatilization due to composting heat and/or rainwater leaching. In most situations, the final product can generally be handled as a dry material. In contrast, through a well-fed digester, all nutrients, except for a bit of sulfur (as H_2S) are conserved in the effluents to feed into the next cycle of growth. Digestion systems generally produce liquid and semi-solid effluents. Whole system designs can take full advantage of gravity flows, but pumps and/or manual handling are almost always necessary at some points.

Benefits of anaerobic digestion

Biogas systems offer a broad range of benefits:

● Nutrient conservation. All nutrients going into a digester are available in the effluents (except for a small amount of sulfur released as H_2S, and some N_2 if the digester feed is imbalanced), thus providing a full spectrum of plant nutrients in the effluents and reducing or eliminating the need for chemical fertilizer inputs. There are certainly many examples of problems resulting from the uncontrolled over-abundance of nutrients: ocean dead zones, algae blooms, eutrophication, etc. However, I suggest that, in more consciously designed systems, the more biologically active nutrients that are conserved from one growth

Permaculture Design #104 May 2017
www.PermacultureDesignMagazine.com

cycle to feed into the next, the greater the opportunities to help create an increasing spiral of life.

● Soil regeneration. Residual organic compounds in the digester liquid and semi-solid effluents increase the humic content of agricultural soils.

● Sanitation. When allowed to go toward completion, anaerobic digestion results in total destruction of many disease vectors that may have been present in the feed materials, with significant reduction of most others, including the most recalcitrant (e.g., Ascaris and other roundworm eggs). Also, the digestion process does not introduce any new pathogen vectors because the anaerobes do not survive in the presence of O_2.

● Odor control. Digestion largely consumes the volatile compounds (what we smell from organic residues). Digesters and their effluents certainly have an earthy odor—these dragons are like any other livestock—but it seems to be quite far less objectionable than that of undigested residues.

● Fly and rodent control. Insects and rodents are generally not attracted to digester effluents—there is no food value left.

● Weed control. The digestion process reduces the viability of many weed seeds in feed material.

● Natural gas. And if all this were not enough, digestion also results in the production of natural gas—without fracking. With adjustments, this biogas (generally 65% CH_4, 35% CO_2,

Biogas for Energy and Education at the Dickinson College Farm

Matt Steiman, Assistant Manager, Dickinson College Farm
Project Leader, Dickinson College Biofuels

Dickinson College in Carlisle, PA, began experimenting with small biogas systems in 2008, when we embarked on a lab-scale system using 2 L (1/2 gal.) bottles as biodigesters to test gas production from different feedstocks. This project, while cumbersome, gave us the bug when we made our first bit of burnable gas from a sheep manure slurry. The following year, a student intern built our first plug-flow digester out of a tractor inner tube. We cut the inner tube to make a sausage shape, plumbed an inlet and outlet pipe into each end, and placed the digester in an insulated, heated box. Within about two weeks, we had enough gas for the student to fry bacon and eggs on a crude home-made stove—Eureka! It was clear right away that a moderately sized (25 gal., 100 L) plug-flow digester is much easier to manage than a small bottle digester—the larger volume and regular turnover of materials were more conducive to a healthy microbial population.

The following year, a second student intern built a larger digester, a 500 gal. (2,000 L) unit made from reinforced EPDM roofing membrane (or pond liner) that we glued into a burrito shape, with various ports for passage of fluids and gas. Our notable innovation for this project was using plumbing floor flanges bolted and caulked through the EPDM membrane to make gas and water-tight seals that held for several years. This digester unit, nicknamed “Frijolcoatl—the Beany Serpent”—was installed in an insulated trench in a dedicated small greenhouse. After much trial and error with elaborate pumping systems, we settled on a gravity-feed method for adding slurry made from diluted cow manure, biodiesel glycerin, and some food scraps. Frijolcoatl was highly productive during the warm seasons and gave us enough gas to cook student lunches on the farm or give demonstrations to school groups on low-tech renewable energy production from waste. Another group of students experimented with small cascading ponds to make use of the nutrient-rich effluent from the digester to grow aquatic biomass plants.

After several years operating Frijolcoatl, we embarked on a new project following the vision of Biogas Bob Hamburg from Omega Alpha Recycling Systems (OARS, www.omega-alpharecycling.com). Together, we designed and built a new 15’ x 30’ (about 4.5 x 9 m) greenhouse dedicated to biogas production. We hired an excavator to dig two 3’ (1 m) deep trenches before the greenhouse went up—these became the foundation for two parallel 1,000-gal. (4,000 L) digesters. These units are made from an intact EPDM tube, with Bob’s uniquely designed plastic end-caps in each end bearing various valved ports for liquid and gas passage. The first unit, called Bathena, was completed in the spring of 2016 and proved to be a big success. Feeding it three times per week during the warmer months, we were able to keep our farm well supplied with biogas for three different kitchens. After startup with a cow manure culture, we ran the digester the rest of the season solely on ground food waste from the college cafeteria. Our production from feeding 50 kg (about 100 lb.) of food waste three times per week was 3-4 m^3 (~100-140 cu. ft.) of burnable gas per day—enough gas to power a single burner stove for about five hours each day; enough that we left our electric stove turned off most of the season. Gas is currently stored and moved around the farm in portable EPDM gas bags on lightweight wooden carts, though we are exploring the possibilities for a more convenient pipeline between the gas shack and various points of use. Our second digester for the greenhouse is under construction now, as are experimental heating systems to keep the project active through the colder months. Liquid effluent from the new digester has been dribbled on our vegetable fields in the off season to fertilize cover crops, and is also distributed to local gardeners by Biogas Bob. We hope to conduct further research on the value of the effluent in the coming year.

In addition to these projects, we have also constructed and used an IBC digester designed by Solar CITIES, and a commercial unit from HomeBiogas in Israel. We continue to use the lab equipment yearly in a digestion exercise for environmental studies students. The possibilities of a biogas project for hands-on educational opportunities and tinkering are literally endless. Biogas systems provide exciting lessons in biology, nutrient management, plumbing, construction, and project safety, to name a few. Students enjoy working with the living system and eating the food they cook with the resulting biogas. ∆

traces of other gases) can be used in any way fossil methane or any other combustible gas is used. Emissions from biogas combustion are similar to those from burning fossil gas, but without the environmental degradation from extraction and transportation. When clean-burning biogas is used to replace biomass or coal as a cooking fuel, indoor air pollution and related health problems are greatly reduced.

Biogas past, present (and future)

There is anecdotal evidence of biogas systems in ages past. Anaerobic sewage treatment applications date from at least the 1800s, and are included in most new installations. Philadelphia, PA, recently increased anaerobic treatment capabilities by 16 million gal. (64 million L) and now produces nearly all the electricity necessary to run the treatment plant. Toward the end of WWII, German (and French/European) farmers turned to biogas systems to maintain their operations. More recently, interest in broader utilization of larger-scale biogas systems was stimulated by oil shocks beginning in the 70s.

Over the past couple decades, larger-scale digesters have begun to proliferate worldwide at sites of large concentrations of organic residues (sewage treatment plants, concentrated animal feeding operations (CAFOs), food processing and food waste management operations). Germany has become a leader in large-scale agricultural digesters, but much of this has resulted from perverse financial incentives/subsidies which seem to justify growing corn crops with the sole purpose of feeding digesters, rather than managing organic residues in a regenerative fashion.

Various digester feeds tend to produce varying quantities of biogas.

Nearly all large-scale efforts are justified by the electricity generation potential of the system. The waste heat from this generation is generally fed back into the digesters to help maintain active temperatures. Liquid and semi-solid digester effluents, although used in one way or another, have largely been viewed as a disposal problem. Over the past decade or so, this view does appear to be slowly shifting, as the potential of digester effluents comes to be more widely appreciated.

However, digesters, especially when symbiotically integrated with other biotechnologies, are appropriate at much smaller and more decentralized scales. There may be tens of thousands of situations in which larger-scale digester systems are appropriate, but there are hundreds of millions of situations where much smaller digesters can have more localized and collectively widespread, regenerative impact. In tropical climates, with design and construction care, ambient temperatures can suffice for adequate year-round gas production from stand-alone digesters. In temperate climates, this is not the case. Digestion activity falls off precipitously as the digesters cool, and the beasts pretty much hibernate below 10°C (50°F). These beasts, even if frozen solid (check all pipes), do tend to return to active lives with the advent of warmer temperatures and gradual re-introduction of feeding.

If one wants year-round continuous digestion in temperate climates, supplemental heat must be provided. How to accomplish this in a regenerative fashion? How to design for symbioses among digesters and other components of permacultural endeavors? OARS (Omega Alpha Recycling Systems, my biogas consulting entity) has always considered greenhouse-digester integration most obvious. Greenhouse temperatures tend to vary greatly. If the excess heat could be transferred to the digester's thermal mass, greenhouse temperatures could be greatly moderated and the digester would be warmed. A well-integrated digester would return this heat to the greenhouse when necessary.

So, yea—the gas is groovy, but the NUTRIENT RECYCLING aspect of digestion provides even greater benefits. Dragon husbandry is a great facilitator of organic materials recycling.

Some notes on biogas possibilities

Nearly all non-woody organic materials may be feed in moderation to an anaerobic digester. All of the above-mentioned benefits will accrue. I strongly suggest that, at a small-farm, homestead, or permaculture level, consideration of installing a digester should be highly analogous to taking on any other type of livestock. The development of smaller-scale digestion systems is quite akin to the domestication of dragons—and I note that there are hundreds of millions of folks worldwide currently participating in the evolution of this process.

Various digester feeds tend to produce varying quantities of biogas. All animal excreta contain lesser biogas potential because the original consumer used much (generally around 2/3) of the energy available (made available, lest we forget, by anaerobes in the animal's own gut!) Thus, there is significantly less biogas potential from manures than from uneaten, far less decomposed organic materials. But that in no way reduces the other benefits of digestion of these materials for nutrient conservation and utilization of the remnants of the embodied solar energy. Unless carefully managed, digesters fed solely on food scraps do have a tendency to go acidic when overfed. The addition of some manures does seem to increase the buffering capacity (pH resilience) of the beasts.

Highly concentrated fats do produce great amounts of gas, but over-feeding such rich materials tends to sicken most digesters not highly engineered and managed to handle them. Generally, dragon feed should have no more than about 5% total fat. Otherwise, goat-bloat-like foaming symptoms may well occur—longer-lasting lipid bubbles that can inhibit biogas release..

Small-scale digester development

I was introduced to biogas systems as a Peace Corps volunteer in Nepal in the 70s. Since then, I've tried to participate in and keep abreast of worldwide development in the field. Currently, there are several hundred million folks around the world involved with development and maintenance/husbandry of smaller-scale digesters. Specific design approaches vary widely, with constant situational adaptation and innovation. However, a huge majority of smaller-scale systems may be encompassed within the following three design approaches.

In general, there are two primary design differentiations. The continuous or batch digester is fed and emptied on a regular basis, whether hourly, daily, or less frequently—more like us and other animals. A batch digester, on the other hand, is filled and emptied all at once (monthly, bimonthly, etc.). Of course, these design approaches are extremes of a continuum, with many viable extended-batch and semi-continuous options. At the extremes, mixed systems are generally large tanks (stomach-like) where all newly incoming materials fully mix with the partially digested material that is already there. Mixed systems have only an average retention time for feed materials, which can range from less than a day to many months. Plug-flow systems are much more like tubes (intestines), where all materials are roughly assured of gradually going through the entire process.

The solar housing is certainly helpful....

The Chinese design

By far the greatest efforts have occurred in China. Since the mid-1900s, China has installed many tens of millions of household-scale digesters, as well as tens of thousands of commune-, community-, city-, and industrial-scale systems. Larger systems have varied considerably in design, but residential-scale has focused largely on a masonry-based, fixed-dome design.

Early on, primary motivations were the sanitation and nutrient conservation aspects of these systems, but the biogas potential soon became a priority. The in-ground masonry-tank system configuration that was developed provides a vessel for digestion as well as adequate gas storage and gas-pressurization for local, household use.

Over the decades and around the world, there has been much success with this design approach. In China, the design has gone through several generations of development. Local stone and brick construction has been replaced by re-usable steel forms and concrete. There have also been tens of thousands of these systems built throughout Asia and beyond.

When well-constructed, this in-ground design can provide very long-term service. But since anaerobic digester activity is so dependent on temperature, these largely buried tanks do best when they are surrounded by warmer earth and air.

The Indian design

This design evolved from British sewage treatment systems of the 19th century and includes a floating drum covering a well/container of organic slurry. These systems may range in size from <55-gal. (200 L) drums to multi-million gallon tanks. The floating drum approach offers gas collection and storage, with adequate pressurization for even community use. Plastic construction has presented many opportunities for smaller-scale systems. There are many concerned Indian and Asian entrepreneurs who are proliferating these digesters.

A recent evolution of this approach has included the replacement of the floating drum with a slightly expandable "fabric," secured to the top of the rim of the tank. This approach has primarily been utilized in electricity-generating medium- to large-scale systems, especially in Europe. However, there have been several efforts at smaller-scale applications. The trick is to get a long-term gas-tight seal between the top of the digester vessel (whatever the material and shape) and the fabric cover. I'm currently working with a farmer in central PA on the installation of such a system in summer 2017, which will be a masonry trough with an EPDM cover.

The sausage design

OARS currently prefers a "sausage" design, where anaerobic re-composition is a multi-stage biological process carried out by a huge variety of microbes, all feeding off the organic residues left by their predecessors, digesting organic materials in sequence. Both the Chinese and Indian designs (and all mixed-tank, stomach-like systems) result in considerable mixing of newly introduced feed materials with those that have been digesting for some time, with a bell-shaped average retention time. In contrast, the intestine-like, sausage approach assures that all feed materials go through the entire re-composition process. Also, while digestion does offer significant sanitation benefits (short of outright sterilization), these benefits correlate strongly with actual time spent within the anaerobic environment. The sausage approach offers far greater assurance that all feed materials experience the desired retention time. For instance, cholera vectors are destroyed by 14 days in a digester—but how to assure that within a mixed digester? While there is some gas storage capacity in the tube, this design does require extra consideration of gas storage and pressurization for use.

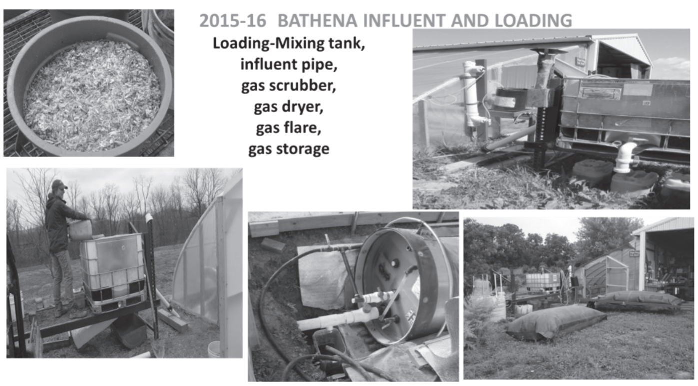
This design approach is proliferating around the world—Asia, Africa, Latin America—and it's the basis for the Dickinson College Farm digester discussed below.

Feasibility of "backyard biogas"

Needless to say, backyards vary tremendously around the world. There have been tens of millions of "home-scale" units built in Chinese agricultural villages. These beasts are generally feed all organic residues from the household—food scraps, field residues, humanures, swine and poultry manures, etc. There are perhaps hundreds of Indian and Southeast Asian entrepreneurs developing backyard, residential, and roof-top variations of floating-drum systems for their domestic markets. African Flexi-Biogas tubular digesters are testing out well in Nepal.

55-gallon drum and inner tube digesters do fine for demonstrating the principle—but so do lighting farts. Gas production from these systems will suffice for boiling water for tea, and they do provide some high-quality liquid fertilizer, but I doubt they are really worth the effort in most situations.

The past 5-10 years has seen the development of smaller systems that may fit into the backyards or basements in residential communities in more (over-)developed areas of North America, Europe, etc. Solar Cities Biogas has largely pursued a DIY approach based on re-purposing international bulk carrier plastic cubes (IBCs) for both digestion and gas storage. The design is constantly evolving. In the Northeast,



Latest biogas system installed at Dickinson College Farm (2015-16): Bathena.

it seems that, when nearly 95°F temperatures are maintained, two IBCs fed all food scraps from a household of four seem to suffice for production of adequate cooking fuel, plus the effluents for regeneration. Hestia offers a geofabric covered tank, which also may suggest much to DIY-oriented folk. And, there is the HomeBiogas System developed in Israel/Palestine—small, well designed system for recycling kitchen scraps at a small-scale. This system is already being copied and marketed in China. The solar housing is certainly helpful and may suffice for warmer latitudes, but without significant heating, these systems will certainly hibernate during cold seasons.

Certainly, loading and unloading a gas-tight vessel is more complex than managing a compost pile! I maintain that, regeneratively speaking, it is well worth the effort. I suggest that a 2 m^3 digester system is the lower end of what might be considered viable backyard biogas-scale.

The Dickinson College story

Through a 2010 David House *(The Complete Biogas Handbook)* workshop I co-organized near Philadelphia, Matt Steiman (Assistant Manager, Dickinson College Farm) and I re-initiated collaboration on biogas efforts.

I have left description of these efforts to Matt, who has overseen the chores required for managing the systems. My assistance has been largely through perseverance in advocating various aspects of the OARS' approach, such as maximizing use of greenhouse heat to warm the digester and making use of digester effluents within the greenhouse.

The second Dickinson beast will have been installed by the time of this reading. It will include some changes based on learnings from the last year's experiences. But it will certainly not be the "final" design—just another step toward learning about intricacies of dragon husbandry.

While I/OARS have been able to contribute bits of labor and a few bucks to Dickinson's efforts, I would hope that my greatest assistance might be seen in the symbiotic approach to digesters/greenhouses—and a bias toward worm-shaped digesters, the next leap forward from the sausage design!

We learned that silicone caulk was not adequate for a long-term seal between the EPDM tubes and the polypropylene endcaps. After I cleaned all this gunk off, Weatherbond water cut-off mastic caulk, carefully applied, has held for over a year. We learned to consider alternative digester heating systems. We learned that gas production can be prodigious. We have not yet learned much of effluent management within the greenhouse…. we have not learned about electricity generation… and many other things. But we figure to keep at it. What else to do?

Resources

Since 1978, the best English-language introduction to biogas systems has been David House's *Biogas Handbook,* although I do have some picayune caveats! I can offer no extensive, meta-references that deal with full utilization of dragon effluents. However, I must reiterate that ALL nutrients (except for a little sulfur) fed to a healthy digester are conserved in the liquid and sludge. Highly diluted (10-20:1) effluents are sufficing to replace chemical alternatives in hydroponic and aeroponic systems. Guess I've been figuring permaculturists would recognize the potentials for dragon husbandry and help manifest and spread word of the possibilities. There are innumerable civil and agricultural-engineering tomes available for far more money. But nearly all their focus is on large-scale systems.

The web offers innumerable and endless research possibilities—just google "biogas." I still consider my omega-alpharecycling.com and dragonhusbandry.com sites worthy of brief historic review and ideas for the future. I also recommend beginning with the contacts and information available through Facebook's "Solar CITIES Biogas Innoventors and Practitioners"—especially for residential systems.

For general and primarily large-scale system information, the US EPA's Agstar website may still be functional, and the American Biogas Council website is expanding (www.americanbiogascouncil.org). Δ

Biogas Bob is the director of Omega-Alpha Recycling Systems (omega-alpharecycling.com) and Dragon Husbandry (dragonhusbandry.com). He promotes regenerative systems like biogas: natural gas without fracking. "Biological Repair NOT a Technological Fix!"