Report

Tinedale Farms Anaerobic Digestion

A Biomass Energy Project

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July 2002

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**Project Manager**

Craig Schepp  
Energy Center of Wisconsin
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Executive Summary

Tinedale Farms LLP in Wrightstown, Wisconsin, is one of the largest dairy production operations in the state of Wisconsin, housing nearly 2,500 animals. Tinedale Farms spent several years researching the various anaerobic digestion technologies that were commercially available. That research culminated in the formation of a new company called Ag Environmental Solutions, LLC (AES). The primary focus of AES is on anaerobic digestion systems, with a stated goal of maximizing solids conversion to methane that can be used for the generation of renewable energy, primarily electricity generation. AES determined that a temperature-phased Anaerobic Digestion (TPAD) system was most likely to meet their short and long-term objectives. It should be noted that the TPAD system is patented (U.S. Patent No. 5,746,919) and assigned to the Iowa State University Research Foundation, Inc., with the licensing of the patent administered by Fox Engineering of Ames, Iowa. AES has obtained a licensing agreement with Iowa State for the TPAD system as it applies to the agricultural industry.

The first AES project was constructed in Wrightstown, Wisconsin, for Tinedale Farms, and is now operational. This project has attracted considerable attention in Wisconsin and nationally, as it is the first TPAD system being operated by the dairy industry in the United States and the first anaerobic digestion system of any kind for the dairy industry in Wisconsin. AES is currently focusing on using the Tinedale Farms project to demonstrate to agricultural producers how to convert manure into renewable energy and other value-added products, thereby enhancing the environment and providing an economically viable option for large dairy operations or dairy cooperatives in Wisconsin and throughout the U.S.

The TPAD system began operating during the late spring of 2001. The system has been operated in the mesophilic range for a time, as AES looked at the reliability of equipment. The flowability of dairy manure has proven to be considerably different than municipal wastewater, causing some delays in the project. However, AES was dedicated to finding the right combination of equipment that could handle the continuous operations needed for this and future projects. AES also spent considerable time to minimize the maintenance requirements of the various system components. This approach, while adding a considerable amount of time to the project, has given AES a vast resource of information that can be used in the future. The proprietary research and development costs incurred on this first project will be extremely beneficial to the future of anaerobic digestion technology for the dairy industry.

Given the added research and development time spent on this initial project, it is not yet possible to complete a thorough economic analysis of the project. However, the major benefits of the TPAD system are expected to be increased biogas production and the associated increase in power generation. In addition, the TPAD process will reduce pathogens in the digested manure, thereby creating a more valuable byproduct that can be used for animal bedding and other value-added products.
Introduction

The dairy industry contributes $10 billion annually to the economy of Wisconsin. Most of the 21,000 dairy farms in Wisconsin are small, with less than 150 head, and operate on relatively small margins of 3-5%. However, the current trend is toward greater numbers of livestock per farm site. It is estimated that there are already more than 100 farms in Wisconsin that have at least 1,000 animals, with many more being proposed or constructed. Non-farming citizens that object to farm odors from existing facilities may lodge complaints with their township or county, triggering reassessment of regulations already in place and subsequent passage of more stringent and expensive regulations. Within the next several years, it is also likely that a new federal and state regulatory framework governing agricultural waste management will be instituted. Ideally, the industry response to the manure management challenge will be cost-effective, sustainable, and adaptable for implementation on both large and small Wisconsin Farms.

Tinedale Farms, LLP, in Wrightstown, Wisconsin, is one of the largest dairy production operations in the state of Wisconsin, housing nearly 2,500 animals. The dairy cows at Tinedale Farms produce approximately 50,000 gallons of manure per day with a solids content of 9-10%. Manure generated at the facility was historically discharged into a series of lagoons, with a capacity of 17 million gallons and later land-applied. Because of its relative proximity to Wrightstown and the increasing cost and difficulty of manure and odor management, Tinedale Farms began actively pursuing other manure management options, including anaerobic digestion. It should be noted that farms have used anaerobic digestion for many years, with varying success. However, farm based anaerobic digestion has typically been accomplished using low technology systems such as covered lagoons or plug flow digesters.

Tinedale Farms spent several years researching the various anaerobic digestion technologies that were commercially available. That research culminated in the formation of a new company called Ag Environmental Solutions LLC (AES). The primary focus of AES is on anaerobic digestion systems, with a stated goal of maximizing solids conversion to methane that can be used for the generation of renewable energy, primarily electricity generation. AES determined that a temperature-phased Anaerobic Digestion (TPAD) system was most likely to meet their short and long-term objectives. It should be noted that the TPAD system is patented (U.S. Patent No. 5,746,919) and assigned to the Iowa State University Research Foundation, Inc., with the licensing of the patent administered by Fox Engineering of Ames, Iowa. AES has obtained a licensing agreement with Iowa State for the TPAD system as it applies to the agricultural industry. The TPAD system has been used at several municipal wastewater treatment plants including Sturgeon Bay and Neenah-Menasha, Wisconsin and Iowa City, Newton, and Waterloo, Iowa. The major benefits that have been attributed to the TPAD system at these facilities are increased biogas production and pathogen destruction, which is increasingly becoming another significant issue for the dairy industry.

The first AES project was constructed in Wrightstown, Wisconsin, for Tinedale Farms, and is now operational. This project has attracted considerable attention in Wisconsin and nationally, as it is the first TPAD system being operated by the dairy industry in the United States and the first anaerobic digestion system of any kind for the dairy industry in Wisconsin. AES is currently focusing on using the Tinedale Farms project to demonstrate to agricultural producers how to convert manure into renewable energy and other value-added products, thereby enhancing the environment and providing an economically viable option for large dairy operations or dairy cooperatives in Wisconsin and throughout the U.S. The overall objectives of AES are summarized below:
1. Develop a long-term waste management strategy that will meet and exceed current and future federal and state regulations.
2. Develop a waste management strategy that is cost-effective and sustainable.
3. Demonstrate that the TPAD system is suitable for agricultural applications.
4. Capture biogas and generate “green” power that will be sold to the power grid.
5. Identify options for producing high-quality products from the anaerobic digestion biosolids.
6. Explore the feasibility of effluent recovery and reuse.

The operation of the first TPAD system for the dairy industry at Tinedale Farms will be used to address several of these objectives.

Drivers for Anaerobic Digestion

Several factors are currently making anaerobic digestion a more attractive option for farmers in Wisconsin and across the United States. The most significant factors are described below:

Large-scale farms – The size of the average farm has been increasing rapidly, with half of the large-scale farms in Wisconsin started during the last two years. Because of the capital costs associated with anaerobic digestion, it typically becomes more cost effective as the size of the farm increases or when several smaller farms can utilize a system implemented through a cooperative arrangement.

Environmental issues – There has been a call by several environmental groups for increased environmental scrutiny of farming operations by the Environmental Protection Agency (EPA) and the Wisconsin Department of Natural Resources (WDNR). This specifically includes manure storage and management, which has been associated with odor and contamination of groundwater and surface water. Increased environmental regulations are likely to result in increased costs for manure management, again making alternative options such as anaerobic digestion viable.

Renewable energy – Utilities are actively seeking sources of renewable energy to meet renewable portfolio standards, which are being proposed and implemented at the federal and state levels. In addition, several Wisconsin utilities have instituted “green” pricing programs where customers pay a premium price for energy generated from renewable sources such as manure.

These were several of the factors that contributed to the decision by Tinedale Farms to construct an anaerobic digestions system.

The Anaerobic Digestion Process

Anaerobic digestion can be defined as the biological oxidation of organic matter by microbes in an environment in which there is no molecular oxygen. The organic matter is a food source for the microbes, which convert it into oxidized materials, new cells, energy for their life processes, and gaseous end products, such as methane and carbon dioxide. Anaerobic digestion can occur at mesophilic (85-100° F) or thermophilic (120-135° F) conditions. The
advantages of digestion at thermophilic temperatures include higher rates of degradation, and therefore, the use of a smaller reactor and a lower capital cost, faster solid-liquid separation, and better control of bacterial and viral pathogens. The major disadvantage is that more heat must be added to the system than is necessary for the operation of mesophilic systems, which can be a significant issue in climates such as that of Wisconsin. However, the system at Tinedale Farms has excess heat production (1,000,000 Btu/hr) after the needs of the thermophilic process are met.

Biogas, one of the products of anaerobic digestion, is typically made up of 55% to 65% methane (CH$_4$), 35% to 45% carbon dioxide (CO$_2$), and traces of ammonia (NH$_3$) and hydrogen sulfide (H$_2$S). Pure methane is a highly combustible gas that has an approximate heating value of 994 BTU/ft$^3$. Biogas can be burned in boilers to produce hot water, in engines to power electrical generators, and in absorption coolers to produce refrigeration.

Biosolids, the other product of anaerobic digestion, can be thickened, dewatered, and dried for use as animal bedding or combined with other organic materials for use as a soil amendment. It should be noted that Tinedale Farms has been exploring these opportunities through the Fox River Valley Organics Recycling (FRVOR) project, which is under the direction of Leslie Cooperband from UW Madison. This ongoing project is attempting to develop opportunities to develop value-added products from materials such as municipal biosolids, dairy manure, paunch manure, and other food wastes generated in the Fox River Valley.
Temperature-Phased Anaerobic Digestion

Farm based anaerobic digestion has typically been accomplished using low technology systems such as covered lagoons or plug flow mesophilic digesters. As stated previously, the primary goal of AES is to maximize solids conversion to methane. Therefore, AES has focused on developing and implementing an advanced anaerobic digestion system that is cost-effective, sustainable, and adaptable for implementation on both large and small Wisconsin Farms. In the U.S., the TPAD process has been successfully applied to the stabilization of municipal wastewater sludges in many full-scale facilities and proven to be capable of producing Class A biosolids, while also producing more biogas than other anaerobic digestion systems. Both laboratory and full-scale installations (Sturgeon Bay, Wisconsin, is one example) of the TPAD process indicate that biogas production is typically at least 25% higher than with other anaerobic digestion processes, which would result in increased revenue from the sale of electricity. Both of these factors were extremely important to Tinedale Farms when considering the type of anaerobic digestion system that would be constructed.

General TPAD System Description

As noted previously, the TPAD system is patented by Iowa State University. A brief summary of the patent claims as related to agricultural waste are summarized as follows:

- Method of treating a waste stream, comprising steps of:
  1. feeding the waste stream into a thermophilic anaerobic reactor;
  2. maintaining thermophilic anaerobic conditions of the waste stream in the thermophilic anaerobic reactor for a pre-determined hydraulic retention time to generate a first biogas effluent comprising method and a first liquid effluent;
  3. feeding the first liquid effluent from the thermophilic anaerobic reactor into a mesophilic anaerobic reactor and;
  4. maintaining mesophilic anaerobic reaction conditions of the waste stream in the mesophilic anaerobic reactor for a predetermined hydraulic retention time to generate a second biogas effluent comprising methane and a second liquid effluent.

- The thermophilic reaction conditions include a reaction temperature ranging from about 45°C to 75°C, with a normal reaction temperature of about 56°C. The mesophilic reaction conditions include a reaction temperature ranging from about 20°C to 45°C, with a normal reaction temperature of about 35°C. The hydraulic retention time in the thermophilic reactor is up to about 10 days, and the hydraulic retention time in the mesophilic reactor is up to about 20 days.

It should be noted that this patent also applies to other waste streams including liquid waste, primary sludge, secondary sludge, and sludge formed from domestic solid waste. The patent is also structured to include the following types of anaerobic reactor designs: fully-packed columns with random-pack or modular media, hybrid columns including an unpacked blanket zone and a packed zone, and suspended growth systems. As noted previously, AES has obtained a licensing agreement with Iowa State for the TPAD system as it applies to the agricultural industry.
Tinedale Farms TPAD System Description

As designed, the TPAD system at Tinedale Farms falls within this general range of parameters described in the previous section. Manure from the free-stall barns is collected using a dry scraping system and combined with parlor water. The manure flows by gravity to a continually mixed equalization basin that is located adjacent to the anaerobic digestion system. The manure is then pumped from the equalization basin through a heat exchanger to achieve thermophilic temperatures prior to entering the thermophilic phase of the TPAD system. It should be noted that the heat exchanger utilizes recovered heat from the water jackets of two engine generators, which operate on the biogas produced from the TPAD system. The thermophilic reactor is completely mixed using two draft tube style mixers. The partially digested manure is then pumped from the thermophilic reactor through a cooling heat exchanger, which brings the temperature down to mesophilic temperatures, and into the mesophilic reactor. The mesophilic reactor, which consists of two equally sized compartments to prevent short-circuiting, is completely mixed using four draft tube-style mixers. The digested manure then flows out the TPAD system by gravity to the existing series of lagoons, or it can be pumped to a solids handling and water clarification process.

Tinedale Farms TPAD System Controls

A customized computer program developed by Telemetry & Process Controls, Inc., of Stillwater, Minnesota, is utilized to control all aspects of the TPAD system at Tinedale Farms, including the following: pumps, mixers, the gas handling system, the water cooling loop, and monitoring the performance of the engine generators. The program also has alarm settings for the various system components and can notify the operator via a paging system of any operational issues. An additional module for the computer system, which has not yet been purchased, includes several other data evaluation tools and performance charting features.
System Startup and Performance

Manure from the existing lagoons at Tinedale Farms was initially used to fill the anaerobic digestion system during late spring of 2001. Raw manure from the barns was then loaded to the anaerobic digestion system, with the manure loading rate gradually increased over a period of several weeks to allow the anaerobic digestion system to become acclimated. During this time period and for the next several months, the anaerobic digestion process was operated as a conventional mesophilic complete mix system because final installation of all process equipment was not yet complete. In late fall of 2001, all equipment was installed and the first reactor of the TPAD system was converted to thermophilic temperatures. During the conversion to thermophilic temperatures, it was determined that the cooling heat exchanger was not providing adequate heat removal, resulting in a temperature beyond the desired operating range in the mesophilic reactor, which severely impacted the biogas production. Several design modifications were made to the cooling heat exchanger, and it began operating effectively in late December of 2001. Therefore, it is anticipated that the biogas generation will begin to increase substantially in early 2002, as the TPAD process begins to stabilize and is continually operate as designed.

Influent Flow

The manure from the equalization tank is continually pumped to the anaerobic digestion system at a rate of approximately 35 gallons per minute or 50,000 gallons per day. The pumping rates are monitored continuously and can be adjusted based on the levels found in the equalization basin. This can be seen in the process flow diagram for the equalization tank and raw wastewater pumping, which is found in Figure 1.

As seen in Figure 1, the equalization basin has a mixer that can be controlled by the computer program described previously. There is also a level sensor in the equalization basin that can be used to monitor the flow and adjust the pumping rate from the equalization basin. Following the equalization basin, the manure is passed through a comminutor to grind up the large solids in the manure, which primarily consist of the wood shavings that are used as bedding at Tinedale Farms. Pump 3 then takes the manure and pumps it to a heat exchanger, which brings the manure up to thermophilic temperatures. The other two primary process pumps can also be seen in Figure 1. Pump 1 takes the thermophilic effluent to the cooling heat exchanger and then to the mesophilic portion of the digester. It should be noted that the pumping rate for Pump 2 is balanced with the pumping rate from Pump 3 to maintain the conditions within the TPAD system. This can be seen in Figure 2, which shows the flow trending of the two pumps. Pump 2 is used to take the mesophilic effluent to the dewatering and solids handling processes. When the solids handling process is not operating, the digester effluent flows by gravity to the existing series of lagoons.
Figure 1: Equalization tank and raw wastewater pumping flow diagram

Figure 2: Raw manure and thermophilic pump trending
Influent Characteristics

Graduate students from the Environmental Science and Policy program at the University of Wisconsin-Green Bay have monitored the manure being directed to TPAD system at Tinedale Farms five days per week since June of 2001. The characteristics of the system influent are summarized below in Table 1.

Table 1: Influent manure characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH</td>
<td></td>
<td>7.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>mg/L as CaCO₃</td>
<td>8,890</td>
<td>1,629</td>
</tr>
<tr>
<td>Total Solids</td>
<td>%</td>
<td>8.13</td>
<td>1.77</td>
</tr>
<tr>
<td>Volatile Solids</td>
<td>%</td>
<td>6.54</td>
<td>1.55</td>
</tr>
<tr>
<td>Fixed Solids</td>
<td>%</td>
<td>1.59</td>
<td>0.47</td>
</tr>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>136,000</td>
<td>45,000</td>
</tr>
<tr>
<td>SCOD</td>
<td>mg/L</td>
<td>47,000</td>
<td>12,000</td>
</tr>
<tr>
<td>Ammonia</td>
<td>mg/L</td>
<td>322</td>
<td>125</td>
</tr>
<tr>
<td>Volatile Fatty Acids</td>
<td>mg/L</td>
<td>1,698</td>
<td>494</td>
</tr>
</tbody>
</table>

The data in Table 1 indicates that there is variability in the influent to the TPAD system, most notably with the solids and the COD. Some of this variation can be attributed to seasonal changes in feed, evaporative losses, and the use of sprinklers/misters in the barns. However, other sources of variation can also be attributed to startup issues that will be discussed in more detail later in this report.

It can be seen in Table 1 that the volatile solids are approximately 80% of the total solids found in the manure. The total solids, volatile solids, and fixed solids content of the influent manure can be seen in Figure 3, a 15-day moving average chart, which is the same manner the remaining charts will also be presented.
It can be seen in Figure 3 that there was a significant increase in the solids during late August, which corresponds with some operational issues related to material handling that will be discussed in more detail later in this report. It should also be noted from Figure 3 that the total solids found in the influent would fall well below the range of what is typically acceptable for plug flow digesters, but well within the range of 3-10%; this is typical for complete mix systems. Therefore, it is not likely that a plug flow system would be a feasible option at facilities similar to Tinedale Farms without some operational changes to the dairy.

**Thermophilic Effluent Characteristics**

The thermophilic effluent has also been monitored five days per week since June of 2001. As noted previously, the first phase of the anaerobic digestion system was not converted to thermophilic temperatures until late in 2001. Therefore, the summary data for the thermophilic effluent reflects a combination of operating conditions, the majority of which were at mesophilic temperatures. The characteristics of the thermophilic effluent can be seen in Table 2.
Table 2: Thermophilic effluent characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>gallons/day</td>
<td>50,000</td>
<td>N/A</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>7.39</td>
<td>0.24</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>mg/L as CaCO₃</td>
<td>11,359</td>
<td>1,386</td>
</tr>
<tr>
<td>Total Solids</td>
<td>%</td>
<td>6.85</td>
<td>1.57</td>
</tr>
<tr>
<td>Volatile Solids</td>
<td>%</td>
<td>5.34</td>
<td>1.42</td>
</tr>
<tr>
<td>Fixed Solids</td>
<td>%</td>
<td>1.51</td>
<td>0.34</td>
</tr>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>129,000</td>
<td>47,000</td>
</tr>
<tr>
<td>SCOD</td>
<td>mg/L</td>
<td>46,000</td>
<td>11,000</td>
</tr>
<tr>
<td>Ammonia</td>
<td>mg/L</td>
<td>327</td>
<td>111</td>
</tr>
<tr>
<td>Volatile Fatty Acids</td>
<td>mg/L</td>
<td>2,188</td>
<td>1,047</td>
</tr>
</tbody>
</table>

When comparing Table 2 to Table 1, it can be seen that the total solids and volatile solids are reduced by approximately 16% and 18%, respectively. Again, it should be noted that the system has not been operating at thermophilic conditions over this entire period, so these results are significantly less than anticipated for steady-state operation as a TPAD system. It should also be noted that the fixed solids are relatively consistent from the influent to the thermophilic effluent, indicating that the draft tube mixers in the digester are performing adequately.

Mesophilic Effluent Characteristics

The mesophilic effluent has also been monitored five days per week since June of 2001. The characteristics of the mesophilic effluent can be seen in Table 3. When comparing Table 3 to Table 1, it can be seen that the total solids and volatile solids are reduced by approximately 22% and 29%, respectively. It should be noted that municipal plants that utilize a TPAD system have been able to achieve significantly higher solids destruction.
Table 3: Mesophilic effluent characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td>gallons/day</td>
<td>50,000</td>
<td>N/A</td>
</tr>
<tr>
<td>PH</td>
<td></td>
<td>7.16</td>
<td>0.30</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>mg/L as CaCO₃</td>
<td>11,378</td>
<td>1,633</td>
</tr>
<tr>
<td>Total Solids</td>
<td>%</td>
<td>6.33</td>
<td>2.39</td>
</tr>
<tr>
<td>Volatile Solids</td>
<td>%</td>
<td>4.89</td>
<td>2.55</td>
</tr>
<tr>
<td>Fixed Solids</td>
<td>%</td>
<td>1.39</td>
<td>1.74</td>
</tr>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>128,000</td>
<td>55,000</td>
</tr>
<tr>
<td>SCOD</td>
<td>mg/L</td>
<td>47,000</td>
<td>13,000</td>
</tr>
<tr>
<td>Ammonia</td>
<td>mg/L</td>
<td>292</td>
<td>146</td>
</tr>
<tr>
<td>Volatile Fatty Acids</td>
<td>mg/L</td>
<td>2,396</td>
<td>1,472</td>
</tr>
</tbody>
</table>

Using a 15-day moving average for determining volatile solids destruction, the anaerobic digestion system at Tinedale Farms had a maximum volatile solids destruction of approximately 48%. This maximum volatile solids destruction occurred in mid-August, just prior to several of the operational problems that were encountered in late August, which will be discussed in more detail later in this report. The volatile solids destruction can be seen in Figure 4.

Figure 4: Volatile solids destruction
Biogas Generation

The biogas generation from the TPAD system is monitored using a series of flow meters purchased in conjunction with the Energy Center of Wisconsin grant received by Tinedale Farms. A process flow diagram of the biogas handling system can be seen in Figure 5.

Figure 5: Biogas handling process flow diagram

The process flow diagram in Figure 5 begins with the biogas from the TPAD system. The biogas initially passes through a condensate trap and can then be flared or sent to the generators. The biogas sent to the generators is passed through an additional biogas treatment system to remove hydrogen sulfide, which could be detrimental to the long-term operation of the generators. It can be seen in Figure 5 that two biogas flow meters are positioned to measure the total amount of biogas and the biogas to the flare.

The flow meters were operational in mid-June of 2001, several weeks after the initial production of biogas. The 15-day moving average for biogas generation from the TPAD system since the flow meters were installed can be seen in Figure 6.
Figure 6: Biogas generation

It can be seen in Figure 6 that the biogas flow increased rapidly during the initial startup of the anaerobic digestion system at mesophilic temperatures. This increase in biogas generation continued until August of 2001, when several operational issues related to materials handling were encountered. These results are consistent with the volatile solids destruction results in Figure 4. The biogas generation began to decrease significantly at approximately the same time as the decrease in volatile solids destruction.

**Biogas Composition**

Similar to the biogas generation, the biogas composition also began to change significantly near the end of August. It can be seen in Figure 7 that the methane concentration began to decrease rapidly and the amount of carbon dioxide began to increase. It should be noted that the methane concentration did reach more than 70% during the initial period of digester operation.
Solids Handling and Management

To date, the majority of the biosolids from the TPAD system have been directed to the existing lagoons at Tinedale Farms. However, several pilot tests have been conducted using various types of dewatering and drying equipment to determine the feasibility of using the digested biosolids as bedding. The primary issue associated with the dewatering of the solids is the fact the solids from the digester are much smaller than the solids in raw manure. The smaller particles are more difficult to separate, resulting in a low capture efficiency for the solids. This results in less solids being available for bedding and more solids in the separator effluent sent to the lagoons. Work continues in this area to improve the capture efficiency and also to research the fate of the nutrients in the digested solids. It should be noted that preliminary tests at Tinedale Farms indicate that the cows prefer the digested biosolids as compared to the wood shavings, perhaps for comfort reasons, as the biosolids are softer than the wood shavings.

As noted previously, Tinedale Farms is an active member of the FRVOR project and will continue to work with this group to identify additional value-added markets for the digested biosolids. The major advantage of the TPAD system in this regard is the pathogen destruction that occurs at thermophilic temperatures, which results in a byproduct that has fewer regulatory restrictions.

System Performance Issues

Several performance issues have been identified with the TPAD system at Tinedale Farms. To date, the most significant system performance issues have been related to materials handling and the cooling of the thermophilic effluent. Some of these system performance issues can be directly attributed to the fact the anaerobic digestion system at Tinedale Farms was originally designed to be a plug flow system. However, several other issues are more specific to the TPAD system as constructed at Tinedale Farms.

The system performance issues that have been encountered are summarized below:
Reactor Design

The tank used for the TPAD system at Tinedale Farms was originally designed to function as a plug flow system. Therefore, extensive tank modifications were required to make it suitable for operation as a TPAD system. This included the construction of additional walls to compartmentalize the tank, as well as provisions for the draft tube mixers. For future projects, round aboveground tanks will be utilized to eliminate this issue. It should also be noted that round tanks are more conducive to mixing, which will likely reduce the horsepower required for mixing.

Materials Handling

Pumping manure has proven to be a significant issue with the anaerobic digestion system at Tinedale Farms, primarily because of the wood shavings that are used as bedding material. The shavings typically have some larger pieces of wood that are problematic in pumping, as well as in the heat exchanger. This was the primary issue that impacted the biogas generation beginning in early August and through the month of September. As noted previously, upon verification of pathogen destruction in the digested solids from the TPAD system, these materials will be used as bedding at Tinedale Farms, thereby eliminating this issue. The proper pump applications have now been installed.

Cooling Heat Exchanger

As noted previously, the cooling heat exchanges have also been a significant factor in terms of the overall system performance. Upon converting the first reactor of the system to thermophilic temperatures, it was determined that the cooling heat exchanger was not functioning as designed, which resulted in a higher than expected temperature in the mesophilic reactor and adversely impacted system performance.

The impacts of the later two issues can clearly be seen in Figure 9, which provides a summary of the temperature data from the TPAD system. It can be seen in Figure 9 that the temperature in both reactors remained relatively constant at mesophilic temperatures during the time period from early June through the middle of August. This corresponds closely with the periods of highest volatile solids destruction and biogas production, and methane content of the biogas.

The material handling issues became significant in mid-August, when several pumps were replaced to allow for a more consistent operation of the anaerobic digestion system. As seen in Figure 8, this results in a reduced temperature in the thermophilic reactor through early September. After the new pumps were installed, the temperature in the first reactor was increased to the thermophilic range, which can also be seen in Figure 8.
In late September and early October, the thermophilic reactor reached the lower end of the thermophilic range and began operating consistently in terms of temperature. However, the issue with the cooling heat exchanger became apparent as the temperature in the mesophilic reactor began to go beyond the desired range in early October. In the last three months of the year, it can be seen in Figure 8 that the changes in the thermophilic temperature are mirrored by the changes in the mesophilic temperature. The net result was that the issues with the cooling heat exchanger effectively prevented the TPAD system from operating at the ideal thermophilic and mesophilic temperatures at the same time.

When combined, the materials handling issues in late August and the cooling heat exchanger issue after that have significantly impacted biogas generation over an extended period of time. These two issues were resolved in late December, and it is anticipated that the system will stabilize in relatively short order.

In addition to the system performance issues, one other issue also proved to be significant. Negotiating a power distribution agreement with the local utility took considerably longer than anticipated. In part, this was because of the innovative nature of the project. However, there were several technical issues encountered regarding the grid inter-tie for the system. Efforts at the statewide level to standardize these types of agreements should minimize these types of issues from occurring in the future. It should be noted that the power distribution agreement was not yet in place during June and July, when both the flow and composition of the biogas would have been adequate to generate electricity.
System Operations and Maintenance

Developing a low-maintenance system was extremely important to Tinedale Farms, as reliability is a critical issue for the farmer as well as the utility that purchased the power generated from the system. Therefore, a number of features have been built into the TPAD system at Tinedale Farms to minimize the amount of maintenance time required. The most important feature is the computer system that controls the TPAD system and the associated paging system. This system allows the operator to perform their regular duties, but it also notifies them if a problem were to develop. When a problem does occur, the paging system provides the operator with a code that identifies the type of system error that occurred, so the operator can proceed directly to that part of the plant or make a determination regarding the urgency of the situation. For example, a generator problem would likely be more critical than a minor pumping issue.

Several other specific features have also been incorporated in the design of the TPAD system. For example, the generators have been equipped with a pump-out and gravity fill feature that reduces the time required for oil changes to approximately 20 minutes. This system also minimizes any opportunity for operator error, as the volume of oil is measured directly as it is being added to the generators. Other pieces of equipment, such as the heat exchangers, were also designed to minimize the need for maintenance and cleaning.

Due to the materials handling issues described previously, as well as the typical issues experienced during system installation and startup, the time required for system maintenance to date has been somewhat higher than anticipated. However, when the system has been performing as designed, the maintenance has been limited to approximately one to two hours per day, which primarily includes daily inspection of the system and minor modifications to the system operating parameters. This work has been completed by Todd Theunis, who is responsible for the operation of the entire TPAD system at Tinedale Farms, including the solids handling and management.
Economic Viability

Given the performance issues that have been described previously, it is extremely difficult to assess the economic viability of the TPAD system at this time. However, Tinedale Farms is still extremely confident that the payback for the project will be in the range of five to seven years, which is generally an acceptable time period for the agricultural industry. The general benefits of operating the system can be discussed as related to power generation, solids utilization opportunities, and avoided costs.

Power Generation

The power generated by the TPAD system at Tinedale Farms is being sold to Wisconsin Electric Power Company (WEPCO). The price being paid by WEPCO is confidential, based on the contractual agreement. However, general revenue estimates for these types of systems can be calculated by determine the electrical output of the system and the price that a utility would be willing to pay.

Solids Utilization

The TPAD system installed at Tinedale Farms provides several opportunities to utilize the digested manure for value-added products such as animal bedding and soil amendments. Again, the pathogen destruction associated with the TPAD system increases these opportunities considerably. Based on a preliminary evaluation and numerous inquiries by prospective customers, it is anticipated that the dewatered and dried solids can be sold as bedding for approximately $50/ton. As noted previously, additional research and development is taking place in this area to improve the capture efficiency of the solids and to determine the fate of the nutrients digester effluent during the dewatering and drying process. As noted previously, Tinedale Farms continues to work with FRVOR in an effort to identify additional value-added markets for the digested biosolids.

Avoided Costs

Using the dried biosolids as animal bedding will allow Tinedale Farms to avoid purchasing the wood shavings currently used for bedding, resulting in an avoided cost approaching $100,000 annually. This will also reduce the hauling costs of bedding by an additional $14,000.

Because the anaerobic digestion process does not significantly alter the total volume of liquid that must be land-applied, research and development efforts are also being initiated by AES to determine the feasibility of water clarification and reuse. These efforts are very preliminary, but have the potential to significantly reduce or eliminate the costs associated with land application.

Other Opportunities

Several additional opportunities that have not yet been explored at Tinedale Farms are also available to further increase the economic viability of the project. Most notable are the ability to utilize hot water from the system for other uses such as cleaning water and the ability to use waste heat to heat buildings. Given the location of the TPAD
system at Tinedale Farms, it will be difficult to take advantage of these opportunities for this project. However, future projects at new or existing dairies can be designed to maximize all the benefits available from the system, thereby decreasing the payback even further.

A preliminary estimate of revenue and cost savings is shown on the next page.
AG ENVIRONMENTAL SOLUTIONS, LLC
Revenue Production & Cost Savings

Revenue Production
Bedding (5475 tons less use of 2060 @ $60) 203,700 18.11%
Electricity (6374 Mw less use of 1080 Mw @ .07) 370,580 32.94%

Expenses of Revenue Production
Maintenance & Labor (.015 per Kwh) 95,610
Other 27,900
Total 123,510 -10.98%

Net Revenue Production 450,770 40.07%

Cost Savings
Bedding (2060 tons @ $60) 124,600 11.09%
Electricity (1080 Mwh @ .045) 48,600 4.32%
Trucking & Field Spreading (4480 loads @ 5500 gal @ 93% solids @ .0125 per gal cost) 286,410 25.46%
Liability Exposure (Trucking, EPA, Lawsuits) 100,000 8.89%
Mortgage's (2500 @ 115 per 6 yr life) 47,917 4.26%
Tax Savings on Write-Off of Capital Expenditure or Lease (Dep or Lease $105,000 per yr @ Fed & State 36%) 66,600 5.92%
Total Cost Savings 593%

Total Net Revenue & Cost Savings 1,125,097 100%

Financial Analysis
Cost per Head (2500 head model) 1,300.00
Payback in Years 2.889
Percent Return on Investment 34.62%

QUALIFYING DATA

AG Environmental Solutions, LLC
Revenue Production & Cost Savings Analysis

The information shown was computed using a farm of 2500 head. The dollar amounts are the best estimate we could ascertain from the present economics and marketplace. We used Tinedale Farms, L.L.P as our model since the TPAD (Temperature Phased Anaerobic Digester) system is located at Tinedale Farms, L.L.P, Wrightstown, WI.

There will usually be differences between the presentation and actual results, because events and circumstances frequently change from farm to farm, and those differences could be material.
Environmental Impacts

The anaerobic digestion project at Tinedale Farms was implemented because of a number of factors, including the overall environmental impacts of the facility in relation to its close proximity to the Village of Wrightstown and the costs associated with manure management now and in the future.

Environmental Benefits

There are several major environmental benefits derived from the TPAD project at Tinedale Farms. The benefits are summarized below:

1. As the volatile solids destruction of the TPAD system increases, there should be a noticeable odor reduction at Tinedale Farms. Again, this was one of the reasons why Tinedale initially began exploring anaerobic digestion as a manure management option.

2. The generation of green power will be a significant environmental benefit of the TPAD system. It will not only reduce the reliance on non-renewable sources of energy, but it will also reduce methane emissions, which are considered to be a substantial greenhouse gas.

3. The ability to produce bedding materials from the digested manure is another major environmental advantage of the TPAD system for several reasons. First the use of the digested solids as bedding reduced the amount of materials that are brought onto the farm. For Tinedale this is approximately one semi-load of bedding materials per week. The opportunity to use the digested solids as bedding is available primarily because the TPAD system achieves better pathogen destruction than the mesophilic system. This is important in terms of herd health, as well as the ability to sell the materials as a value-added product.

4. The operation of the TPAD system at Tinedale Farms has resulted in several improvements in the overall operation of the facility. Perhaps most significant is the fact that the data being collected for the TPAD system has been extremely valuable in identifying ongoing operations and maintenance issues. For example, in one instance, an increased flow of approximately 2-3 gallons per minute was being seen at the TPAD system. A subsequent investigation determined that a pipe had developed a significant leak that had not been previously detected. By identifying this problem, Tinedale Farms was able to fix the problem and reduce the amount of water being used, which also translates into a reduction in the amount of liquid that must be hauled offsite for land application.

Environmental Problems

To date, no major environmental issues have been identified in conjunction with the operation of the TPAD system at Tinedale Farms. In fact, as the system begins operating more efficiently and producing more biogas, the odors associated with Tinedale Farms should be reduced significantly, thereby meeting the project goals of developing a long-term waste management strategy that will meet and exceed current and future federal and state regulations and develop a waste management strategy that is cost-effective and sustainable.
Conclusions

The TPAD system at Tinedale Farms began operating during the late spring of 2001. The system has been operated in the mesophilic range for a time as AES looked at the reliability of equipment. The flowability of dairy manure has proven to be considerably different than municipal wastewater, causing some delays in the project. However, AES was dedicated to finding the right combination of equipment that could handle the continuous operations needed for this and future projects. AES also spent considerable time to minimize the maintenance requirements of the various system components. This approach, while adding a considerable amount of time to the project, has given AES a vast resource of information that can be used in the future. The proprietary research and development costs incurred on this first project will be extremely beneficial to the future of anaerobic digestion technology for the dairy industry. Only recently has the anaerobic digestion system been switched over to the TPAD process.

Given the added research and development time spent on this initial project, it is not yet possible to complete a thorough economic analysis of the project. However the major benefits of the TPAD system are expected to be increased biogas production and the associated increase in power generation. In addition, the TPAD process will reduce pathogens in the digested manure, thereby creating a more valuable byproduct that can be used for animal bedding and other value-added products. Results in late December indicated that the system is beginning to operate more efficiently, and it is expected that the biogas generation will increase substantially in early 2002. AES continues to be extremely committed to the anaerobic digestion of dairy manure using the TPAD process and is confident that the project will have a payback period of approximately five to seven years.