Anaerobic Digester at Craven Farms

A Case Study

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Introduction

Tillamook County on Oregon's northern coast is home to almost 24,000 people and nearly the same number of cows. The county's fertile land and heavy rainfall — an average of 90 inches annually — have encouraged development of the region's 150 dairy farms and fostered the success of the local Tillamook creamery cooperative.

Founded in 1886, Tillamook County's Craven Farms today faces environmental issues not recognized when the family owned-and-operated dairy first began.

However, most of the dairy farms lie only 15 miles from the Pacific Ocean in well-watered valleys just below the Coast Range. The combination of rain, high water tables, and more than 120 pounds of manure per cow per day creates water pollution problems for the county. Two of the region's other key industries — shellfish beds and tourism — are especially vulnerable to high fecal coliform bacteria levels in the county's water.

Dairy farmers in Tillamook County are under financial and regulatory pressure to manage the manure their cows produce. Although the waste management systems farmers commonly use reduce the amount of manure in runoff, they do not remove harmful bacteria from the manure. Neither do they provide farmers with ways to offset farm costs. This case study explores an alternative for handling dairy waste that does both. Anaerobic digestion of manure is an effective method of making manure less environmentally harmful while providing farmers with economic benefits.

Craven Farms, a family-owned-and-operated dairy for generations in Tillamook County, completed construction of an anaerobic digester at its main farm site in January 1997. In addition to reducing bacteria in the farm's manure, the digester system provided income to the dairy from electricity sold to the local public utility district and fiber solids sold as animal bedding. This practical, working demonstration of digester technology at Craven Farms could encourage other dairy farmers in Tillamook County and elsewhere in Oregon to install digesters or join in building a cooperative digester system. In doing so, dairy farmers could solve a business problem while also playing an active role in solving the problem of local watershed pollution.

Project Background

Regulating Animal Waste

For years, the U.S. Environmental Protection Agency and the Oregon departments of Environmental Quality and Agriculture have investigated animal waste pollution in Tillamook County's rivers and bays. In the 1980s, the EPA's Rural Clean Water Program targeted Tillamook County as a site needing extensive manure management. The program helped willing county farmers finance the installation of manure storage-and-use facilities designed to keep waste from mixing with rain and groundwater.

Also during the 1980s, Oregon began requiring water quality permits for dairy farms and other confined animal feeding operations. Compliance with water quality laws remained mostly voluntary until a new state law in 1987 instituted stronger inspection rules and stricter penalties for violators. The Oregon Department of Agriculture has lead responsibility in the state for addressing agriculture-related pollution problems in Tillamook County. The department also scrutinizes the area's compliance with federal water quality laws under an agreement with the U.S. Environmental Protection Agency.

In 1998, the EPA singled out dairy farms and other animal feedlot operations as key contributors to water pollution. The agency announced that it planned to create federal rules for feedlot waste management.

Getting Started

Craven Farms, under the management of Jeffrey Craven, owns 800 cows on two farms. The main farm is in Cloverdale, Oregon, just east of Coast Highway 101, less than 10 miles from the Pacific Ocean. In 1994, Craven Farms became interested in building a plug-flow anaerobic digester at its main dairy site. The dairy already had in place some of the necessary components of a digester system, including a mix tank, a manure pump, a solids separator and a solids storage building. Installing a digester would enable the dairy to generate electricity for on-farm use or for sale to the local power company. The system also would produce heat for space heating in the milking parlor and for heating water. The farm could use the clean fiber solids left after the digester process or sell the fiber to other local farmers for animal bedding.

Jeffrey Craven considered the digester's environmental benefits to be a strong factor in motivating him to install the system. The digester's heat would destroy the fecal coliform bacteria that are present in raw cow manure and keep the bacteria from polluting the local watershed. Separation of fiber solids from the digester effluent would reduce by about 25 percent the amount of harmful excess nutrients in the liquid effluent when compared to raw manure. Sale of the solids outside of the area would reduce the risk of pollution in the local watershed.

Constructing the digester system meant Craven Farms would need to make a significant investment. However, Craven expected to recover the investment within a reasonable time by using or selling the electricity and other by-products generated from the digester system.

Craven worked with digester expert Mark Moser of Resource Conservation Management, Inc., in Berkeley, California. Moser managed the project for Craven Farms. He designed the system, obtained the necessary materials and equipment and provided consultation for system startup and troubleshooting. Craven Farms retained management responsibility for getting permits, overseeing construction and running the digester system.

Nutrient Loading

Manure used as fertilizer provides soil with nutrients such as nitrogen and phosphorus that crops need. However, if those same nutrients flow from farms into local streams, their growth-enhancing benefits can become detrimental. Manure runoff can increase plant growth in streams and lakes by loading the water with excess nitrogen and phosphorus in a process called "nutrient loading." As more plants decay in the water, they increasingly compete with fish for oxygen. The result is a potential decrease in fish populations.

Project Goals

Craven Farms wanted to design, build, start up and operate a plug-flow digester system to achieve the following goals:

1. Production of 60 cubic feet of biogas per cow per day.
2. Production of electricity at the assumed heat rate of 15,000 Btu/kWh or better.
3. Keeping a generator working 85 percent of the time or better.
4. Production of electricity in excess of farm needs.
5. Production of supplemental space heat.
6. Production and sales of digested fiber solids.
7. Sales of digested solids outside of the local drainage basin to reduce local nutrient loading.
8. Reduction of bacteria and nutrient loading to pastures by applying digester effluent rather than raw manure slurry.
9. Reduction in the cost of liquid manure handling.
10. Operation of the system to achieve a payback of the digester's construction costs in five years or less.
11. Demonstration of the viability of an anaerobic digester system on an operating dairy farm in Oregon.

The anaerobic digester at Craven Farms can process the manure from more than 1,000 cows as a way to protect the environment and generate farm income.

Project Description

Digester Technology

Anaerobic digestion and power generation at the farm level began in the United States in the early 1970s. Several universities conducted basic digester research. In 1978, Cornell University built an early plug-flow digester designed with a capacity to digest the manure from 60 cows.

In the 1980s, new federal tax credits spurred the construction of about 120 plug-flow digesters in the United States. However, many of these systems failed because of poor design or faulty construction. Adverse publicity about system failures and operational problems meant that fewer anaerobic digesters were being built by the end of the decade. High digester cost and declining farm land values reduced the digester industry to a small number of suppliers.

In recent years, however, increasing awareness that anaerobic digesters can help control animal waste odor and disposal has stimulated renewed interest in the technology. Dairy farmers faced with increasing federal and state regulation of the waste their animals produce are looking for ways to comply. New digesters now are being built because they effectively eliminate the environmental hazards of dairy farms and other animal feedlots.

Typical Dairy Waste Management Practice

Using a tractor to blade manure straight from the soil into nearby sloughs and streams once was common practice for dairy farmers. Today, Tillamook County dairy farmers often use tractors to scrape manure slurry from concrete pads that keep the slurry from the soil. They then move the manure into above- or below-ground storage tanks that contain the slurry during the wet season. During the growing season, when the danger of runoff contamination is less, farmers may apply a specific amount of manure as fertilizer to their fields. Regulations restrict the application amount to avoid nutrient loading and fecal coliform contamination in local watersheds.

Most Tillamook County farms confine cows during the region's rainy season from October through March, making it necessary to scrape manure from barn floors for storage in tanks.

It is often the environmental reasons — rather than the digester's electrical and thermal energy generation potential — that motivate farmers to use digester technology. This is especially true in areas where electric power costs are low. Anaerobic digester systems can reduce fecal coliform bacteria in manure by more than 99 percent, virtually eliminating a major source of water pollution. Separation of the solids during the digester process removes about 25 percent of the nutrients from manure, and the solids can be sold out of the drainage basin where nutrient loading may be a problem. In addition, the digester's ability to produce and capture methane from the manure reduces the amount of methane that otherwise would enter the atmosphere. Scientists have targeted methane gas in the atmosphere as a contributor to global climate change.

A covered building, located between the digester and the farm's storage lagoons, houses a separator that screens out fiber solids from the digested manure effluent.

There are three basic digester designs. All of them can trap methane and reduce fecal coliform bacteria, but they differ in cost, climate suitability, and the concentration of manure solids they can digest.

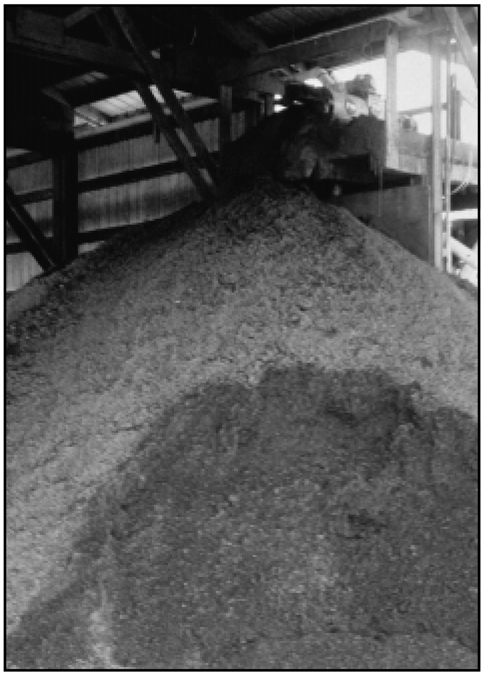
A *covered lagoon digester*, as the name suggests, consists of a manure storage lagoon with an impermeable cover. The cover traps gas produced during decomposition of the manure. Covered lagoon digesters are used for liquid manure (less than 2 percent solids) and require large lagoon volumes and a warm climate. This type of digester is the least expensive of the three.

A *complete mix digester* is suitable for manure that is 2 percent to 10 percent solids. Complete mix digesters process manure in a heated tank above or below ground. A mechanical or gas mixer keeps the solids in suspension. However, complete mix digesters are expensive to construct and cost more than a plug-flow digester to operate and maintain.

Plug-flow digesters are suitable for ruminant animal manures having a solids concentration of 11 percent to 13 percent. In a plug-flow digester, raw manure slurry enters one end of a rectangular tank and decomposes as it moves through the tank. New material added to the tank pushes older material to the opposite end. Coarse solids in ruminant manure form a viscous material as they are digested, limiting solids separation in the digester tank. As a result, the material flows through the tank in a "plug." Anaerobic digestion of the manure slurry releases gas as the material flows through the digester. A flexible, impermeable cover on the digester traps the gas.

A plug-flow digester requires minimal maintenance. Inside the digester, suspended heating pipes allow hot water to circulate. The hot water heats the digester to keep the slurry at 25°C to 40°C, a temperature range suitable for methane-producing bacteria.[1] The hot water can come from recovered waste heat from an engine generator fueled with digester gas or from burning digester gas directly in a boiler.

[1]The temperature range is equivalent to 77°F to 104°F.



Fiber separated from the effluent collects below the separator and is stored before being sold or used. Leftover liquid continues on to the farm's storage lagoons.

Pipes welded in place along the digester's 12-foot walls recycle waste heat from the gas engines to warm the manure slurry as it is digested.

The plug-flow digester design offers a high-temperature variation. High temperature speeds the digestion process and reduces the required volume of the tank by 25 percent to 40 percent. However, there are more species of anaerobic bacteria that thrive in the temperature range of a standard design (thermophillic bacteria) than there are species that thrive at higher temperatures (mesophillic bacteria). High-temperature digesters also are more prone to upset because of temperature fluctuations, and their successful operation requires close monitoring and diligent maintenance.

In 1994, about 25 digester systems were operating on commercial farms in the United States. Nine of them were plug-flow systems. The only plug-flow digesters operating west of the Mississippi were two systems in California.

Proposed Craven Farms Digester Design

In 1994, the site at Craven Farms housed 800 cows in two freestall barns. Before construction of the digester, manure management consisted of daily scraping of the manure and liquids from the barns. The slurry then flowed through a channel to a collection tank. The slurry was either pumped from the collection tank to a solids separator or channeled directly to storage lagoons. The liquids from the separator flowed to the storage lagoons.

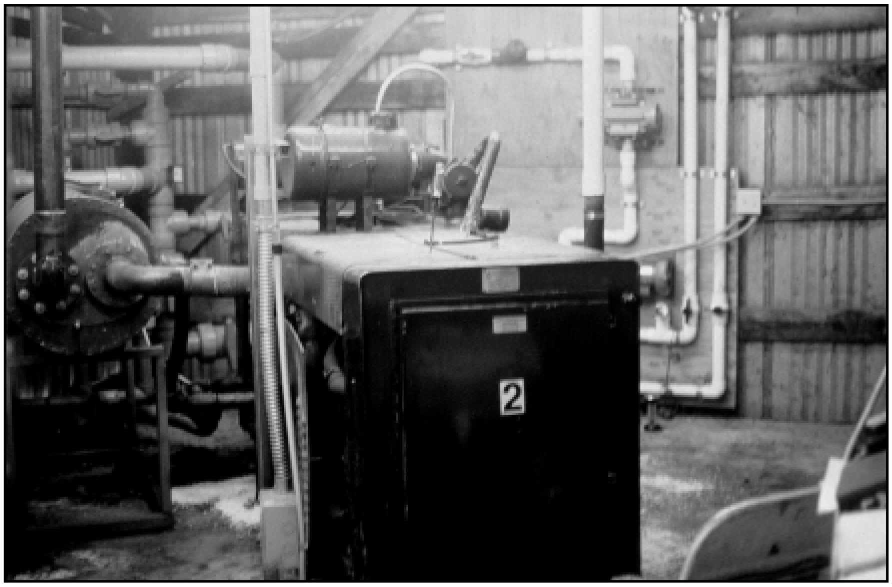
Digester designer Mark Moser proposed a plug-flow digester system as a low-cost, highly reliable option suitable for digestion of the high-solids manures collected at the Craven Farms dairy. The complete digester system would need the following components, some of which the farm already owned:

- mix tank
- piping system
- digester
- effluent storage
- gas utilization

These components function together in the plug-flow digester system. Raw manure and barn liquids collect in the mix tank, where the solids concentration may be adjusted. More manure can be added to the mix tank to increase solids concentration to meet the digester's need for a mixture containing 11 percent to 13 percent solids. To reduce solids concentration to the appropriate level, milking parlor washwater or liquid organic wastes such as cheese whey can be added. The mix tank also allows sand and rock to settle out.

From the mix tank, the manure slurry is pumped to the digester. After a 20-day travel time through the digester, digested manure slurry overflows into an effluent chamber in the digester. This effluent is then pumped to a solids separator, where the fiber solids fall out and are collected for dry storage. Potential uses for the fiber solids include animal bedding and composting. The liquids from the separator flow to storage lagoons and are later applied to land as fertilizer.

The gas collected in the digester is pumped to one or more gas engines. Before entering the engines, the gas is filtered to remove condensate, then pumped to two-inch water column pressure with a gas blower. Gas production volume is metered. Cleaning the gas to remove its corrosive hydrogen sulfide, although desirable, may not be necessary if the engines are maintained with frequent oil-changes.



In the engine room, gas is pressurized in the pipes along the back wall while pipes in the back left corner circulate hot water to the digester.

The gas engines drive induction generators that produce electricity. Waste engine heat is captured in a water-filled heat exchanger. Some of the heated water is pumped to the digester to heat the slurry during the digestion process. The heated water also can be used to supply hot water and space heating through secondary heat exchangers.

Initial Craven Farms Digester Design

Moser's first design for the Craven Farms digester had a capacity of 240,000 gallons with dimensions of 24 feet wide by 112 feet long by 12 feet deep. The manure produced by the Craven Farms dairy herd was expected to produce 60 cubic feet of biogas per mature cow per day, for a total daily gas production of 48,000 cubic feet.[2] See **Table 1**.

Craven Farms assumed the business would sell 50 percent of the digester's fiber output and use the rest. Waste heat from the engines would be piped to the milking parlor for hot water and space heat during winter months. The value of the waste heat, which would offset electricity costs, was estimated to be $3,500 annually.

[2]Biogas, or "digester gas," consists principally of methane and carbon dioxide. Methane, a combustible gas, comprises 55 percent to 75 percent of biogas, by volume. In comparison, natural gas typically contains at least 90 percent methane.

Table 1 — Initial Design Calculations		
Cows	800	
Manure volume		
Cubic feet (assumed)	2	cubic feet per cow per day
Pounds (assumed)	120	pounds per cow per day
Gallons (assumed)	16	gallons per cow per day
Manure production		
Cubic feet	1,600	cubic feet per day
Gallons	12,800	gallons per day
Gallons (rounded down)	12,000	gallons per day
Digester size		
Capacity	20	days
Volume	240,000	gallons
Gas production		
Per cow (assumed)	60	cubic feet per cow per day
Total	48,000	cubic feet per day
Energy value		
Per cubic foot of biogas	575	Btu per cubic feet
Total per day	27,600,000	Btu per day
Electric capacity		
Heat rate (assumed)	15,000	Btu per kWh
Per day	1,840	kWh per day
Per year	671,600	kWh
Hours per year	8,760	hours
Engine capacity (min)	76.67	kW
Availability	85%	
Electric output		
Price (assumed)	$0.04	per kWh
Available output	570,860	kWh
Projected sales	$22,834.40	per year
Solids output		
Production	8	cubic yards per day
Price (assumed)	$11.00	per yard
Sales volume	50%	
Projected sales	$16,060	per year
Thermal output		
Heating offset value (assumed)	$3,500	per year
Total value of outputs	$42,394	per year

Financing and Economic Considerations

Estimated System Cost

In 1994, based on the initial design, Moser estimated the full construction cost of the Craven Farms digester would be about $241,700. **Table 2** shows a breakdown of the costs. However, because Craven Farms already owned several components of the complete digester system, the out-of-pocket costs for the system would be less. The estimated value of those in-place components was $86,000, reducing the estimated Craven Farms project cost to $155,705. Not included in the estimated costs were the value of labor, construction equipment and materials supplied by Craven Farms.

The Craven Farms project received a U.S. Department of Energy grant from the Pacific Northwest and Alaska Regional Biomass Energy Program. In 1994, the energy program issued a competitive solicitation for demonstration projects and selected the Craven Farms project for a grant of $77,850.

The potential value of the project's outputs — electricity, space heat and fiber product — was estimated to be about $42,400 per year. Subtracting estimated operation costs, the project was expected to have net annual revenue of $33,660. From these estimates, Craven Farms anticipated a simple payback period for its investment of 4.6 years, even without government grant assistance for the project.

The project qualified for loan financing through the Oregon Office of Energy's Small Scale Energy Loan Program. The loan program issues low-interest, long-term loans to qualified borrowers for Oregon projects that produce energy from renewable resources or that conserve energy resources.

Table 2 — Estimated Construction Costs (Initial Design)		
Component	out-of-pocket	in-place value
Structures and equipment:		
Mixing tank	$0	$15,000
Manure transmission	475	
Manure pump	0	7,000
Digester	68,178	
Gas and hot water transmission	3,338	
Electrical transmission	2,000	
Engine-generator and building	47,026	
Solids separator	0	27,000
Solids storage building	0	37,000
Other costs:		
Startup propane	4,416	
Engineering	20,000	
Expenses	4,000	
Contingencies	6,272	
Total costs	$155,705	$86,000
Value of equipment in place	$86,000	
Full construction cost estimate	$241,705	
Operating costs and revenue:		
Estimated operating cost	$0.013	per kWh
Annual operation cost	$8,731	per year
Estimated value of outputs	$42,394	per year
Net income	$33,663	per year
Simple payback	4.6	years

Construction

Work Plan

The project proposal called for work on the digester system to begin in January 1995 and system start-up to begin by September 1995. Resource Management, Inc., would continue to provide consultation and trouble-shooting assistance during the initial six months of operation.

The work plan included five tasks**:**

1. ***Design:*** Expected to take six weeks, the design task involved consultation between Jeffrey Craven and Mark Moser about final plans and specifications for the system to be installed. This task would also include negotiations with the local utility, Tillamook People's Utility District, for sale of the power output.
2. ***Equipment Procurement:*** The second task, expected to require up to one month, was ordering equipment appropriate to the design.
3. ***Construction:*** The construction task, requiring three-to-five months, included construction of the digester and installation of all necessary equipment.
4. ***Startup:*** Digester and engine startup, troubleshooting, and training of operators was expected to take five weeks.
5. ***Operation:*** The project included supervision and consultation during the first six months of operation as Craven Farms assumed control of the digester.

Construction Details

Preliminary grading of the project site was completed by the end of December 1994. In early 1995, Moser began negotiations with the local utility about power sales and the electrical intertie. He also discussed the digester concept with the Oregon Department of Agriculture.

By the end of June 1995, Moser had completed a preliminary site survey and a partial set of plans and had obtained bids for the concrete work. The manager of the Tillamook-area MEAD Project had expressed interest in buying digested fiber output from the Craven Farms digester.

Craven Farms had begun informal discussions with the Oregon Office of Energy for loan financing through the Small Scale Energy Loan Program.

In mid-1995, Craven Farms was struggling through a period of business uncertainties. Feed prices were high and revenues were low because of poor dairy industry performance. As a result, Jeffrey Craven postponed making any final decisions on sizing the digester. At the end of September 1995, the dairy indefinitely postponed decisions on final plans and specifications for the digester and suspended its application for loan financing. It looked doubtful then that the Craven Farms digester would ever be built.

However, about six months later, in April 1996, Craven Farms decided to proceed with the project. Foreseeing the dairy's long-range needs, Craven asked Moser to enlarge the digester design so the digester would have the capacity to digest manure from a 1,000-cow dairy herd. In the new design, the digester would have a capacity of 320,000 gallons and dimensions of 28 feet wide by 130 feet long by 12 feet high. See **Table 3**.

Moser renewed discussions with the Tillamook PUD about the price to be paid for electricity produced from Craven Farms biogas. Craven Farms reactivated its application for loan financing from the Office of Energy. The office issued a $98,000 loan to Craven Farms in October 1996.

Construction of the digester began in July 1996. Several unforeseen events delayed construction and added to the cost. The farm's existing manure pump did not perform as expected and had to be replaced with a new pump that would deliver an adequate flow rate. The two used industrial-grade Ford 460 engines bought for the digester system were in poor condition. The Portland area machine maintenance subcontractor found that the engine blocks of both engines needed to be replaced. In addition, one of the generators needed to be rebuilt.

The digester heat rack was installed in September, and manure slurry began filling the digester chamber by early October. The two rebuilt 65-kW engine-generator sets were installed in October.

Firing on propane began in December 1996. Starting the engines on propane meant the waste heat from the engines could first be used to warm the digester to the temperature range needed for sustaining the methane-producing bacteria. Even though the system was not yet running on biogas, it was generating electric power.

The polyethylene digester cover was installed on January 13, 1997, and the engines were fired on biogas three days later. At the time of system startup, the digester was processing the manure from about 600 cows.

Mead Project

The Tillamook County Soil and Water Conservation District joined with the Tillamook People's Utility District in 1989 to form the Methane Energy and Agricultural Development (MEAD) project. The goal of MEAD is to develop a large-scale dairy manure digester (150,000 tons per year) that would convert dairy and other organic waste into energy, fertilizer and compost products.

The Craven Farms dairy is 30 miles away from the proposed MEAD project site, and the cost of hauling manure that distance made reliance on the proposed MEAD digester impractical for the business. However, MEAD expressed interest in buying fiber from the Craven Farms digester to begin production of a compost product that would be essential to the success of the MEAD project.

Although the MEAD project would give many dairy owners a new option for managing manure disposal, construction cannot begin until financing is found for the project's estimated $12 million cost.

Permits

Moser and Craven discussed the digester project with the Oregon Department of Agriculture (ODA) early in the design stage. The project ultimately required ODA to give site plan approval. However, the county soil conservation district treated the digester as a manure storage facility, and the digester did not need any special building permits from Tillamook County.

Although anaerobic digestion would eliminate the risk of fecal coliform bacteria pollution, ODA was concerned about the potential for excess nutrient loading when the farm spread the digested manure effluent onto land. The digesting process removes some of the nutrients by separating out solids, but digested manure effluent still contains nitrogen and phosphorus. Poorly managed land application of the effluent could lead to nutrient loading. However, the department did not require the farm to change its nutrient management plans.

Power Sales

For the first year of operation, the Tillamook People's Utility District (PUD) agreed to buy all the electric power output of the digester system at a rate of $.035 per kilowatt-hour. The revenue from power sales would favorably offset the dairy's power purchases. In the first year of operation, Craven Farms would pay a rate of $0.028 per kilowatt-hour for electricity from the utility. An additional benefit to the PUD would be a net reduction in peak energy demand in southern Tillamook County, where Craven Farms is one of the largest electrical consumers.

Table 3 — Final Design Calculations

Cows	1000	
Manure volume		
Cubic feet (assumed)	2.2	cubic feet per cow per day
Pounds (assumed)	120	pounds per cow per day
Gallons (assumed)	16	gallons per cow per day
Manure production		
Cubic feet	2,200	cubic feet per day
Gallons	16,000	gallons per day
Digester size		
Capacity	20	days
Volume	320,000	gallons
Gas Production		
Per cow (assumed)	60	cubic feet per cow per day
Total	60,000	cubic feet per day
Energy value		
Per cubic foot of biogas	575	Btu per cubic foot
Total per day	34,500,000	Btu per day
Electric capacity		
Heat rate (assumed)	15,000	Btu per kWh
Per day	2,300	kWh per day
Per year	839,500	kWh
Hours per year	8,760	hours
Engine capacity (min)	95.83	kW
Availability	85%	
Electric output		
Available output	713,575	kWh
Farm use (estimated)	580,000	kWh
Power cost savings (estimated)	$11,211	per year
Net power available for sale	133,575	kWh
Price	$0.035	per kWh
Net electric revenue	$4,675	per year
Solids output		
Production	10	cubic yards per day
Price (assumed)	$10	per yard
Sales volume	50%	
Projected sales	$18,250	per year
Offset on-site bedding costs	$18,250	per year
Thermal output		
Heating offset value (assumed)	$3,500	per year
Total value of outputs	$55,886	per year

Tillamook People's Utility District uses two meters to monitor the small amount of electricity bought by Craven Farms and the much larger amount the farm produces and sells to the utility.

Interconnection and Power Transmission

The Tillamook PUD supplies the dairy with the three-phase electricity needed to run large equipment. Although the design for connecting the dairy to the utility's electrical distribution grid had been approved, the proposed connection did not function as anticipated. One problem was with the devices that shut down connections and otherwise protect the farm or utility in case either experiences system difficulties. Craven Farms hired an electrical engineer to design and install additional undercurrent sensors needed in the event of a loss or serious reduction in power supplied to the farm.

Fiber Sales

At full capacity, the digester system would produce an estimated 10 cubic yards of digested fiber solids per day. This fiber material is suitable for use as a compost extender. When dried, the fiber can be used as animal bedding. Craven Farms estimated sales of at least 50 percent of the fiber output. At an average price of $10 per cubic yard, Craven Farms anticipated income from fiber sales of $18,250 per year. See **Table 3**.

Hot Water

Engine heat would be recovered through heat exchangers. The heat would be used to maintain the digester temperature and to heat water for farm use. A planned heat loop would send heat to a hot water accumulator tank to supply the milkhouse water heaters. Upon final hookup of the waste heat recovery loop, three electric hot water heaters would no longer be included on the farm's electrical energy load. The anticipated savings in energy costs and demand charges for these water heaters was about $3,500 annually.

Selling Electricity

A farmer doesn't need an engineering degree to sell power to a local utility, but understanding the basics of three-phase power and electricity distribution methods helps. The local utility can help a farmer determine if selling electricity will be feasible. The Tillamook People's Utility District suggests farmers considering a digester project take at least three key steps:

1. Contact the local utility about whether it has a small-power purchase rate schedule in effect. In Oregon, regulated utilities must offer producers of 100 kWh or less a contract to purchase the power. People's utility districts, cooperatives and municipal utilities don't have the same mandate, but some of them — like Tillamook People's Utility District — create their own small-power rate schedules.
2. If the local utility does not have a small-power rate schedule, try to negotiate a rate. The purchase rate can vary, but it often is close to the same rate at which power would be sold to the producer.
3. Once rates are determined, work with the utility or local soil conservation service to understand requirements for connecting farm-produced power to the utility. Issues include transformer condition, protection device installation and wiring appropriate for the local utility's method for distributing three-phase electricity.

Actual Capital Costs

The final as-built cost of the system was $318,450. **Table 4** shows a breakdown of the construction costs. This total includes the value of usable equipment in place before construction. A grant from the Pacific Northwest and Alaska Regional Biomass Energy Program reduced the Craven Farms investment by $77,850 (about 24 percent of the final cost). The final out-of-pocket cost to Craven Farms was $153,600, not including $6,000 of in-kind labor and equipment investment. To finance the cost, Craven Farms received a $98,000 loan from the Oregon Office of Energy.[3] See **Table 5**.

Table 4 — As-Built Construction Costs

Component	out-of-pocket	in-place value
Mixing tank	$0	$15,000
Manure transmission	500	
Manure pump	9,500	
Digester	128,000	
Gas and hot water transmission	3,500	
Electrical transmission	2,000	
Engine-generator and building	47,950	2,000
Solids separator	10,000	27,000
Solids storage building	0	37,000
Startup propane		5,500
Other costs		
Engineering	26,500	
Expenses	4,000	
Contingencies	0	
Total costs	$237,450	$81,000
Value of equipment in place	$81,000	
Full project cost	$318,450	

Current Operations

One year after start up, the digester system was operating below full capacity, largely because of the size of Craven Farm's herd. Designed to process the manure volume produced by 1000 cows, the digester was handling about 75 percent of that volume as of January 1998. Craven Farms anticipates increasing the size of the dairy herd. In the meantime, the dairy has fitted a truck to haul manure to the digester from its second farm site about five miles away. The truck will haul digester effluent liquids to a new storage lagoon at the second farm site.

In routine operation, manure collection tank contents are pumped once a day to the digester. Each day, Craven Farms staff observes engine generator settings, reads biogas meters and makes adjustments as needed. The effluent tank pump and the solids separator press are operated daily. In keeping with the design objective of simple operation, there is no monitoring of the energy content of the gas (Btu value) or the acidity (pH) of the digester contents — useful but not vital information for farmers. During the first six months of operation, the turbochargers on both rebuilt engines failed and were replaced. Used exhaust heat exchangers developed leaks and had to be replaced.

Table 5 — Financing

Capital Expenditures		
Full project cost	$318,450	
Less equipment in place	(81,000)	
Total expenditures		**$237,450**
Financing		
DOE Bioenergy Grant		$77,850
Farm investments		
In-kind labor and equipment	$6,000	
Oregon SELP loan	98,000	
Cash	55,600	
Total farm investments		$159,600
Total financing		**$237,450**

[3]Craven Farms refinanced its debts and paid off the Office of Energy loan in May 1998.

Table 6 — Cost and Revenue Projections		
Operating costs		
Digester and power generation		
Average capacity	75	kW
Electricity output (rounded)	660,000	kWh per year
Estimated maintenance expense	$0.015	per kWh output
Annual maintenance cost	$9,900	per year
Fiber		
Annual production		4,000 cu. yd.
Fiber recovery system maintenance	$1	per cu. yd.
Annual maintenance cost	$4,000	per year
Fiber delivery	$3.00	per cu. yd.
Annual delivery cost	$12,000	per year
Total operating costs	$25,900	per year
Revenues and cost savings		
Electricity price	$0.035	per kWh
Electricity sales	$23,100	per year
Fiber price	$10	per cu. yd.
Fiber sales	$40,000	per year
Water heating cost savings	$3,500	per year
Total	$66,600	per year
Net annual income	$40,700	per year
Total farm investments	$159,600	
Simple payback on total investment	3.9	years

The digester operated at just over half capacity during most of the first year. Biogas use for the first year was about 11.1 million cubic feet. Electric power sales for the first year were 383,300 kilowatt-hours. Revenues totaled $13,400 for electricity sales and $26,000 for fiber.

After the first year, annual revenues are expected to be $66,600, with the system operating on average at 75 percent of full capacity.[4] Operating costs after the first year are expected to be $25,900 per year. The net annual return of $40,700 will achieve a simple payback of the total farm investments in 3.9 years.[5] See **Table 6**.

Conclusions

Most of the Craven Farms project goals have been achieved. Even though the system did not operate at full capacity during the first year, the system produced revenues from electricity sales, fiber sales and dairy cost offsets. The potential exists for further cost savings when a heat loop is installed to provide hot water for the washhouse. Craven Farms can reasonably expect to recover its investment within the original goal of five years.

The construction costs of the Craven Farms digester system were greater than anticipated. The final cost was about $237,450, excluding the value of components Craven Farms already had in place before starting the digester project. The full project cost exceeded the original estimate by about $76,745 or 32 percent. The difference, however, is partly explained by the redesign of the system to increase its capacity. The original estimate was based on a 240,000 gallon digester capacity. The digester as built was 33 percent larger, with a capacity of 320,000 gallons.

Other reasons for the higher as-built costs were unexpected expenses. The used engines required major, unanticipated renovation. The existing manure pump was inadequate and had to be replaced. Additional electrical engineering expenses arose when the protective relays of the electrical intertie did not function as expected. Completing construction during difficult winter weather added to the overall as-built project cost.

Dairy producers from Oregon and elsewhere in the Pacific Northwest have visited Craven Farms since the digester system began operating. They have observed the operation of the digester, finding the digester system to be less complicated and much quieter than they expected. They

[4]The calculation assumes the digested manure from 750 cows will yield 48,750 cubic feet of biogas per 24-hour period and that the energy content will be 600 Btu per cubic foot. The assumed engine efficiency is 23 percent (15,000 Btu/kWh output), with an estimated 8 percent of generated power used internally.

[5]Assuming a full project cost of $318,450, as shown in Table 4, and no government grant assistance, the same estimated rates of revenue would achieve a simple payback of full project costs in 7.8 years.

are interested to learn that the fiber and liquid outputs from the system are more uniform and easier to manage than raw manure.

Oregon and other states in the Pacific Northwest region have a large potential to generate biogas and electricity from dairy cow manure, but low electricity rates have kept digester technology from widespread adoption. Nevertheless, dairy farms west of the Cascade Range are mostly freestall barns with daily scrape manure collection, which is an ideal beginning for plug-flow digestion systems. Plug-flow digesters have had the greatest success of all the different types of digesters built on farms in the United States. The technology is functional and efficient. Ten years of experience have improved the design and reduced digester system failures.

As dairies have grown larger in dairy regions such as Tillamook County, manure management has become a critical concern. Anaerobic digestion is a manure management option that can make cow manure a source of farm income and farm-cost offsets. Digesters modeled after the Craven Farms project offer dairy operators a simple system, practical to operate and maintain, that can generate a return on investment while greatly reducing manure management problems. The system effectively eliminates the problem of bacterial pollution from the dairy operation.

Although each dairy has unique characteristics that must be considered in estimating project costs, the Craven Farms dairy has demonstrated that this technology is suitable to dairies in Oregon. The potential revenues from electricity and fiber sales, combined with the savings on hot water and heating bills, make a manure digester a wise investment. Craven Farms has shown that it is an investment that can be both financially sound and environmentally smart.