DRAFT REPORT:
TRANSITION TOWARD RESOURCE RECOVERY ON DAIRY FARMS:
A CASE STUDY OF AA DAIRY

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EXECUTIVE SUMMARY

This report provides information about the application of resource recovery at AA Dairy Farm located in Candor, NY. AA Dairy has successfully implemented the concept in part by installation and operation of an anaerobic digester, diesel engine cogenerator, solids-liquid separator, liquid-waste storage lagoon and including practices of composting and land applications of effluent in support of these principles.

AA Dairy is presently a 460-530-cow dairy operation (averaging 500 cows) with plans to expand to 1000 cows. Located on a 2,200-acre farm in Candor, in the southern Fingerlakes region of Upstate New York. The dairy started operating in the summer of 1993. AA Dairy has successfully installed an anaerobic digester – a covered 352,000-gallon concrete tank - in June 1998 to reduce odors, improve water quality, and foster good community relations. The other reason for installing the digester was to contribute to the profitability of the farm operation by producing electricity from the byproduct biogas, selling composted solids marketed as "Fields of Dreams Compost" and utilizing liquid effluent as crop fertilizer. As a result, AA Dairy was the recipient of the New York State Governor's Environmental Award for 1999.

Extensive relevant data have been documented daily since the operation of the digester began in 1998. Approximately 15,000 gallons of manure is fed to the digester every day. Data collected reveals that biogas production per cow exhibits an increasing trend with an average of 60-100 CF/cow/day, or about 35,000-50,000 CF/day. Digester biogas consists of methane (50-55%), CO_2 (40-50%), H_2S (0.1-0.36%), and other trace gases. Average electricity generation ranges from about 60kW to 80kW. Average net electricity sold to the local utility (New York State Electric & Gas (NYSEG)) is about 367 kWh/day. Heat recovered from biogas conversion process is stored in a 4000-gallon tank and used only to warm the digester. Average propane gas of 4900 gallons/year is used for other heating needs. Digested manure slurry is pumped to a screw separator and separated into solid and liquid streams. The solids content from the digested effluent and separated solids is approximately 8.6% and 24.0% respectively. This digested fiber is composted and sold commercially. Digested liquid waste has little odor (an earthy smell) and is stored in a 2.4 million-gallon plastic-lined storage lagoon and is used for field applications. AA Dairy is now experimenting with reusing some of the compost (after sterilizing it) as bedding for cows.

Total capital cost for the current resource recovery system is $363,000 with an annual operation and maintenance cost of approximately $12,000. With a herd size of 1000 cows, a selling price for excess electricity at $0.0525 cents/kWh and a buying price from the grid of $0.09/kWh, it was estimated that a payback period of 4 years could be achieved. Given similar selling and purchase prices, a herd size of 500 cows would result in a payback period of 8 years. Our analysis implied that economic viability of the system is most sensitive to purchased price of electricity, selling price of excess electricity, and capital cost.

This report suggests that the system will be even more financially viable when AA Dairy can offset heating costs. The use of separated solids as bedding material for cows could also increase financial viability of the system. However, if the selling price of the compost were doubled from

the present average price ($13/yd^3), the use of separated solids, as bedding becomes less beneficial economically than selling solids as commercial compost.

Currently there is only a handful of operating digesters nationally. Compared to other digester systems, AA Dairy is unique in that it fully utilizes all streams coming out of the digester. AA Dairy produces finished compost from the separated solids, generates most of its on-farm thermal and electrical energy needs, and sells excess electricity to the grid. AA Dairy has successfully managed and maintained the system and has continuously generated electricity for 3 years. AA Dairy is one of the best examples of a dairy farm using a digester at this point.

AA Dairy is in the process of developing a business plan for doubling milking herd size to 1000 cows while keep attuned to the concept of total resource recovery. It is increasingly important to think of the system as more than just an anaerobic digester, since it is actually an integrated system for generating electricity and thermal energy while creating an opportunity for entrepreneurial activities and value-added byproducts. In other words, it is a system that can be optimized for producing value-added byproducts.

The application of a resource recovery system at AA Dairy has offered several insights:

- **Significant monetary and non-monetary benefits.**
  Monetary benefits cover electrical and thermal energy generation, and sales of digested solids (compost), while non-monetary benefits are derived from greatly reduced pathogens, weed seeds, odor, and BOD; high-quality liquid fertilizer for land applications, decreased truck traffic, and better relations with neighbors.
- **Projected payback period of 4-8 years.**
  If AA Dairy continues to operate at a current herd size of 500 cows, the total cost of the system will be paid back in 8 years. However, if the farm is expanded to 1000 cows, the payback period shrinks to 4 years.
- **Criticality of buying and selling price of electricity.**
  The viability of the resource recovery system at AA Dairy is sensitive to purchased and selling price of electricity. The higher the offset between purchased and selling prices, the greater the economic viability of the system.
- **Electrical energy conservation is important.**
  With average annual electricity generation of 621,200 kWh (assuming generator efficiency = 21%) which exceeds the on-farm average electricity demand of 485,800kWh, little effort has been made to conserve electrical energy on the farm. Conserving on-farm energy use will increase the sales of excess electricity and will increase the economic viability of the system.
- **Opportunity for entrepreneurial activities.**
  Indoor aquaculture, greenhouses, algal farms, and possibly on-farm milk pasteurization can use the excess heat and electricity generated, and other byproducts, such as liquid effluent and carbon dioxide. Therefore, excess electricity and heat can open the door to entrepreneurial ventures or partnerships on or near the farm.
- **Good management is crucial.**
  The operation of the whole system needs regular attention and maintenance (such as checking and adding engine oil), daily data recording and attention to details in order to maintain superior performance of the overall system.

1. PURPOSE

The purpose of this report is to provide information about the application of resource recovery practices at AA Dairy Farm located in Candor, NY. It is intended to illustrate resource recovery concepts at a dairy farm scale to an interested dairy community. AA Dairy has successfully implemented the concept in part by installation and operation of an anaerobic digester, diesel engine cogenerator, solids-liquid separator, liquid-waste storage lagoon together with practices in support of these principles, such as composting of solids and irrigation of the liquid effluent. We provide economic information about the system at AA Dairy, document the operation of the system and relevant data collected since implementation of the anaerobic digester in 1998.

2. INTRODUCTION

The changing face of agriculture with larger animal production units and recognition of the pollution potential of dairy farms has resulted in greater regulation in the US. Dairy farmers are increasingly under pressure to control agricultural waste pollution from their operations. In New York, there are about 8700 dairies with approximately 700,000 milk cows, which represent a significant State industry in economic value (Jewell and Wright, 1999) and at the same time presents a challenge environmentally equivalent to the State's domestic waste treatment problems. Odor, runoff from land-applied manure, manure spills leading to contamination of water supplies and reports of sicknesses and deaths attributed to *e. coli* from dairy manure in drinking water supplies in New York and the mid-west highlight the problems of manure management on the dairy farm (Scott, et. al., 2000). It is clear that agricultural livestock practices can result in many undesirable effects. Innovative solutions to waste management should be observed and they should address the complete operation, including total resource recovery, economic considerations and animal health (Jewell and Wright, 1999).

It starts with anaerobic digestion

An anaerobic digester breaks down organic material in manure into a slurry and a methane rich gas called biogas. The biogas is a mixture of methane, carbon dioxide, other trace gases such as H_2S and ammonia. Used as fuel, the biogas can be converted to electrical and thermal energy to operate a dairy system. The separated fiber from the slurry can be utilized when dewatered for bedding or composted for humus material. The separated liquid from the digester has an earthy smell with some ammonia present and can be used as a liquid fertilizer. Thus, it is possible to completely eliminate dairy waste problems (odor, pathogens, nutrient loss via volatilization and runoff) with a digester. While the primary purpose of a digester is for waste management and odor elimination, the use of a digester is further enhanced by the energy and nutrient stream by-products (e.g. hydroponics solutions for plant growth and recycling animal feed as fertilizer [Jewell and Wright, 1999]).

A key concept of total resource recovery in dairy waste treatment begins with anaerobic digestion. Extensive research on anaerobic digestion of animal waste has been conducted over the past two decades (Jewell et al., 1978; Jewell et al., 1980; Walker et al., 1984; Walker et al., 1985; Pellerin et al., 1987). Equally important, other research has concluded that a key is efficient and effective conversion of biogas produced from the digester into electricity and thermal energy as well as other byproducts, so that all materials are utilized and recycled (Jewel et.al., 1978; Walker, et.al., 1984; Koelsch, et.al., 1990; Jewell and Wright, 1999, Lutsey and Scott, 2001).

In recent years dairy farmers have increasingly become interested in installing and operating an anaerobic digester with odor control as a primary reason, while energy cost reduction and potential earnings from excess electricity generation are additional motives. Detailed information on many digester systems can be found in Koelsch (1990); Lusk (1998; http://www.osti.gov/servlets/purl/1364-uGaHco/ webviewable/1364.pdf); and Nelson and Lamb (2000; http://www.misa.umn.edu/%7Emnproj/pdf/hauby%20final3.pdf). As this information is readily available, this report will not provide comprehensive information on anaerobic digestion. We approach this topic from the position that the anaerobic digester is a proven technology.

At AA Dairy there is a major concern for the environment. The dairy is owned and operated by a family (Robert Aman and sons Wayne and Aaron Aman) who subscribe to the total resource recovery concept. In 1998 the Amans began to use a methane recovery (biogas) technology with their confined free-stall animal facility along with installation and operation of an engine cogenerator, solids separator, and construction of liquid-waste storage lagoon. As a result, odor pollution is reduced significantly, while producing other by-products such as electric and thermal energy, digested fiber and liquid fertilizer. The farm currently produces approximately 15,000 gallons of manure per day.

3. FARM DESCRIPTION

3.1. AA DAIRY

The AA Dairy is an approximate 500-cow[1] dairy operation located on a 2,200-acre farm in Candor, in the southern Fingerlakes region of Upstate New York. The dairy started operating in the summer of 1993 and has successfully installed an anaerobic digestion system in June 1998[2] to reduce odor, improve water quality and community relations while contributing to the profitability of the farm operation by producing electricity from the methane gas generated by anaerobic digestion, composted solids, called "Fields of Dreams Compost," and liquid fertilizer. It was the recipient of the New York State Governor's Environmental Award for 1999. Figures 1 and 2 show the Amans and an aerial view of AA Dairy farm, respectively. Figure 3 illustrates the layout of AA Dairy. The milking center and bunk silos are sized to meet the capacity of a 1000 cowherd because Amans' original plan was to expand to a 1000 cowherd. They plan to build another 500-cow free-stall barn next to the existing 500-cow free-stall barn (Figure 3).

[1] Milking herd size ranges from 460 to 530 with average of 500 cows

[2] The construction of anaerobic digester begun in October 1997 and was completed in June 1998.

Figure 1. The Amans (from left: Wayne, Aaron, and Bob Aman)

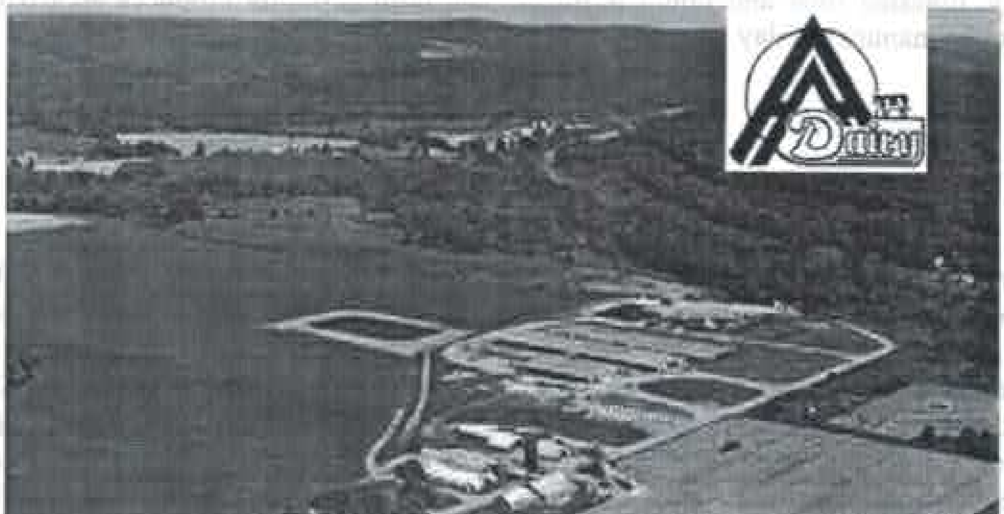


Figure 2. The view of AA Dairy farm from the air in 1997.

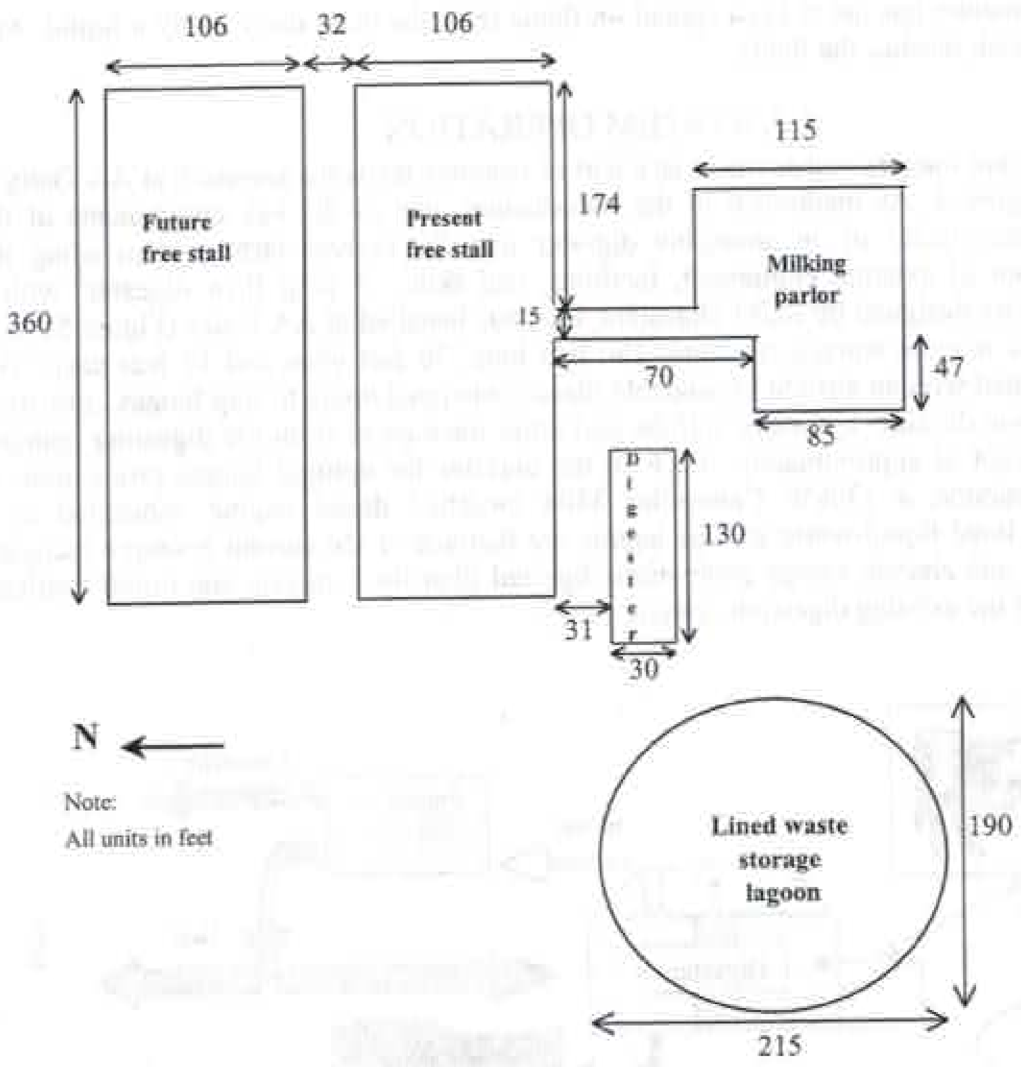


Figure 3. Layout of AA Dairy

Before the anaerobic digester was built, the manure and waste wash water produced at the farm were stored in an underground pit at the back of the holding area. Due to equipment problems and limited land to spread the manure, the contents of the manure pit had to be pumped into slurry trucks every day and taken to crop fields for disposal. Local residents were constantly expressing concerns about odor, truck traffic, and a possible threat to water quality. Under NY's right to farm law the community could not prevent the farm from operating (Wright and Perschke, 1998). Robert Aman was knowledgeable of the anaerobic digestion process as a manure handling alternative from the beginning of operations at Candor, NY and when a favorable opportunity developed to install a plug-flow anaerobic digester AA Dairy did so in June 1998. This technology and action reestablished a good standing in the neighborhood. The installation of the digester reduced odor, reduced impacts on the environment and reduced manure transport over the roadways. At the same time, the digester promised economic benefits through energy production. Since the integrated manure management system was put into operation, raw manure has never been spread on fields from the main dairy. Only a liquid, with odor much reduced, reaches the fields.

3.2. SYSTEM OPERATION

Overview of current manure management as a part of resource recovery approach at AA Dairy is illustrated in Figure 4. As mentioned in the introduction, one of the key components of the system is the installation of an anaerobic digester into the current farm system using the maximum amount of existing equipment, facilities, and skills. A plug flow digester[3] with a 1,000-cow capacity designed by RCM Digesters, Inc. was installed at AA Dairy (Figure 5). It is a buried concrete manure storage structure, 130 feet long, 30 feet wide and 14 feet deep. The digester is equipped with an airtight expandable black rubberized dome to trap biogas consisting of methane, carbon dioxide, hydrogen sulfide, and other trace gases from the digesting manure. The manure is kept at approximately 100°F in the digester for optimal biogas production. A solids-liquid separator, a 130kW Caterpillar 3306 modified diesel engine connected to a generator, and a lined liquid-waste storage lagoon are features of the current resource recovery system. Thermal and electric energy generation, digested fiber for compost, and liquid fertilizer are byproducts of the existing digestion system.

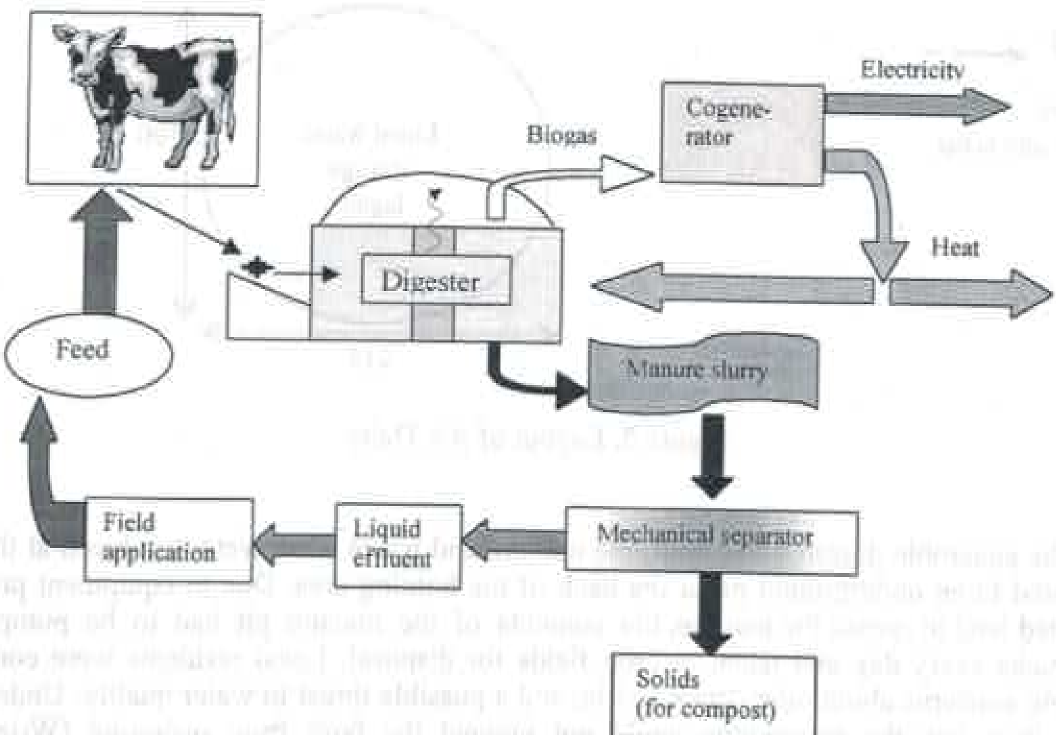


Figure 4. Overview of resource recovery system at AA Dairy

[3] There are 2 major types of digesters, mixed digester and plug-flow digester. Each type has its own advantages and disadvantages. If properly designed, the digester should produce biogas continuously with minimal effort required for managing and maintaining the digester. Five key components in designing a digester are: digester size, construction materials, structural integrity, heating and insulation, and manure flow (Koelsch, et.al., 1990).

Figure 5. Side view of digester at AA Dairy with biogas flare in the foreground

3.2.1. ANAEROBIC DIGESTION DESCRIPTION

Manure is continuously scraped from the 106 foot by 360 foot free-stall barn and is gravity-fed into a cross alley with step dams. The barn is insulated below the rafters with 1.5 inches of foil faced urethane insulation to prevent freezing in the free-stall barn, to keep the alley scrapers running during the winter, as well as to limit the heating requirements for the manure. Newspaper, sand, sawdust, and approximately 10 yd^3/week of kiln-dried shavings are used for bedding. A 20 Hp submersible manure pump delivers fresh manure to the digester once a day over a period of 1.5 hours. Approximately 15,000 gallons of manure are fed into the digester each day. The new plug of manure added daily at one end, pushes the material already in the digester slowly through the system. A complete digestion process takes about 20 days, but because the digester has been designed for 1000 cows the retention time is about 40 days for operation with 500 cows. Methanogenic bacteria in the manure, when kept at an optimal 100°F (mesophillic range), cause the manure to decompose in the warm slurry. This produces biogas consisting of methane (about 50%-55%) carbon dioxide (about 40-50%), a small amount of sulfide compounds (0.1-0.36%)[4], and other trace gases.

3.2.2. COGENERATION

Data has been collected daily and the average biogas flow from the digester at AA Dairy (herd size of 500 cows) has been between 35,000-50,000 CF/day, or about 60-100 CF/cow/day (see the "results" section). The gas is collected, filtered, measured and slightly pressurized before being used to fuel a 130kW (3306 Caterpillar) engine. The engine is a diesel block with a natural gas head that has been converted to run on methane. The engine runs an induction generator to produce electrical energy at the current average of about 70 kW (~613,000 kWh/year) with downtime around 5%. Electricity produced meets the electricity needs for the dairy farm and provides some excess electrical power for sale to the local utility (New York State Electric & Gas (NYSEG)) at wholesale prices.

[4] Hydrogen sulfide is a highly corrosive gas especially when saturated with water vapor. It is corrosive to burner units and heat exchangers in boilers, furnaces, water heaters, and also speeds the development of acidic conditions in engine oil.

Because the biogas generator is available only 95% of the time, a backup diesel generator is necessary for emergencies, such as when the engine-generator set was taken offline for repairs or when the grid is down. It is more cost effective to use the backup generator instead of drawing power from the grid because the cost of electricity is as high as $0.12/kWh (Minott and Scott, 2001). The engine generator is down for weekly maintenance, which usually happens during the daytime (for less than one hour) when the farm is charged peak prices. Initially, when AA Dairy started to use the engine generator, purchasing electricity from the grid was a regular occurrence. Paying for insurance and the demand charge for connecting to the grid were the primary reasons why AA Dairy incurred electric utility charges in 1999 and 2000. Currently, AA Dairy pays much less (compared to the years of 1999 and 2000) because the farm rarely draws power from the grid and the insurance cost is cheaper.

Heat exchangers transfer heat from engine hot water loops to another loop which stores hot water in a 4000-gallon tank. Stored hot water is currently available only to warm the digester. Initially it was expected to use the stored hot water for other farm needs to offset propane use. However, it was observed that heat recovered from this hot water loop lost too much heat during the cold months to be used effectively for other farm heating needs.

3.3.3. LIQUIDS AND SOLIDS HANDLING

After digestion, the treated slurry is pumped to a screw press slurry separator with a 7.5 Hp pump. The separated roughage or fiber (total solids is approximately 24.0%) is transferred to a compost area and the excess liquid (total solids is about 5.2%) is pumped to a plastic-lined liquid storage lagoon (Figure 6). There is a slight ammonia odor during the separation process, however, this will not be an off site odor problem since the ammonia is lighter than air and is rapidly diluted away from the source.

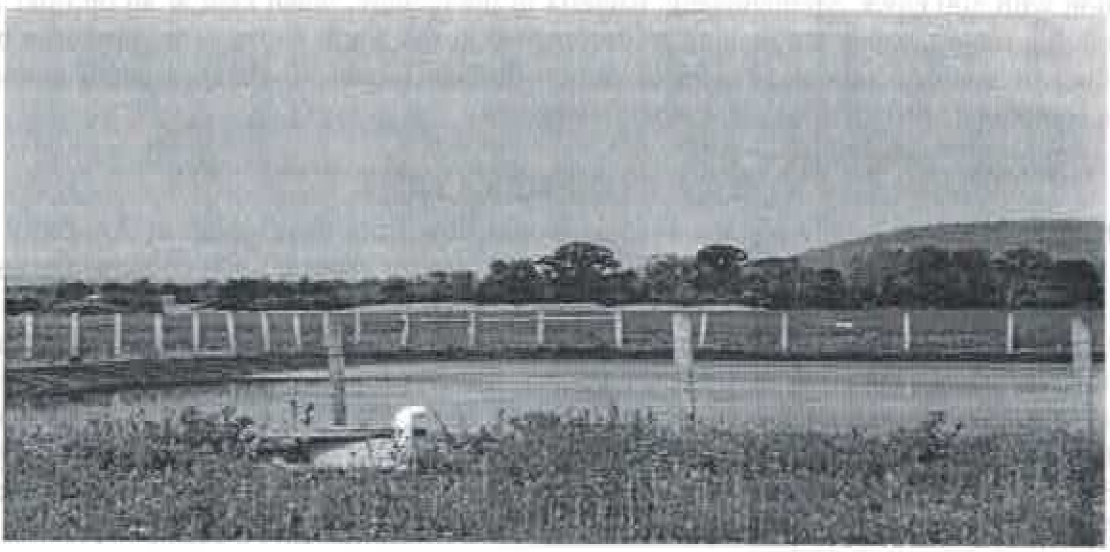


Figure 6. Plastic-lined lagoon

Recovered solids have the physical characteristics similar to a moist peat moss (a dry matter content of 20 - 30 percent and a pH of ~8) and are essentially devoid of weed seeds. The finished compost is sold in various ways, in large bulk quantities, small bulk quantities, and in 20-pound-bags at local farm and garden suppliers. The composted fiber has been approved for organic food production and is marketed as "Fields of Dreams compost" (Figure 7). AA Dairy is experimenting with reusing some of the sterile compost as bedding for cows. AA Dairy monitors the milk closely to make sure that there is not an increase in somatic cell counts from using the separated solids for bedding.

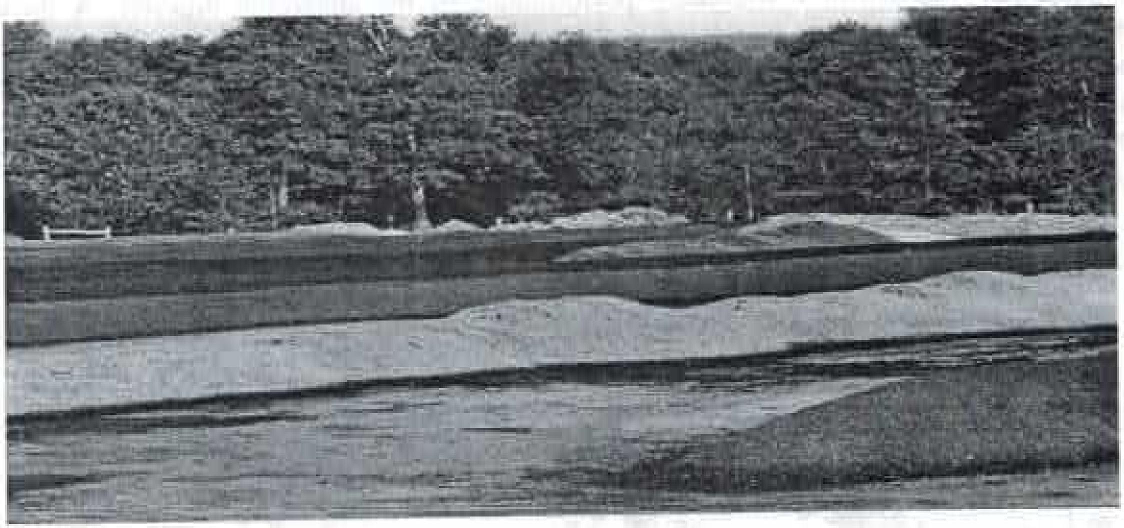


Figure 7. Compost piles at AA Dairy

The liquid effluent flows by gravity to a 2.4 million gallon plastic-lined storage lagoon. The liner is used to avoid leaching to a shallow groundwater table due to gravel (porous) soils at the farmstead. The stored liquid waste is spread on fields either via 4000-gallon slurry wagons, or distributed through a pipeline system installed on the AA Dairy farm to irrigate cropland (corn, alfalfa, and grass) at the main farm or other farm locations within 4 miles of the main farm. Thus, soil compaction and truck traffic through the village can be eliminated. The application of liquid is accomplished with a "traveling gun" system for field irrigation.

AA Dairy is unique in that it produces finished compost from the separated solids in addition to thermal and electric energy generation. AA Dairy has successfully maintained good management of the system and has been continuously generating electricity for 3 years. Undoubtedly, at this point AA Dairy is one of the most prominent dairy farms using digesters.

4. RESULTS

The Amans have collected daily data since the operation of the digester in June 1998. The data consist of biogas production, electricity generated, electricity sold to NYSEG, electricity purchased, oil added and replaced for the diesel engine, CO_2 concentration in biogas stream, average milk production per cow, water consumption per cow, and propane consumption. Data are presented in Figures 8-15. Due to significant daily fluctuations of data, all the results (except for propane use) were analyzed based on a 50-day (point)-moving average to minimize inter-daily variations, and is shown as a solid line.

4.1. BIOGAS PRODUCTION AND ELECTRICITY GENERATION

Figure 8. shows daily total biogas production for the herd for the period of 1998-2001. Values range from about 35,000 – 50,000 CF/day and overall these data show a slight increasing trend with time. Figure 8. presents biogas production per cow per day for the period of 1999-2000 and it depicts an increasing trend as well. During the last 2 years, total biogas production appears to drop during the last quarter of each year. This is due to a fewer number of cows during this period and not because of a decreased performance of the anaerobic digester. A decline in digester temperature is likely correlated to the reduction in biogas production (Figure 9). There are some findings showing that digester temperature is a key factor affecting biogas production from dairy manure (Koelsch, et.al., 1989; Koelsch, et. al., 1990, Vetter, et.al., 1990). Digester temperature averaged 95°F and 100°F at the inlet and outlet of digester respectively, varied correspondingly from 88°F to 108°F and 94°F to 115°F over the 3 year period.

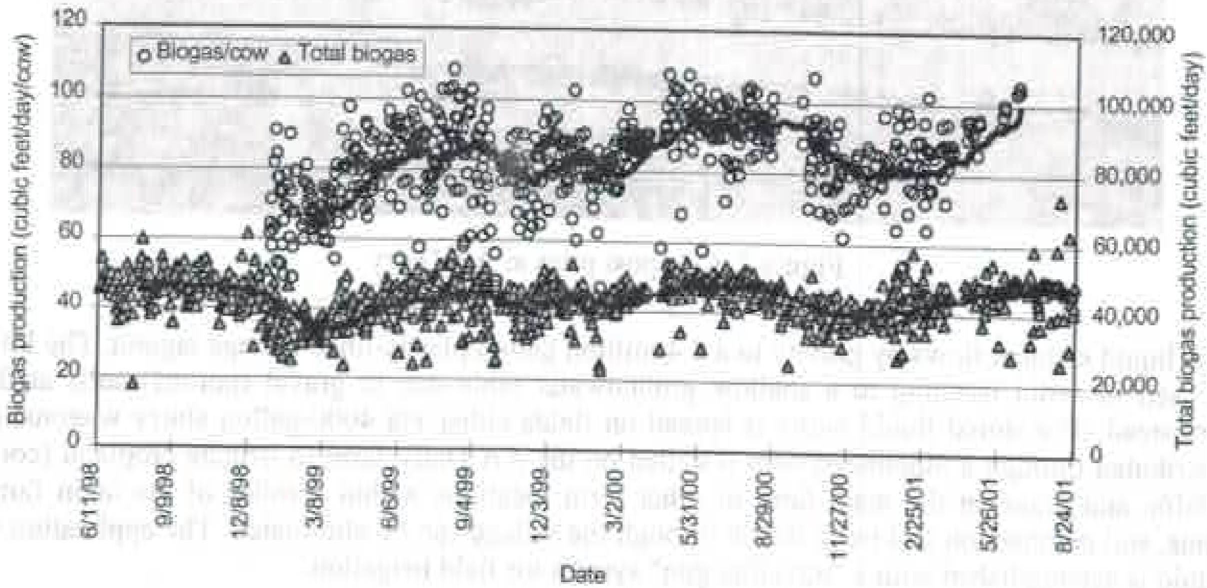


Figure 8. Total biogas production and biogas production per cow per day, 1999-2001

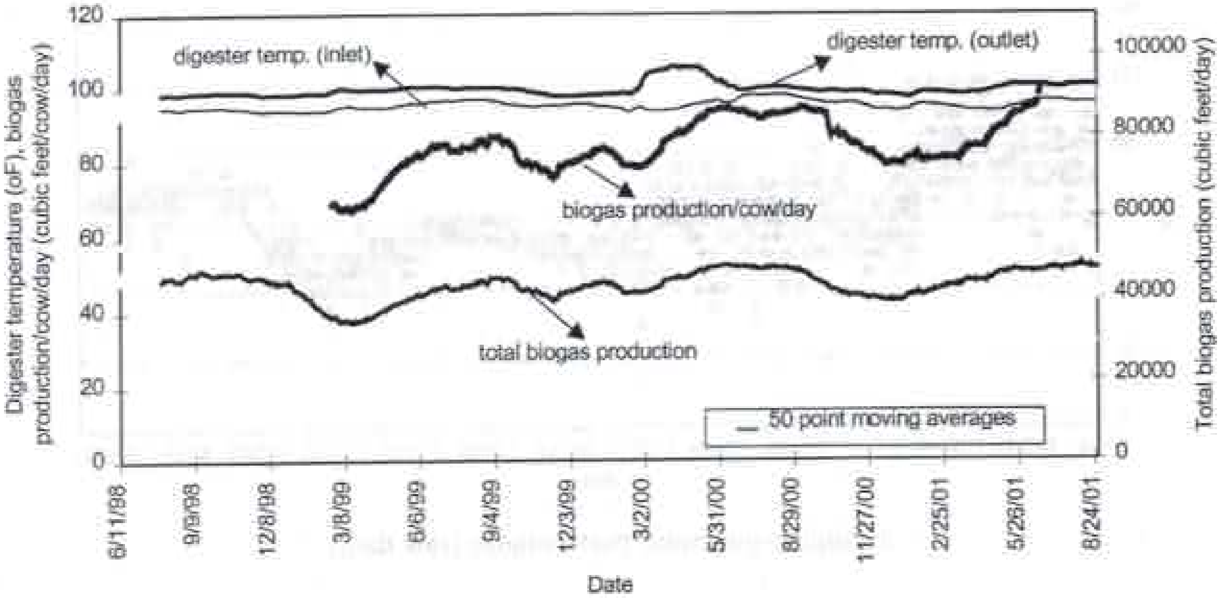
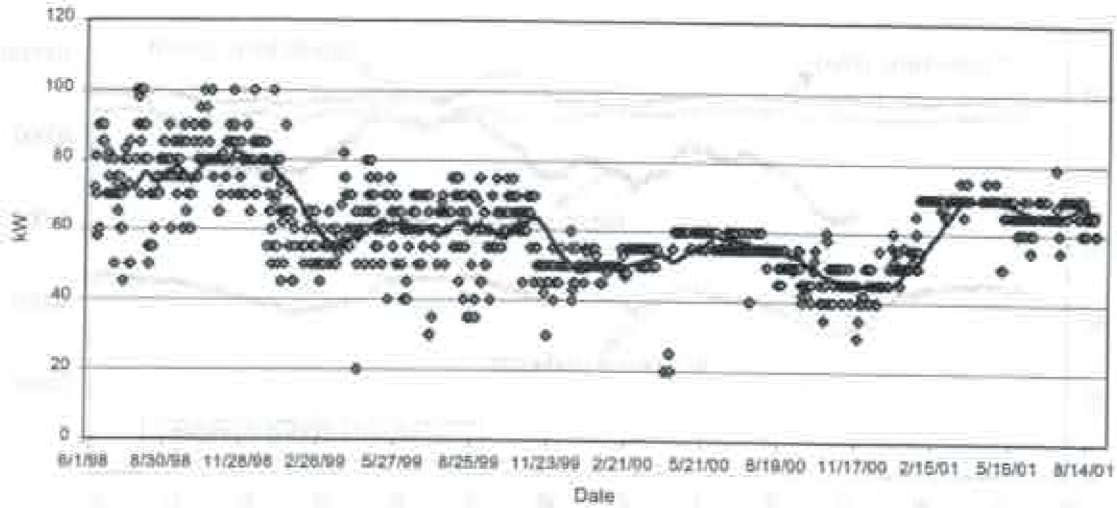


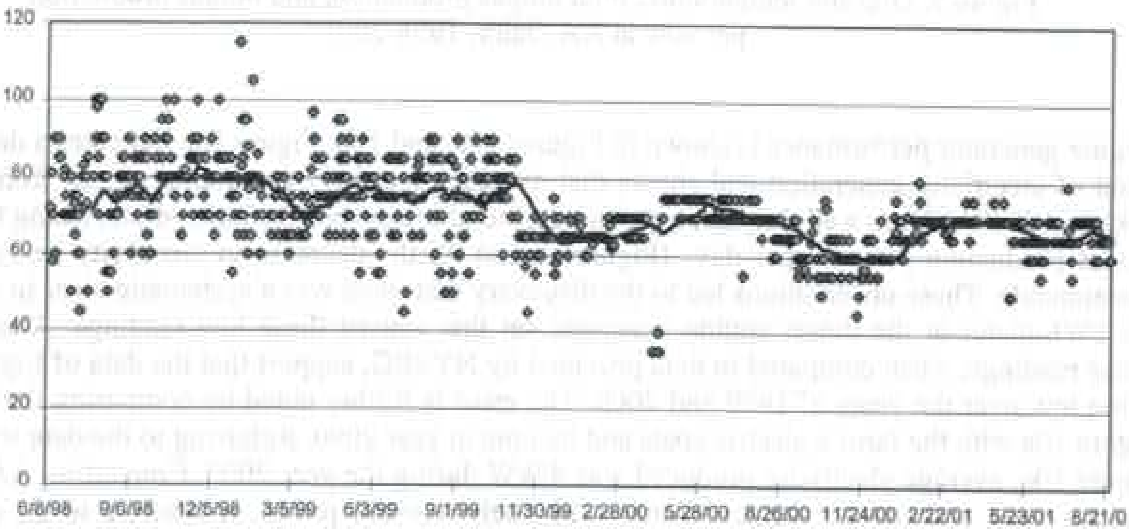
Figure 9. Digester temperature, total biogas production, and biogas production per cow at AA Dairy, 1998-2001

Engine-generator performance is shown in Figures 10a. and 10b. Figure 10a indicates a declining trend of electricity generation and shows that average electricity generation ranges from about 45kW to 80kW. Given a slightly growing trend of total biogas production and increasing trend in biogas production per cow per day (Figures 8 and 9), the decrease in electricity generated is questionable. These observations led to the discovery that there was a systematic error in reading the kWh-meter at the diesel engine generator set that caused these low readings. Also, these meter readings, when compared to data provided by NYSEG, support that the data of Figure 10a is too low over the years of 1999 and 2000. The error is further noted by comparing the data of Figure 10a with the farm's electric costs and income in year 2000. Referring to the data shown in Figure 10a, average electricity produced was 48kW during the year 2000. Converting AA Dairy electric costs and income in accordance with their relevant prices, it resulted in an average electricity generation of 70kW during 2000.

In order to correct for the error in the meter readings and to be consistent with the data recorded from NYSEG, we adjusted the results of Figure 10a by adding 15kWh to the daily meter reading collected from 1/1/99 to 1/31/01. The adjusted engine-generator performance is presented in Figure 10b. Applying a 50-day (point)- moving average, Figure 10b reveals that electricity generation ranges from about 60kW to 80kW with the average of 70kW.



a. Engine-generator performance (raw data)



b. Engine generator performance (after adjustment)

Figure 10. Engine generator performance at AA Dairy, 1998-2001

Electricity generation (after adjustment) and net electricity sold to the grid are presented in Figure 11. The results imply that electricity produced on the farm ranges from approximately 1400 to 2000 kWh/day (~ 60-80 kW), while the net electricity sold to the grid ranges from –240 to 720 kWh/day. Net electricity to grid is the total electricity sold to grid minus the amount of electricity purchased from the grid. The negative net electricity in summer 1999 shows that the farm experienced a net energy deficit (electricity produced was less than that needed). At all

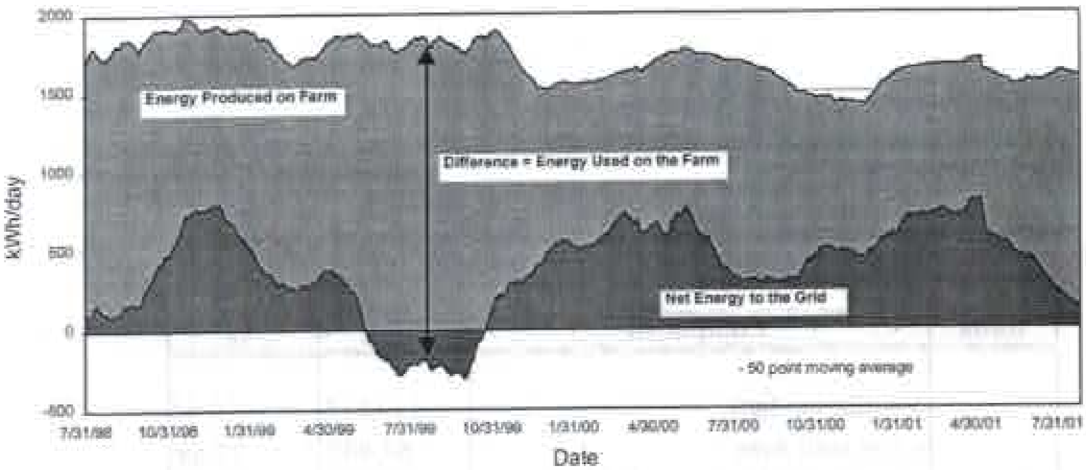


Figure 11. Energy produced and net energy to grid at AA Dairy, 1998-2001

times, in general, excess electricity beyond farm demand was supplied to the grid. There were of course, short periods for engine maintenance when the backup generator was not operated or not available.

Summary of electricity use at AA Dairy is presented in Table 1. An energy audit revealed that electrical energy use on the farm peaks during summer months (June-September) due to significant energy use by ventilation fans in the free-stall barn, milking parlor, and holding area. Free-stall fans consume the highest electric energy and are only used during warm months (May –October) to cool the cows (Table 1). As a result, electricity available to sell during these months is less than during the cool periods of the year (Figure 12). The difference between energy produced and net energy sold to the grid is energy used on the farm (Figure 12).

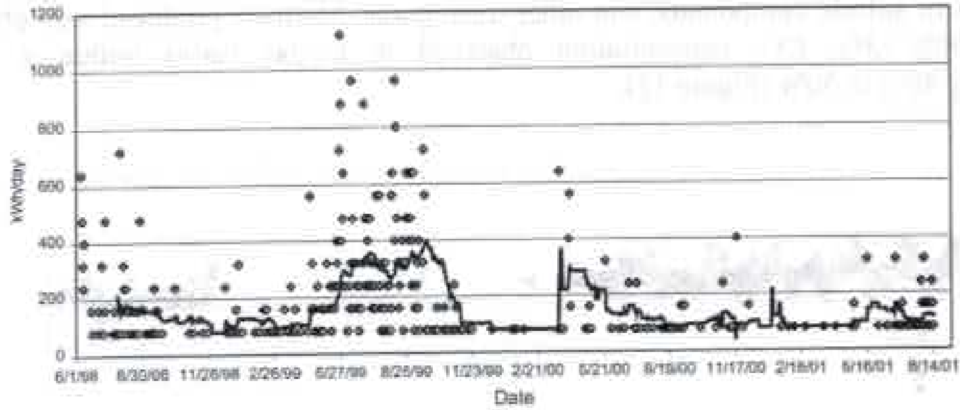
Table 1. Estimated electricity use at AA Dairy (October 1999-September 2000)

Rank	Equipment	kWh	%
1	Ventilation fans	150,813	36.44
	- free stall barn[1]	*64,907*	*15.68*
	- others (parlor, hosp., holding)	*85,906*	*20.76*
2	Vacuum pump	83,220	20.11
3	Refrigeration	54,355	13.13
4	Lighting	75,586	18.26
	- free stall barn[2]	*31,262*	*7.55*
	- others (parlor, milk room, office, staff, mach stor, shop, outdoors)	*44,324*	*10.71*
5	Air Compressor	21,462	5.19
6	Manure Handing	14,529	3.51
7	Water pump	6,439	1.56
8	Milk pump	2,862	0.69
9	Milk Pump AFD	179	0.04
10	misc/unaccounted	4,424	1.07
	Total farm electric usage	**413,869**	**100.00**

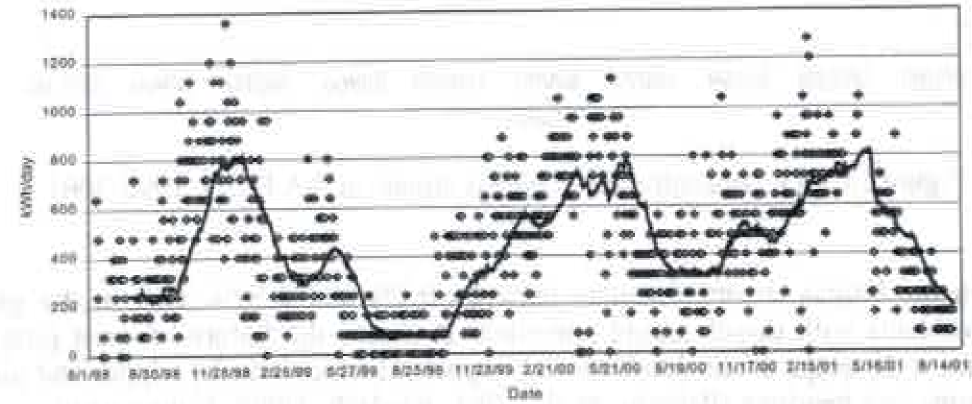
[1]Used for cooling cows, only turned on from May-Oct (6 months)

[2]Supplements day light, excessive use from Sept-May (9 months)

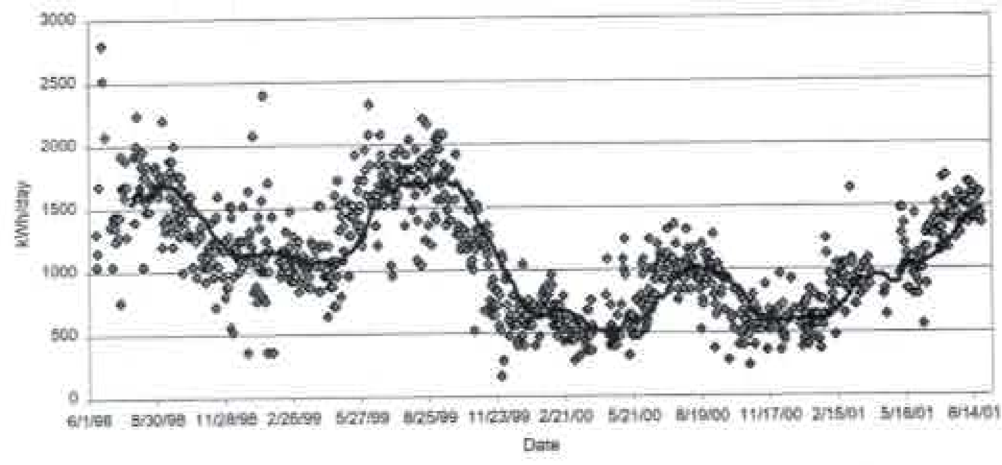
Source: Minott and Scott, 2001



a. Electricity purchased from grid



b. Electric sold to the grid



c. Electricity used on the farm

Figure 12. Electricity scenario at AA Dairy, 1998-2001

4.2. BIOGAS COMPOSITION AND EFFECTS ON ENGINE PERFORMANCE

As mentioned earlier, biogas produced from the digester consists of methane, carbon dioxide, a small amount of sulfide compounds, and other trace gases. Methane produced was observed to be around 50%-55%. CO_2 concentration observed in biogas varies within a range of approximately 40% to 50% (Figure 13).

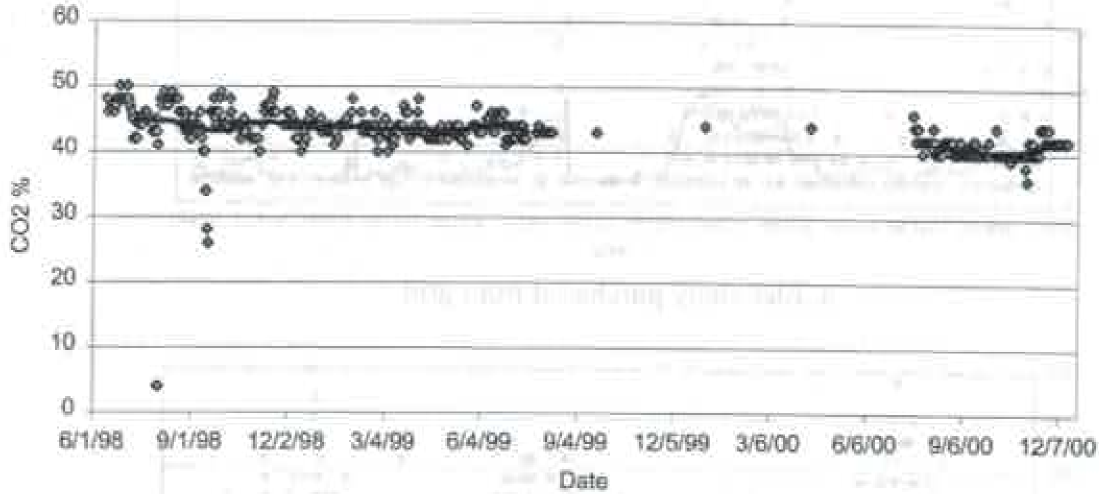


Figure 13. CO_2 concentration in biogas stream at AA Dairy, 1998-2001

H_2S levels in the biogas stream fluctuate between 0.1% and 0.36%. H_2S in the gas creates significant problems with diesel engine operation. It causes the failure of wrist pins in diesel engine because it develops acidic conditions in engine oil which attacks copper and alloys used in the wrist pins and bearings (Pellerin, et.al., 1987; Koelsch, 1990). Consequently, preventing engine damage due to H_2S presence in the biogas is critical. AA Dairy's solution to this problem is to check the oil daily, adding oil if necessary plus performing a complete oil change once a week (every Saturday, Figure 14).

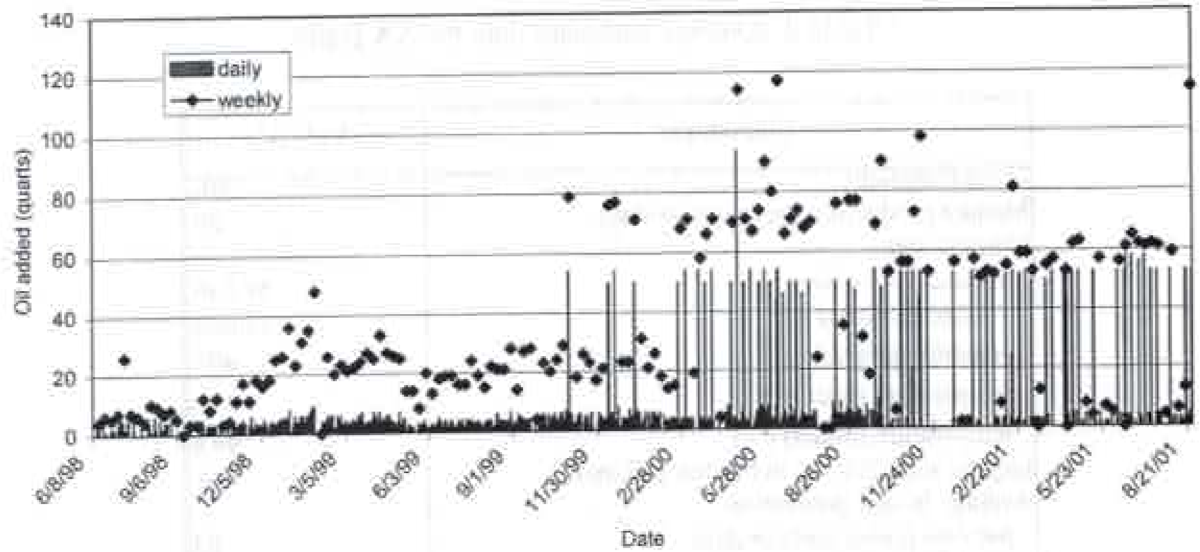


Figure 14. Daily and weekly sum of oil added, 1998-2001

Not all of the machinery and equipment at AA Dairy are electrically powered. Some applications use propane, fuel oil, or diesel fuel to meet thermal loads (Minott and Scott, 2001). Propane is purchased monthly for heating the water used to wash milk lines and to provide radiant heat in the milking parlor during cold months. Figure 15 shows propane usage and costs at AA Dairy for 2000 and to date in 2001.

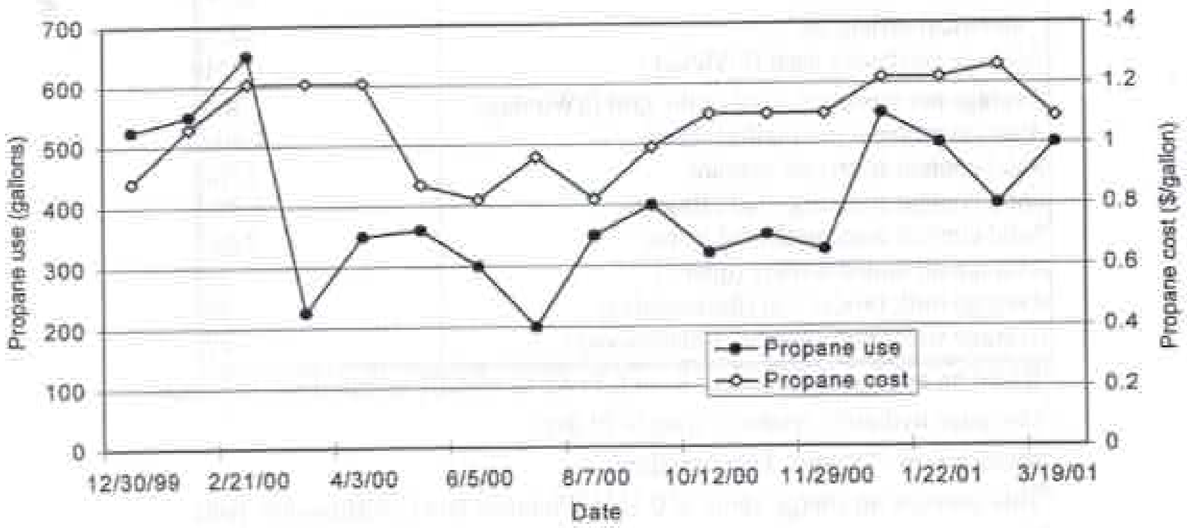


Figure 15. Propane usage and propane cost at AA Dairy, 1999-2001

We summarize all data available from resource recovery application at AA Dairy in Table 2. Most of the values presented are based on average daily data collected from 6/1/98 to 8/26/01.

Table 2. Average summary data for AA Dairy

Component	Values[1]
Cows (nominal)	502
Manure production (gallons/cow/day)	*30*
Digester size	
volume (cubic feet)	*54,600*
volume (gallons)	*352,000*
retention time (days)	*40*[2]
temperature (inlet) (°F)	95.4
temperature (outlet) (°F)	99.8
Lagoon size (volume in million gallons)	*2.4*
Average biogas production	
per cow (cubic feet per day)	83
total (cubic feet per day)	43,447
Biogas composition	
methane	*55%-65%*
CO_2	43%
H_2S[3]	*0.3-0.36%*
Average electrical output	
per cow (kWh/day)	3.4
total (kWh/day)	1,702
yearly output (kWh/year)	621,189
generator capacity (kW)	130
generator reliability	*95%*
electrical efficiency[4]	21%
Average electricity used (kWh/day)	1,331
Average net electricity sold to the grid (kWh/day)[5]	367
Average propane use (gallons/year)	4,900
Solid content from raw manure	*12%*
Solid content from digested effluent	*8.6%*
Solid content from separated solids	*24%*
Average oil added weekly (quarts)	35
Average milk production (lbs/cow/day)	73
Average water consumption (lbs/cow/day)	22

[1]Based on average daily values from 6/11/98 to 8/26/01 except those in italics

[2]Designed hydraulic retention time is 20 days

[3]Measured by "Draeger Tube" method

[4]This assumes an energy value of 0.161kWh/cubic feet (550Btu/cubic feet)

[5]Net electricity sold to the grid is electricity sold to the grid minus electricity purchased from the grid

5. ECONOMIC ANALYSIS

5.1. DIGESTER SYSTEM COST

Total capital cost of the current digester and energy converter system is $363,000. The cost breakdown is presented in Table 3. Costs of several items are not included: an irrigation system, which was projected to be $45,000 (Wright and Inglis, 2001); alley scrapers; manure spreading and any off-site manure storage. We assumed yearly expenses for the operation and maintenance for the total system as 1.5 cents per kWh of electricity generated (Wright and Perschke, 1998; Nelson and Lamb, 2000). For the purpose of this analysis we presumed the average electricity generation of 70kW, or 613,200 kWh/year, for a herd size of 500 cows. Thus 1000 cows will produce about 140 kW, or 1,226,400 kWh/year. Assuming 5% downtime this number is reduced to 1,165,080 kWh/year. Hence, operation and maintenance costs were expected to be about $17,500. These costs include occasionally replacing the cover and removing the grit in the bottom of digester, oil addition and replacement of the diesel engine, engine and generator repairs, daily maintenance to check the system, and scheduled overhauls. It was estimated that the pumps need replacement every 7 years and the replacement cost is included in the O&M cost for purposes of this analysis.

Table 3. Project cost of resource recovery system at AA Dairy

Component	$
Digester	
- manure pump (20 Hp)	9,000
- engineering design	20,000
- concrete digester (incl. floating insulation, gas containing cover, 2 hot water heating circuits)	160,000
subtotal	***189,000***
Energy conversion	
- engine generator (used) & switching equipment	15,000
- rebuild the engine	2,000
- rebuild the generator	9,000
- plumbing, electric, and mechanical systems	9,000
- run cable to utility hook-up	8,000
- electrical engineer consultant	18,000
subtotal	***61,000***
Solids separation	
- effluent pump (7.5 Hp) & variable speed drive	3,000
- separation equipment	25,000
- building for separator equipment	25,000
subtotal	***53,000***
Liquid waste storage lagoon	
- lagoon (excavation, fence, pipe, outlet structure)	18,000
- plastic liner	42,000
subtotal	***60,000***
TOTAL	**363,000**

Source: Wright and Perschke, 1998

5.2. FINANCING FOR SYSTEM

The digester system was financed with a combination of direct technical assistance, a grant, and private AA dairy funding. EPA's AgSTAR program offered direct technical assistance for the project, valued at $24,000. Also, a grant of $120,000 was provided by the local Soil Conservation District, which left the remaining balance of $219,000 for AA Dairy.

5.3. POTENTIAL REVENUE GENERATION

Potential revenue is obtained from electricity and heat offsets, sale of excess electricity, as well as that of digested fiber as a compost product. For simplicity, it was estimated that electricity produced met the total long-term electricity needs of the farm plus provision of excess to be sold to the grid. Therefore, potential electricity savings are predicted from the electricity cost before the system (digester, cogenerator, solids separator, lagoon) existed. Data in 1997 revealed that the dairy bought electricity from the grid for a total of $36,700 (at $0.09/kWh) for the year. It was intended that heat recovered from the heat recovery loop would be used for heating the digester and for providing hot water needs on the farm such as for washing the milking lines, warming the milking parlor floors, and providing some radiant heat in the milking parlor. Hence, potential heat saving was estimated as the total cost of purchased annual propane (Figure 13), which was $5,700 (12/30/99-12/26/00).

Potential earnings from electricity sales were estimated by selling excess electricity to NYSEG at a rate of $0.025/kWh and $0.0525/kWh. These two rates represent the purchase price by NYSEG prior to June 2001 ($0.025/kWh) and after June 2001 (0.0525/kWh). It was assumed that the average electricity produced from 500 cows was 70 kW and maximum yearly potential earnings were obtained by subtracting the annual average of electricity used on farm from the annual average production of electricity. Potential earnings from digested fiber (solids) were calculated by multiplying the finished compost generated from the separation process with an average selling price of $13/yd^3. In fact, the composted fiber is sold at various prices depending on the quantity purchased:

- $14.80/yd^3 for 1-4 yd^3 of purchased compost
- $12.95/yd^3 for 5-40 yd^3
- $11.10/yd^3 for 40+ yd^3
- $2 per 2/3 ft^3 (0.025 yd^3) hand-packed bag (approximately 20 lbs)[5]

Table 4 shows potential revenue for herd sizes of 500 and 1000 cows. "Actual revenue" was also estimated from 1999 and 2000 data. Table 4 demonstrates that actual values are quiet close to respective potential values, except for heat savings. This is because heat recovered was used only for heating the digester. Hot water from the diesel engine heat recovery loop was not great enough to do more than to maintain the digester operating temperature at 100 °F during the winter months and not adequate to supply heat for other farm needs. However, a more efficiently designed heat recovery system could be implemented to recover a greater amount of the exhaust engine heat. Thus, elimination of propane cost, although desirable, is not realistic with the existing system of heat recovery.

[5] Weight of compost per unit volume varies because compost density depends on its moisture content. When the moisture content at AA Dairy is 70%, the density is 842 lbs/yd^3 (based on sample of May 4, 2001).

Table 4. Annual potential and actual revenue generation

Component	Potential		Potential (high price)*		Actual (500 cows)	
	500 cows	1000 cows	500 cows	1000 cows	1999	2000
Offset electricity costs @ $0.09/kWh	36,700	73,400	36,700	73,400	24,600	32,600
Offset heating costs	5,700	11,400	5,700	11,400	0	0
Sale of excess electricity @ $0.025/kWh	6,050	12,100	12,700	25,500	1,600	5,700
Sale of solids @ $13/yd³	34,200	68,400	34,200	68,400	n/a	20,500
TOTAL	82,650	165,300	89,300	178,700		58,800

*High price is when the excess electricity is sold at $0.0525/kWh

5.4. ECONOMIC VIABILITY

In order to assess the economic viability of the current digester/engine system at AA Dairy, several hypothetical scenarios are compared to see how sensitive economic analyses are to various variables. Although the cost of the project was partially supported by grants and assistance, it was assumed, for our analyses, that the initial project cost was $363,000. We then conducted a net present value analysis to calculate payback period. The scenarios considered are:

- ***Projection of 500 cows.*** Assumes herd size is 500 cows with potential revenues based on the original design calculations shown in Table 2. Electricity generation was assumed 70 kW, the offset on-farm electricity value was 9 cents/kWh, and excess electricity price is 2.5 cents/kWh (for electricity sold prior to June 2001). Solids produced were assumed at 6.7% of total raw manure (~ 15,000 gpd) fed to the digester and sold at the average of $13/yd³.
- ***Projection of 500 cows with increased electricity selling price.*** Same as above, however assumes a value of 5.25 cents/kWh for excess electricity generated (effective June 2001).
- ***Actual (500 cows).*** Assumes herd size will remain 500 milking cows. Revenue generation used was based on actual data of 2000 (Table 2).
- ***Projection of 1000 cows.*** Assumes herd size is 1000 cows (original plan), and electricity production will increase to 140 kW. Due to its limited life span, current engine generator will not be used. As using one 150-kW-engine generator is more economical than using two 130-kW-engine generators, one 150-kW engine generator and its associated components are added to the system resulting in the increase in capital cost by $20,000. Therefore, total capital cost raises to at least $383,000. Values of offset on-farm electricity and excess electricity prices were the same with current prices of 9 cents/kWh and 5.25 cents/kWh respectively. Solids produced would be doubled from the production of 500 cows and sold at $13/yd³.
- ***Effect of capital cost.*** Assumes the capital cost can be reduced to $350,000 or $300,000 while other costs are similar to the projection of 1000-cow scenario.

Other assumptions made in this analysis are:

- Time value of money or discount rate used varies between 10% and 14%[6]. This includes inflation, risk, depreciation, interest, and other related factors. Therefore, it is apt to vary widely.

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[6] Lusk (1998) used a value of 14% while Wright and Perschke (1998) used a value of 8%.

- Inflation of 3% was used for operating and maintenance cost, digested fiber price, and propane cost (heat saving). Likewise, this value can vary between a range of 2-5%. Fortunately, whether it is 2% or 5%, the analysis is not very sensitive to this term.
- Operation and maintenance costs were assumed at 1.5 cents per kWh of electricity generated (Wright and Perschke, 1998; Nelson and Lamb, 2000)[7].
- Insurance cost was taken into account. It was calculated as 1.5% of the capital cost and was assumed to decrease by 10% annually.
- Electricity cost is $0.09/kWh, which is the current buying price from NYSEG. This cost is used to determine how much a farm saves by generating its own electricity.
- Electricity price when selling electricity to a utility was $0.025/kWh. This price is used to determine the income a farmer receives for generating excess energy. In summer 2001 the rate increased to $0.0525/kWh.
- Electricity inflation was ignored because history has shown that electricity prices have been relatively constant.

Table 5 presents the results of these analyses. The results imply that economic viability of the system is sensitive to purchased electricity price, selling price of excess electricity, and capital cost. Furthermore, the larger the herd size, the greater the economic viability of the system. When the herd size increases to 1000, projected pay back period is half of that of 500 cows. Referring to the payback period for the "actual" (or original) scenario, there is a need to eliminate propane cost for existing scenario. The analysis (not presented here) shows that if the system could offset the propane cost (heating cost), payback period for original scenario would shrink to 11 and 16 years for discount rates of 10% and 14% respectively.

Table 5. Payback period of varying scenarios

Scenario	Payback (years)	
	TV=10%	TV=14%
Projection of 500 cows (electricity price $0.025/kWh)	7	9
Projection of 500 cows with increased electricity price ($0.0525/kWh)	6	8
Actual (500 cows, electricity price $0.025/kWh)	13	20+
Projection of 1000 cows with increased electricity price ($0.0525/kWh)	3	4
Capital cost of $350,000 (1000 cows, electricity price $0.0525/kWh)	3	3
Capital cost of $300,000 (1000 cows, electricity price $0.0525/kWh)	2	2

Another potential economical benefit that needs to be considered is the usage of separated solids as bedding material for cows. If this can be successfully implemented, the farm will save bedding cost up to $24,000/year (for 500 cows) while still having compost sales of $21,000 (at its average selling price of $13/yd^3). Approximately 40% of separated solids produced are used for bedding. Evidently, the viability of the system depends on the selling price of the compost.

[7] Nelson and Lamb (2000) noted that the value of 1.5% was high compared to actual experience at other digesters, even after more than 10 years of operation.

The higher the selling price, the more viable the system is. Of course, there are some other costs need to be added for this purpose.

When finished compost is used for bedding, our estimation showed that the sum of bedding saving and compost sales is less than total potential compost sales of \$34,200 (at its average selling price of \$13/yd^3). Our estimation was based on assumptions that compost need for bedding is 0.3 ft^3/day/cow (MWPS-18, 1985; Zehnder, et. al., 1998) and the volume of finished compost is 50% of the volume of separated solids (Rynk,et.al., 1992). Using separated solids or compost for bedding purpose needs further research to assess to what extent the use of the separated solid bedding will affect biogas and manure slurry production.

In addition to potential revenue generation presented in Table 4, there are other potential benefits that are not included in this analysis:

- Greatly reduced pathogens, weed seeds, odor and the chemical oxygen demand (BOD) compared to untreated manure. Maximum weed contamination found in the finished compost is 1/liter, while COD of effluent is reduced by 36.5%. Benefits to the community in odor reduction are important for better neighbor relations.
- Replacing fossil fuel with freely available biogas, which is a renewable fuel, for electricity generation
- Nutrients in the liquid are apparently more available to growing crops than conventional fertilizer.
- The need for trucking and spreading manure daily is reduced because the separated liquid can be stored for long time since it does not have significant smell. The labor associated with trucking and manure spreading is also lowered.

6. FUTURE CONSIDERATION

AA Dairy is now in the process of completing a business plan for doubling its size to 1000 cows. In order to advance the concept of total resource recovery, it is increasingly important to think of the system as more than an anaerobic digester, but an integrated system for generating electricity and thermal energy which can create an opportunity for entrepreneurial activities and byproducts. We view that innovative technologies to convert the energy present in biogas from anaerobic digestion of dairy waste manure to electricity and heat are increasingly important to sustain dairy activities. Two potential innovative systems for further consideration are suggested: fuel cells and microturbines. Both systems offer greater thermal and electrical energy efficiencies than a diesel engine generator (Lutsey and Scott, 2001). Accordingly, each requires a thorough analysis as a cogeneration system using biogas and should be studied in detail to verify these unproven technologies on farms. In addition, how best to optimize the value-added byproducts is extremely interesting for analysis. Aquaculture, greenhouses, algal farms, and possibly on-farm milk pasteurization should be studied as each may be able to use the heat and electricity, as well as other agricultural byproducts, such as carbon dioxide and a liquid effluent. Finding appropriate nutrient management systems will create another income opportunity from the available nutrients.

7. RECOMMENDATIONS

Some options for increased financial returns, which might be pursued, are:

- Using separated solids as bedding could make the existing operation more viable. Further research would be needed to assess the impact of introducing this separated solid bedding on production and composition of biogas, liquid effluent and compost.
- Increase the selling price of the finished compost.
- Eliminate or reduce propane costs by using recovered heat from the engine generator set in other thermal applications, not just for heating the digester.
- Implement green energy incentives or tax credits for anaerobic-digester-generated energy and efficient co-generation of heat and electricity such as proposed by the Senate (U.S. Senate, 2001).
- Realization of net metering such that it will offer higher rates for selling excess electricity.
- Increase electricity generation efficiency.
- Business partnership opportunities on or near the farm for optimizing the use of byproducts may be explored and implemented.

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