# Small Digester Case Study – Keewaydin Farm, Stowe, Vermont

Prepared by: M. Charles Gould, Extension Educator, Michigan State University

Reviewed by: Jonathan Rivin, University of Wisconsin Extension, Steve Safferman, Michigan State University, and Julie Smith, University of Vermont Extension

## Farm overview

Keewaydin Farm is a third generation family farm owned and operated by Les and Claire Pike at the edge of the resort community of Stowe, VT. The dairy farm milks an average of 90 Jersey cows and at any given time there are 60-70 replacements (young stock). Alfalfa for haylage and grass hay are grown over 135 acres. In 2007, the farm was recognized as a Vermont Dairy of Distinction. This award recognizes farms that maintain a well-kept farmstead.

## Anaerobic digestion system overview

The Model AnD 1B22 digester (Figure 1) is a scalable and modular plug flow digester. It was designed and built by Avatar Energy, LLC, 1981 N. Broadway, Suite 430, Walnut Creek, CA 94596. The digester vessel and end cone (snout) holds about 28,000 gallons. The designed loading rate is 1,000-1,200 gallons/day with a hydraulic retention time of 20 days. The digester operates at 105˚F. Biogas is stored in the vessel. Operation of the digester is shared. The farm has certain minimal responsibilities such as lubrication and checking the oil in the genset. Avatar does the maintenance, such as changing the oil in the genset and repairs. The digester was commissioned the summer 2011 but actually started working spring 2012. Rumensin® is not used in the herd.

Figure 1. Avatar AnD 1B22 digester at Keewaydin Farm. Photo courtesy of Charles Gould.

## Why the digester?

The reasons the farm installed the digester were to reduce the farm's annual electricity bill and provide a ready source of bedding for the milk cows. Electricity bills were increasing every year and sawdust and wood shavings were expensive and becoming increasingly hard to find.

## Anaerobic digestion system

Following is a diagram (Figure 2) and description of the system from inflow of feedstocks into the digester to electricity generation.

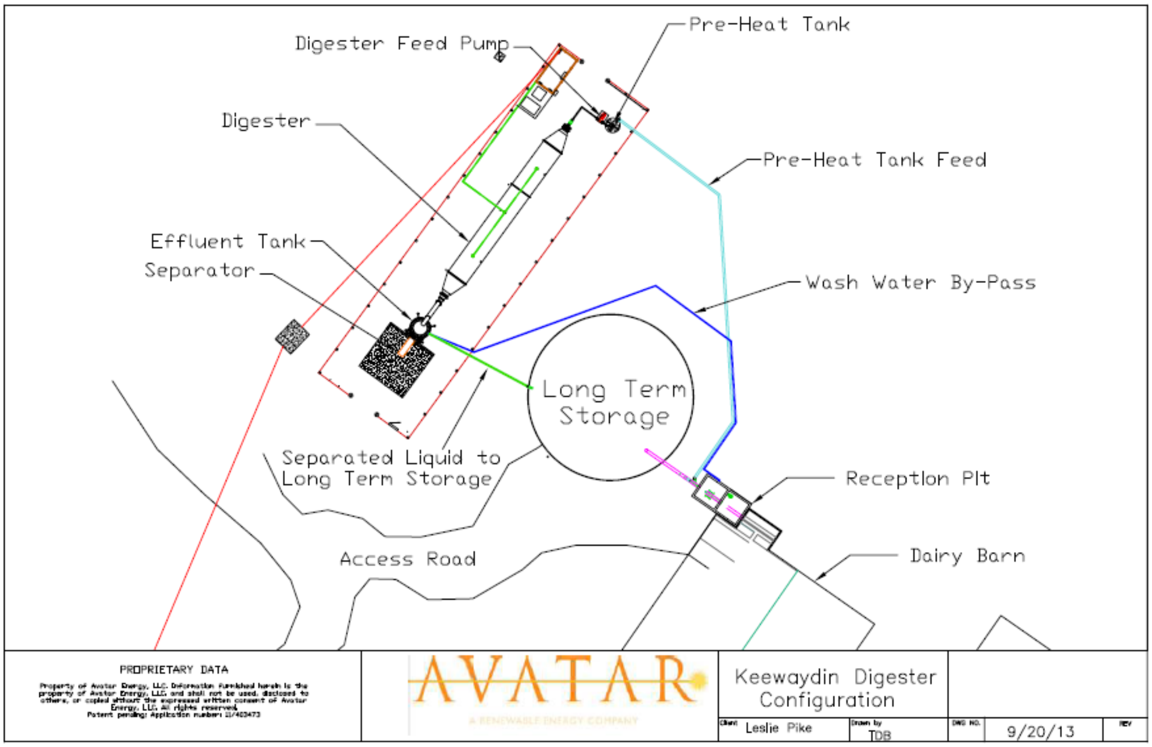
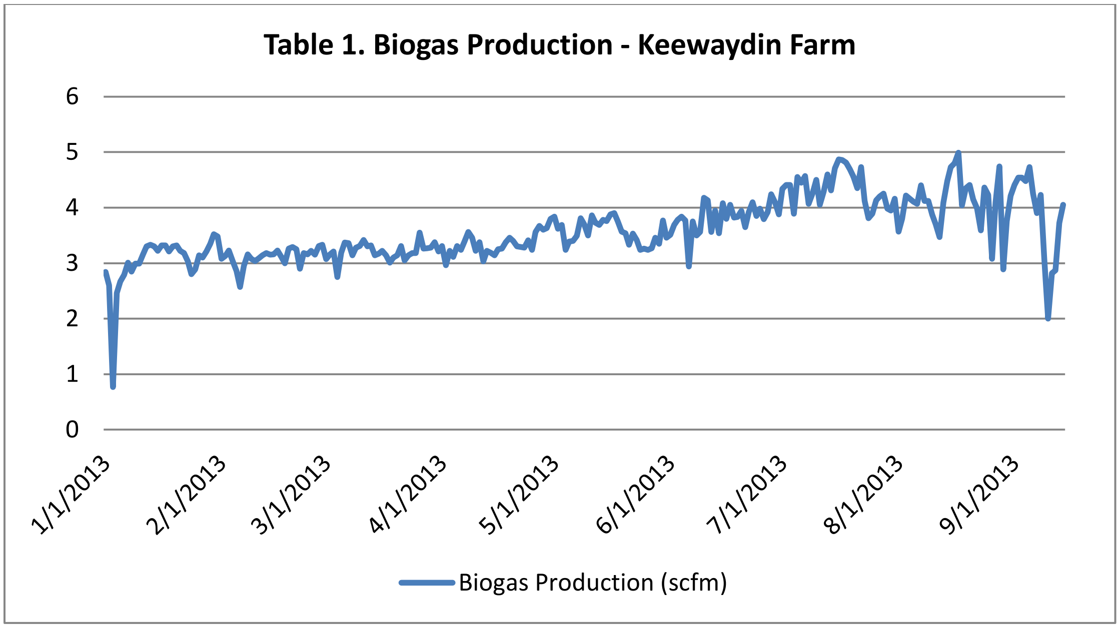



Figure 2. Keewaydin Farm digester configuration. (Used with permission from Avatar Energy LLC)

- **Manure collection:** Alley scrapers scrape manure off the barn floor every three hours into a reception pit. The reception pit holds about a day and a half of manure. If needed, 300-400 gallons/day of milking parlor water can be pumped into the reception pit to reduce viscosity.
- **Off-farm feedstock use and storage:** The digester only receives manure from the milking herd. Off-farm feedstocks are attractive and available to the farm, but the farm won't take them until the digester works properly with just on-farm feedstocks and more storage capacity is added. The farm uses a SlurryStore® to hold filtrate from the separator and parlor water during the winter months when it cannot be land applied. In Vermont it is against the law to spread manure between December 15 and April 1. The addition of off-farm feedstocks to filtrate and parlor water would greatly reduce the farm's storage capacity during the time manure cannot be applied.
- **Preheat feedstocks:** Manure is pumped from the reception pit to a 400 gallon preheat tank. The preheat tank is heated to 105˚F four times per day (i.e. four 400 gallon batches/day). When a batch reaches 105˚F, it is pumped into the digester. There are no chopper pumps to macerate manure anywhere in the system.

- **Digester vessel:** The digester vessel is made out of ½ inch thick fiberglass. It measures 8 feet in diameter by 60 feet long and has an effective manure holding capacity of 22,472 gallons. With the end cone, the total volume of manure in the digester is about 28,000 gallons. Heat from the genset heats glycol that is circulated in tubes spaced six inches apart that are wrapped around the outside of the digester. The external digester wall is coated with 3-4 inches of spray foam insulation. Thermocouples mounted in thermowells in the digester wall allow continuous monitoring of the temperature within the digester.
- **Mixing:** Biogas is pumped out of the vessel's headspace, runs through an air pump, and is reinjected into the digester through manifolds along the floor of the interior. The bubbling action of the biogas mixes the slurry within the digester. The biogas is not compressed.
- **Digestate solids separation:** A PT&M Model E-6 screw press is located on a pedestal underneath the digester's effluent outlet. It is fed by a 5 hp Boerger pump. The screw press yields about 2 cubic yards/day of fiber at 65% moisture. There is no long term storage for solids because each day the milking herd and dry cows are bedded with this fiber. Analysis of the fiber by Avatar indicates a moisture content of 63-65%. Fecal coliform tests performed by Avatar show a $>10^4$ reduction in gas forming colonies relative to raw manure entering the digester. Since bedding with digested solids, incidence of mastitis has dropped significantly, in particular in the summer months. It should be noted that the calves and maternity pens are bedded with sawdust.
- **Filtrate:** 372,000 gallons of filtrate are generated per year. The filtrate is stored in the SlurryStore® until it is land applied on growing crops. Avatar did not have a recent analysis of the filtrate, but indicated it is typical to see the concentration of organic-N shift from ~60% to ~40% and the $NH_3$-N shift from ~40% to ~60%. A sample of the fiber and filtrate will be sent in August 2013 to a lab at the University of Vermont for a nutrient analysis.
- **Biogas collection:** Biogas is stored in the top 18 inches of the digester. There is no separate biogas storage.
- **Biogas treatment:** Biogas passes through two canisters filled with ¾ inch limestone rock to reduce moisture in the gas. Direct injection of air into the digester headspace to reduce $H_2S$ proved to be unsuccessful, due to the redeposition and reduction of sulfur formed on the inside surface of the digester. The canisters capture and drain moisture in the biogas. Avatar's analysis of the biogas indicates there is typically 62-64% methane and 37-35% $CO_2$ as measured with a Bacharach $CO_2$ analyzer. Hydrogen sulfide levels vary from 1,800-2,000 ppm by Draeger tube measurement.
- **Biogas production:** The digester is fed 1,280 gallons manure per day (equivalent to 75 head of milking cows). The biogas output averages between 4,500-6,600 scf/day at a flow of between 3 and 4.5 scfm. The genset is rated to recover a total of 0.143 MMBTU/hr. Table 1 shows biogas production from January through September 2013. The September 2013 downward spike is due to a bypass of the flow meter while the genset was overhauled.




Used with permission from Avatar Energy LLC.

- **Electricity generation:** The primary use for the biogas is electricity production. Excess biogas is flared off. An I-Power ENI 20 genset (a modified GM 3L 4-cylinder engine and a WEG generator) designed to run on natural gas produces both heat and electricity. The genset is designed to produce 20kW continuous output. Because the genset is oversized, relative to the digester's expected biogas production, the digester controls turn on the genset when the digester pressure reaches 105 inches water column and turns it off when the pressure drops to 20 inches water column. This allows the genset to produce an average output of 8kW. The genset operated without $H_2S$ scrubbing for 5,700 hours. The engine block and starter were replaced by Avatar staff in mid-September of 2013, requiring four days of down time. Gross average monthly kW output from January through August 2013 was 3,420 per month and net (i.e. parasitic load) was 2,605 per month. This represents actual output taken from the farm's electrical bill. The farm is part of a net metering group which consists of the digester, the farm, the farmhouse, and three other homes owned by the farm. The net metering rate is 15.33 cents/kW, which was determined by averaging individual rates across the group members. In May 2013, total electricity production from the system exceeded the power consumed during installation, start-up, system troubleshooting and operation. By June 2013 the system was producing more power than it consumed on a daily basis. The farm has been realizing savings on their electrical bill since June 2012. In July 2013 for example, the farm's electrical bill was reduced by $512 to $464. In 2013, the average parasitic load was 22%. However, since June 2013 the average has been 16%. Parasitic load refers to the power used to operate equipment that that is deducted from the total power produced.

  The farm sends Stowe Electric Department a letter every month indicating what percent of power is to be allocated to each of the six members in the net metering group. On average 15% of the electricity produced is allocated to the digester and 85% is allocated to the barn. Oil changes are scheduled every 220 hours.

## Economics

The contract price to the farm for the anaerobic digestion system (digester plus building, reception pit, manure pumps and genset) was $512,000. The farm was awarded $241,000 through the USDA Natural Resources Conservation Service Environmental Quality Incentives Program and $250,000 from a Vermont Clean Energy Development Grant for a total grant award of $491,000. The farm contributed the remaining $21,000. Later the farm was awarded a $9,200 Vermont Agency of Agriculture BMP Grant to cover other expenses. Additionally, the farm has paid $4,000 in unforeseen expenses.

The farm does not own the digester until the last payment is made. The last payment is $50,000, or 10 percent of the cost of the digester. The digester has to be finished and running satisfactorily for 45 days before the last payment is due. Once the digester is owned by the farm, a service contract will start for a set fee for five years. The fee is based on digester performance and hours the genset is running. The service contract is renewable at the end of the five years for another five years at a slightly higher rate.

Because the digester did not reach consistent operation until summer of 2013, it is difficult to determine a true value of the energy produced. However, a window to what that value might be was provided from January through August 2013. Based on power company records, the gross value of the electricity produced was $4,178 and the net value after subtracting the digester parasitic load was $3,182.

Avatar no longer sells the AnD 1B22 digester. Avatar provided the following estimated breakdown of capital costs for the AnD 1B37-12 digester (Table 2), which is slightly larger than the AnD 1B22 model but has the same components (Figure 3).

**Table 2. Avatar System AnD 1B37-12 estimated capital costs.**

| | |
|---|---|
| Approximate Herd Size | 100 Milkers |
| Hull Length (feet) | 50 |
| Hull Diameter (feet) | 12 |
| Generator Size | 20 |
| Generator Efficiency | 25-30% |
| Core Pricing: | |
| Avatar Core Technology | $290,000 |
| Labor | $120,000 |
| Engineering | $5,800 |
| Startup/Commissioning/Contingencies | $11,600 |
| Third Party Equipment and Subcontractors: | |
| Feedstock Handling | $40,000 |
| Generator | $50,000 |
| Pre-processing | $20,000 |
| Digester Barn | $60,000 |
| Excavation | $30,000 |
| Electrician | $25,000 |
| Interconnection | $36,000 |
| **Total System Price (installed)** | **$688,400** |
| Optional Equipment: | |
| Co-Substrate Equipment | $30,000 |
| Separator | $40,000 |
| $H_2S$ Reduction | $8,500 |

Used with permission from Avatar Energy LLC.

In terms of additional sources of revenue from the digester, the farm does not participate in a carbon credit exchange due to the complexity of the paperwork involved and restrictions on time. However, based on recent fiber output, the farm estimates it will save an average of $750/month by not having to buy sawdust and wood shavings to bed the milking herd.

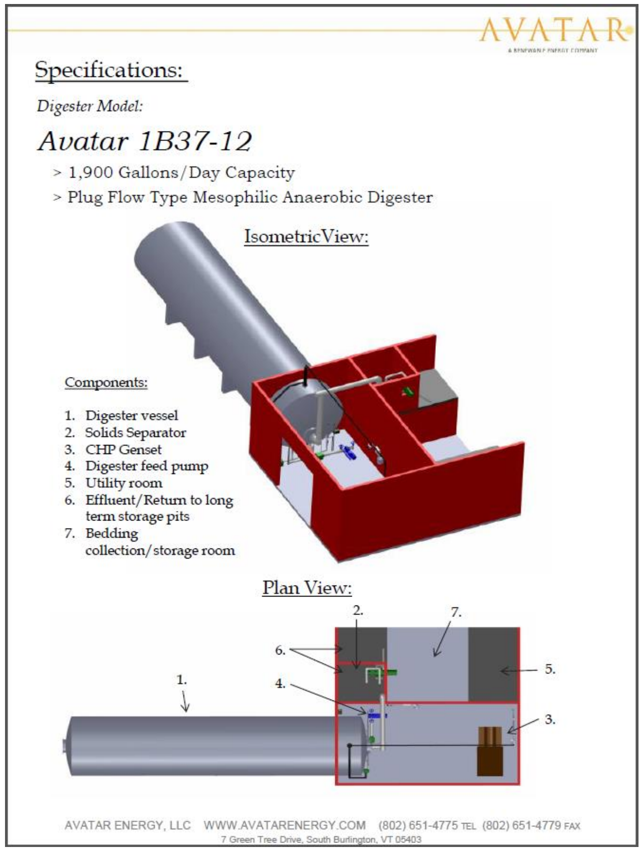



Figure 3. Specification sheet for the Avatar AnD 1B37-12 digester. (Used with permission from Avatar Energy LLC)

## Testing

Avatar monitors pH through monthly sampling of the digestate. Temperature is monitored continuously through thermocouples located at the pre-heat tank and in two locations in the digester. Biogas production is continuously monitored using a Sage Instruments mass flow meter. Total Solids/Volatile Solids are monitored monthly by sampling and analysis in Avatar's lab in South Burlington, VT.

Digester biogas pressure is monitored continuously using an Omega Instruments pressure transducer in the biogas line. Volatile Fatty Acid measurements are not monitored as a process parameter, but as performance indicator.

Parameters that cannot be measured accurately on site are sent to the Avatar lab in South Burlington, VT. These parameters include Total Solids, Volatile Solids, Volatile Organic Acids and Fecal Coliform counts. Avatar uses fluorescent microscopy to qualitatively study the methanogen populations. Additional tests are sent to third party labs. Nutrient analyses and microbial profile analyses are sent to Dairy One (Ithaca, NY).

## Operational requirements

It is estimated that the required time commitment by farm staff to operate the digester is two hours per day. In addition to the time it takes to operate the digester, it is estimated that farm staff spend two hours per day doing routine system maintenance and repairs. Process monitoring is done by Avatar personnel twice a month at approximately one hour per visit. Of the activities performed by farm staff, making repairs to the digester system cause the most disruption to the normal daily activities on the farm. There has been significant downtime while operating the system. Avatar is paying the annual operating expense. The operating expenses are much higher than projected when the project was designed because of many costly repairs.

## Financial

The digester has not been in operation long enough to arrive at a reasonable estimation of profit and loss.

## Reported problems/Failures in specific areas

Below are problems or failures experienced by the farm in five specific categories:

1) Site planning and design

- None noted.

2) Engineering

- A biogas leak was ignited by a motor that was not explosion-proof. The motor was replaced and cabinets rebuilt to prevent trapping of biogas.
- Feeding the screw press by gravity did not work as specified by Press Tech Manufacturing. Avatar installed a Boerger rotary lobe pump and bypass loop to correct this problem.
- In the original design, the pump that fed the digester was positioned such that it could not be serviced without emptying the digester hull. That has since been corrected.

3) Construction and equipment

- Avatar's in-house designed pump that fed the digester failed multiple times in the first 18 months of operation and was replaced with a Boerger rotary lobe pump at Avatar's expense. The new configuration has functioned properly since installation.
- The digester insulation used initially failed to perform as specified by the manufacturer. At Avatar's expense the insulation was removed and replaced with spray-on urethane foam. The digester now maintains a steady mesophilic temperature.
- The heat exchanger in the genset was configured incorrectly and was not providing adequate heat for winter digester operation. Avatar personnel identified the problem and successfully reconfigured the heat exchanger. Outgoing hot water temperatures from the genset are routinely between 150ºF and 165ºF.
- Preheat agitation system failed at low ambient temperatures due to the high viscosity of cold manure. A second impeller was added to the mixing shaft to insure adequate mixing in all seasons.
- Temperature sensors in digester failed to work properly, necessitating quarterly calibration.
- The level sensor in the digester failed. The output of this sensor is not used as a control parameter.
- Float switches used to sense preheat tank levels did not operate properly and were successfully replaced with Houle level sensors at Avatar's expense.
- The soil and gravel base under the digester was not compacted adequately before the digester was built. Consequently, the cradles that support the digester began to sink into the ground. The digester was raised and 1" thick steel plates were placed beneath the cradles at Avatar's

expense to distribute the weight of the digester over a larger area. This has prevented further sinking of the cradles and stabilized the digester.

4) Biogas utilization and systems

- I-Power (the genset manufacturer) appears to be out of business now. Avatar personnel have taken on the responsibility for operating and maintaining the generator.

5) System control and operation monitoring and control

- The controller software has received several upgrades to correct operational issues such as inconsistencies in the display of cubic feet of biogas generated by the digester. The controller software is still in the process of being upgraded to a more user-friendly interface.

## Lessons learned from the farm's perspective

- Be very deliberate and thoughtful before agreeing to be an R&D project for a company with little digester building and operation experience. We are still in the R&D phase and hope to eventually prove that digester systems on small farms can work out and pay off in the end.
- Clear and honest communication between the farmer and the digester vendor promote trust and feelings of goodwill.
- Talk to an attorney. However, it should be understood that because anaerobic digestion is a relatively new technology there probably are not any attorneys who are familiar enough with these systems to draw up a good contract that foresees all possible problems. Talk to current owners of other systems to get their recommendations on contract content.
- Maintain more control over the construction process. We could have saved Avatar and the farm money if we had had more input during the construction phase.

## References


- Personal interview by author with Les, Claire and Suzi Pike, Keewaydin Farm.
- Email communication by author with Guy Roberts, Avatar Energy LLC.


**Who to contact:**

M. Charles Gould
Extension Educator-Agricultural Bioenergy and Energy Conservation
Agriculture and Agribusiness Institute, Michigan State University
Toll Free: (888) 678-3464, ext. 68829 Email: gouldm@msu.edu

**Acknowledgements**
The author would like to thank **The North Central Regional Center for Rural Development** (NCRCRD) for funding in support of this work. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author and do not necessarily reflect the views of NCRCRD, Michigan State University or Michigan State University Extension, and reflect the best professional judgment of the author based on information available as of the publication date. The author would like to thank Guy Roberts (Avatar Energy LLC) and Les Pike (Keewaydin Farm) for providing the information necessary to makes this case study possible.