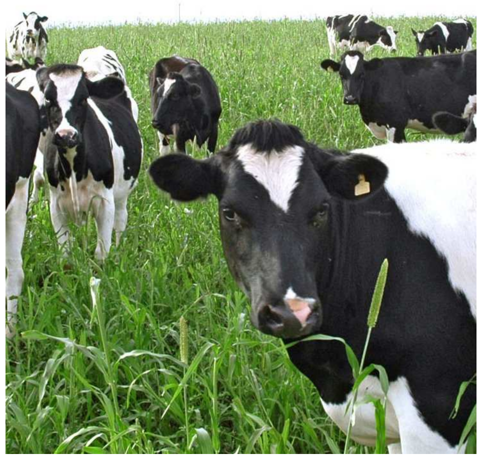
Woodstock Anaerobic Digester
Business Center Plan



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Woodstock Anaerobic Digester Business Center Plan

I. Executive Summary

Brief description

The Anaerobic Digester Business Center (ADBC) maximizes profitability from gas and effluent produced from the anaerobic digestion of dairy cow manure and reduces the potential for non-point source pollution from nutrients generated by farming operations while being compatible with and supportive of the core dairy farm business operations and finances.

Purpose of plan

This business plan is presented to support decision-making for investment in an anaerobic digester operated as a business center within the established family owned dairy farm LLC to manage manure and associated by-products produced by the farm's 700 lactating cows.

Outcomes and benefits

The ADBC integrates a digester and by-products into daily farm operations to:

1. Manage dairy manure in a sustainable, environmentally responsible manner that does not add nutrients beyond the capacity of the farm's land and crop resources to utilize.
2. Ensure compatibility with the farm's core dairy business and infrastructure.
3. Produce minimum labor and financial impact on core business.
4. Reduce cost of core business inputs.
5. Generate income and grant offsets to capital and operating expenses.
6. Avoid and reduce community nuisance impacts.
7. Maximize by-product value.
8. Enhance the farm's community image.
9. Develop by-products from digested manure that move nutrients off the farm.
10. Reduce greenhouse gas emissions.

II. Business Description

The Anaerobic Digester Business Center (ADBC) is compatible with and supportive of the farm's core dairy operation. The ADBC maximizes profitability from gas and effluent produced by anaerobic waste digestion and reduces the potential for pollution from nutrients produced by farming operations. A plug flow digester will decompose dairy manure from lactating cows into products useful to the farm and which can be sold off the farm to off-set costs and to reduce nutrients on the farm. This type of digester is suitable for decomposing dairy manure and is less expensive to build and less complex to operate when compared to a complete mix digester.

In contrast to a complete mix digester, the ADBC does not involve the farm in an auxiliary waste management business that would require a considerable investment of time and resources in identifying, negotiating and acquiring tipping contracts, assuring regular feedstock deliveries, dealing with odor and other nuisance issues, monitoring solid waste regulations and permits, managing increased truck traffic to and from the farm, and handling by-product packaging, storage, marketing and distribution. The ADBC digester uses farm generated waste—straw or sawdust (not sand) bedding—and has the capacity to handle similar waste from the farm's heifer barn and neighboring farms. Importantly for by-products, consistency in feedstock is assured, which not only ensures consistency in the volume of gas produced, but also in the nutrient and fiber content of the effluent, making soil amendment products more predictable and thus more marketable. Integral to the ADBC is a system for cleaning bio-gas to produce bio-methane.

Once up and running with the support of outside grants, the profitability of the ADBC is dependent on careful management of equipment, labor and other inputs and the production, sale and use of four by-products: gas, electricity, fibers and fertilizer.

1. Low BTU bio-gas produced by the anaerobic decomposition of dairy wastes will be cleaned to make high BTU bio-methane.
2. The clean gas will fuel an engine generator-set (gen-set) to make electricity and connect to the grid to off-set farm electricity costs. Clean fuel will reduce operating and capital costs associated with the gen-set and create opportunity for market diversification in the future.
3. Half to three quarters of the effluent from the digester will be separated, with digestate fibers recycled and used as bedding by the farm's milking cows, saving the cost of purchasing straw, sawdust and similar materials.
4. Separated liquid will be recycled through the plug flow digester. Excess will be stored with unseparated effluent and applied to crop land to maintain soil quality and saving fertilizer, lime and manure-spreading material and labor costs.

Management of the ADBC will require the training and attention of one employee. The plug flow digester, storage systems and equipment as proposed in *The Woodstock Nutrient Management Feasibility Study* produced by Wright-Pierce in Phase 1 (July 2007) will need to be engineered and specified for the farm site.

Financing requires a mix of public and private funds to accomplish environmental objectives, especially in the context of the lowest farm milk prices in 30 years.

The ADBC integrates digester and by-products into the farm operation to:

1. Manage dairy manure in a sustainable, environmentally responsible manner that does not add nutrients beyond the capacity of the farm's land and crop resources to utilize.
2. Ensure compatibility with the farm's core dairy business and infrastructure.

3. Produce minimum labor and financial impact on core business.
4. Reduce cost of core business inputs.
5. Generate income and grant offsets to capital and operating expenses.
6. Avoid and reduce community nuisance impacts.
7. Maximize by-product value.
8. Enhance the farm's community image.
9. Develop by-products from digested manure that move nutrients off the farm.
10. Reduce greenhouse gas emissions.

III. Technology

- A conventional plug-flow anaerobic digester is recommended for these reasons:
  1. Used to digest slurries having a solids content of 8 to 14%, typical of dairy manure.
  2. Less capital intensive and less complex to operate when compared to a complete mix digester.
  3. Does not get the farm into the waste management business—adding waste other sources, negotiating and acquiring tipping contracts, assuring regular waste deliveries, increasing truck traffic to and from the farm, handling and disposal of by-products.
  4. Uses farm generated waste—straw or sawdust (not sand) bedding—with capacity to handle similar dairy waste from neighboring farms.
  5. Consistency in feedstock not only ensures consistency in gas production, but also in the nutrient and fiber content of the effluent, making soil amendment products more predictable and thus more marketable.
  6. Emphasizes the digester as a waste management system vs. an energy producing system.

- A gas cleaning system to produce bio-methane from bio-gas is recommended for these reasons:
  1. Increases electrical power output by 20%.
  2. Lower SO_2 emissions.
  3. Reduces generator-set breakdowns and revenue losses.
  4. Reduces generator-set operating, maintenance and capital expense.
  5. Provides future option to sell electricity at peak demand.
  6. Provides future option to sell bio-gas as a natural gas and propane replacement.

A. Anaerobic Digestion

1. Anaerobic vs. aerobic decomposition

Anaerobic digestion (AD) (also called anaerobic composting) is a biological process in which unstable, biodegradable organic materials are broken down by bacteria in an **oxygen-free** environment. AD speeds up and contains the process of manure decomposition, producing gas and a stable, nutrient rich slurry. The slurry can be separated into liquid fertilizer and moist, fluffy, peat-like solids.

Aerobic composting accomplishes the same end in the **presence of oxygen**. Aerobic composting of manure typically involves mixing dewatered manure with an added bulking agent (wood chips, sawdust, etc.) to produce a similar humus-like substance.

Aerobic decomposition takes place in feedstock piles that are “aerated” by frequent turning to expose materials to oxygen-rich air; anaerobic digestion takes place in a sealed, heated environment (much like the cow’s stomach) that does not contain oxygen. Both processes require the activity of different types of bacteria to break down complex fats, proteins and carbohydrates into simpler elements.

Anaerobic digesters use two types of bacteria. During the digestion process, much of the organic matter in manure is converted to volatile fatty acids (VFAs) by acidogenic bacteria; VFAs are then consumed by methanogenic bacteria to produce methane, carbon dioxide and small amounts of other gases. Nitrogen, phosphorus, and potassium are transformed by these microbial processes, but not destroyed. Only by working together can these bacteria produce the complete digestion of the organic material into bio-gas. Digester heat, pH balance, and feedstock must be appropriate to both sets of bacteria.

Both decomposing processes transform manure into a biologically stable state. Heat generated in both processes destroys pathogens and weed seeds contained in the original manure feedstock.

Anaerobic digestion is more chemically complex and technically demanding than an aerobic composting process. AD requires a smaller footprint and shorter retention time to realize a final, stable product. By producing gas, liquid and solids, AD makes more complete use of the original manure resource.

2. Anaerobic Digester Challenges

On-farm anaerobic digesters have a mixed record of success in the United States. Digesters are capital intensive, difficult to manage and maintain, and used primarily to generate electricity. Operating a digester can detract attention from the farm’s core business and requires added expertise.

Because the gas produced by digestion is ‘dirty’ due to the presence of hydrogen sulfide, generators used to produce energy all too frequently break down or require replacement despite regular maintenance regimes. In states where electricity prices are low or where negotiations with local utilities are difficult, it is hard for farms to justify the investment as an energy generating system. Fear of digester failure due to concerns about management of feedstock is an additional barrier to adoption.

As summarized by Burke (2001),

The rate and efficiency of the anaerobic digestion process is controlled by:

- The type of waste being digested,
- its concentration,
- its temperature,
- the presence of toxic materials,
- the pH and alkalinity,
- the hydraulic retention time,
- the solids retention time,
- the ratio of food to microorganisms,
- the rate of digester loading,
- and the rate at which toxic end products of digestion (organic acids, ammonia, nitrogen, and hydrogen sulfide) are removed.

Success with an anaerobic digester:

- ➢ Begins with a well-engineered design that fits the specific manure management needs of the farm, uses quality components, is properly installed and includes follow-up technical support.
- ➢ Requires training and a staffing commitment to monitor and operate the digester, including daily checks on temperature, pH, gas production rates, and overall function of the digester.
- ➢ Uses a handling system that collects manure every day.
- ➢ Ensures that feedstock is free of ingredients that can kill the bacteria (e.g. antibiotics, fungicides, copper sulfate) or clog the digester (e.g. sand) or contaminate effluent (e.g. herbicides or pesticides like clopyralid or picloram) or damage components (e.g. twine, tools, plastic gloves, etc.)
- ➢ Pays close attention to potential for corrosion of essential equipment.

As AD technology improves, manure odor reduction becomes more important, soil and water resources are enhanced, renewable energy values increase, AD management research and training becomes more available and markets for value-added residual products develop, the future for on-farm AD looks bright.

3. Anaerobic Digestion Benefits

The benefits of AD accrue to farms and communities alike:

- ➢ <u>Reduction in manure volume</u>: Anaerobic digestion destroys more volatile organic compounds and produces more gas than aerobic digestion. Anaerobic digestion reduces the volume of original manure solids by 50 to 60% and concentrates nutrients. Organic nitrogen compounds are converted to ammonia, sulfur compounds to hydrogen sulfide, phosphorus to orthophosphates, and calcium, magnesium, and sodium are converted to a variety of salts. Waste is stabilized, minimizing opportunity for further degradation if stored and maximizing availability of nutrients for plant use when land spread. Liquid effluent is more efficient to pump and spread than raw manure. (Kramer 2004, NRCS 2007, Lazarus 2008, Baadstorp 2004)

- Nitrogen: Because nitrogen (N) in unprocessed manure is not in a form easily accessible to plants, much runs off after land application posing the potential for non-point source pollution. Digesters convert most of the N into ammonia with a negligible loss of N through volatilization. The effluent contains 60 - 80% ammonia. The higher the percentage of N in ammonia form, the less uncontrolled release of N from organic compounds to the soil. Stabilized nutrients maximize fertilizer benefits and minimize leaching losses. (Lusk 1998, Mosher n.d., Martin 2004, 2005, Baadstorp 2004)

- Nutrient balance: Separation of solids from the effluent after anaerobic digestion reduces the mass of nitrogen (N) and phosphorus (P) in the remaining liquid fraction. In one study of a plug flow dairy manure digester this reduction was measured at 18% for N and 38% for P. (Martin 2005, Burke 2001, Baadstorp 2004)

- Odor: Bacteria in the digester significantly reduce odor-causing compounds. The stabilized waste is subject to minimal degradation and associated odor during storage. (Jacobson et al. 2005, Lazarus 2008, Martin 2005, Wilkie 2000a, Wilkie 2000b)

- Weeds: A significant reduction in the survivability of seeds reduces weed growth on cropland fertilized with digestate effluent and the associated cost of pesticides and labor. (Pillars 2003, Allan et al. 2003, Katovich 2004)

- Flies and rodents: Fly eggs are killed during anaerobic digestion. (Pillars 2003) and rodents are less attracted to digested effluent than manure. (Leggett et al. 2001)

- Pathogens: Pathogens like E. coli, Salmonella and Cryptosporidium do not survive the temperatures of the digester. (Harrison et al. 2005, Martin 2005, Topper et al. 2006, Mosher ND)

- Greenhouse Gas Emissions: When manure is stored in pits or lagoons, methane is released into the atmosphere. An anaerobic digester reduces the damaging effects of methane, which is 21 times more potent than carbon dioxide in causing global warming. Under anaerobic conditions, nitrous oxide, another greenhouse gas, is not produced at all: “Given the absence of oxidized forms of nitrogen in dairy cattle manure and the requirement of anaerobic conditions for methane production, the potential for nitrous oxide emissions is nil.” (Martin 2005)

- Oxygen demand: Anaerobic digestion reduces the total volatile solids and chemical oxygen demand in dairy manure which decreases the potential for depletion of dissolved oxygen in waters. These reductions are significant due to the potential for these wastes to enter surface waters by non-point source mechanisms. (Martin 2005)

- pH: Field spreading effluent can increase soil pH with a corresponding reduction or elimination of liming, thus saving labor and cost. (Martin 2004, 2005)

- By-products: Bio-gas can be used for digester heating, bio-drying of solids, electric and steam generation, heating and transportation. The liquid effluent is easily spread on fields as fertilizer at opportune times and in a nutrient-available form for crop uptake, with an associated reduction in manure handling labor and fertilizer costs. Kramer's (2004) study of 16 operational dairy digesters in Wisconsin reported savings in avoided fertilizer purchases ranging from $41/head to $60/head per year. Solids can be recycled on the farm as bedding material reducing the volume of effluent spread on farm soils. When sold to other farms for bedding or to plant growers and as a soil amendment, the amount of N and P applied to the farm's cropland is also reduced.

4. Types of Anaerobic Digesters

Plug flow systems are used to digest slurries having a solids content of 8 to 14%, typical of dairy manure, and are the simplest and least expensive to own and operate. The Hydraulic Retention Time (HRT, average amount of time soluble compounds are retained in the digester) is typically 20 days. A plug flow system needs to be heated. The production of gas is relatively constant due to the constant and consistent stream of manure. Similarly the effluent is consistent in volume and content.

Complete mix digesters process slurries having a solids content of 4 to 8% and generally include use of additional off-site feed stocks such as food wastes, grass clippings, etc. Variable feed stocks create variability in bio-gas production, at times more than the system might be able to handle (Wright-Pierce 2007). Fats, oils and grease (FOG) can create other problems for digester operation: foam, acid imbalance, etc. Altogether a complete mix digester is more challenging and expensive to operate and maintain, is a more costly capital investment, requires more administrative time to secure feed stocks and is more apt to cause nuisance issues (odor, truck traffic, etc.) among neighbors. On the other hand, the ability to digest alternative waste streams can significantly increase amount of bio-gas produced and return substantial income from tipping fees.

B. Bio-methane from Gas Cleaning

The removal of carbon dioxide, hydrogen sulfide and other impurities from bio-gas produces bio-methane with a much higher energy content— 970 BTU/cubic foot vs. 600 BTU/cf +/- for bio-gas—and is comparable to natural gas and propane (Krich et al. 2005).

It can be used on the farm as a replacement in propane fueled equipment and can be sold off-farm to industrial or commercial users of natural gas or propane.

On-farm conversion of bio-gas to bio-methane is just beginning to be an operational reality in the US. The 2,200 head Scenic View Dairy in Fenton, Michigan is successfully cleaning and selling bio-methane from a complete mix digester to a natural gas utility through a natural gas pipeline (and using solids for bedding). An interview with the utility indicated excellent satisfaction with the bio-methane and no problems with either pressure or quality. Using a strategy to take advantage of peak prices in electric and natural gas markets and offset farm electric costs, the farm is also set up to generate electricity from the cleaned gas. (Michigan 2006, Follow-up interviews)

Systems for cleaning bio-gas have a relatively small footprint. Given a 10-year operating life the capital investment compares favorably to the cost of gen-set breakdowns, repairs and 2-year replacement cycle. The cleaned gas increases energy efficiency by 20%. Cleaned gas gives the farm the future option to generate and sell electricity at periods of peak demand, because unlike gen-sets fueled by raw bio-gas, engines can be shut down without risk of failure due to corrosion and easily restarted. Also in the future clean gas could be stored and sold to replace natural gas or propane.

At present the replacement market does not exist. While school buses and tractor trailers retrofitted to run on natural gas can use bio-methane, a review of area schools revealed short bus routes and no fueling infrastructure. And while there are several large distribution companies in the area, there is no ability for a tractor trailer to refuel with natural gas when away from the distribution center.

If natural gas prices increase in the future, the farm could take advantage of the market of large-scale industrial businesses that use propane or natural gas in consistent amounts year-round, by employing a low-tech approach consisting of two 180,000 cf gas tube trailers (one to receive and store gas on the farm; the other to deliver and store gas for the end user) and a hired tractor to transport the trailers from farm to user and user to farm. The AD can hold gas for several hours while the trailers are in transit. The user's propane burner can be regulated to convert back and forth between bio-methane and propane fuels should there be a lapse or short-fall in bio-methane production. Because bio-methane is not liquid it can not be stored in a propane tank; the cost to liquefy would be excessive. Locally, Frito Lay or United Natural Foods are potential future markets.

As far as peak power production is concerned, this may be a possibility in the future with the use of a Smart Meter.

IV. Anaerobic Digestion Business Center
Value-added Products

1. Bio-methane

The typical composition of bio-gas produced by anaerobic digestion of dairy manure is about 60% methane, 35% carbon dioxide along with small amounts (less than 2% each) of hydrogen sulfide (H_2S), water and ammonia. Because bio-gas is highly corrosive (due to hydrogen sulfide and water) and has a low energy density—600 BTU/cf—its uses are limited to specially adapted engine-generator sets (gen-set) and boilers. H_2S concentration can be higher depending on animal diet and the amount of sulfur in farm water. Over 70% of the energy value in bio-gas is lost when converting bio-gas to electrical power. (Environmental Energy & Engineering Co. 2008) Heat produced by the gen-set can be utilized by the digester for heating or drying.

Preventive maintenance of the gen-set fueled by bio-gas is a significant responsibility requiring frequent oil changes (every 300 hours or 12 days) and engine maintenance (e.g. replacing spark plugs, air filters, etc.). By operating the gen-set continuously, the equipment temperature can be kept high enough to prevent condensation and sulfuric acid formation. (Mears 2001) Replacing a gen-set can add as much as $100,000 every 1 to 2 years to the cost of the AD. Since most systems use only one engine, breakdowns without a back-up generator are also costly in terms of lost revenue. While a back-up system should be built in to the AD budget, oftentimes funding programs see the item as redundant. Often called the Achilles heel of AD, many systems cease operation because grant funds are not available to replace a failed gen-set, nor can the farm afford the cost.

For all these reasons, as well as increased BTU output and reduced SO_2 emissions, the ADBC includes a gas cleaning system. Until such time as other markets become viable (see above), clean bio-methane will fuel an ADBC gen-set to convert gas to electricity. Information about the gas cleaning system is available from Richard Callahan (see bibliography).

Safety Concerns:
Hansen (2001) summarized the safety risk from the production of gas in a digester as follows:

> Methane in a concentration of 6 to 15% when mixed with air is an explosive mixture. Since it is lighter than air, it will collect in rooftops and other enclosed areas. It is colorless and relatively odorless, detection may be difficult. Extreme caution and special safety features are necessary in the digester design and storage tank, especially if the gas is compressed. [Compression is not assumed for this project.]

To mange this risk Barker (2001) recommends:

- Buildings should be well ventilated.
- Explosion-proof motors, wiring and lights should be used.
- Flame arrestors should be placed on gas lines leading to burners or engine

carburetors.
- Periodic system checks for gas leaks must be performed.
- Gas detection and alarm devices must be utilized.

2. Electricity

Connecticut has the second highest electricity costs in the United States. These costs are driven by generation service costs (vs. distribution and transmission costs) which in turn are driven by the cost of fuel. The price of electricity follows the price of natural gas. The Department of Energy predicts a long-term increase in energy costs. (Blakey 2008)

As a class 1 renewable-energy producer the ADBC can connect to the grid to take advantage of Connecticut's net-metering statute. Also called 'behind-the meter' it means that the farm in effect runs its meter backward; the savings equate to 18 to 19¢ per kWh. Any net excess generation (NEG) that is electricity produced over and above the farms' use during a monthly billing period is carried over to the following month as a kilowatt-hour (kWh) credit. At the end of an annualized period, the utility will pay the farm for any remaining NEG at the utility's avoided-cost or wholesale rate, averaged at 8¢/kWh in 2008.

In addition the farm is eligible to claim Renewable Energy Credits currently valued at $30 per MW. RECs are calculated from the total production of the renewable energy system, whether or not they are "consumed" on site. To claim the RECs, the farm must have a revenue-grade meter to measure the output of the renewable energy equipment and is responsible for selling the RECs. The farm must register with New England Power Pool Generator Information System, which verifies eligibility. This system ensures that only parties with eligibility are generating the appropriate RECs and that each REC is only sold once. In time a market will develop for small generators to sell their RECs to an aggregator or broker, who will, in turn, sell them to a larger utility or generator that needs them to meet the Renewable Portfolio Standard. (Connecticut Department of Public Utility Control 2009, North Carolina Solar Center 2009, Energy Information Administration 2009)

The carbon credit market is just beginning to develop. Ownership of carbon credits is the same as ownership of RECs, and the marketing of the credits is expected to take a similar direction. Carbon credits can be sold separately or bundled with RECs.

Renewable Energy Production Tax Credits may be available to the farm based on the net sales of energy to a third party. When net metering, the PTC would be based on the net amount of energy purchased by the utility, currently 1¢ per kWh.

Group or "neighborhood net metering" wherein several meters owned by one farm can be included in a net metering arrangement is not yet allowed in Connecticut. It is permitted in Massachusetts and Vermont and soon in Rhode Island. This is policy change that could be taken up as a request to the Connecticut Department of Public Utility Control.

Therefore the farm's two meters would need to be consolidated into one to take full advantage of net metering.

A note on waste heat: It is anticipated that waste heat, in the form of hot water, will be available from the gen-set jacket liquid cooling system and exhaust system. This heat can be utilized in the AD system, for hot water production and/or for heating or drying purposes. Engineering should maximize its use.

3. Liquid

When the digestate or slurry left from digestion is dewatered, the remaining liquid containing 2-3% solids is nutrient rich, odor-free, pathogen-free with significantly reduced weed seeds. The liquid can be stored and land spread as needed, replacing some of the farm's fertilizer costs for corn and hay production, reducing weeding and herbicide costs and reducing lime costs and associated equipment and labor inputs. The liquid retains 40 to 60% of the original nutrients depending on the efficiency of the separation system. (Bonhotal interview 2008, Martin 2005, Burke 2001, Baadstorp 2004) Nutrient testing would be required to assure a proper fertilization regime and would be used to quantify fertilizer, lime and other savings to the farm.

Liquid can be recycled for use in the digester or other farm uses. The Wright-Pierce Phase 1 Study (2007) estimated the plug flow digester would need 9,700 gallons of recycled water (assumes about 10 gallons per cow) to effectively operate, leaving 17,000 gallons per day available to land spread as fertilizer.

At least half of the digestate would be separated into liquid and solid components. The unseparated slurry would be stored with excess liquid and land spread, thereby providing organic soil amendments in addition to fertilizer.

4. Fibers

Separated AD solids, typically called fibers, have the same odor, pathogen, and weed characteristics as the liquid stream and typically come from the separator at about 60% moisture. Fibers are used for bedding and soil amendments.

Estimated fiber production:

- 800 cows (712 lactating and 88 dry) = 5,550,920 pounds of dry (100%) matter manure solids.
- Digestate at 60% dry matter = 9,251,533 pounds of fiber (4,625 tons).
- At 945 pounds per cubic yard (at 60% dry matter) this equates to 9,790 cubic yards produced. Measured in 15-yard dump trucks = 653 loads.

1. Solids as Bedding Material

The principal use of the separated digestate solids will be for bedding the milking herd to replace straw, sawdust or other materials. This produces an avoided cost for the farm. The cost of sawdust has been increasing significantly and availability is becoming a concern. Imported bedding has a negligible effect on the farm's overall nutrient balance such that the substitution of digestate solids for other organic material will not significantly change nutrients in the waste stream. (Cornell 2008) Half to three-quarters of the effluent stream from the digester will be separated and used as bedding material on the farm.

Does the use of fiber as bedding adversely impact udder health or milk quality?

The Cornell Waste Management Institute conducted a multi-farm applied study of the use of solids bedding on herd health. In sum, the Cornell study found that well managed solids "can provide an economic benefit without compromising herd health." (2008)

Farms in the study used different sources of solids: fresh separated manure solids; anaerobic digested, separated solids; and separated partially aerobic composted solids. While the study did not distinguish among solids, digestate solids have several advantages over those from unprocessed or partially composted manure. Solids removed from the digester are pathogen free with a light fluffy character that reduces compaction and is less apt to cling to teat skin. (VanderHaak n.d.)

The five dairies that provided financial data to the Cornell study saved an average $37,000 per year on labor and bedding costs. Considered on a hundred weight basis, savings ranged from a low of 1¢/cwt to a high of 26¢/cwt, with an average of 12¢/cwt. (Bonhotal et al. 2008) The farm with the highest return benefited from off-farm sales of solids.

The study revealed that: (Cornell 2008)

> Sand bedding started out "cleaner" than Dried Manure Solids (DMS) bedding, but once in the stalls, the bacterial load of several organisms was highest in sand……A comparison of bacterial concentrations in unused and used air-dried DMS versus composted DMS did not show composted to be consistently lower and calls into question the value of composting DMS prior to bedding.
>
> Bacteria in the unused bedding had little to no effect on bacteria in the used indicating that bacterial levels in used bedding are more dependent on bacterial levels in the manure of the cows using the stalls and how well the stalls are scraped, rather than the cleanliness of the bedding before it is placed in the stalls.
>
> Levels of *Streptococcus*, *Klebsiella* and gram negative and positive bacteria were significantly higher on the teat ends of cows bedded on DMS versus those bedded on sand, but Somatic Cell Counts (SCC) and mastitis for those cows did not differ between bedding materials. Although mastitis differed among farm/bedding strategies, bacteria levels and properties of bedding had no effect on mastitis incidence. Lactation number, stage of lactation and SCC were the significant variables. Decreased levels of *Klebsiella* in the used bedding increased the odds of

having an abnormal SCC for one Farm Bedding Strategy (FBS), and decreased moisture and fine particles in the used bedding increased the odds of having an abnormal SCC for a different FBS. For all others, abnormal cell counts were affected only by season, lactation number and milk production.

Concern that continued use of DMS will increase SCC was not borne out using linear regression of 10 years' worth of linear score data. Although 2 of 6 farms showed an increase in linear score while using DMS, it was not different from the change in linear score prior to using DMS.

Lameness was higher in cows bedded on sand compared to DMS.

Photos of DMS bedding are available at: http://cwmi.css.cornell.edu/beddingphotos.pdf

A study of effluent from a plug flow digester on a New York farm reported these pathogen results: (Martin 2004)

> …a mean reduction in the density of members of the fecal coliforms group of enteric bacteria that approached 99.9 percent. For the pathogen, *Mycobacterium avium paratuberculosis*, reduction slightly exceeded 99 percent. *M. avium paratuberculosis* is responsible for paratuberculosis (Johne's disease) in cattle and other ruminants and is suspected to be the causative agent in Crohn's disease, chronic enteritis in humans. No regrowth of either organism during storage was observed. Thus, it appears that anaerobic digestion of dairy cattle manure also can reduce the potential for the contamination of natural waters by both non-pathogenic and pathogenic microorganisms. (page 4)

Similar findings have been reported in other studies (Harrison et al. 2005, Martin 2005, Topper et al. 2006, Mosher n.d.).

2. Other fiber products

As part of the business planning research other uses for fibers were explored: substitute for peat in potting mixes, fuel pellets, compost. While each had merits, none proved to be feasible at this time:

- While the scale of the market matched, the $1 million cost of packaging equipment to prepare the fibers for use by a plant grower made the potting replacement option not economical. Drying, storage and transport were related cost issues.
- An option to use the fibers as produced as a fuel for a biomass boiler proved incompatible with the furnace feed and grating systems. Storage and transport were related cost issues.
- The cost of drying fibers from 60% moisture to 10% to make fuel pellets, along with labor, storage and marketing costs made the product not feasible. Concerns about the potential for salts in the fiber to cause corrosion was another factor.

- The cost of equipment, labor, facilities and marketing made composting fibers not feasible.

For future product and market development, a summary of this research is found in the Appendix.

V. Management

Interviews with operators and designers of digester systems suggest that one suitably trained person can successfully manage a digester, especially in the start-up year. Once the system is tested and functioning and the operator gains experience, it may be possible to cut back labor. However given the importance of keeping all components well maintained and operational, designation of a full-time person is highly recommended.

Operating, output and other records will be maintained. These will be helpful in assessing costs and making recommendations for system improvements.

No packaging, storage or marketing of by-products is envisioned by the ADBC as all will be utilized by the farm.

VI. Facilities and Equipment

A description and layout for a plug flow digester is found in the Phase 1 Wright-Pierce study as well as recommendations for the use of the existing manure pit under the milking barn and the existing lagoon for liquids.

VII. Risk Factors

1. Milk prices are the lowest seen in 30 years. At the same time feed, fuel, fertilizer, and other farm costs have escalated.
2. Grants are absolutely essential to viability. Given farm economics the proposed 59% grant offset may be too conservative. The farm will need assistance to prepare grants and obtain all renewable energy credits.
3. Engineering and operating challenges are real. The ADBC must be sized, engineered and built to the specific site and needs of the farm with adequate training and technical assistance provided by the manufacturer over time.

VIII. Financial Information

1. Funding sources

The success of this business depends on offsetting at least 59% of the engineering, facility and equipment costs of getting the AD up and running.

The Phase 1 Wright-Pierce study identified potential sources of funding. Since that report was prepared, one of the most promising sources is the **Rural Energy For America Program Grants/Renewable Energy Systems/Energy Efficiency Improvement Program (REAP/RES/EEI).** The grants are awarded on a competitive basis and can be up to 25% of total eligible project costs. Grants are limited to $500,000 for renewable energy systems. Eligible renewable energy projects include projects that produce energy from wind, solar, biomass, geothermal, hydro power and hydrogen-based sources. The projects can produce any form of energy including, heat, electricity, or fuel. For all projects, the system must be located in a rural area, must be technically feasible, and must be owned by the applicant.

Another potential source of funds is the **Rural Energy for America Program Guaranteed Loan Program (REAP LOAN).** The REAP Guaranteed Loan Program encourages the commercial financing of renewable energy (bioenergy, geothermal, hydrogen, solar, wind and hydro power) and energy efficiency projects. Under the program, project developers will work with local lenders, who in turn can apply to USDA Rural Development for a loan guarantee up to 85% of the loan amount.

Native Energy (www.nativeenergy.com) purchases the projected renewable energy and carbon credits in advance from farmers to help fund development of anaerobic digesters. The organization should be contacted again when engineering is underway (Jonathon Webb, 802-861-7707).

To stimulate the development of generating capacity in the state, the CT DPUC offers monetary grants and other financial incentives to assist commercial and industrial customers with the cost of installing customer-owned electric generating equipment. (Connecticut Department of Public Utility Control 2008) The three page application takes about two months to approve and if it is approved determines the actual amount of the incentive grant.

While generating facilities that utilize renewable forms of energy are eligible to receive these capital grants, AD projects may qualify for higher incentives through programs offered by the Connecticut Clean Energy Fund, for example through the On-Site Renewable Distributed Generation Program. (www.ctcleanenergy.com)

The Connecticut Environmental Assistance Program (EAP) may be helpful, as it allows for the Connecticut Commissioner of Agriculture to reimburse any farmer for part of the costs that qualify under the EAP in order to maintain compliance with Connecticut

Department of Environmental Protection approved agricultural waste management plan. (http://www.ct.gov/doag/cwp/view.asp?a=3260&q=398986)

The Energy Efficiency and Conservation Block Grant Program (www.eecbg.energy.gov) provides funds to units of local and state government to develop and implement projects to improve energy efficiency and reduce energy use and fossil fuel emissions in their communities. These funds may be applicable as a goal of the program includes: Purchasing and implementing technologies to reduce and capture methane and other greenhouse gases generated by landfills or similar sources.

2. Financial statements

a) Budget Assumptions

1. Herd size starts with 700 milking cows and increases by 6% per year.
2. Inflation rate of 3% per year assumed on electricity price, bedding value, and all expenses except depreciation and interest.
3. Total investment for the digester facility is $1,979,977 based on facility cost projection of $1,687,283 from the Wright-Pierce Study plus an additional $292,694 for the gas cleaner.
4. Grant(s) totaling 59% of the project cost are assumed. This is the level of grant funding required to achieve breakeven cash flow in Year 1 of the project.
5. Bio-gas production of 80 cubic feet per cow per day is assumed.
6. An energy level of 650 BTUs per cubic foot of bio-gas is assumed.
7. Thermal efficiency of 25% (plus 20% improved efficiency due to gas cleaner) resulting in 30% thermal efficiency.
8. It is assumed that 3,412 BTUs is required per kWh of electricity produced.
9. Utilization rate of 90% is assumed in Year 1, reduced by 5% per year as facility ages and requires more repair resulting in more down time.
10. An electrical rate of $0.18 per kWh is assumed based on net metering. Most of this income is in the form of savings to the dairy enterprise on electricity that would have been purchased.
11. Surplus electricity is sold at a wholesale rate of $0.12 per kWh including energy credits based on eight cents wholesale price plus one cent Production Tax Credit plus three cents Renewable Energy Credit. Farm consumption is estimated at 1,286 kWh/cow/year.
12. Bedding savings realized of $60 per cow per year for the farm which is shown as income for the digester enterprise.
13. A five year economic life on equipment and 20 year economic life on buildings is assumed for depreciation and loan term calculation. This results in a blended life of 16 years on the overall facility. Depreciation is calculated based on straight line recovery of the full investment with no salvage value. Principal payment is based on "P+I" over the term of the loan. The loan amount is assumed to be the full investment net of grant funding.

14. Interest rate of 5% per year projected on the remaining balance of the amount financed. It is assumed that all of the net (of grant funds) investment is financed.
15. Repairs are estimated based on 3% of investment amount.
16. Property taxes are estimated at 1% of the investment amount.
17. Fire and liability insurance is estimated at 0.5% of investment amount.
18. Labor cost is based on one full-time operations/maintenance manager at $15 per hour plus 30% for benefits resulting in a $40,000 per year cost.
19. The budgets show an operating loss but breakeven cash flow beginning in Year 1. This is because depreciation expense on the full investment is less than the principal payment on the loan (which is net of grant cost sharing).

b) Proformas

Breakeven Budget

Woodstock Anaerobic Digester Business Center

Projected Income and Expense Statements

		2010	2011	2012	2013	2014
Assumptions:						
Number Cows		700	742	787	834	884
Inflation Rate		3%	3%	3%	3%	3%
Capital Investment		$ 1,979,977				
Percent Funded by Grants		59%				
BioGas Production/Cow/Day (Cu Ft)		80	80	80	80	80
Annual BioGas Production (Cu Ft)		20,440,000	21,666,400	22,966,384	24,344,367	25,805,029
BTU Produced per Year (650 BTU/Cu Ft)		13,286,000,000	14,083,160,000	14,928,149,600	15,823,838,576	16,773,268,891
Thermal Efficiency (with gas cleaner)		30%	30%	30%	30%	30%
Effective BTU's/Year		3,985,800,000	4,224,948,000	4,478,444,880	4,747,151,573	5,031,980,667
Potential Annual kwh Produced (3412 BTU/kwh)		1,168,171	1,238,261	1,312,557	1,391,311	1,474,789
Utilization Rate		90%	85%	80%	75%	70%
Annual kwh Production		1,051,354	1,052,522	1,050,046	1,043,483	1,032,352
kwh Production per Hour of Operation		133	141	150	159	168
Estimated Farm Consumption		900,000	954,212	1,011,465	1,072,153	1,136,482
Price per kwh		$ 0.180	$ 0.185	$ 0.191	$ 0.197	$ 0.203
Surplus Electricity (Sold back @ Wholesale)		151,354	98,310	38,581	0	0
Wholesale Price per kwh (with energy credits)		$ 0.120	$ 0.124	$ 0.127	$ 0.131	$ 0.135
Income:						
Electricity Value (Net Metering)		$ 162,000	$ 176,911	$ 193,151	$ 205,244	$ 209,146
Wholesale of Surplus Electricity		$ 18,162	$ 12,151	$ 4,912	$ -	$ -
Bedding Savings		$ 42,000	$ 44,520	$ 47,191	$ 50,023	$ 53,024
Total Income		$ 222,162	$ 233,582	$ 245,254	$ 255,266	$ 262,170
Expenses:						
Depreciation	16 yrs	$ 123,749	$ 123,749	$ 123,749	$ 123,749	$ 123,749
Interest	5.0% of investment	$ 40,590	$ 38,053	$ 35,516	$ 32,979	$ 30,442
Repairs	3.0% of investment	$ 59,399	$ 61,181	$ 63,017	$ 64,907	$ 66,854
Property Taxes	1.0% of investment	$ 19,800	$ 20,394	$ 21,006	$ 21,636	$ 22,285
Insurance	0.5% of investment	$ 9,900	$ 10,197	$ 10,503	$ 10,818	$ 11,142
Manager/Maintenance Salary		$ 40,000	$ 41,200	$ 42,436	$ 43,709	$ 45,020
Professional Fees		$ 500	$ 515	$ 530	$ 546	$ 563
Miscellaneous Expense		$ 1,000	$ 1,030	$ 1,061	$ 1,093	$ 1,126
Total Operating Expenses		**$ 294,937**	**$ 296,318**	**$ 297,817**	**$ 299,437**	**$ 301,181**
Net Profit (Loss)		**$ (72,775)**	**$ (62,736)**	**$ (52,563)**	**$ (44,170)**	**$ (39,011)**
Cash Flow:						
Add Back Depreciation		$ 123,749	$ 123,749	$ 123,749	$ 123,749	$ 123,749
Less Principal Payment		$ 50,737	$ 50,737	$ 50,737	$ 50,737	$ 50,737
Excess (Deficit) Cash Flow		**$ 237**	**$ 10,276**	**$ 20,449**	**$ 28,841**	**$ 34,001**
Cumulative Excess(Deficit)		$ 237	$ 10,513	$ 30,962	$ 59,803	$ 93,804
Debt Balance	$ 811,791 (initial balance)	$ 761,054	$ 710,317	$ 659,580	$ 608,843	$ 558,106

90% Utilization Budget

Woodstock Anaerobic Digester Business Center

Projected Income and Expense Statements

	2010	2011	2012	2013	2014
Assumptions:					
Number Cows	700	742	787	834	884
Inflation Rate	3%	3%	3%	3%	3%
Capital Investment	$ 1,979,977				
Percent Funded by Grants	59%				
BioGas Production/Cow/Day (Cu Ft)	80	80	80	80	80
Annual BioGas Production (Cu Ft)	20,440,000	21,666,400	22,966,384	24,344,367	25,805,029
BTU Produced per Year (650 BTU/Cu Ft)	13,286,000,000	14,083,160,000	14,928,149,600	15,823,838,576	16,773,268,891
Thermal Efficiency (with gas cleaner)	30%	30%	30%	30%	30%
Effective BTU's/Year	3,985,800,000	4,224,948,000	4,478,444,880	4,747,151,573	5,031,980,667
Potential Annual kwh Produced (3412 BTU/kwh)	1,168,171	1,238,261	1,312,557	1,391,311	1,474,789
Utilization Rate	90%	90%	90%	90%	90%
Annual kwh Production	1,051,354	1,114,435	1,181,301	1,252,179	1,327,310
kwh Production per Hour of Operation	133	141	150	159	168
Estimated Farm Consumption	900,000	954,212	1,011,465	1,072,153	1,136,482
Price per kwh	$ 0.180	$ 0.185	$ 0.191	$ 0.197	$ 0.203
Surplus Electricity (Sold back @ Wholesale)	151,354	160,223	169,837	180,027	190,828
Wholesale Price per kwh (with energy credits)	$ 0.120	$ 0.124	$ 0.127	$ 0.131	$ 0.135
Income:					
Electricity Value (Net Metering)	$ 162,000	$ 176,911	$ 193,151	$ 210,883	$ 230,242
Wholesale of Surplus Electricity	$ 18,162	$ 19,804	$ 21,622	$ 23,606	$ 25,773
Bedding Savings	$ 42,000	$ 44,520	$ 47,191	$ 50,023	$ 53,024
Total Income	$ 222,162	$ 241,235	$ 261,964	$ 284,512	$ 309,039
Expenses:					
Depreciation 16 yrs	$ 123,749	$ 123,749	$ 123,749	$ 123,749	$ 123,749
Interest 5.0% of investment	$ 40,590	$ 38,053	$ 35,516	$ 32,979	$ 30,442
Repairs 3.0% of investment	$ 59,399	$ 61,181	$ 63,017	$ 64,907	$ 66,854
Property Taxes 1.0% of investment	$ 19,800	$ 20,394	$ 21,006	$ 21,636	$ 22,285
Insurance 0.5% of investment	$ 9,900	$ 10,197	$ 10,503	$ 10,818	$ 11,142
Manager/Maintenance Salary	$ 40,000	$ 41,200	$ 42,436	$ 43,709	$ 45,020
Professional Fees	$ 500	$ 515	$ 530	$ 546	$ 563
Miscellaneous Expense	$ 1,000	$ 1,030	$ 1,061	$ 1,093	$ 1,126
Total Operating Expenses	**$ 294,937**	**$ 296,318**	**$ 297,817**	**$ 299,437**	**$ 301,181**
Net Profit (Loss)	**$ (72,775)**	**$ (55,084)**	**$ (35,853)**	**$ (14,925)**	**$ 7,858**
Cash Flow:					
Add Back Depreciation	$ 123,749	$ 123,749	$ 123,749	$ 123,749	$ 123,749
Less Principal Payment	$ 50,737	$ 50,737	$ 50,737	$ 50,737	$ 50,737
Excess (Deficit) Cash Flow	**$ 237**	**$ 17,928**	**$ 37,159**	**$ 58,087**	**$ 80,870**
Cumulative Excess(Deficit)	$ 237	$ 18,165	$ 55,324	$ 113,411	$ 194,281
Debt Balance $ 811,791 (initial balance)	$ 761,054	$ 710,317	$ 659,580	$ 608,843	$ 558,106

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Appendix 1. Other fiber products

1. AD fibers and Aerobic compost

Similar to compost produced by aerobic decomposition, AD fiber is a stable product, and is not prone to further decomposition. AD fiber typically contains more lignin and cellulose fibers and slightly lower levels of nutrients than an aerobic compost. Because of the highly controlled nature of the anaerobic decomposition process in the digester, if consistency in feedstock is maintained, the fibers will maintain consistency as a finished product for nutrient levels, weeds, pathogens, etc.

Characteristics of Manure Compost and Fibers

Characteristics	Units of measure	Compost	Fiber
Total Nitrogen	% dw	2.2	1.4
Total Phosphorus	% dw	1.3	1.1
Total Potassium	% dw	3.0	1.6
Calcium	% dw	2.1	2.3
pH		8.74	8.58
Conductivity	mmhos/cm	11.01	9.92
Organic matter	% dw	79	86.7
C/N ratio		20	37
Moisture	%	66.1	69.2
Stability	mg CO_2-C/g OM/day	1.5	5.6

From Alexander (2008).

The Martin (2004) study measured influent at 7.4 pH, effluent at 7.8 pH, separated liquid at 7.9 pH and solids at 8.5 pH. See also DeBruyn and Ferguson (2008).

While the literature is consistent in acknowledging 99.9% pathogen destruction (Topper et al. 2006, Martin 2004) it is less so regarding weeds. Some sources report that 20 days in a mesophilic digester at 95 to 105 F destroys close to 100% of seeds, other research says some weed seeds remain, likely due to the variability of feedstock and digesters used in the studies. Trials done by Zauche (2005) and MacConnell (2006) with fiber-based potting mixes have not reported any weed growth.

Compost on the other hand if maintained at 140F for 3 days does demonstrate close to complete seed destruction.

In conventional manure management systems, weed seeds maintain most of their viability as they pass through animals, storage and spreading such that seeds are repeatedly applied to fields. After a few years using AD effluent, farmers report that weeds are substantially reduced, and that herbicide use can also be reduced. (Bowman 2009)

As with aerobic compost, uses for AD solids as a soil amendment include:

Container mixes and potting soils
Topsoil blends
Erosion control
Nursery beds
Turf establishment
Athletic fields
Backfill for trees and shrubs
Vegetable and fruit crops

The markets for AD fiber are the same as for aerobic composts:

- Horticulture—landscape contractors, retail garden centers, nurseries and green houses;
- Recreation—golf courses, athletic fields;
- Bulk suppliers—topsoil blenders, compost and mulch brokers;
- Agriculture—fruit, vegetable, feed and grain producers;
- Land reclamation—remediation of contaminated soils, gravel pits, erosion control and as a final landfill cover;
- Public agencies—parks and recreation, roads and highway, buildings and grounds, public works and sanitation, schools and athletic fields, and airports.

Discussions with the CT DOT indicated significant use of compost and strong interest in the product given testing to assure compliance with standards. However, the department does not directly buy soil amendments. Rather DOT contractors include the materials they anticipate using in their bids. Standards and a listing of compost suppliers are attached.

AD fiber is an untested addition to the soil amendment menu. Very few operators of digesters are selling to this market. Because buyers are not familiar with AD fiber properties and how use will affect their business, sellers have to introduce and educate the market. As benefits can be isolated and marketed there is opportunity for price differentiation (fertilizer, fungicide, etc.). One of the market entry problems gathered from landscaper interviews is that all too often farm produced composts have been experienced as irregular or inconsistent in performance. For AD fibers this underscores the need for a regular testing regime to verify nutrient analysis.

In the future, the value of AD fiber as a soil amendment will be influenced by:

- Consistency of product quality/attributes
- Volume availability
- Transport costs
- Benefits
- Competition from substitutes

Interviews with landscapers and plant growers and visits to home center type box stores revealed that the prices of compost, manure compost and topsoil have not increased from the values reported in the North Canaan Nutrient Management Study (Wright-Pierce 2006). Unlike the strong market found in that part of CT, the lower population density of the Woodstock area indicated that the farm would have a significant market challenge to move the projected volume of fibers as a compost product from the site either bagged or loose to landscapers and home gardeners. Labor and marketing costs when added to processing, packaging and storage costs indicated a low probability for a successful venture at this time.

2. AD fiber as a replacement for peat

Solids separated from digester effluent consist primarily of cellulose and lignin; the material is similar in composition to peat. Like peat, fibers are a stable material, resistant to further decomposition. An aging study conducted as part of work to determine potential for use in potting mixes, confirmed that the storage does not degrade the fiber or adversely affect its use as a plant growing medium (MacConnell 2006). When consistency in feedstock is maintained in the digester (as on a dairy farm vs. a commercial waste operation), the resulting fibers are a consistent product with predictable characteristics. Fibers have the same physical characteristics as peat, including bulk density, water retention and porosity, to support root development with sufficient space for water and air and to retain moisture. (MacConnell 2006, Oakley 2006, Zauche and Compton 2005, Zauche 2006)

AD fiber differs from peat in several important ways. Fibers are alkaline with a pH of 8.5 to 7.5 and fibers contain nutrients that can be taken up by plants; peat on the other hand is very acidic with a pH of 3.6 to 4.2 and is not a significant source of nutrients. Thus AD fibers cannot be directly substituted for peat, but rather need to be acidified according to the specific needs of the plant.

When separated from the digestate slurry, fiber is typically 60% moisture. Peat is typically 40% moisture. Drying the fibers does not adversely affect the material. Because nutrients are water soluble, fibers must be stored undercover to protect against rain, snow and other sources of water which might unbalance the nutrient distribution. These differences are primarily issues for packaging and storage.

Fibers have higher electro-conductivity (salts) than peat due to the presence of nutrients; trials have not shown that trait to be problematic for nutrient uptake by plants. Fertilizer savings may be obtained over peat-based mixes, which require the addition of fertilizer to compensate for the substrate's lack of nutrients.

When compared to dairy compost, fibers have better buffering capacity to maintain the pH of a potting mix and, most important, greater porosity (Zauche 2006 and MacConnell 2006). Since fibers and compost values derive from the specifics of the originating manure, quantification of typical comparative values show ranges. Fibers and compost have similar NKP values, e.g. fiber N= 1-2% vs. 1-3% for compost, fiber K = 1.6 vs.

compost about .2 - 3%, fiber P: .2-1% vs. compost P .2-1%, and thus lower conductivity than compost. The two materials have comparable pH values (fiber 8.5, compost 8.4), C/N (fiber: 20-40, compost 11-20) and conductivity (fiber 9.9, compost 11). (Alexander 2008, Zauche 2006, MacConnell 2006, Cornell 2004, DeBruyn 2008).

Because of peat's capacity to hold large volumes of water and nutrients and release them slowly, peat-based plant growing media is the industry standard. Potting mixes contain 60% to 80% peat by volume. Peat however is becoming increasingly expensive and less available due to peat bog destruction and environmental protection laws. Growing consumer awareness and interest in green, sustainable horticulture practices has created an opportunity for alternatives.

Research conducted independently at the University of Washington (MacConnell) and the University of Wisconsin-Platteville (Zauche and Compton), have resulted in 'recipes' or formulas which adjust the chemical composition of fiber for use in soilless potting mixes. These recipes are proprietary and have been submitted for patent approval.

Phytotoxicity (toxins in the material which harm plants) is a major concern of plant growers and is the principal reason for their limited use of compost. Variability of compost is due to lack of management and testing. Often associated with residues of the herbicide clopyralid, other sources include heavy metal content, soluble salts, organic acids and oxygen deprivation resulting from incomplete decomposition of the source material. (Blewett et al. 2005)

Organix, Inc. is the first company to commercialize solids as a peat replacement. The claims for RePeat:

> In addition to looking, feeling and smelling like peat; RePeat™ is more pH neutral than peat moss (6.5 vs. 4.5); RePeat™ has low salt content and as a result has low electrical conductivity; RePeat™ has excellent porosity and water holding capacity like peat; Cationic exchange ability is comparable to mined peat and Bulk density (weight) of RePeat™ soil amendment is very similar to that of peat.

These characteristics are also claimed in work done by Zauche and Compton at the University of Wisconsin at Platteville. They found that AD solids

- Contain more humic acid than compost and within 30% of peat
- Need to be mixed with other materials for optimal plant growth
- In mixes produce plants with 30 to 40% more growth than peat
- Are better at maintaining pH than compost due to a high buffering capacity

Because plant needs for moisture, nutrients and aeration vary by type, so too must potting soil 'recipes' made from digester solids (or peat) vary. MacConnell, Zauche and Compton have developed recipes for geranium, petunia, phlox, begonia and impatiens as well as for orchids (lady slippers). Trials done to determine if AD solids broke down faster than peat resulted in no differences in breakdown rate, an important data point for perennials.

Patent pending recipes include perilite, vermiculite and other amendments. Their economic analysis suggests that solids based potting mixes would cost about 20% less than peat based mixes. Other savings to growers may be obtained from reductions in fertilizer and better growth yields that can bring plants to market sooner.

Peat is purchased in tractor trailer load quantities by very large plant growers at about $27 per cubic yard ($1 per cubic foot). Peat supplies are tightening and peat is increasingly seen as an unsustainable product. Plant growers would switch if performance of the alternative was comparable and did not create additional costs or plant management problems.

Growers who most closely match the anticipated volume of fibers use compressed peat (2 to 1) in 55 cu ft bags (110 cu ft of material). Bales are picked up with a fork lift and dumped into a fluffer. Newer equipment will shred a larger bale, 128 cu ft compressed or 256 cu ft loose, and eliminate the fluffer. In either case, loose material would not fit the operation. Storage is another concern with as much as 1/3 of annual usage, some 500 to 600 pallets, stored outside. 90% of the material is used between March and June.

To package fibers for this market the moisture content of the fiber would need to be reduced from 60 to 40% and could be accomplished by capturing waste heat from the digester. Only one manufacturer of compression packaging equipment was found. At an estimated $1 million, the cost of the system rendered the market infeasible to pursue at this time.

There may be opportunity to provide loose product to smaller growers. A least cost approach (perhaps about $20,000) to packaging would be to blow fibers into a hopper attached to a filling machine and loosely pack in Super Bags. Without compression, these bags would not be stackable and would have to be stored undercover to prevent concentration of nutrients, another significant expense.

Would plant growers switch from peat to AD solids? Not without trials.
A conference call that brought researchers together with George Elliott, a horticultural professor at UCONN, helped to design a strategy. Elliot specializes in soilless potting mixes and is working with the Freund Farm on Cow Pots; he brought knowledge and interest to the conversation.

The discussion pointed out that like dairy farmers, plant growers are extremely cautious when it comes to the adoption of a new technology or as in this case, a new potting mix. Not only is there concern about performance (despite research findings), but also about changes that would have to made in plant management systems, for example water and fertilizer. A grower would have to try the recipes in their operation to see firsthand how the mixes worked before they would consider making a change.

Plant growers need to be convinced of product worthiness and to assess management impacts (labor, fertilizer, water). The goal would be to interest one grower in becoming a

AD solid potting mix producer, both for the core business as well as for resale. Should a patent be approved, the grower would license the process for a modest fee. A least one CT plant grower is interested in a pilot study—growth trials using AD solids recipes for various bedding and perennial plants. Oversight by UCONN (Elliott) would add to credibility. If feasible, periodic analysis of AD solids for nutrient, pH, moisture and other requirements would be required. Since the plug flow AD process and manure feedstock tends to be consistent it is assumed that there will be little variation. Recipes could be adjusted for seasonal feed changes.

As part of this project, a proposal to conduct plant trials was developed for consideration by CT DEP and US EPA 319 Nonpoint Source Program.

3. AD fibers as fuel

Since peat is used as a fuel in loose, pelletized and briquette forms, the possibility of using the fibers as fuel was explored. The systems available to make wood pellets are also used for peat and could be used for fibers. Before digestion, manure has similar BTU values as peat: 8,500 BTU per pound on a 100% dry weight basis. (Mark 2006) After digestion the BTU value would be reduced to about 7,250 BTU per pound on a dry weight basis. (Auvermann 2009, Koelsch 2009) These fibers at 60% moisture would have significantly less BTU value (1,768 to 1,887) and require significant energy input to reduce to 10% for pelletizing even if residual heat from the gen-set could be used to pre-dry the material. Various alternatives for separating more liquid from solids was investigated (centrifuge, screw press filter), but did not produce a viable option (they were costly and could not remove moisture below 30%). Ash content, chemical and salt residues were raised by stove manufacturers as potential concerns.

Discussion with biomass furnace operators indicated that the fibers in a loose form would not be compatible with grating and combustion processes. Even if appropriate the amount of fiber produced was considerably less than the high volume of wet green wood used. The low cost of wood fuel was another barrier.

Appendix 2. Bio-gas and Bio-methane Characteristics

Constituents	*Units*	*Natural Gas*	*Bio-gas*
Methane (CH_4)	Vol%	91	55-70
Ethane (C_2H_6)	Vol%	5.1	0
Propane (C_3H_8)	Vol%	1.8	0
Butane (C_4H_{10})	Vol%	0.9	0
Pentane (C_5H_{12})	Vol%	0.3	0
Carbon Dioxide (CO_2)	Vol%	0.61	30-45
Nitrogen (N_2)	Vol%	0.32	0-2
Volatile Organic Compounds (VOC)	Vol%	0	0
Hydrogen (H_2)	Vol%	0	0
Hydrogen Sulfide (H_2S)	ppm	~1	~500
Ammonia (NH_3)	ppm	0	~100
Carbon Monoxide (CO)	ppm	0	0
Water Dew Point	ºC	<-5	Saturated
Heating Value	BTU/SCF	1031	~600

Source: Jensen and Jensen (2000) referenced in Monnet (2003) Comparison of constituents in natural gas and bio-gas, as cited in Bothi (2007).

Appendix 3: CT DOT Mulch Standards

From Section M.13, Roadside Development
http://www.ct.gov/dot/cwp/view.asp?A=3517&PM=1&Q=417886#M.13.06

M.13.05—Mulch Materials:
1. Wood Chips: Wood chips shall be obtained from sound, green wood, and shall be 1/8 inch (3 millimeters) nominal thickness with not less than 50% of the chips having an area of not less than one square inch (650 square millimeters), nor more than 6 square inches (3900 square millimeters). The material shall be free from rot, leaves, twigs, shavings, debris, and any material injurious to plant growth.
2. Hay: Hay shall be from acceptable grass or legume mowings, free from weeds, reeds, twigs, debris or other objectionable material. It shall be free from rot or mold, and shall have a moisture content of not more than 15% when delivered to the project. No salt hay shall be used.
3. Wood Fiber Mulch: Wood fiber mulch or wood cellulose fiber mulch shall be material manufactured for mulching seeded areas. The material may be made from coniferous or hardwood trees. It shall be free from shavings, rot, mold, foreign material or debris. It shall be of uniform texture. It may contain a nontoxic marking dye. The moisture content of the material when delivered to the project shall not be more than 12% by weight (mass). It must be capable of forming a homogeneous slurry when mixed in water. It shall be delivered to the project in clean, new, sealed containers bearing the brand, net weight (mass), and name and address of the manufacturer.
The Engineer reserves the right to draw such samples and perform such tests on any mulch material as deemed necessary to assure that the material meets all requirements.

M.13.06—Compost:
Compost shall be a stable, humus-like organic material produced by the biological and biochemical decomposition of source-separated compostable materials, separated at the point of waste generation, that may include, but are not limited to, leaves and yard trimmings, food scraps, food processing residuals, manure and/or other agricultural residuals, forest residues and bark, and soiled or non-recyclable paper. Compost shall not be altered by the addition of materials such as sand, soil and glass. Compost shall contain no substances toxic to plants and shall not contain more than 0.1% by dry weight (mass) of man-made foreign matter. Compost shall pose no objectionable odor and shall not closely resemble the raw material from which it was derived. Compost shall have a minimum organic matter content of 30% dry unit weight (mass) basis as determined by loss on ignition in accordance with ASTM D 2974. Compost shall be loose and friable, not dusty, have no visible free water and have a moisture content of 35 – 60% in accordance with ASTM D 2974. The particle size of compost shall be 100% less than 1 inch (25 millimeters) in accordance with AASHTO T 27 and shall be free of sticks, stones, roots or other objectionable elongated material larger than 2 inches (50 millimeters) in greatest dimension. The pH of compost shall be in the range of 5.5 - 8.0. The maturity of the compost shall be tested and reported using the Solvita Compost

Maturity Test and must score 6 or higher to be acceptable. The soluble salt content of compost shall not exceed 4.0 mmhos/centimeter as determined by using a dilution of 1 part compost to 1 part distilled water. Compost may be either commercially packaged or used in bulk form. All compost shall be from DEP regulated, permitted or approved facilities. All compost material must be environmentally acceptable and must be accompanied by a Materials Certificate and Certified Test Report in accordance with Section 1.06.07. The Engineer reserves the right to draw samples and perform tests as may be deemed necessary to assure that the material conforms to these specifications.

M.13.07.13—Peat:

…

(b) Compost conforming to Article M.13.06 may be substituted for peat.

Appendix 4: Fact Sheet: CHP Biopower/Anaerobic Digestion: Have you asked all the right questions?

Sjoding (2005)

Introduction

There are a number of questions that need to be asked at an early stage when considering the installation of a biopower/anaerobic digestion system at your dairy or feedlot. It is the purpose of this factsheet to help ensure upfront communication regarding a proposed biopower/anaerobic digestion system. Categories of questions include type of digester technology, digester experience of project developer, economics and financing, coproduct revenues, management and operations, power equipment, energy production, permits, utility sales and interconnection, and technology specific questions. The following list of questions and related comments are intended as examples of key questions. This list is not intended to be comprehensive. Different types of manure (dairy, beef, swine, and poultry) produce different volumes of methane. This factsheet is principally targeted to the dairy industry. However, much of the factsheet is more broadly applicable.

Type of digester technology

What type of digester is proposed? There are a number of digester technologies. As a general rule, simpler technology is better for dairy and feedlot operations (there is less chance for problems). In addition, digesters can operate at a variety of temperatures with different methane bacteria being used to create the biogas. A mesophilic system operates at 95 to 105 degrees F, while a thermophilic operates at a higher 125-135 degrees. An ambient system operates at outside air temperature and slows down or stops in the winter. A list of digester technologies includes:

- Completely mixed mesophilic
- Completely mixed thermophilic
- Contact and anoxic gas floatation
- Plug Flow/mesophilic - simple
- Fixed film
- Covered lagoon/ambient - simple
- Vacuum

What makes the proposed technology/design different/better than any other? What is the basis of the claims? Has any third party (university, USDA, or EPA) verified these claims? If so, who specifically has made that verification? What is their contact information? How is digester efficiency measured? What is the efficiency range of the design? What factors influence that efficiency?

How concentrated does the waste have to be for the process?

Does the process digest parlor wastewater? If so, what is its proportion of the waste stream? Does the process digest flush wastewater?

Digester experience of project developer
How many commercial digesters have you designed/built? How many are currently operating? What age and size are they? How long does it take to go from contract signing to operation?

Please provide references of the people you have done work for, or you are currently under biopower contract with?

Economics and financing
What is the cost range per dairy cow for the complete facility ($/cow)? What factors affect the range in costs?

Does the cost estimate include electrical generation equipment with electrical switch gear and interconnection to the utility? If not, what is that cost?

What outside sources of funds are available to help fund the construction of a digester? What experience have you had in securing outside funds for digesters, including bank financing?

Will a bank treat a digester system as an asset of the dairy?

Co-product revenues
Economic and financial success often requires revenue streams in addition to power sales. This is especially true in areas of the U.S where the cost of power is relatively low. A variety of other products can be sold including green power, carbon credits and digested fiber. Additional products, such as a crystallized phosphorous fertilizer from the digested liquid, are also under development by Washington State University. It is important to resolve at an early stage of discussions the availability and ownership of coproducts and the degree of reliance upon them for financial success.

What will be the revenue components from the facility? Upon what factors are these estimates based? What assistance is provided in accessing those markets?

Management and operations
What changes in dairy or feedlot operations are recommended or required? What will be the operational labor and management requirements for this digester? What training and support is provided for operating the digester?

Sand is a commonly used bedding material. What happens to the sand that is mixed with the manure?

How may this digester change or limit current or future dairy management decisions?

Power equipment
What type of generator set is recommended for digesters on dairies and feedlots? Which manufacturers are chosen and why?

What are the maintenance requirements for the "genset"? What are the warranties for each of the major components? Who specifically will offer those warranties?

Energy production
What is the typical and range of energy output for the particular type of digester technology? (kWh/cow/day)

How many kWh/cow/day does the proposed system produce? (Normal is 2 to 3)

What will the generator size per cow be? (a normal generator size is kWh / 24 = 0.2 kWh/cow)

Permits
What are the required regulatory permits for my location? Who deals with securing the required permits (building, air quality, health, solid waste, etc?)

Utility sales and interconnection
How much will the utility pay for the power? The answer is in $/kWh and varies from utility to utility and state to state. What rate do you project for my location? Who will negotiate the sale of power?

What does a typical power sale contract look like? (length of contract, selling rate basis, other sales costs (wheeling, etc.).

Is the utility supportive of this project and of interconnection to its electrical system?

Does the utility pay extra for the green power or carbon credits?

Technology specific questions

Plug Flow Digester
What percent of volatile solids conversion to gas does a conventional plug flow digester produce? The answer should be 35 to 40 percent.

Appendix 5: Fertilizer Values

Manure per cow per year	48700#/2000=24.35 tons			
times		**N**	**P**	**K**
Analysis (lb/ton of manure)		10	5.5	8.5
equals				
Pounds of nutrients produced per cow per year		243.5	133.9	207.0
times				
current market value per pound (6/29/09)		$ 0.359	$ 0.280	$ 0.580
equals				
Value of manure nutrients per cow		$ 87.42	$ 37.50	$ 120.05
times				
number of cows		800	800	800
equals				
Value of manure nutrients per herd		$ 69,933	$ 29,999	$ 96,036
Total value of all nutrients per herd			**$ 195,969**	
Total value per cow			**$ 244.96**	

The process of putting manure through the digester does not change the amount or balance of nutrients.
Anaerobic digestion reduces the volume of manure by 50 to 60% and concentrates the nutrients.
Anaerobic digestion converts nutrients into a form more accessible to plants, enhancing fertilizer value and reducing potential for run-off.
Liquid effluent is more efficient to store, pump and spread than raw manure.

Appendix 6: Plug-Flow Digester Diagram