May 2013
Policy Brief No. 005

Biological Biomass: Present and Future Applications

Darrell McGie

Introduction

Biological Biomass uses microorganism functions and processes to provide useful, efficient, and quantifiable work. This illustrates the basic function of biological biomass: using forms of biological chemistry to maximize the functions of natural processes. Examples of purposeful work include: 1) reduction (decomposition) of solid and liquid wastes; 2) production of secondary energy products via biological fermentation/conversion processes, such as ethanol and hydrogen; 3) mitigation of harmful environmental impact (bioremediation); 4) secondary energy production processes (cogeneration); and 5) the dissociation of specific cellular functions and components of particular organisms (bacteria and algae) that, under scalable conditions, provides an opportunity to generate specific, marketable products.

This brief narrows the focus of biological biomass to two areas of consideration – one in the present and one in the future. The first is *digester-based biogas production* presently used in cogeneration applications. The second is an introduction of new research on *cellular dissociation*. Here, a specific diatom is being examined for its ability to produce marketable products. At first glance these two topics may appear unrelated, but the arena of biological biomass research is comprised of many conceptual options for future application. This brief intends to discuss possible *pathway connections* between the two, especially in the realm of future renewable energy systems (e.g. electricity generation, fuels, thermal production). Lastly, this brief includes general discussion of current regulatory parameters affecting biological biomass. Subsequent research will seek to design a regulatory framework that retains important environmental protections, yet allows for more harmonious renewable energy production, economic incentives to initiate projects, and innovative mechanisms to finance those projects.

Anaerobic Bacteria and the Production of 'Biogas' for Cogeneration

Anaerobic bacteria are ancient forms of life that evolved prior to oxygenation of the earth's atmosphere, and thus can exist in an oxygen-free (anaerobic) environment. They function as decomposers and, under conditions of optimal environment (temperature and food source), reproduce exponentially. A byproduct of the decomposition process is a methane-rich gas (referred to as 'biogas') that is utilized as a feedstock fuel for cogeneration technologies.

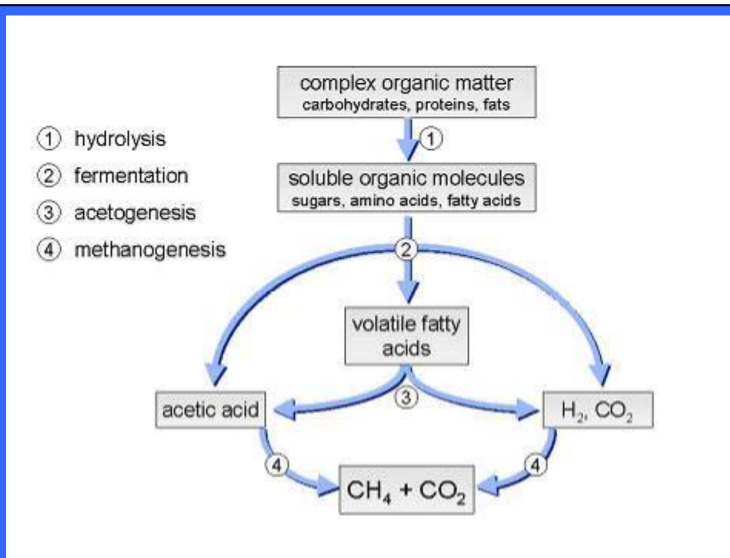

Figure 1. Anaerobic digestion process of four bacterial groups

Source: IWEA

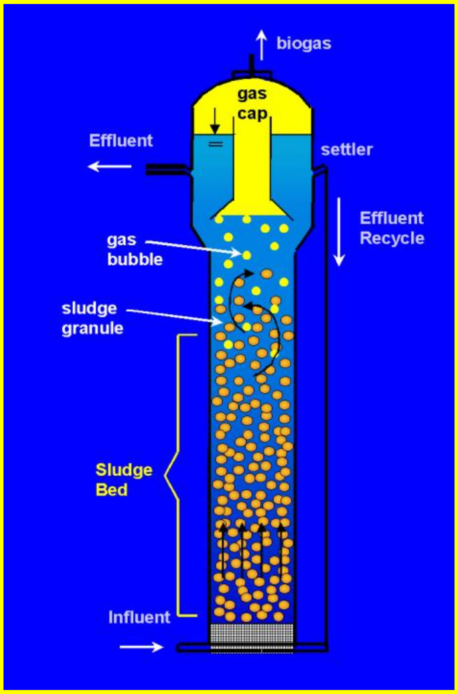

Figure 2. Re-circulating upward flow

Source: Field. 2003.

Figure 3. Anaerobic digester at the City of Corvallis Wastewater Treatment Plant
Source: D. McGie

There are four distinct groups of anaerobic bacteria in the digestion process (Figure 1), each having a distinct function in the decomposition process. The first group is ***hydrolytic bacteria*** that break down complex organic molecules into soluble sugars, amino acids, fatty acids, and glycerol. The second group, ***fermentive bacteria***, convert the above products into organic acids (acid-forming), alcohols, and ketones. The fermentive process varies depending upon temperature, pH, and redox potential. The third group of ***acetogenic bacteria*** converts the fatty acids and alcohols into hydrogen, carbon dioxide, and acetic acid. The final stage of decomposition by ***methanogenic bacteria*** produces methane from the acetic acid. The end result is the formation of a useful fuel commonly referred to as biogas, which is combustible due to the methane component (USDOE 2004:n.p).

The process is applicable to any agricultural, animal, human or food waste material produced at a scale that justifies the capital cost of necessary equipment and the effort to survive the regulatory approval process. The technology is of particular interest to confined animal feeding operations (CAFO) that generate significant wastes and face regulatory pressure to reduce their environmental impact. Governmental incentives designed to help offset costs exist as well, though uncertainty about the amount and time span is a concern (USDA. 2009:13).

The combustion of biogas (also referred to as digester gas) is best accomplished by maximizing production capability by using an anaerobic 'digester' tank. The tank is typically a large, enclosed vessel that effectively allows the anaerobic bacteria to consume solid biotic wastes (Figure 2). The type and size configuration of digesters depend on the type of waste (Figure 3). Spatial separation among the varying groups of bacteria is a key factor for efficient conversion of solids to biogas production; vigorous mixing is required (Vavilin. 2005:113).

Since the desire is to maximize loading and capacity over time, the challenge for anaerobic digester systems is to maintain stable operation. This requires close monitoring of system disturbances, such as overload and temperature, and electronic control of the digester processes. Experience with various digester configurations indicate that properly designed electronic control systems, based on simple and available sensors (using a pH electrode and gas flow meters), are able to respond rapidly to disturbances, control tasks at different time scales, adjust flow rate, update production parameters automatically. In other words, digester technology maximizes the efficiency of biogas production by manipulating the physical, spatial, and chemical characteristics of this particular group of bacteria (Liu 2004:189).

Present-day cogeneration technologies that pair biogas with a reciprocating engine have a proven track record of reliably providing electricity, except in the instance of equipment failure due to siloxane damage (Figure 4). The failure is due to the combustion of biogas. Digester bacteria do not reduce or consume siloxanes, which are found in detergents, shampoos, deodorants, and cosmetics. Instead, siloxanes accrete onto internal moving parts over time and cause significant mechanical failure.

Removing chemical contaminants in biogas, whether in the wastewater treatment process or in dairy installations, is a

Reciprocating engine

A reciprocating engine is simply a very large internal combustion engine engineered to efficiently uses biogas as a fuel. A properly sized electricity-producing generator is physically attached and powered by the engine. Problems with engine occur when siloxane deposits accumulate internally and cause structural damage to moving components.

Siloxane Deposits

Burned Valve

Figure 4. Reciprocating engine and siloxane-related damage.
Source: D. McGie

critical focus. Contaminants that limit cogeneration capability (and cause equipment failure) increase maintenance costs and reduce biogas production (Graening 2003:2).

Facing such known limitations during the transition from present technology, is a reason why conducting further research is important for the future of biological biomass. Conceptual application of potential future solutions, as described in the next section, is a good example of how the field of study is evolving.

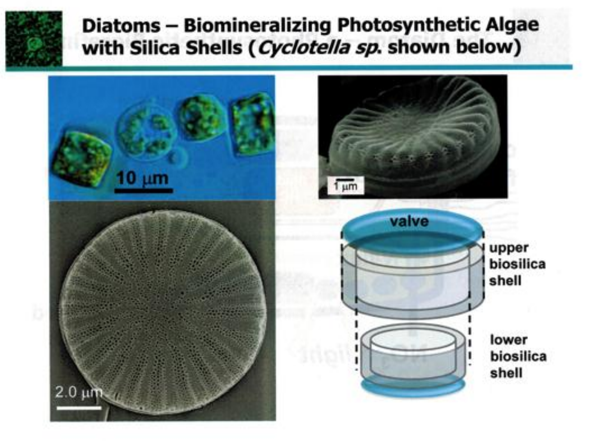

Figure 5: Microphotograph of the diatom showing actual size, shape, and characteristics.

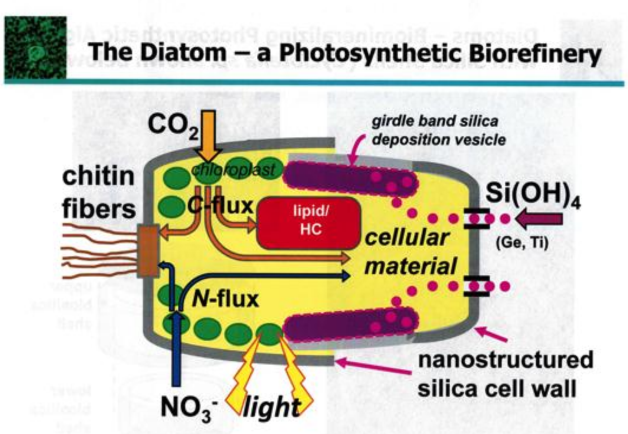

Figure 6: Section drawing of functional components of the diatom.

Research on Future Biological Biomass Products[1]

An OSU research project harnesses the unique biosynthetic capacity of the diatom, a type of algae that extracts silicate from the ocean to create its silica-based cellular walls. A section drawing to identify cellular components is shown in Figures 5 and 6. The diatom functions in the natural state by processing silicon ($Si(OH)_4$) from its surrounding saline environment, to girdle its exterior shell with a band of protective silica. The diatom also formulates a lipid partially derived by intake of CO_2. Propulsion by the organism is accomplished by controlled vacillation of chitin fibers. All three components (silicon, lipid, and chitin) are the focus of the research because they comprise important materials having potential market value.

[1] (Note: The following information was provided by Dr. Rorrer during a personal interview conducted on March 16 for the purpose of exploring research on future biomass applications.)

A research team led by Dr. Gregory Rorrer identified three diverse product streams as shown in Figure 7 (next page). First, the diatom yields metal oxide nanomaterials with marketable value in the electronics industry. Second, harvesting cellular hydrocarbons derives a potential lipid-based biofuel. The biofuel is analogous to the lipid-based fuels found in biodiesel products. Third, chitin microfibers are harvested through a process of hydrolysis to yield glucosamine, a medicinal compound having value in the present commercial market.

A process of cultivation began once the three identified products were shown to be extractive. The team designed scalable systems using an approach to mazimize the growth potential of the diatom. Using lab measurements and computer scaling alorithims, the team predicts commercial viability for the glucosamine and metal oxide nanomaterials. Marketing a biofuel from lipid production remains an open question because of the relatively low yield capability of the process, but at a minimum, the derived biofuel could be utilized for energy generation to help offset production process costs.

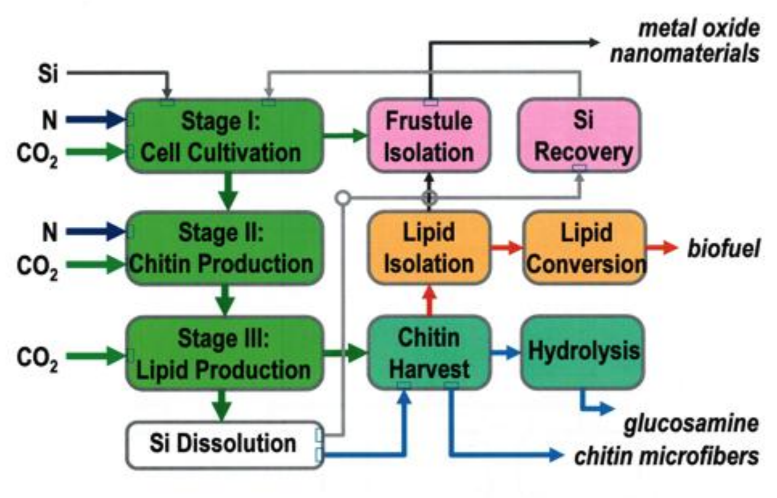

Figure 7: Three potentially marketable products OSU research team.

Source: Dr. Gregory Rorrer, School of Chemical, Biological, and Environmental Engineering, Oregon State University

Research on future applications, such as the diatom example described, could offer additional biomass opportunities by providing marketable products. Unfortunately, the desire to directly harvest marketable fuels for energy applications remains elusive. Additional policy analyses should help understand why. The present day limitations will undoubtedly change, as future applications become known.

Regulatory Overview

Cogeneration and combustion of biogas serves as a good model to examine regulatory complexity and capital funding concerns. Biogas digesters are subject to multiple regulatory requirements, including Federal and State permitting for solid waste handling, transportation, and disposal under the *Resource Conservation and Recovery Act*. The combustion of biogas is subject to air quality regulations while water quality is protected under *Clean Water Act* (surface waters) and the *Safe Drinking Water Act* (subsurface impacts). Proponents of a digester-based cogeneration technology, public or private, face additional oversight challenges during permitting and zoning process. What may at first seem like a good idea – turn waste into renewable energy resource – quickly becomes a problematic exercise. Also, *procedural uncertainties and waste regulations* affect capital financing opportunities and thus have an impact on timely implementation (USEPA 2012:13).

One of the most perplexing aspects of regulatory oversight is *air quality*. Without a digester to process waste, gross amounts of methane-rich gas are suspected of being freely emitted without regulatory oversight. Without capture, there is no viable regulatory mechanism available to limit such non-point source emissions. However, biogas is a captured waste product and identified as a point source under law and thus subject to air quality oversight. Therein lies a perversity of regulatory limitation: raw emission of climate-impacting methane with no ability to regulate versus biogas for cogeneration (and a source of renewable energy) that is subject to strict regulatory oversight. This conflicted juxtaposition provides a ripe opportunity for further research and recommendations.

Proponents of biogas cogeneration also *struggle to find allies in the environmental community*. For instance, the Sierra Club views digester technology through its lens of CAFO concerns (environmental and social damage associated with CAFO operations) (Sierra Club 1993:n.p). While CAFO concerns are certainly admirable, opposition to digester technology by such a large sector seems somewhat disingenuous given the multitude of impacts such operations present when they do *not* try to reuse their waste stream. The Sierra Club does endorse small-scale digesters “on smaller farms which are working towards adopting…potentially sustainable practices” but how such farms acquire the finances to implement such technology, given the dominant ideological opposition and regulatory restrictions, is an open question.

In conclusion, the intent of this brief is to begin a pathway of discussion to address policy concerns surrounding biological biomass, which enjoys policy support but faces perverse regulatory barriers. Also, the environmental community is selectively supportive. Both actions limit capital acquisition for digester-based cogeneration projects. Research on future biological biomass opportunities, though largely theoretical, appears to offer the potential for a variety of products. This biomass sector may require extensive research to assist with implementation.

References

FAO. N.d. Renewable biological systems for alternative sustainable energy production. Chapter 1 – Biological energy production. Produced by Agricultural and Consumer Protection. Retrieved online from http://www.fao.org/docrep/w7241e/w7241e05.htm#TopOfPage

Field, J. 2003. Anaerobic Granular Sludge Bed Technology Pages. Retrieved from http://www.uasb.org/discover/agsb.htm#egsb

Graening, G.J. 2003. Detecting Siloxanes in Sewage & Landfill Biogas. MSW Management. Retrieved from http://www.mswmanagement.com/mw_0303_detecting.html

Liu, J., G. Olsson, B. Mattiasson. 2004. *Control of an Anaerobic Reactor Towards Maximum Biogas Production.* Water Science and Technology. Vol. 50. No. 11. p. 189-198. IWA Publishing.

Oregon Department of Energy (DOE). 2004. *Digester Technology*. Retrieved from http://egov.oregon.gov/ENERGY/RENEW/Biomass/biogas.shtml

Rorrer, G. 2013. The School of Chemical, Biological, and Environmental Engineering. Oregon State University. Personal Interview.

Sierra Club. 1993. SIERRA CLUB GUIDANCE: METHANE DIGESTERS AND CONCENTRATED ANIMAL FEEDING OPERATION (CAFO) WASTE. Retrieved online from http://www.sierraclub.org/policy/conservation/methane_digesters.pdf

US Department of Agriculture. 2009. Cooperative Approaches for Implementation of Dairy Manure Digesters. Research Report 217. Retrieved online from http://www.rurdev.usda.gov/rbs/pub/RR217.pdf

US Department of Energy (USDOE). 2004. *Methane (Biogas) from Anaerobic Digesters.* Retrieved April 23, 2005 from http://www.eere.energy.gov/consumerinfo/factsheets/ab5.html

US Environmental Protection Agency (EPA). 2012. Technology Market Summit. Case Study for Participant Discussion: Biodigesters and Biogas. Retrieved online from http://www.epa.gov/agstar/documents/biogas_primer.pdf

US Food and Drug Administration (USFDA). n.d. n.p. Retrieved from http://www.fda.gov/ora/inspect_ref/itg/itg36.html

Vavilin, V.A., I. Angelidaki. 2004. *Anaerobic Degradation of Solid Material: Importance of Initiation Centers for Methanogenesis, Mixing Intensity, and 2D Distributed Model*. Wiley InterScience.