Institute for Energy and the Environment
Vermont Law School
164 Chelsea Street, PO Box 96
South Royalton, VT 05068
802.831.1151

ANAEROBIC DIGESTION AT COMPOST FACILITIES IN VERMONT[1]

Objective

The prospect of combining anaerobic digestion with a composting business in Vermont is particularly timely: this project can serve as a model for how the entire state of Vermont manages its organic waste stream. With the advent of Act 148, renewable energy, and pollution of waterways as hot-topic issues, there has never been a better time to invest in anaerobic digestion (AD). This system has the potential to integrate policy areas previously separated. The company will close loops and identify synergies in municipal solid waste, water quality, renewable energy, business, and food production spheres. To have a demonstration of a high-quality economically feasible and environmentally beneficial closed-loop system will be invaluable to the state as it strives to meet its sustainability goals. This project has the opportunity to be that model.

This paper addresses ways in which a compost business in Vermont can manage the liquid effluent byproduct from the anaerobic digestion of food waste. Because the exact specifications of the digester and in turn the nutrient make-up of the liquid effluent are unknown at this time, this paper makes recommendations for the design of the digester to maximize the opportunities for on-site management. The recommended on-site solution is the combination of a high-rate anaerobic digester (an up-flow anaerobic sludge bed) with a constructed wetland and greenhouse. This style of digester is an appropriate pretreatment option for constructed wetlands and allows for a reduction in the size of wetland required, thereby reducing cost and increasing the likelihood of the success of the system. The authors are unable to determine the cost of this system due to its highly site-specific nature. More detailed cost estimations will have to be undertaken by technology and design firms. The proposed on-site solution has the benefit of truly closing the loop on the food waste management cycle. Off-site solutions, however, have costs that are easier to quantify and reduce the managerial and regulatory oversight required by the company. The off-site solution considered is to dispose of the liquid effluent at a wastewater treatment facility. Unfortunately, solutions that manage the effluent off-site can burden already stressed systems, such as municipal wastewater treatment facilities and farmers, and serve to perpetuate the stigmatization of organic matter as purely waste. With proper consideration,

[1] The Vermont Law School Energy Clinic at the Institute for Energy and the Environment does not offer legal advice. Please consult with legal counsel licensed in the appropriate jurisdiction on how best to apply any recommendations contained herein.

design, and deployment of applicable technology, on-site management of the liquid effluent is not only possible, but is environmentally preferable.

State Regulatory Considerations

State officials in Vermont are dealing with multiple environmental issues. Three key programs are currently in place to deal with major resource concerns, including Act 148, the generation of renewable energy, and the clean-up of the state's waterways. Anaerobic digestion of food-waste and the on-site management of the liquid effluent are central to the spirit of these efforts and it is important to make these affinities abundantly clear to state officials.

Act 148: In 2012, the Vermont State Legislature unanimously passed Act 148, the Universal Recycling and Composting Act. The legislature passed the law with the intent to manage *materials* rather than *wastes*[2]. Compost companies are already intimately familiar with materials management. Organics recovery realizes the benefits of resource conservation and greenhouse gas reductions and additionally those resources will be doing more than nourishing the soil. AD is a step further for organics management to energy generation.

SPEED program: Vermont established the Sustainably Priced Energy Enterprise Development (SPEED) program in 2005 to encourage the development of renewable energy projects in the state. In 2009, Act 45 revised much of the original SPEED program to include a standard offer component. The standard offer acts as a feed-in tariff and guarantees qualified generators of renewable energy long-term contracts for fixed prices with the utility. In 2015, the legislature amended the definition of "renewable energy facility" under the SPEED program to include food-waste anaerobic digesters, citing the implementation and compliance challenges of Act 148 as a major driver.[3] The only food-waste anaerobic digester project currently participating in the standard-offer program will receive 20.8 cents per kilowatt-hour generated. The standard offer program specifically reserves 500MW for food-waste AD, with the possibility of an additional 500MW depending on price and competition from other qualifying facilities. This recent acknowledgement and the inclusion of food-waste AD in the SPEED program show state approval for these kinds of systems. In 2015, Act 56 was passed by the legislature and included anaerobic digesters utilizing food waste in the definition of what qualifies as renewable energy. Act 56 also transfers ownership of renewable energy credits from standard offer projects to utilities <u>except for projects using methane from agricultural operations</u>.

Vermont's Clean Water Act: In 2015, the Vermont Legislature passed Act 64, Vermont's Clean Water Act. The law is a recommitment to the standards established by the federal Clean Water Act and appropriates funds to help farmers, loggers, and towns reduce runoff into waterways. Though the Lake Champlain clean-up effort may be the headline grabber,

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[2] Report to the Vermont Legislature: Solid Waste Infrastructure Advisory Committee
http://www.anr.state.vt.us/dec/wastediv/solid/documents/SWIAC2014/SWIACReportFINAL.PDF

[3] Vermont Public Service Board Docket No. 7873. February 17, 2015.

this law will help keep excess nutrients out of all waterways in the state. Many AD projects to date in Vermont have simply relied upon extra capacity in slurry pits on farms to manage the liquid effluent. It is clear that this strategy is inadequate. For one, aging farm infrastructure cannot guarantee actual containment of nutrients. Additionally, though there are guidelines in place to restrict nutrient spreading to certain weather conditions and times of years, farmers have strict crop schedules and cannot always abide by these regulations. Finding means other than paying farmers to deal with large amounts of concentrated nutrients would go a long way toward improving the health of Vermont's waterways.

Treatment of the Liquid Effluent

As mentioned above, the specifications of the digester, and thus the nutrient make-up of the liquid effluent, are currently unknown. The liquid effluent will, in any event, certainly be nutrient rich (i.e., contain phosphorous and nitrogen) and will likely have elevated levels of suspended solids, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and other contaminants. The liquid effluent therefore cannot be directly discharged into the waters of the United States, such as the Winooski River which runs near the proposed facility and subsequently into Lake Champlain. Instead, it must be treated off-site or on-site.

Off-site Treatment

The Montpelier Wastewater Treatment Facility (MWTF) on Dog River Road in Montpelier is located approximately 10 miles from the proposed facility in Moretown. The MWTF treats and disinfects wastewater which is then discharged into the Winooski River. MWTF charges a minimum of seven cents ($0.07) per gallon for leachate and five cents ($0.05) per gallon for non-leachate wastewater disposal. The cost may be as much as 30 cents ($0.30) per gallon, however, depending on the specific content of the liquid. Thus, the cost would range from $150 to $900 to dispose of 3,000 gallons at the MWTF.

The company will need to deliver the liquid effluent to the MWTF by either transporting the liquid effluent itself or paying for a transportation service. There are several wastewater hauling companies that service the region surrounding the facility for a fee of 10 cents ($0.10) to 30 cents ($0.30) per gallon (see Appendix "A"). This would add an additional cost of $300 to $900 for 3,000 gallons, for a total cost of disposal between $450 and $1,800. (See Table 1, below, for calculations of present value for the cost of transportation and disposal over various numbers of years.) The transporter will be required to possess the necessary permits, licensing, and insurance for transportation of the liquid. The company will likely need appropriate permitting as a generator, however, which should be included as part of the construction of its digester.

PRESENT VALUE FOR TRANSPORTATION & DISPOSAL OF LIQUID EFFLUENT AT WATER TREATMENT FACILITY

# of	Cost of transportation plus disposal per gallon.					
Years	$0.15	$0.20	$0.25	$0.30	$0.35	$0.40
5	$31,396.51	$41,862.02	$52,327.52	$62,793.03	$73,258.53	$83,724.04
10	$73,745.71	$98,327.61	$122,909.51	$147,491.41	$172,073.31	$196,655.22
15	$130,868.42	$174,491.23	**$218,114.03**	**$261,736.84**	$305,359.65	$348,982.45
20	$207,918.40	$277,224.54	**$346,530.67**	**$415,836.81**	$485,142.94	$554,449.07
25	$311,847.28	$415,796.38	$519,745.47	$623,694.57	$727,643.66	$831,592.75
30	$452,031.77	$602,709.03	$753,386.28	$904,063.54	$1,054,740.79	$1,205,418.05

Interest rate: 6% Gals. per day: 3,000

Table 1. Present Value Calculation for Transportation and Disposal of Liquid Effluent

To self-transport the liquid effluent, the company would need to purchase a tank truck, such as a septic truck or similar. Alternatively, it may be able to utilize a liquid tank trailer. Either option may require special permits and licensing. The cost of septic trucks, which generally can haul between 3,000 and 5,000 gallons of liquid, range from $50,000 for an older, well-used truck to $150,000 and above for a new one. It is likely that the company would be able to purchase a good-conditioned used truck for $75,000 to $100,000.

Rather than purchasing a tank truck, the company may be able to use equipment it already owns to haul a ball-and-hitch type liquid tank trailer. The price for such a trailer with around 3,000 to 5,000 gallon capacity can range from $5,000 to $30,000. The image below is an example of a used trailer with three (3) 2,800 gallon tanks on a ball-and-hitch trailer with a 2" liquid pump. The asking price for this trailer, which is located in Montana, is $12,500. The cost of a larger, fifth-wheel type trailer which can haul as much as 9,000 gallons and more ranges from $25,000 to $100,000. A fifth-wheel trailer must be pulled with a large tractor-truck and is therefore not recommended. As a potentially more cost effective alternative to purchasing a tank trailer, the company may be able to utilize its skilled personnel to purchase or build a trailer and attach a container and pump to the trailer.

Figure 1: Ball-and-hitch trailer.[4]

Comments about Wastewater Treatment Facilities

Current wastewater treatment facilities are technologically complicated, financially expensive, and energetically wasteful. Towns and cities pipe sewage wastewater to

[4] Image from TruckPaper.com, Sandhills Publishing Co., found at http://www.truckpaper.com/listingsdetail/detail.aspx?OHID=5828797 (accessed on Dec. 12, 2015).

processing facilities where it undergoes a series of treatments intended to purify the water back to acceptable standards. Law requires these facilities to treat sewage to "secondary standards," which equates to a removal of 85% of suspended solids and biodegradable material.[5] In typical treatment processes, aerobic bacteria break down organic matter with the input of massive amounts of energy to oxygenate the sewage. What happens to the other 15%? The majority of sewage treatment facilities in the U.S. simply dilute the remaining phosphorous and nitrogen and discharge into waters of the United States.[6] Unfortunately, many places still believe that "the solution to pollution is dilution." Not only does this practice require large capital investments in tanks and pumps and huge inputs of chemicals and energy, it does not provide a high degree of purification. Treatment plants handle the water and the nutrients within it as two burdens, instead of as assets.

For these reasons, the off-site solution is not recommended. On the other hand, constructed wetlands (CW) and bioremediation are low-tech, comparable cost to conventional treatment facilities, and require minimal energetic inputs.

Constructed Wetlands and Bioremediation

Constructed wetlands are treatment systems that use physical, chemical, and microbiological processes to remove nutrients and pathogens from wastewater.[7] Plants growing in a gravel substrate take up nutrients, while the gravel harbors microbiologic activity that destroys many pathogens. However, constructed wetlands call for careful design considerations to ensure their success in the face of problems like clogging, space requirements, and cost.

Substrate clogging is a common problem that stifles the performance of constructed wetlands. The organic loading rate, gravel size, and total suspended solids are the main factors that affect the incidence of clogging in constructed wetlands. Therefore, pretreatment of wastewater entering CWs is recommended to prevent clogging. Several studies indicate that the use of an anaerobic digester to pretreat wastewater in a constructed wetland is more effective than typical pretreatment options such as septic tanks or Imhoff Tanks. High organic loading rates contribute to the growth of sludge production in the gravel substrate. The sludge either originates from the influent or remaining organic matter contributes to bacterial growth in the CW. The accumulation of sludge in between the gravel reduces the performance of the wetland. By controlling the organic load received by the wetland, clogging can be controlled. Studies suggest a maximum loading rate of 20gCOD/m^{2}d to avoid clogging in a vertical flow CW.[8] To further optimize CW performance, larger gravel can be used, which delays clogging longer than small gravel. Though fewer studies exist to determine exact suspended solid load, the type of digester

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[5] Jewell, William J., *Resource-recovery Wastewater Treatment*, American Scientist 82.4 (1994): 366–375. Web.

[6] Ibid.

[7] Ruiz, I., et al., *MUNICIPAL WASTEWATER TREATMENT IN AN ANAEROBIC DIGESTER - CONSTRUCTED WETLAND SYSTEM*, Environmental Technology 29.11 (2008): 1249-1256.

[8] Winter, K. J., and D. Goetz, *The impact of sewage composition on the soil clogging phenomena of vertical flow constructed wetlands*, Water Science & Technology 48.5 (2003): 9-14.

recommended has been proven to remove 63-79% of total suspended solids in a pilot project.[9]

The issues of space and cost are intertwined. CW systems can be sized to specifications of the water they will be treating. The less intensive the process of nutrient removal has to be, the smaller the CW can be. Combining the CW system with AD reduces the wetland area by as much as 90%, though more typically, area reductions are in the range of 30-60%.[10] The footprint of AD systems is very small, they have low operating costs, and their construction costs are similar to that of CW alone, so the combination of the systems is better than either in isolation. AD combined with CW reduces sludge generation, effectively lowers organic loading rates and removes total suspended solids, and reduces cost and area required when compared to CW alone.

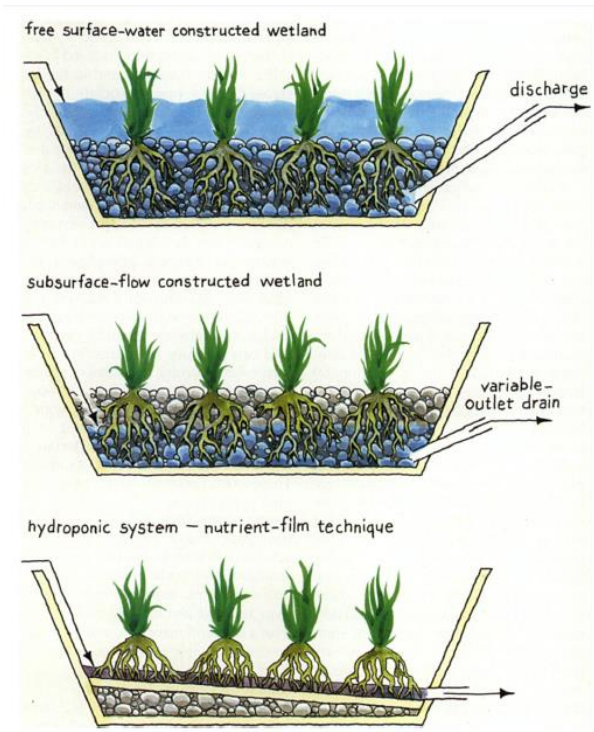


Figure 2: Nutrient film technique.[11]

An approach taken by one researcher in Ithaca, NY combines AD technology and a sort of constructed wetland called nutrient film technique (NFT). Typical CW systems are either free surface-water (FSW) or subsurface-flow (SSF) systems. FSW systems are typically deep ponds in which the water is released at the surface and aquatic plants grow up and out of a gravel substrate at the bottom of the tank. In SSF systems, the water is released into the gravel substrate and the plant roots take up the nutrients. NFT systems are hydroponic and a shallow layer of water is fed to the plants, which are supported by their own root mass. There are no problems with substrate clogging as in the other systems and atmospheric oxygen reaches the plants' roots easily, requiring no mechanical aeration. (See Figure 2, at left, for further clarification.)

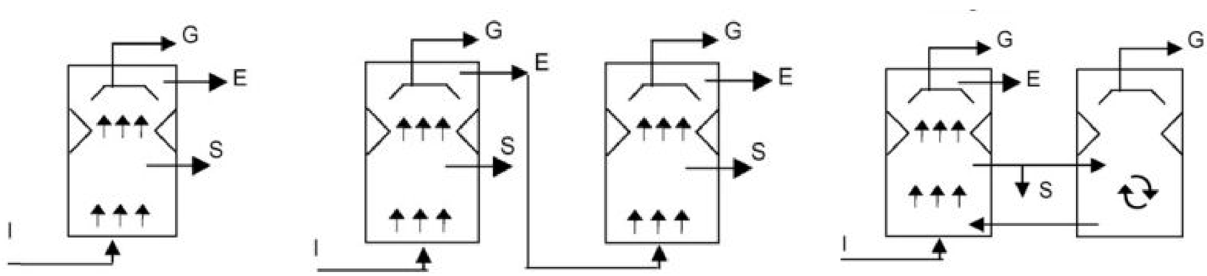
Digester Design

[9] Álvarez, J. A., et al., *Performance of a UASB-digester system treating domestic wastewater*, Environmental Technology 25.10 (2004): 1189-1199.

[10] Álvarez, J. A., I. Ruíz, and M. Soto, *Anaerobic digesters as a pretreatment for constructed wetlands*, Ecological Engineering 33.1 (2008): 54-67.

[11] Jewell, William J.. *Resource-recovery Wastewater Treatment*, American Scientist 82.4 (1994): 366–375. Web.

The most commonly used anaerobic digestion technology for domestic sewage treatment is the upflow anaerobic sludge bed reactor (UASB).[12] In this process, liquefied organic matter enters the bottom of the digester and rises until it meets a solid-liquid-gas (S-L-G) separator. The solids remain in the digester, resulting in a sludge accumulation that is periodically purged in a one-step system (Figure 3.1). The liquids separate from the methane gas that is collected and processed. Two-step UASB systems are either UASB-UASB or UASB-CMSS (Completely Mixed Sludge Stabilization). Specific to this situation, it may be beneficial to purge the accumulated sludge after just one UASB processing and add that organic matter to the composting process. A two-step UASB digester may also be attractive for its higher efficiency of methane conversion. A UASB-UASB (Figure 3.2) process takes the sludge and the liquid effluent from the S-L-G separator and processes it again in an additional UASB digester tank, collecting any additional methane produced. A UASB-CMSS digester (Figure 3.3) takes the sludge resulting from the UASB digester, homogenizes it, collects the resulting methane, and then returns the sludge to be reprocessed in the original UASB digester tank. These engineering considerations are important when sizing the wetland and determining payback. The two-step process will generate more methane but will have higher investment in digester infrastructure. The single-step process may be desirable if looking to augment the composting input stream and to reduce AD investment. However, the methane generation potential is lower for the single-step process and high levels of volatile fatty acids and total suspended solids remain in the liquid effluent, requiring a more in-depth constructed wetland design.



3.1: One-step UASB **3.2: Two-step UASB-UASB** **3.3: Two-step UASB-CMSS**

Figure 3: I, Influent; E, Effluent; G, Biogas; S, Sludge.[13]

Proposed Solution: On-Site Management

The proposed solution for this project is the on-site management of its liquid effluent with the combination of a UASB-CMSS reactor with an NFT constructed wetland.

We recommend a two-step UASB-CMSS digester to enhance the biodegradation of the influent food-waste substrate and to increase the methanogenic activity through increased mixing of the solid sludge. UASB-CMSS digesters were shown to remove 46-53% of chemical oxygen demand (COD) and 63-79% of biological oxygen demand (BOD) and

[12] Ibid, FN 8.

[13] Ibid.

reduce volatile fatty acid (VFA) concentration for volumes of almost 7,000 gallons.[14] Furthermore, the volume of the CMSS digester can be lower relative to the UASB digester, reducing investment when compared to a two-step USAB-USAB system. The UASB digester operates at ambient temperatures, while the CMSS digester can be set anywhere from 30 to 35°C with a resulting effluent pH of 7.27.[15] These conditions are suitable for combination with a constructed wetland.

The NFT system sets plants on an impermeable, inclined surface on which the nutrient-rich water flows. Eventually, the plants develop large root masses that hold the plants in place. All terrestrial plants can be grown this way and the nutrient ratios required by the plants are less limiting than in substrate-based systems. This system eliminates problems with substrate clogging, so less attention needs to be given to the exact characteristics of the digester effluent.

Plants like cattails are a good option for the first step in the CW, as they have the ability to remove substances with high oxygen demand from the water. After the cattails remove BOD and bacteria, more sensitive plants with higher commercial value can be grown. This system can take place in a greenhouse that operates year-round in Vermont, is entirely self-contained, and requires little energy aside from the sun. The energy generated by the AD and the revenue from the commercial plants will offset costs of the system. Any residual liquid coming out of the constructed wetland can simply seep into the ground through the outdoor nutrient flow beds, though the system can be sized so that the irrigation needs of the plants are met by the influent amount. Another idea is that any excess liquid can be stored in the greenhouse in large tanks painted black to provide thermal mass to help moderate the temperature of the greenhouse throughout the year and act as a back-up water source if needed. (See Figure 4, below, to see what the combined UASB-CMSS NFT system might look like. See also Appendix "B".)

The pilot system running this project accepted up to 10,000 gallons (40 cubic meters) per day, with no changes made to the temperature or content of the wastewater. The system was able to reach secondary-discharge standards at a hydraulic depth of application of 40 centimeters, but at depths of less than 10 centimeters per day, the BOD and SS were reduced to less than 5 milligrams per liter. With loading rates at 1.5 to 2 centimeters per day, the total phosphorous levels in the effluent were less than 1 milligram per liter and nitrogen levels less than 2 milligrams per liter. For nutrient removal efficiencies of more than 80%, a space of 40 square meters per cubic meter ($40m^2/m^3$) of wastewater flow per day is required. Using the 3,000 gallons in our scenario, the space required for the NFT beds would be less than a quarter of an acre (i.e., 3000 gallons*.003785 gallons/1 cubic meter = 9 cubic meters * 40 square meters = 960 square meters per cubic meter = 0.237 acres). The system would fit comfortably where the current greenhouses are located on the property, with easy access to the nearby powerlines.

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[14] Álvarez, J. A., et al., *Performance of a UASB-digester system treating domestic wastewater*, Environmental Technology 25.10 (2004): 1189-1199.

[15] Ibid.

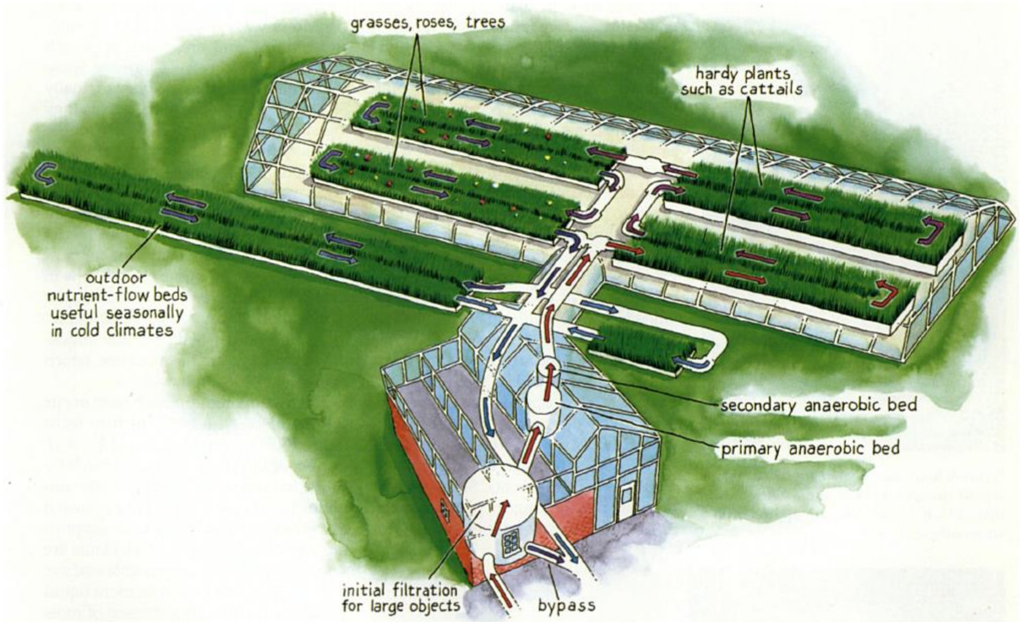

Figure 4: Combined UASB-CMSS NFT System.[16]

Next Steps

If the company accepts the recommendations herein, the Energy Clinic would like to continue assisting the project moving forward. For example, next semester the Energy Clinic can draft a Request for Information (RFI) and/or a Request for Proposal (RFP) to build a system such as recommended and get a better evaluation of the costs associated therewith. We can also aid with the initial permitting process, including cost analysis. With information from the specific technology, once identified and selected, we can better estimate methane generation and its projected revenue. Similarly, we will be able to estimate earnings from the commercial section of the greenhouse. These figures will give a clearer picture of the payback period of the proposed design and its feasibility.

Thank you for allowing us the opportunity to work with you. We look forward to the possibility of assisting you going forward.

Paige Heverly and Doug Cortes
Institute for Energy and the Environment
Vermont Law School Energy Clinic
December 2015

[16] Jewell, William J., *Resource-Recovery Wastewater Treatment*, American Scientist 82.4 (1994): 366–375.

Appendix "A"

Wastewater Hauling Companies[i]

Company	Price Estimates
Hartigan Company Middlesex, VT (802) 223-3452 Contact: Paul	4,000 gallons –10 cents per gallon
P&P Septic Service Williston, VT (802) 658-6243 Contact: Darrin	1,000 gallons – 29 cents/gallon 3,000 gallons – 20 cents/gallon

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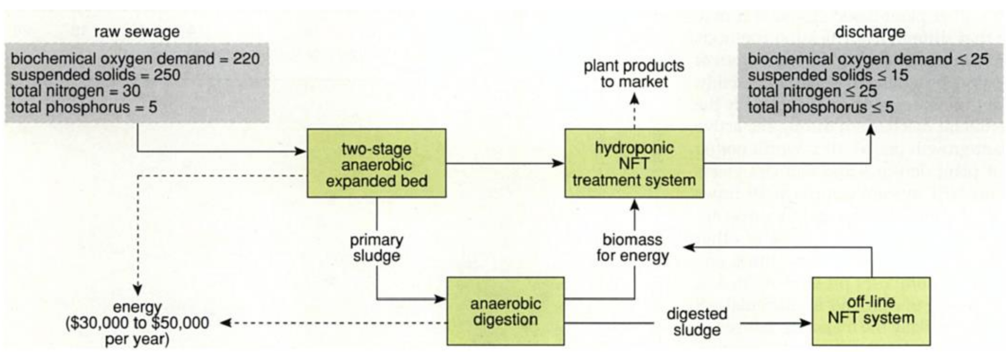
Appendix "B"

Diagram of AD NFT System at 10,000 Gallon Load[ii]



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[i] Estimated prices, not actual bids, for transportation of liquid effluent only; does not include the cost of disposal.

[ii] Jewell, William J., *Resource-Recovery Wastewater Treatment*, American Scientist 82.4 (1994): 366–375.