Climate Friendly Farming™ Project
Dairy Anaerobic Digestion Technology Report

Year One Report

Project Component Leads: Shulin Chen

Introduction

Dairy farms are becoming more intensive (more animals per unit of land) in an effort to lower costs. This leads to more animal confinement, less land on which to spread an increasing nutrient load, and environmental problems with manure management. Most dairies in Washington State now use some sort of manure lagoon for storage, a system that leads to emissions of methane, ammonia, and nitrous oxide. Anaerobic digesters are being explored as one promising alternative technology to manage manure. Digesters can capture methane for power generation and also produce fiber and nutrient water by-products that can facilitate the export of nutrients off farm economically. Barriers to this technology include capital costs, markets for the fiber, handling of the nutrient rich water by-product, and optimizing the biological processes.

The current personnel of the anaerobic digester technology team include Goksel Demirer, Visiting Faculty; Zhiyou Wen, Research Associate; Mr. Wei Liao, PhD graduate student, Mr. Simon Smith, PhD graduate student, Mr. Craig Frear PhD graduate student, Mr. Cary Swanson, fabrication technician, and Dr. Bincheng Zhao, Dairy Systems Modeling. Dr. Shulin Chen is providing overall leadership to this work, with significant cooperation from Dr. Claudio Stockle, Modeling, and Craig MacConnell, Whatcom County Extension Agent.

Overall Goal

The goal of the dairy technology component is to develop a new generation of nutrient management system for dairy farms that reduces greenhouse gas emissions. The central technology of the system is an anaerobic digester which is complemented with a nutrient recovery system and a decision support system.

Progress Report by Milestone

1) Evaluation and completed evaluation of a pilot scale digester operation in years 1-2 with the building and completion of a commercial digester in years 3-5.

- A survey was conducted on the most suitable anaerobic digestion (AD) technology for dairy manure application. The survey included published literature, web resources, and personal interactions. The results indicated that (1) most existing animal manure AD are used for swine and poultry manures which are much easier to be digested than dairy manure because of the high fiber concentration in the dairy manure; (2) plug flow digesters are considered more suitable for dairy manure than other types of digesters due to the high solids concentration in the dairy manure.

- The extensive survey mentioned above led to a new AD system concept being developed within the Agro-Environment and Bioproduct Engineering (AEBE) research group in the Department of Biological Systems Engineering at Washington State University (WSU). A feature of this new system is to treat solids and liquid separately for the production of high quality fiber. Continuous research over the course of the year has resulted in improvements and clarification to the original design which will be discussed later in the report.

- As stated in the Executive Summary, the opportunity to partner with a dairy in the construction of a commercial digester led us to make changes in the overall plan for the anaerobic digestion component of the Climate Friendly Farming™ Project. Instead of evaluating and completing an evaluation of a pilot digester in years 1 and 2 it has been decided to immediately build a digester from the best of existing technology and evaluate its performance during year 2. In addition, we are on track to build a pilot scale digester of our new design during year 2 and complete evaluation of its performance in year 3 – maintaining the potential for commercialization and actual commercial construction in years 4-5. We are actively seeking the additional resources necessary for commercializing our novel AD system. Thus the Digester Technology Team is on track by year 5 to fulfill evaluation and construction milestones for not just one digester system but two systems with a corresponding comparison of their strengths and weaknesses.

2). Construction and evaluation of the first digester system using existing technology-Vander Haak.

- Our partnership with Darryl Vander Haak enabled the completed construction of the first commercial dairy digester in Washington State at the Vander Haak Dairy in November of 2004, thus satisfying the construction milestone originally intended for year 4.

- Presently, members of the AD team have just completed a methodology and protocol for evaluation of the Vander Haak digester. Researchers are planning to visit on-site personnel in early February to apprise and teach the personnel on how to collect and transport samples for eventual analysis at the WSU Wastewater and Water Quality Laboratory. Data collection for evaluation will be conducted during year 2 with a final evaluation of the technology in year 3.

3). Obtaining matching funds for development of a pilot digester system of novel design—AEBE system.

- Several grants were applied for in order to secure funding to continue with bench top experiments and to develop prototype models for eventual pilot scale demonstration. The following matching grants were secured: Washington State Department of Ecology-$100,000 plus an additional $66,00 in match from other interested WSU departments (for building of a pilot scale demonstrator); Washington Technology Center--$70,000 plus an additional cash match of $35,000 from Andgar Engineering (for building of a prototype to the final pilot scale demonstrator); and USDA-NRCS-$683,920 (for monies needed to further study fiber suitability and marketing as well as struvite production for utilization of the nutrient rich effluent). Grant application milestones were marked for year 3 and thus this milestone has been reached. Efforts to secure additional funding will continue.

4). Construction and evaluation of a pilot scale digester system of novel design-AEBE system.

- Through the securing of the above mentioned grants and partnerships the following timeline is in place for a July 1, 2005 build-out of a 25-cow COD equivalent mobile pilot scale demonstrator using the AEBE novel design.

    - October 1, 2004 - build out of 1-cow prototype at WSU Dairy Center
    - October - January - evaluation of prototype at WSU Dairy Center
    - January – May – Build out and evaluation of 10-cow prototype
    - May 15 - Final schematics for 25-cow mobile pilot scale demonstrator
    - July 1 - Build out and delivery of demonstrator to WSU Dairy Center

- Evaluation of the mobile pilot scale digester will occur at several test locations throughout the state. Sites under strong consideration include the WSU Dairy Center, the WSU Composting Facility, Yakima Conservation District, Northwest Indian College, Spokane Indian Tribal land, and a dairy farm north of Spokane. Protocols developed for evaluation of the Vander Haak digester will be used for evaluation of this demonstrator although new parameters will be added to allow for testing of the municipal solids to be co-digested using this particular model. Thus construction of the AEBE pilot scale digester will be completed during year 2 but the evaluation will not be complete until year 3. Once complete a comparison report of the two evaluated digesters should be available by the end of year 3.

5). Laboratory and bench scale experimentation for optimization of scientific and engineering design of the AEBE digester system.

- Researchers within the AEBE team spearheaded by the work of Dr. Wen and students Liao and Smith have made great strides in optimizing and improving performance while at the same time resolving some difficult engineering concerns. The improvements being done are a direct result of innovative research equipment such as the 5-reactor in series set-up that have been running in our hot room for over a year now. In addition, researchers have just completed developing an initial C++ coded model of the anaerobic digestion process and are now inputting parameters to determine the validity of outputs against experimental data. Once the validity is verified, the resulting working model will be instrumental in efficiently determining reactor parameters that will be needed for optimization of the final pilot scale system. Although the wealth of experimental data and analyses developed is too large for incorporation here a brief summary of the more pertinent findings is given below; all which hope to advance to you our ability to meet our goals of reducing size and cost while simultaneously maintaining biogas production and creating a more valued fiber product (for a more detailed description of the actual AEBE digester system please see Appendix A):

    - Typical dairy digesters cost about $730/cow and produce electrical revenue at about 1/10 that number, $73/cow. With these numbers, these digesters are barely economical and still need government subsidy to pay off their capital costs. By reducing our residence time from a typical 21 days to 5 days we estimate that the volume of our reactor can be reduced by at least 50%. Consultation with engineering firms has shown that this kind of reduction could result in around 10-15% reduction in costs and considerably more if the reduction would allow for the use of a cheaper construction material (i.e. pre-molded plastic instead of reinforced concrete). Thus, our system simply by its use of liquid/solid separation is able to significantly reduce the previously quoted number of $730/cow and thereby make our system more economically viable.

    - Currently, the biogas production obtained by WSU researches is about 0.5 L biogas/L reactor volume/day, this value is obtained at 5 days retention time. If the retention time is shorted to 2 days retention time, the biogas production rate is around 0.7 L biogas/L reactor volume/day. We believe that these production rates could be further enhanced by several efforts: (1) enhancing the fed manure COD; (2) facilitating the gas transfer from liquid to gas phase by intensifying mixing or gas stripping; and (3) using the fixed film to enhance the bacteria population. Effort (1) is being done hopefully achieving our target of 0.8 L biogas/L reactor volume/day (5 days retention time) and 1.0 L biogas/L reactor volume/day (2 days retention time) by late February. Effort (2) will be performed from January to April, and the gas production target will be further enhanced to 1.0 and 1.3 L biogas/L reactor volume/day at 5 day and 2 day retention time, respectively. Effort (3) will by started February and finished by July, the target of biogas production is 1.3 and 1.5 L biogas/L reactor volume/day for 5 and 2 days retention time, respectively. If this final 1.5 L biogas/L reactor volume/day is achieved it will allow our digester system to produce biogas quantities that are close to that being produced by existing technology despite the fact that we will not be digesting any of the solids.

- Preliminary bench scale results from our innovative solid reactor technology are in and first protoype studies are under way. The results of the bench scale studies using the optimized conditions of four hours treatment at 50° Celsius using two washings at a water to solid manure ratio of 2 to 1 show that more than 98% of the fecal coliform in the original manure solid is removed during the process and physical properties of the fiber such as water holding capacity, air space, and total porosity are very similar to the most widely used soil amendment, peat moss. Thus, by meeting the performance criteria of peat moss, the WSU AD design has the potential for producing a high value fiber co-product for high sale as a soil amendment replacement to the non-sustainable peat moss. Presently, composted AD fiber sells for approximately $10/ton as a bedding replacement but as a replacement for peat moss our fiber could sell for approximately $25/ton which is the wholesale price of peat moss. Fiber end-use suitability studies were originally scheduled to begin year 3 and this goal is on target. The future plan is to have the optimized solids digester of the AEBE system be further optimized by Craig MacConnell and to have it market tested. Please see the Whatcom Dairy Report for further information on the digested solids experiments.

6). Intellectual property protection and patent application.

- On December 27 of 2004 a provisional patent application was placed on behalf of the inventors by the Washington State University Research Foundation (WSURF) via a sub-contracted patent attorney in Portland, Oregon. A description of the actual invention that was used in the preliminary patent application is enclosed in the appendix to this document. Please note that the actual disclosure was for all parts of the digester system including the work being done by Craig MacConnell on fiber development.

7). Implement a nutrient recovery system that can work in parallel with the digester system so as to treat the high nutrient effluent.

- The aforementioned USDA-NRCS Conservation Innovation Grant will be used to study struvite production from the nutrient laden effluent. The plan within that proposal is to optimize an existing struvite (phosphorus based fertilizer) crystallization technology developed by North Carolina State University to the dairy manure being processed by the digesters. This work is to be done by Dr. Joe Harrison and his research team at Puyallup. Plans are being developed for the crystallizer to be installed at the Vander Haak digester. Experiments with a pilot-scale system at a waste lagoon in Snohomish County are yielding information that is helping guide design of the unit for the Vander Haak digester. A pump engineer has been consulted to devise an improved method of conveying wastewater to the unit.

- In addition to that study, the AEBE research group is presently advertising for a post doctoral position experienced in nutrient precipitation to join the research team and to further spearhead our incorporation of struvite technology into the complete digester system. Original milestone goals for this topic area were scheduled for year 3 and as with much of the digester research, we are currently ahead of schedule.

8). Completion of a commercial digester (second one of AEBE design) by end of year 5.

- Although completion of two commercial digesters was not in the original plan there is hope for a potential second commercial digester of AEBE design for completion by the end of year 5. Upon completion of the pilot scale demonstrator in mid year 2 and further completion of its evaluation in year 3 (along with continued research) we will potentially have a system that will be capable of commercial interest and success. To that end, Andgar Engineering has already become an active participant with an eye on being a potential primary licensee, fabricator and marketer of the technology. WSURF, Andgar and the Climate Friendly Farming™ Digester Technology team are in the early stages of developing suitable patents (see above description of provisional patent application) and determining the paying of patent costs and corresponding licensing agreements.

Washington State University Novel Anaerobic Digestion System

"A Complementary solid and liquid anaerobic digester system for co-production of biogas and high quality fiber from animal and other high-solid waste streams"

An Invention Disclosure to the Washington State University Office of Intellectual Property Administration

By the Washington State University Department of Biological Systems Engineering Agri-environmental and Bioproducts Engineering Research Group Anaerobic Digestion Team

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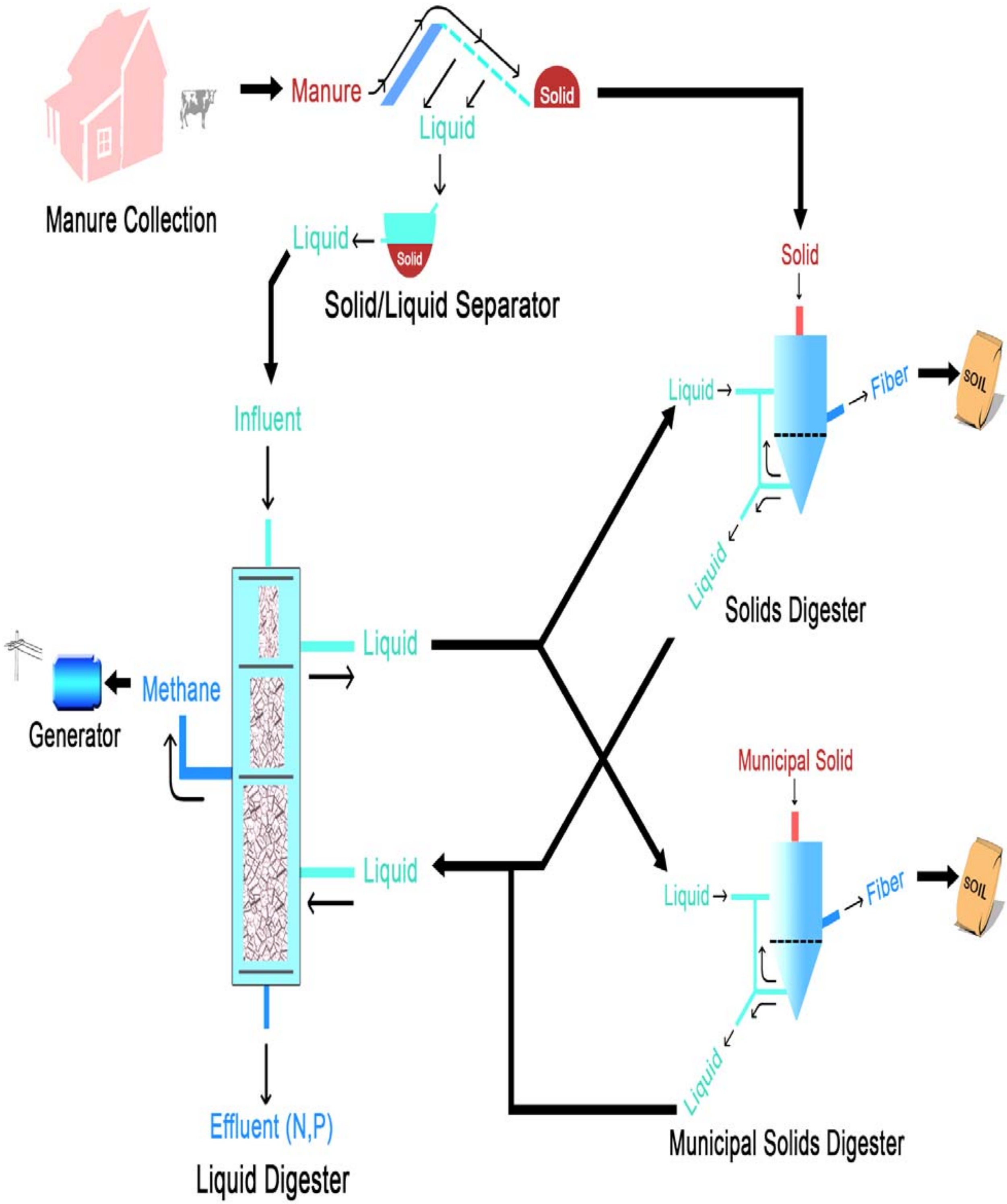
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Effluent (N,P)
Liquid Digester
Municipal Solids Digester

Background
As environmental regulations become more stringent and energy prices rise, there is increasing interest world wide in using anaerobic digestion technology for the treatment of manures from concentrated animal feeding operations. The major limitation to a wider adoption of this technology is still its high capital cost. For example a state of the art plug flow anaerobic digester for a 1,500 cow dairy farm presently being built in Whatcom County in Washington State is projected to have capital costs of $1.6 million. Although there is a wealth of knowledge and numerous inventions related to anaerobic digestion (AD), the current technology still cannot offer a cost effective solution to the farms; particularly those with high solids content such as dairy farms. This reality is put in perspective when it is noted that, although according to the EPA AgStar program the need for AD in large dairy farms is in excess of 6,500, the number of operating digesters in the US is less than 50; a startling low number that is primarily due to high capital costs and low value of methane produced. Similar situations exist in many other countries throughout the world and in particular, Europe and although many digesters have recently been built, very few of these units are economically viable without governmental subsidy or inflated electricity prices. Technological advancement is required to make AD cost effective in order to meet the market demand.

The high cost of AD for animal manure treatment stems from two fundamental facts: (1) the high fiber content in manure solids and (2) the slow growth rate of the anaerobic bacteria.

- Manure fiber consists of mainly cellulose, hemicellulose, and lignin. These fiber components are more difficult to break down biologically than other constituents of manure such as dissolved organics or proteins and lipids. They are so difficult in fact that the majority of these fiber components cannot be digested even in the existing AD's operating at mesophilic temperatures and with a typical hydraulic resident time of 20-30 days.
- The microorganisms involved in anaerobic digestion are a consortium of bacteria of different types. The first group breaks down complex molecules to simple organics in a process called hydrolysis, the second group converts these simple organics to organic acids in a process called acidification, and the third group converts the organic acids to methane in a process called methanogenesis. Although these bacteria act as a consortia and to a large extent work in a synergistic manner, they do differ in their rate of growth and required growth conditions, with the methanogenic bacteria in particular requiring a much longer period for growth. With this poor growth rate, a long retention time is required for the liquid manure to remain in the reactor so an adequate bacterial population will grow and act on converting the waste. Making the situation far worse is that any attempts to speed up the process by pushing the manure through the digester faster not only further diminishes the limited chances of digesting the fiber but reduces the overall digestion efficiency because the increased flow rate leads to bacterial loss through the effluent. Once the bacteria are lost a whole new population of slow growing micro-organisms has to be re-developed leading to even more delay.

The present strategy for dealing with high concentration but poorly digestable fiber and slow bacterial growth is to use a plug flow reactor with long retention times. The long retention time allows for the bacteria to grow and digest some of the solids and fiber. The draw back is that it leads to large reactor volumes needed to handle the enormous volume of liquid slowly passing through and staying in the system. This large reactor volume leads to added capital cost.

Another strategy that can be used to overcome the slow growth rate and therefore enhance the bacteria population and their ability to digest the manure is to provide suitable 'homes' for the bacteria where they can attach and be retained no matter how fast the flow in the digester. This can be accomplished by providing inert supporting surface area that the bacteria can attach to. Unfortunately, it is the first problem of the high solid contents of the animal manure that makes this strategy impractical by blocking the flow through the support media. Thus, it is the first problem of high solids and fiber content that is of primary importance and which must first be solved before the second problem of bacteria retention can be remedied through the use of fixed film or support media.

Another limitation to the adoption of AD is that no matter how effective the engineering design can be in improving the performance with respect to solids content and bacteria, the resulting capital costs currently cannot be overcome by the sale of the produced methane. For example, in areas like the Pacific Northwest, electricity selling at $0.05/kwh is far too low of a price to support the overall economics. Thus, anaerobic digestion in the Pacific Northwest is in need of co-products to improve the economics. One possible co-product is to sell the resulting undigested fiber once it has been dewatered from the effluent stream. Presently, AD systems are selling this fiber by-product as a bedding replacement for an approximate value of $10/ton but the potential exists for selling the fiber by-product for considerably more as a soil amendment if proper pre-treatment is accomplished ($23/ton wholesale price for peat moss).

Lastly, many existing AD's have opened up their operations to co-digestion of municipal solid wastes and therefore allow for the collection of tipping fees to process the waste as well as the sale of the additional electricity. Although success has been reported in adopting animal manure AD's to co-digestion systems involving manure and added liquid digestates, such as whey, there has not been much success in co-digesting the manure with high solids municipal wastes such as yard trimmings, food waste and fish/animal remains. This is in part because these particular municipal wastes re-introduce the problem of high solids already discussed above. Municipal systems are also in great need of sustainable disposal of their high solids waste and if an existing high solids digester for manure can also co-digestate other high solids wastes then the local economies and environments will be better off; not to mention the operators of the AD that could charge extra tipping fees and utilize the contained carbon to generate added electricity.

Thus, our conclusion for improving the viability of anaerobic digestion of high solid manures is to revolutionize the existing practice of using high resident time plug flow reactors that are focused primarily on one revenue stream of methane. The resulting revolutionary system first deals with the difficulties of high solids treatment and then incorporates the innovations of fixed film and high rate reactors to the problem of bacterial growth and retention. The new system is designed to accomplish this while drastically reducing volume and capital costs while also providing improved revenue through emphases on high quality fiber production and co-digestion.

Invention Description

Even though anaerobic digestion is a mature technology that has proven capable within numerous markets, the fact remains that the present technology simply is not meeting the needs of the commercial sector that is having to deal with high solids waste and high solids animal waste in particular. To remedy this situation an innovative AD system has been developed that addresses the previously mentioned challenges and limitations facing high solids digestion and as a result better meets the needs of the commercial sector by engineering a system capable of supplying increased revenue at a reduced capital cost. The system is innovative in two general ways. First, the system takes existing technology and AD ideas and incorporates them together in a novel overall concept that best addresses the concerns with fiber, bacterial growth, retention time, capital cost, and options for additional revenues. Second, the system introduces several new individual components that allow for the system as a whole to work more efficiently and attain its performance goals.

Novel Overall Approach (Please refer to diagram A for reference to the overall system)

As pointed out before, numerous digestion concerns and problems are brought about by the presence of a high percentage of solids in the waste; a solids waste that in the case of dairy manure and many of the other high solids is basically un-digestable because of the high fiber or lignocellulosic content. As stated before, the general concensus is to design high residency plug flow reactors in an attempt to digest or partially digest this fiber. The result is a large, capital intensive, basically in-vessel concrete lagoon; and these systems simply have not proven economically viable without subsidy. Commercial concerns and innovators have attempted to remedy this economic problem by adding ad-hoc components to the status quo plug flow reactor. Although these components have led to marginal improvements (RAS, gas recirculation, flexible covers, pre-heated mixing chambers, parallel digesters sharing common heat exchangers, horseshoe shapes, convection mixing, pressurized flow, etc.) the fact still remains that they attempt to digest all of the manure as is, including the fiber, and the residency times stay large and consequently the economics stay dicey.

It is our belief that the best approach to dealing with the high solids or fiber problem in AD is to separate the solids from the liquid manure and treat the solids and liquid separately; especially since many farms already practice some degree of liquid/solids separation in the first place. By removing the solids from the liquid stream it makes it possible to design high rate AD reactors for the remaining liquid which use support media that is no longer encumbered by the failures that could result from solids interference. Subsequently, the high rate AD opens up the possibility for drastic reductions in retention time and reactor volume leading to a decrease in capital outlay while still maintaining an adequate energy production and COD removal rate. For example, our early calculations show that when comparing a state of the art 20-25 day plug flow reactor to our reactor design, the use of a 5 day or less retention time brought about by the use of a high rate reactor utilizing a low solids (~1-2%) liquid stream results in a reactor volume that is at least 50% smaller (this is because for each increase in retention time, a reactor has to be enlarged to store the additional amount of manure that will be residing in the reactor). Discussions with engineering firms familiar with digester construction have stated that a 50% reduction in volume, ignoring differences in complexity and changes in construction material, would result in a 10-15% reduction in overall digester construction and capital costs. Even better is the possibility that our high rate liquid reactor might perform optimally at days fewer than even 5 days; producing a reactor that is well over 50% smaller and therefore more readily manufactured out of cheaper construction materials. If this is the case (preliminary lab scale research shows the potential for residence times lower than 5 days) then the capital cost savings could be well above the previous conservative estimate of 10-15%. It should be noted that we are not unique in our belief that the solids should be removed with the resulting liquid solution being digested through more suitable high rate, non-plug flow reactors (Wilkie, University of Florida). What distinguishes our overall approach from other solid/liquid proponents is that we do not envision the solids stream as a waste or low-valued product suitable only as a possible bedding replacement, but rather have chosen to invent a solids reactor that turns the solids into a product of higher value.

In our system, the solids are being treated in their own parallel vessel while the liquids are being processed. The belief behind the solids reactor is that the solids, with proper pretreatment, are capable of being sold as a high value commodity soil supplement not unlike peat moss. It is this second major revenue source, potentially twice as large as that accrued by the conventional plug flow digester fibe, that can make our AD system cost effective; especially if the electrical production can be maintained at or near that presently produced by the conventional digesters.

Another innovation of the system is the integration of the two reactors. The solids and liquid reactors are interconnected and work in concert by sharing of liquid (leachate) that allows for the solid reactor to work and the liquid reactor to attain more volatile solids for conversion to methane. It is this leachate interconnectedness that not only brings added efficiency to the system but answers a pertinent question that might be asked of our system, " even though some digestion difficulties were solved in the liquid reactor by separating out the solids, why isn't it the case that the solids digestion problems were simply moved to another reactor". The answer is two fold. First, this new solids reactor is not designed primarily for methane production but for fiber production and by altering the purpose of the reactor many of the earlier concerns and difficulties are removed. Second, the novel leaching approach allows for the washing and removal of a considerable amount of volatile solids from the fiber; converting the volatile solids to methane during a brief reaction period as opposed to the lengthy one needed by the plug flow reactors. The leachate is taken from and recycled back to a particular part of the liquid reactor so that the process is most efficient.

Lastly, the overall approach, applied to a system with dual solid reactors-- one each for manure and other high solids, also adds to the cost effectiveness by introducing more revenue streams via tipping fees and added energy and fiber production. This is done all at low added cost because of the modular construction of the solid reactors.

Thus, this system when seen as a whole is capable of:

- reducing digester volumes by at least half and thereby reducing capital costs considerably through the use of a smaller footprint, less material requirements, and potentially less expensive and easier fabricated construction material;
- retaining the bacteria and digesting at a vastly improved rate, thus allowing for less potential for down time and improved yield in tipping fees; and
- increasing revenue through a potential doubling of fiber sales.

Novel Individual Components

Within the overall novel schematic discussed above are some individually unique and novel components. Each of the components is listed below with an adjoining description of their role and novelty.

High Rate Liquid Reactor of Unique Design

Laboratory testing and mathematical modeling have enabled us to design and optimize a high rate reactor for the digestion of a liquid manure stream that contains a low concentration of solids that currently is optimize at near or less than 2% total solids concentration. This high rate reactor utilizes support media, compartmentalized baffling, and mixing, which by themselves are not unique to the study of anaerobic digestion, but in our case are optimized through the modeling to produce a digester that minimizes the retention time and reactor volume while maintaining effective biogas production and COD removal by:

- Arranging baffles and compartments to certain volumes which thereby maximize the performance of the individual hydrolysis, acidifying and methane producing bacteria;
- Providing just the right type and quantity of support media to maximize the growth rate and retention of the individual bacteria populations within the individual compartments while minimizing cost and clogging problems;
- Designing a mixing system that maximizes flow and therefore nutrient and bacterial interaction within a compartment while not over-mixing laterally between compartments so as to destroy the anticipated 'phased' growth of the individual bacteria groups;
- Developing an environment through novel mixing that allows for improved degassing of the liquid and thereby attaining an improved yield of methane as opposed to letting a portion of the gas escape in the effluent;
- Designing an overall flow from input to output that allows for mixing with minimal required energy input while still maintaining the necessary loading rate, retention times, and turn-over so as to avoid 'crusting and blocking' by the remaining solids in the liquid stream.

Solids Reactor for Production of High Quality Fiber

A thermophilic, continuous, solids reactor has been designed to treat the separated solids for development of a fiber product for sale as a soil amendment with attributes equivalent to peat moss. The solids reactor works by continuously loading the solids into a container and spraying into the solids a liquid diverted from the liquid reactor that has been heated using waste heat from the biogas-electrical conversion process. As the liquid leaches through the solid manure it physically washes the solids, extracting proteins, fats, oil and other soluble organic material from the fiber, producing, after a brief residence time, an effluent that contains high levels of COD that is then sent back to the liquid reactor for further digestion and biogas production. The process is made more efficient by using the following devices:

- The previously mentioned combined use of liquid between the two reactors which supplies a leachate that has a pH which hastens the washing process and is capable of returning high COD levels for improved biogas production;
- An internal loop for recycling the effluent from the solids reactor back to the top of the solids reactor with only a small portion of the flow being diverted back to the liquid reactor allowing for

better conservation of the heat energy needed for the solids reactor and improved rate of washing of the solids;
- An internal mechanism that is curved in shape similar to a U or S-tube that allows for better leachability within the solids; and
- A reverse flow auger that allows for continuous removal of the treated fiber while at the same time dewatering and conserving the leachate.

The above design allows for the production of a fiber that meets all US Environmental Protection Agency's requirements for classification as a Class A Biosolids for sale and packaging as a soil amendment and which in addition matches the physical attributes of permeability, moisture retention, air content, and pH that are prized in peat moss (lab tests confirm the pathogen and physical parameter requirements).

Parallel Solids Reactors for Co-Digestion of Manure with Other High Solids

The WSU system recognizes the potential of co-digestion for both the generation of added revenue for the farmer but also as a means for treating other high solids waste that are in need of disposal such as food, yard, animal, and food processing waste. The WSU system is unique in that it is not a true co-digestion where all of the incoming liquid waste streams are mixed. Our system concentrates on co-digesting a "other high solids waste stream" in a parallel solids reactor that is for the most part separate from the liquid stream being digested as well as the manure solids stream being digested in the other parallel solids reactor. Like before, this other high solids reactor works by heating and utilizing a small portion of the liquid reactor's liquid stream as a leachate. After a short residence time, the other high solids will be either washed of a considerable portion of their volatile solids and COD or hydrolyzed which will then be later returned to the liquid reactor for added electrical production and revenue. This system of co-digestion is unique and novel in that it:

- Aims to be a pre-treatment of the other high solids from sources such as municipal waste streams. The process allows for either a rapid breakdown of organic solids into molecules, a reduced smell, and/or a shortened composting time once it is transferred to a municipal composting facility. Collection and processing fees or so-called tipping fees could be attained from local industries and municipalities for this pre-treatment service;
- Provides for a separated treatment process that reduces the risk of bacterial 'crashing' that could result from such mixing. For example, the introduction of high solids such as food waste or fish waste could alter the chemical make-up of the incoming waste stream to the point where the existing bacterial populations would be stressed to the point of death and population destruction. Such a catastrophic event would lead to the souring or crashing of the digester. In our system, the only mixing of the waste streams occurs after significant separate digestion and treatment has occurred; thereby drastically reducing the risk of chemical or biological upsets;
- Keeps the potential revenue streams homogenous by having the fiber from the manure waste separate from the municipal waste fiber. As a result, two fiber products, the manure turned soil amendment and the compostable, pre-treated other solids, are available for separate processing, transportation, and sale.
- Effectively treats a variety of other solid mixtures. The WSU system will come with a turn-key set of operating procedures to be used for a variety of potential solids mixtures. The set of procedures will allow the farmer to digest a variety of solid mixtures and still attain optimal treatment and revenue because the system will be run at a pH, loading rate, chemical mixture, leaching flow rate, etc. that is specifically engineered for that particular solids mixture.