MICROBIOLOGICAL MATRIMONY

COMPATIBILITY OF DIGESTION AND COMPOSTING

Biogas production strips out the odorous VFAs that are problematic to composting, and converts them directly into biogas energy, for which they are biochemically ideally suited. The resulting residue is more readily — and less odorously — compostable.

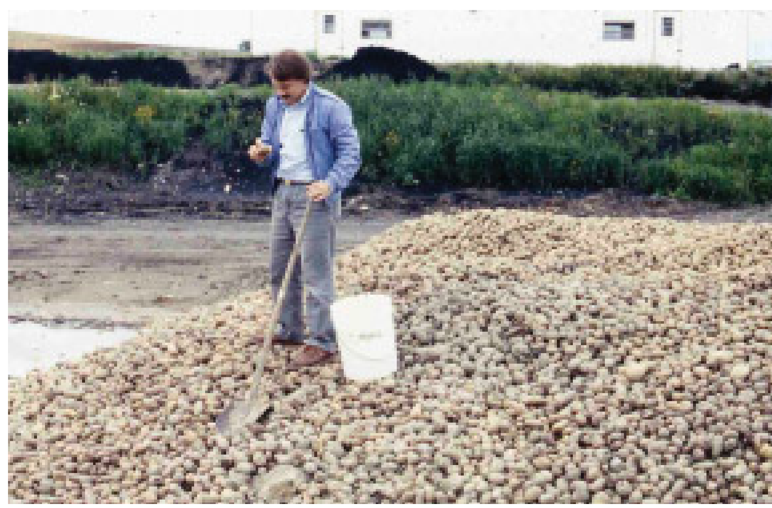
William F. Brinton

CAN organic waste help in the energy picture *and* result in a decent soil amendment product? An emerging view of organics recycling attempts to bridge the divide between returning organics to land from composting *and* capturing their energy content.

This new perspective has been implemented slowly and strongly in European countries over the last decade, uniquely combining biogas capture and composting in dual facilities where composting plays a secondary but indispensable role as post treatment stabilization after energy capture from the fresh feedstock. The approach is being modeled in some U.S. research laboratories such as Woods End and the University of California, Davis, and tested at green waste recovery facilities such as Norcal Waste Systems in California, potato processors in Canada and aquaculture facilities in Maine.

To grasp how this combination works, it is essential to appreciate the underlying microbiology that differentiates composting and biogas technologies, two approaches that for most purposes are diametrically opposite, i.e. aerobic versus anaerobic. Yet, they are compatible, each having strengths in basic biochemical mechanisms the other does not possess. Research and field trials are showing how putting these technologies together gets far more bang from the scrap.

The new mandate goes like this: High energy compounds in organic waste — especially green waste containing grass, manure and food scraps — should first be treated anaerobically to recover intermediary byproducts for biogas (methane energy), and then the residue composted aerobically to prepare a stabilized soil amendment. Ironically, the energy compounds in the raw waste — volatile fatty acids or VFAs — are a core cause of the unpleasant odors in the initial composting phase. An anaerobic-aerobic two-stage process essentially taps VFAs for a higher and better end use for energy production, and creates a less volatile feedstock for composting.



Will Brinton (top photo) identified the thread of volatile fatty acids and their connections to energy production and challenges to composting while researching how to manage record amounts of potato culls in Aroostook County, Maine in the late 1980s.

That's the theory. How this was recognized by Woods End Laboratories, Inc. is a somewhat more circuitous path, beginning in the late 1980s in Maine, following the thread of VFAs, which provide the common link. A decade of robust potato farming in Aroostook County left processors and farms with record amounts of culls — discarded and undersized tubers. Left in large piles in fields and ditches, these became an odor nuisance to surrounding communities, a threat to groundwater quality and a serious vector for potato disease. Earlier attempts at composting had not been successful (see "New Sense of Quality Comes to Compost," *BioCycle*, 1989).

Woods End applied basic biochemistry to explain why previous efforts at composting had failed. Organic acids formed during early rotting of the tubers before compost windrows were formed meant that aerobic microbes could not readily grow. The chief culprit was acetic acid — CH_3COOH — present in such large concentrations that local farmers referred to landspread potato culls as "natural herbicide." The answer was to raise the pH of 4.8 – 5.0 of the pulpy mass before composting. The project went on to be a huge success, resulting in publication of a potato cull composting manual, and the method spread into maritime Canada where Prince Edward Island adopted composting as an official strategy to remediate virus-infected potatoes.

VFA compounds became a focal point for Woods End after this, from the point of view of odor and residual phytotoxicity. Now, 15 years later, this experience with potatoes has run full course, and we are picking up the theme of VFAs and acetic acid for their huge potential for *biogas energy* recovery — a virtual alternative to composting, but not exclusive of it.

These new efforts are not limited to potatoes. Large sources of VFAs exist in virtually all fresh green wastes and especially food scraps, and they are noted as the chief source of odor complaints when things go wrong. As the country heads into a new era of energy awareness and alternative energy production, it is timely to join the processes — biogas capture and composting — together. Biogas production would strip out the odorous VFAs that are problematic to composting, and convert them directly into methane energy. Theoretically, the resulting residue would be more readily — and less odorously — compostable.

BASICS OF BIOWASTE MICROBIOLOGY

A simplified chemical equation for aerobic *respiration* as generally understood for composting is as follows:

$$C_6H_{12}O_6 + ☺ + O_2 \Rightarrow CO_2 + H_2O + \Uparrow \text{energy}$$

where $C_6H_{12}O_6$ is a carbohydrate that with addition of microbes (☺) and presence of oxygen (plus nutrients and water, etc.) yields carbon dioxide, water vapor and released heat energy ($\Uparrow$). In reality, there is also fixed carbon left over, i.e., humus.

As a matter of fact, composting as it occurs is not strictly aerobic for it possesses intrinsically the biological ability for semi-anaerobic fermentation steps at any point in the process. This results from unavoidable episodes of oxygen stress, such as occur in between turnings, during air on/off cycles, in "microclumps" of wastes and biofilms sticking on collection containers. Normally, composting is not disturbed by partial fermentation, since the same organisms that ferment are also "good guys" responsible for aerobic composting. This is due to their "facultative" biochemistry defined as the capability to switch from use of oxygen to alternate nonaerobic respiration, whenever sufficient air is absent. That is, when oxygen is present, they'll be aerobic.

VFA levels as low as 2,000 ppm in composts can exert up to a 50 percent depression on plant seedling emergence. Photo (above) of roots exposed to potato cull wastes high in VFAs illustrates their impact on plant growth.

Woods End worked with Norcal Waste Systems on measuring biogas production during the first stage of composting green waste and food residuals in the Polyflex (Ag-Bag) pods (see Table 1 for data).

In contrast, *semianaerobic fermentation* is typically found in putrescible food scraps or piles of potato culls, and it sets up the theoretical potential to have biogas capture incorporated into composting. In semi-anaerobic fermentation,

$$C_6H_{12}O_6 + ☺ \pm O_2 \Rightarrow CO_2 + CH_3COOH\ (VFA) + H_2O$$

where the same carbohydrates now exposed to reduced oxygen will ferment by-products, in this example, acetic acid. Acetic acid is one of many possible volatile fatty acids that include lactic, propionic, butyric, valeric and caproic — compounds bearing such colloquial names as "milk acid," "rancid-acid," "vomit-acid" and "goat-acid," a vivid suggestion of their potential to be odorants. The volatile fatty acids are the primary products of carbohydrate fermentation in early stages of biogas digesters, as they are in animal rumen.

Key to the argument for utilizing these compounds for higher purposes, organic acids are true "energy storage" compounds, packing a huge amount of ATP energy. (ATP, adenosine triphosphate, is "the universal currency of free energy in biological systems," (Stryer, *Biochemistry* 3rd Edition, Stanford University, 1993.)) The fatty acids are crucial compounds that later convert into CH_4 — methane energy. This is the point where the waste handling paths potentially diverge. One way leads into anaerobic conditions where these energy storage compounds are exploited for their potential hydrogen (H_2) and methane (CH_4) content, The potential is to put all this microbial chemistry together in a chain of processes within a single facility yielding energy and compost.

or into eventual aerobic composting.

The final link in the pathways is true anaerobiosis. This is where bacterial metabolism occurs only after oxygen is totally depleted. On a scale up to 20.9 percent O_2 (ambient air), anaerobic conditions begin only at the low end, or around 0.02 percent O_2. Under these circumstances:

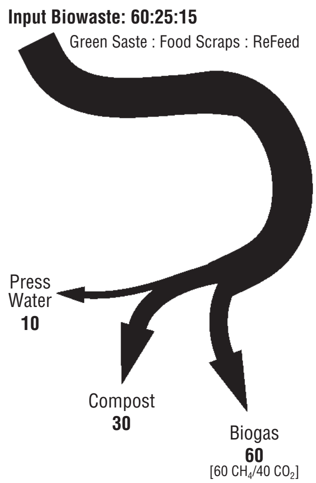
$$C_6H_{12}O_6 + ☺ => CO_2 + CH_4$$

or

$$[Acetate]\ CH_3COOH + methanogen \longrightarrow CH_4 + CO_2$$

where the same carbohydrate or organic acid from semianaerobic reactions now yields "biogas" — a mixture of carbon dioxide and methane.

Figure 1. Carbon cycle, compost/co-digestion facility



In compost piles, anaerobic degradation is not very common, certainly not as much as the loose use of the word "anaerobic" suggests. Anaerobic reactions are significantly constrained by the presence of oxygen — any amount of it — and for this reason methane production is extremely rare in most ordinary cases. Even more so, "methanogenic" processes require specialized, slow-growing organisms uniquely adapted to production of methane in noxious environments.

Laboratory bioreactors (top) provide accurate measures of the bioenergy content in various composting feedstocks. The methane monitor (bottom) provides readings from the bioreactor units.

BIOGAS CHEMISTRY

Exotic names for the bacteria specialized in methane production in fresh wastes include *Methanosarcina* and *Methanobacterium* species, and common names recognized in animal rumen and excreted in manure include *Ruminococcus* and *Clostridium* species, important in first stage fermentation that yield the needed fatty acids. Clostridium species also can be found in composts as spores that will germinate and grow when oxygen is depleted. Although methane production mostly occurs as these organisms consume acetic acid, there are other bacteria organisms present that oxidize the other larger fatty acids down to acetic acid and thus release energy in the form of methane.

The potential is to put all this microbial chemistry together in a chain of processes within a single facility yielding energy and compost. In other words, we are first taking off biogas for its valuable energy content, and then taking off CO_2 in composting and using the expended heat for sanitation, drying and stabilization. The overall scheme is illustrated in Figure 1, a diagram showing the hypothesized carbon cycle of such a facility.

Laboratory biogas reactors provide accurate measures of what can be expected from a particular waste stream, critical information before doing any engineering. There are a number of ways to conduct lab bioreactor assays. Generally these methods are similar to stability tests, but the goal in this case is not to measure oxygen demand — which is in fact zero in anaerobic systems — but to determine potential for combined $CO_2 + CH_4$ production. The gases also need to be separated to understand their purity.

Figure 2 illustrates a typical lab reactor output with raw potato processing sludge. A burst of biogas — all of it CO_2 — is evidenced in the first three days. Then a lag-phase follows as the pH buffering of the system kicks in (the arrow in Figure 2 indicates pH adjustment), followed by the rapid gain of methanogens — accounting for the biogas rate seen from day 10 to 14 — and the continued high level of methane purity (almost 75 percent) even as the rate declines, out to day 30. There's an ideal and an economic point when the brew should be discharged. In this case, after 30 days, the material became feedstock for composting, with much of the odorous VFAs stripped from it. In other words, the final material was now more ideally suited to composting than it was before.

Table 1 summarizes the types of laboratory assays that can be conducted for biogas. Table 2 shows the results of a full analysis of yield and equivalent bioenergy

Figure 2. Biogas production rate of Canadian potato sludge with and without additional dairy-manure inoculation

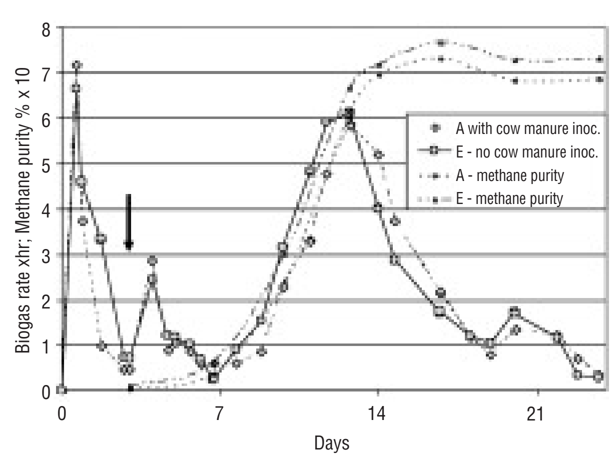


Table 1. Standard laboratory assays employed for biogas capture studies

Type of Lab Biogas Test	Typical Test Duration, Days	Example Of Procedure
ISO Biogas	3	Determines toxicity of substrate
Single batch process	21	Gives quick overview of methane production ability
Continuous process with recurring feed	90	Helps set ongoing proficiency for actual reactors
BM100 – EA UK	100	Determines stability of waste as real alternative to landfill
Continuous process with recurring feed plus biomass recirculation	180	Determines highest potential efficiency for continuous biogas reactions

Highly putrescible raw wastes such as food scraps are particularly useful candidates as methane precursors.

Table 2. Biogas yield data from lab reactors

Material	Initial Moisture %	Biogas Yield Ft^3/Ton Wet	Methane Quality %	Methane Yield Ft^3/Ton Wet	Million BTU/Ton	kwh Rate	Gross Value $/Ton
MSW[1,2]	71	4,202	54.7	2,298	2.30	182	29.09
MSW- garbage mix[3]	50	5,197	35.0	1,842	1.84	146	23.31
Potato scraps	82	2,780	46.5	1,293	1.29	102	16.37
Compost leachate	96	436	61.9	270	0.27	21	3.41

[1]Source: Norcal Waste Systems and Woods End Lab; [2]Commercial source separated organics (food waste and paper fraction); [3]Mixed waste from an Eweson rotary drum plant in U.S.

Table 3. Commonalities and differences in inhibitory microbiology for composting and methane production

Process	Inhibitors Of Process	Most Favored Conditions
Composting	Acidity, VFA, absence of oxygen, too much ammonia (NH_3)	pH 6.5 – 8.5; sufficiency of air, high porosity; optimal moisture and nutrients, heat
Biogas	Acidity, salinity, H_2S, presence of oxygen, some metals, too much ammonia and propionic acid	pH 7.2 – 7.8; homogeneity, constant VFAs; high CO_2, low heat

value of four differing waste streams. What these wastes had in common was a previous acidifying phase in which VFAs were produced — albeit not intentionally. By studying how systems behave — systems that may be regarded as nonoptimized composting — it's possible to project how they can be maneuvered to become high-value bioenergy inputs. To illustrate the usefulness of lab testing, a leachate from a food scrap composting site is included in the table. The leachate exhibited surprising bioenergy potential, i.e., it is possibly an ideal substrate to be injected into a biogas reactor.

GREEN WASTE, FOOD SCRAPS AS IDEAL FEED

Our position is that highly putrescible raw wastes such as food scraps are particularly useful candidates as methane precursors. Rich in complex polymers like protein and polysaccharides, these materials favor a rich variety of bacteria and enzymes. However, under oxygen-limiting circumstances (typical in food waste collection bins, garbage transport trucks, plastic curbside bags) these also cause fermentation to short-chain fatty acids. It is nearly impossible to prevent some amount of fermentation from happening, no matter how well handled and how promptly a material goes into a composting process. (Sometimes, when compost sites are singled out for having produced odors, the truth may actually be that the composting process is simply releasing compounds already present in the waste.)

Methane scientists talk about the necessary "acidogenic" — or acid producing — phase needed prior to methane production. This refers to a hydrolysis phase that initiates fatty acid production. However, it is apparent from our research and field work that food scrap piles already possess features of this acid producing phase. In other words, part of the overall methanogenic process already has taken place in the green waste destined for composting.

For most putrescible garbage, the biological process "sticks" in Phase 1 — production of odorous organic acids, with a commensurate drop in pH (food scraps may drop to pH 4.8 or even lower). Compost organisms, as well as methanogens, are hardly productive at low pH values (one thing they share in common), and both require adjustments. So there are a range of limits and needs as illustrated in Table 3.

While compost systems that become imbalanced and need correction often are easily remedied by remixing and aeration, the same is not necessarily true of biogas digesters, which are more finicky. For this reason, in contrast to compost approaches, methane processes tend to be modeled carefully at the lab bench level before any engineering design begins.

VFA'S ROLE IN COMPOSTING

As noted earlier, the focus at Woods End previously was on managing odor and phytotoxicity attributable to fatty acids, which in levels as low as 2,000 ppm in composts can exert up to a 50 percent depression on plant seedling emergence, and reduce compost heating. But VFAs are not necessarily undesired in composting, even if biogas production is not intended. First, they are important energy storage compounds, and guarantee that in episodes of oxygen stress, the system's energy is preserved and handed over to aerobic organisms later, when favorable conditions return. If the VFA level is not large, and aeration cycles are carefully regulated, the nuisance factor from odor may be kept to a minimum. It may be helpful to think about build up of organic acids in composting similarly to how increases in lactate concentrations typically occur under exercise conditions where the body's rate of energy demand is not met sufficiently by aerobic respiration, i.e., the tissues cannot obtain or process oxygen quickly enough.

In closed-system composting where air flow is entirely dependent on technology, including tanks, drums and Ag-Bag (Polyflex) composting (and possibly other forms of membrane covered piles), lactic acid bacteria are likely to be present (they tolerate aeration), and a low constant level of VFA production — chiefly lactic and acetic — is readily discoverable. Depending on concentrations, this may slightly dampen the process, and thereby extend the composting time. Yet, the flip side is that it confers a buffering against the high pH values found in many hot composts that are responsible for so much loss of nitrogen as ammonia.

Studies conducted by Woods End covering a variety of food scraps, high oil fish wastes and potato culls bear this out, showing how splitting the waste stream to yield energy and compost simultaneously could be an opportunity to kill two birds with one stone. In addition, trials conducted on client sites provide strong evidence that compost made from two-phase systems that have had a VFA-acid phase at one point, attain equal if not higher quality at the end — especially with regard to nitrogen content — when compared to the mass being processed only by high-heat composting from the beginning. Furthermore, introduction of the VFA-acid phase may have actually accelerated the composting phase overall because the feedstocks, especially those with high cellulosic content, were "preconditioned" and decomposed more rapidly and with less odor later under aerobic conditions. VOCs emitted at transition points will be the key challenge.

Composters rightly may ask if the digestate is too anaerobic or if it has sufficient carbon remaining to heat and stabilize the wastes.

SMOOTH TRANSITION FROM ANAEROBIC TO AEROBIC

Composters rightly may ask if anaerobic digester output is compatible at all with composting or soil application — if the digestate is too anaerobic or if it has sufficient carbon remaining to heat and stabilize the wastes. Another important concern relates to whether raw digester output is itself properly sanitized with regard to fecal organisms and potential anaerobic pathogens. Since methane reactions are largely conducted under nonthermophilic (35°C) conditions, the concept of pathogen reduction via higher temperatures must be cautiously approached.

The digester industry is demonstrating how these materials are sanitized by microbial mechanisms other than heating alone; at the same time composters are demonstrating that post-digester treatment by composting provides a further guarantee for stabilization. For example, if a biogas reactor is not accepted as a Process-to-Further Reduce–Pathogens (PFRP), then composting must have enough energy provided from the output to drive the needed heating. Some European rules treat bioreactor output as sanitized compost only when it receives two weeks additional aerobic management. Woods End findings support published research showing that organic acid significantly inhibits pathogen regrowth and *E. coli* expression, potentially a triple-whammy in favor of the two-stage approach.

Important considerations are therefore how to adjust output to be suitable for composting and how long anaerobic traits of digester output persist as the material is exposed to aerobic conditions. Because anaerobic fermentation also is conducted by facultative organisms, the transformation from digesters to aerobic composting is not nearly as problematic as it might seem. The general finding is that aerobic conditions return fairly rapidly, thanks to the buffered pH of methane output, tempered by lowered carbon — meaning less organic matter to stabilize.

It is challenging to flip the whole discussion around and view composting from the perspective of the green-waste biogas industry. From this perspective, composting alone has obvious weaknesses. For example, the carbon-energy of the organic materials, won by considerable photosynthetic effort, is being "wasted" or combusted and released in composting — in fact, much of it as *excess* heat — that is, more heat than is needed to sanitize the material under optimal conditions, and much more than needed to remove excess water formed. While carbon released as CO_2 from composting is biogenic and therefore carbon-neutral, from a farming perspective, too much is released and not enough remains for humus manufacture. Another offset to composting alone is that many of the fats and oils (equal to high energy compounds in the anaerobic view) linger unsatisfactorily as VOCs and phytotoxic VFAs. This is why compost can be odorous and plant-reducing for extended periods of time, with the whole process playing out as a vicious cycle of incomplete degradation leading to unstable end products.

From the biogas perspective, these constraints are not only *not* a problem, they represent ideal preconditions for energy capture. In contrast to composting, anaerobic digestion does have a positive energy balance in a lifecycle analysis. A ton of organic waste has potential to produce about 5,000 ft^3 of biogas. Table 2 presented earlier shows the range of values from a variety of materials. Add to that the final value of the end compost with its enhanced nutrient availability.

This view has led the Woods End team along with clients handling green wastes, the Maine aquaculture industry and potato processors, to explore multiple technologies for energy capture and composting, essentially restirring the pot. The working model seems to be that the final compost output has the same if not higher value than if the methane phase had not been performed at all. The carbon cycle diagram (Figure 1) helps make this whole process clear.

In summary, some of the downsides of either composting or traditional anaerobic digestion are improved upon by a combination of the two. In composting, VFA production leading to VOC emissions, and high heat leading to ammonia emissions, are now strengths for biogas production. The only details that remain are how to select and build the right technology combinations and how to deal constructively with existing — and hopefully temporary — political obstacles to alternative energy that have thus far under-valued gaseous bioenergy in America.

These new approaches have been successfully demonstrated, but have not been economically exploited. Fortunately, the barriers that have traditionally separated methane production from composting, i.e., the moisture factor and the equipment required, have been completely bridged. With more experimentation, it is very likely that we will see further breakthroughs in this area. In the not too distant future, composting facilities (and biogas facilities) will all contain a mixture of recovery technologies sharing much of the same equipment. ■

Will Brinton is president of Woods End Laboratories in Mt. Vernon, Maine (www.woodsend.org).