

# Economic Evaluation of Commercial Dairy Anaerobic Digester

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## Background

Only one US-based economic study on dairy farm AD adoption exists, a US EPA (2004) study that is now somewhat dated and, importantly, limited in its scope, as it examines only a few revenue streams in analyzing overall project economics. While the most documented and studied revenue stream from AD is its power production and associated electrical sales, many other revenue streams have the potential to improve overall economics and provide additional project stability and viability. The need for multiple co-products beyond simple power production is especially true in regions of the country like the Pacific Northwest where received prices for produced electricity are well below the national average of \$0.09/kWh (US-EIA, 2007). Examples of other added revenues include carbon credits, renewable energy green tags (offsets) (CCX, 2008), fibrous solids sales and bedding offsets (King, 2003), co-digestion tipping fees, and state/federal tax credits. Beyond adding additional revenue to an AD project, development of these additional co-products and markets allows for development of an integrated biorefinery around core AD technology that in turn improves sustainability, environmental stewardship and climate management. The purpose of the analysis presented in this chapter was to examine the economics of AD technologies for dairy manure under alternative co-product marketing scenarios. Using projections based on the operating commercial test-bed digester, common economic tools including net present value (NPV), internal rate of return (IRR) and modified internal rate of return (MIRR) were used to gauge the economic performance of a baseline digester. Several co-product marketing scenarios were then formulated to determine how the feasibility of the digester is affected against the baseline. Conclusions drawn can be used by researchers, AD developers and producers to develop next-generation dairy ADs.

## Co-Product Summary

### *Electricity*

Most digesters in operation today have the capacity to generate electricity. Determining the price for electricity produced from biogas remains an ongoing issue for potential adopters. Producers seeking economic benefits from electricity generation have several options including power purchasing agreements, net metering, green tag sales, and tax credits. The power purchase agreement is a contractual arrangement between the producer and the local utility. Entering into the agreement requires negotiation, and the contract does not guarantee a renewal. Further, utilities may have expensive technical interconnect requirements, and/or may require costly feasibility studies before power purchase agreements are accepted.

Net metering is an alternative to power purchase agreements. Washington State net metering policy requires utilities to accept power produced from renewable fuels. Net metering is an offset system; if the amount of energy produced exceeds the producer's need, it creates a credit (WSL, 2006). Utilities have argued that retail power prices would increase because of the instability caused by higher levels of aggregate power demand being met by net metering systems (Cook and Cross, 1999). This increase in price could occur because of the fact that utilities are often not compensated for transmission and distribution under net metering systems (Cook and Cross, 1999). Further, when utilities are regulated such that they set energy prices according to the fully distributed costs, they have no incentives to promote energy conservation or to purchase energy from other renewables, as their profits remain the same (Wirl, 1997). This analysis implies that utility management will generally support local AD projects out of non-economic motives, which emphasizes the importance of fostering partnerships.

Sales of green tags are an increasingly popular option for digester operators looking to profit from their excess electricity. The green tag purchase replaces a certain block of traditionally produced energy with an equally sized block of renewable energy. This option allows citizens who view green power as a priority to pay extra to support it.

#### *Tipping Fees*

Manure is not the only feedstock that can be digested. Dairy ADs can also accept other wastewaters and waste solids, primarily from the food processing industry. Like manure, these additional substrates are digested by the bacteria within the digester, but as discussed in a previous chapter, their increased organic loading and biodegradability can increase biogas production, particularly when co-digested with manure. Tipping fees for receiving substrates may raise revenue substantially and increase electrical production for digester owners. Nutrient overloading concerns do exist, also as previously discussed, and there are concerns about possible contaminants, inhibitors, and pathogens arriving with the substrates, potentially impeding the AD process or the marketing of co-products. For dairy producers, these concerns, particularly those about pathogens, also generate worries about potential for new regulatory requirements. Many national and state governments are in the process of developing new rules and regulations to govern what materials can be co-digested, and under what conditions (WSDOE, 2009).

#### *Digested Fiber*

Dairy manure contains a considerable portion of fibrous solids both before and after digestion, made up largely of recalcitrant lignocellulosics. Many industry professionals feel that effective utilization and marketing of the fiber byproduct is the key to enhanced adoption of AD technology on dairy farms. Presently, non-AD manure management strategies mechanically separate raw fiber. This raw fiber product, which has a 67-75% moisture content and relatively high fecal and pathogen contamination, has minimal value and a small market with prices received

around \$3/yd<sup>3</sup>. A higher value (\$9-30/yd<sup>3</sup>) can be attained upon composting for 30-60 days and then either marketing it or re-using it as bedding on the farm. Potential markets for the composted fibrous material include topsoil bedding, nursery greenhouse bulk soil, turf top-dressing, peat replacement, bedding replacement, other compost replacement, and transportation erosion control. Prices for these products range from \$9-27/yd<sup>3</sup> with the higher prices coming from bagged residential products or the nursery industry (King, 2003). Unfortunately the bagged products incur considerable infrastructure costs and are a relatively small and volatile niche market.

AD treatment of the fiber component as it runs through the digestion cycle with the rest of the manure represents a potential cost savings over conventional compost treatment (King, 2003). The AD process can significantly destroy indicator pathogens, remove odor, reduce wastewater contamination concerns and partially destroy weed seeds. Fiber, mechanically separated from other AD products after digestion, has been in at least some cases actively marketed to off-farm markets as discussed above or (more typically) used on-farm as an animal bedding replacement (Figure 4.1).



Figure 4.1: Fibrous product after AD and mechanical separation

Though there is significant potential, analysis shows that of the existing 92 dairy digesters in the U.S., only six have marketed their fiber product for purposes other than bedding (US-EPA, 2007). The majority of those dairies are selling at the lower end of potential product prices—approximately \$7-8/yd<sup>3</sup> delivered—and these prices were attained only after some additional treatment beyond the AD process (King, 2003). The question, thus, still remains whether effective production technologies and adequate high value, large markets can be attained for AD treated fiber. In this economic study, a patent-pending value-added process is compared to the lower value use as a bedding replacement. WSU developed this process for the nursery industry as a peat-replacement product made from the solids.

### *Carbon Trading*

Dairy farms with AD systems are eligible for carbon trading on the Chicago Climate Exchange (CCX) (CCX, 2008) as well as other similar entities. For digester owners, carbon trading is a potential source of revenue because methane emissions from a lagoon storage baseline are reduced. However, without compulsory emissions caps such as those in countries that signed the protocol, CCX prices are low. Potential revenues for digester owners are further reduced by large brokerage commissions required for trading.

In addition, there is the need to develop working protocols approved by national and global markets for additional potential parts of the AD process. Of particular interest is allowing carbon credits for substrates diverted from an assumed baseline of landfill disposal.

### *Other Potential Co-products*

While the primary potential sources of revenue for dairy manure digesters have been noted, several other sources may exist for some digesters. Notable among the possibilities are sales of scrubbed methane, which can be either used as transportation fuel or injected into natural gas pipelines. Additional opportunities include the value of services derived from waste heat and sale of fertilizer-grade nutrients in the form of struvite, phosphorous-rich solids, ammonia salts, or others. These additional revenue sources are potentially important; however, insufficient reliable economic information was available at the time of the study to include them in this analysis, so they are mentioned here only as potential sources of revenue. Their technology development is discussed in ensuing chapters.

## **Methods and Assumptions**

The commercial test-bed digester served as the “base digester” scenario for economic analysis. Construction of the digester began in June 2004 and was completed in November 2004. A “start-up” phase occurred between the end of construction and when the digester was fully operational in March 2005. The construction costs are presented in Table 4.1.

Table 4.1: Construction Costs

Component	Cost (\$)
Pit	19,435
Digester	498,913
Gas Mixing	27,777
Co-Generator	282,087
Engine Building	95,637
Total Capital Cost	923,849
Other Costs <sup>a</sup>	212,515
Total Cost	1,136,364

<sup>a</sup> Other costs include engineering costs, feasibility studies, and administrative costs.

Assumptions underlying the base scenario relied on data from the first two years of digester operations provided by the digester owner, the company that constructed the digester, and the Washington State University research team working with the digester. To allow for comparison with previous studies, analysis started with a scenario based on the test-bed digester's actual construction costs, manure from the 500-cow herd, revenue from electricity sales and tax credits, and digested fiber used as on-farm bedding. Successive scenarios included additional grants, trucked-in manure from 250 neighboring cows, co-digestion of substrates, substrate tipping fees, value-added sale of excess fiber, and carbon trading. This sequence of seven scenarios concluded with a "base digester" scenario that was fully representative of the operational digester. Sensitivity analysis was then conducted for an additional nine scenarios.

Three economic indicators were calculated for each scenario—net present value (NPV), internal rate of return (IRR), and the modified internal rate of return (MIRR). For investment in the digester to be considered feasible, the NPV must be positive and the IRR must be greater than the minimum acceptable rate of return, normally the discount rate (Kay and Edwards, 1999). The MIRR corrects for the fact that IRR calculations assume that any potential revenue can be reinvested and earn returns equal to the IRR; thus IRR has the potential to make overly optimistic assumptions about the reinvestment of interim cash flows generated by the project.

For this economic analysis, the digester is assumed to be an independent enterprise from the dairy, so that the results of this major investment could be examined independently (US-EPA, 2007). The revenue and operating cost expectations for the "base digester" scenario are presented in Table 4.2. The first two years of net income reflect historical operations data for the digester.

Several categories of expected real operating costs were based on the average of the first two years of operation. Two exceptions were that we assumed lower building and equipment repairs because some of the costs in the first two years were related to needed modifications that were not anticipated during construction. Also, as the farm gained experience using residual heat from the digester, utility expenses dropped markedly and were expected to stabilize at a lower level than either of the first two years of operation. Ongoing legal fees were expected to follow the second year's experience and a variety of miscellaneous expenses also associated with startup were not expected to continue. Expected maintenance costs were extrapolated from a twelve-year maintenance schedule provided by the construction company. As noted in a footnote to the table, they were greater in some years than in others. For example, regular engine overhauls were expected every two years and major engine overhauls were expected every four years. These irregular costs were included in the economic calculations. The real cost saving incurred by using digested fiber as bedding was assumed to increase 5% per year in years 4–7. This expectation was driven by the fact that a large mill in the area had recently installed a cogeneration unit fueled by wood waste, reducing the local supply of sawdust bedding.

Table 4.2: Base Digester Revenue and Operating Costs

Source	Year 1 (\$)	Year 2 (\$)	Typical (\$/yr)
<i>Revenue</i>			
Electricity Sales	97,088	90,617 <sup>a</sup>	97,088
Tax Credit	38,835	36,247 <sup>a</sup>	38,835
Avoided Bedding Cost	18,000	18,000	18,000 <sup>b</sup>
Tipping Fees	82,169	121,564	111,767
High Value Fiber	10,265	2,372	6,319
Carbon Credit	4,932	16,425	14,527
Other Income	4,306	2,331	0
<b>Total Revenue</b>	<b>255,595</b>	<b>296,615</b>	<b>286,536</b>
<i>Operating Costs</i>			
Manure Delivery	47,539	18,016	32,778
Building Repairs	7,088	16,058	3,500
Engine Repairs	11,569	25,808	11,569 <sup>c</sup>
Equipment Repairs	27,199	49,668	29,000
Oil	24,187	25,795	24,991
Utilities	30,139	16,949	6,000
Legal Fees	9,645	751	751
Other Professional Service	11,212	4,810	8,011
Miscellaneous	11,898	224	4,297
<b>Total Operating Expenses</b>	<b>180,475</b>	<b>158,078</b>	<b>120,894</b>
<b>Income Above Operating Expenses</b>	<b>75,119</b>	<b>138,537</b>	<b>165,641</b>

<sup>a</sup> Herd size dropped from 500 in the first year to 416 in the second year. In each scenario, herd size was held constant at 500 (or in one scenario, 1,300) in all years. Electricity sales and tax credit were adjusted to a 500-cow herd when calculating total revenue for year two.

<sup>b</sup> Avoided real bedding costs are expected to increase 5% per year in years 4-7.

<sup>c</sup> Expected engine real repair costs are \$34,517 every fourth year and \$25,808 in years 6, 10, 14, etc.

Real revenue expectations and pertinent technical coefficients for the “base digester” are presented in Table 4.3. Most were based on the first two years of experience, but there are exceptions. Expected electricity volume and value-added fiber sales volume were based on the first year because the modeled herd was based on that year’s 500-cow herd. Expected substrate volume and corresponding tipping fees included inedible eggs that were only received beginning in the second year. Carbon credit volume was based on the second year because the digester owners fully engaged in that market only in the second year. The costs and revenues used for the analysis began after the four-month startup phase ended. Income exceeded operating costs during the start-up phase by \$3,588, and this amount was discounted and credited to the initial cost. The “base digester” scenario had actual investment costs of \$1,136,364. Grants covered 38% of the total investment cost. The physical depreciation period was conservatively estimated to be twenty years for the digester (pit, digester, and gas mixer) and seven years for the co-generator. The milking herd in 2006 consisted of 500 cows. Manure was trucked in from

another 250-cow milking herd. Based on 2006–2007 substrates from salmon carcass and cheese whey and 2007 food waste from inedible eggs, real tipping fees were expected to add \$111,767 in annual receipts. Electricity was sold for \$0.05/kWh, including green tag sales. A tax credit of \$0.02/kWh was received and was expected to continue over the life of the digester. The value of carbon credits was computed at prevailing early 2008 CCX rates of \$3.98/carbon credit with a 50% commission charge. Nearly 85% of the extracted fiber was used as pathogen-free bedding, and 468 tons were sold as value-added fiber soil amendment.

Table 4.3: Real Revenue Expectations for the Base Digester

Revenue Source	Unit	Year 3	Based On
Electricity Production	kWh	1,941,760	Year 1
Electricity Value	\$/kWh	0.035	Average
Green Tag Sales	\$/kWh	0.015	Average
Tax Credit	\$/kWh	0.02	Average
Trucked in Manure	Cow	250	Average
Hauling Cost	\$/cow	131	Average
Substrate Volume			
Salmon Carcasses	Truckload	893	Average
Cheese Whey	Truckload	500	Average
Inedible Eggs	Truckload	300	Year 2
Tipping Fee Charged			
Salmon Carcasses	Truckload	66	Average
Cheese Whey	Truckload	66	Average
Inedible Eggs	Truckload	66	Year 2
Fiber Sales Volume	Cubic Yard	468	Year 1
Fiber Sales Price	\$/cubic yard	13.50	Average
Carbon Credit Volume	Credit	7,300	Year 2
Carbon Credit Price	\$/credit	3.98	2008
Herd Size	Cow	500	Year 1
Total Cows	AU	1,013	Year 1

The real discount rate was set at 4.0% based on the opportunity cost of farm capital. While this figure was considerably higher than the real interest rate for capital borrowed to construct the digester, it was close to the average of the 4.3% rate of return to U.S. farm assets reported by Blank for the period 1960–2002 and the 3.4% rate of return to U.S. farm equity based on ARMS data (USDA, 2008) for the period 1996–2006. Two additional assumptions were applied to all scenarios. The first was that the potential investor is risk neutral, so the analysis did not make any adjustment for higher risk. The second was that manure management real net costs did not change over the planning period.

## Scenario Discussion

Sixteen scenarios were studied, beginning with a primary scenario involving only 500 cows and only electrical production, no co-product sales. Each subsequent scenario then added a new item of interest to the previous scenario, building on subsequent items like a pyramid. The seventh scenario was considered the “baseline scenario,” which reflected the practices of the actual test-bed CFF digester in Lynden. Subsequent scenarios analyzed the sensitivity of the baseline with respect to changes in the discount rate, depreciation, electricity generation revenues, herd size, fiber sales, and carbon credits. The NPV, IRR, and MIRR for the sixteen scenarios are reported in Table 4.4.

### *Electricity Sales from 500 Cows*

In Scenario 1, which provides a reference for direct comparison with previous studies, the full cost of the digester was borne by the owner, manure entered the digester from the 500-cow herd, electricity was produced and sold, and digested fiber provided a cost saving through its use as bedding only. No manure was received from other cows, no substrates were received, and no co-products were sold. Because the digester was used at far less than its capacity, the physical depreciation period was expected to be forty years for the digester and fourteen years for the co-generator. This scenario provided had a NPV of nearly -\$650,000 and an MIRR of 1.8%. Electricity sales, even with green tags and tax credits, were grossly inadequate to make this investment in an oversized digester economical. The results from this scenario are somewhat in line with the US EPA (2004) report, which noted that economic feasibility was dependent upon adequate digester sizing and electricity sale prices, both of which were more positive in their study (due to proper sizing and higher electrical prices than in PNW).

Table 4.4: NPV, IRR, and MIRR for Sixteen Scenarios (Bishop, 2009)

Scenario	NPV (\$)	IRR (%)	MIRR (%)
1. 500 cows, electricity @ \$0.05/kWh + \$0.02/kWh tax credit, fiber used for bedding, 4.0% real discount rate, forty-year depreciation	(644,556)	-	1.8
2. 1 with grants = 38% of digester cost	(202,073)	2.0	3.1
3. 2 with manure trucked in from 250 cows, thirty-year depreciation	(727,607)	-	-9.7
4. 3 with substrates, twenty-year depreciation	(404,597)	-3.3	-0.2
5. 4 with tipping fees for substrates	1,094,948	17.1	9.1
6. 5 with sale of excess fiber at \$13.50 per cubic yard	1,185,416	18.1	9.3
<b>7. Base Digester: 6 with credits @ 50% commission<sup>a</sup></b>	<b>1,375,371</b>	<b>20.0</b>	<b>9.9</b>
8. 7 with 3% discount rate	1,579,458	20.0	9.3
9. 7 with 5 % discount rate	1,196,597	20.0	10.4
10. 7 with thirty-year depreciation	1,970,747	20.5	8.8
11. 7 with no power generation	319,750	9.3	6.4
12. 7 with 1,300 cows, no substrates	1,270,566	19.3	9.6
13. 7 with sale of all fiber at \$13.50 per cubic yard	1,424,067	20.7	10.0
14. 7 with sale of all fiber at \$20 per cubic yard	1,623,366	22.7	10.5
15. 7 with 25% commission on carbon credits	1,470,349	20.9	10.1
16. 7 with credits at ECX price of \$20.48, 50% commission	2,164,889	27.4	11.6

<sup>a</sup> Revenues in excess of operating costs for the first ten years of the base digester are, respectively, \$75,119; 138,537; 165,641; 143,592; 167,487; 154,241; 169,520; 146,572; 169,520; 155,282. After year 6, net revenues stabilize on a four-year rotation.

### Grants

One of the purposes of public grant support for private investments is to help compensate for the learning costs of implementing new technologies. The digester in this analysis was the first such project completed in Washington, and it was considered likely that subsequent adopters would benefit from that experience through some reductions in costs. This assumption is supported by cost differences between digesters installed in the 1980s and digesters installed today. While the basic technology is similar, recently installed digesters provide cost savings and fewer technical deficiencies. In the case of the CFF test-bed digester, federal and state construction grants for this project were received shortly after construction was completed. In Scenario 2, the value of the grants received was subtracted from the digester's investment cost. Although still negative, this scenario added \$442,000 (the amount of the grants) to the NPV. For this scenario, the IRR was 2.0% and the MIRR was 3.1%.

### *Transported Manure*

As the primary feedstock for the digester, the amount of manure directly affects the amount of electricity produced. In addition to the digester owner's 500-cow herd, the digester received manure from 250 cows on a neighboring dairy approximately 1 mile away, which was subsequently returned after processing. This resulted in a large cost for transporting manure to and from the digester. Manure from the neighboring dairy was transported by the digester owner without payment or tipping fees for the manure. With the increased amount of manure, it was expected that the physical depreciation period would decrease to thirty years for the digester and 10.5 years for the co-generator. The cost to the digester owner of transporting the manure was much greater than the value of the additional electricity generated.

The estimated NPV for Scenario 3 was more than a half million dollars lower than for Scenario 2, and the MIRR was -9.7%. Even at extremely small transport distances (~1 mile), transport costs exceeded the gains in gas production and electrical sales. This is an important conclusion from the study. Many proposed projects throughout the nation are community digesters that are planning to transport liquids by truck and it is easy to see from this study that the transportation costs could have a large negative impact on the overall economics of such projects. Early data from a community digester project in Tillamook, Oregon, corroborate our results. Interestingly, in some cases, piping of the manure is a viable alternative. In the test-bed digester, manure is piped nearly a mile underground from the main farm to the digester, thus allowing for localized transport without the daily transportation costs and only the initial piping costs.

### *Substrates and Tipping Fees*

The digester received food wastes including salmon carcasses, cheese whey, and inedible eggs from several local food processors. Costs for transport to the digester were borne by the food processor, which in addition paid a tipping fee to the digester owner. Substrates accounted for only 16.03% of this digester total influent during the period monitored (2004-2005). However, because it has higher energy content than manure, approximately half of total digester gas production came from the substrates. Even without considering tipping fees, the value of the additional electricity generated by the substrates in Scenario 4 added nearly \$325,000 to the estimated NPV. However, the NPV, IRR, and MIRR remained negative. Tipping fees from substrates were the largest source of revenue to the digester. When they were included in the Scenario 5 calculations, estimated NPV grew by nearly \$1.5 million and resulted in the first scenario with a positive NPV, meaning that the rate of return on the investment is greater than the cost of the capital (i.e., the interest rate). The IRR was 17.1% and the MIRR was 9.1%.

One important caveat to these findings is that the cost of on-farm nutrient loading from substrates was not considered in the calculation of financial returns. Any farm importing substrates in excess of their nutrient capacity must either remove nutrients from the farm or acquire more land to receive the extra nutrients at the

correct agronomic rate. This analysis did not quantify the value of nutrients, either in terms of increased removal costs or in terms of marketable value. Marketable value exists if the effluent can be processed and sold as a fertilizer for agricultural operations with high nutrient demands. However, this value would be reduced by transportation costs that would depend on the distance to the areas where nutrients are marketed. The base scenario's NPV was large enough that some added transportation costs would not alter the viability of the investment, especially if the digester owner could earn revenue from selling liquid effluent. Additional analysis of this scenario compared to a manure-only baseline showed that annual revenues for the digester almost quadrupled under the co-digestion scenario with 72% of all co-digestion scenario receipts directly attributable to the addition of substrates (Frear et al., 2009). Clearly, substrate addition and, more specifically, tipping fees have a profound effect on digester economics.

### *Fiber Sales*

Scenario 6 assumed that 15% of the fiber was sold as a soil amendment after pretreatment by a patent-pending WSU process (MacConnell, 2006), instead of being used for bedding replacement. The WSU process requires very little capital or operating expenditures and as such no additional costs were calculated. Assumed revenues were based on early market analysis of the treated product, which estimated a potential market value of \$13.50 per cubic yard. Under Scenario 6 sales of the soil amendment added about \$90,000 to the estimated NPV, increased IRR by 1% and MIRR by 0.2%.

### *Carbon Credits and Base Digester*

Carbon credits provided the final source of revenue for the "base digester" scenario. Without access to the European Carbon Exchange (ECX), the digester used the Chicago Climate Exchange (CCX) market value for carbon credits. Even with a 50% commission, the sale of carbon credits in Scenario 7 added \$190,000 to expected NPV, 1.9% to IRR, and 0.6% to MIRR. Thus the base digester was expected to generate an NPV of nearly \$1.4 million with a 20% IRR and a 9.9% MIRR. The estimated NPV was large enough to suggest that even if costs exceeded expectations by nearly 75%, the digester remained profitable. The size of the IRR and MIRR for the base digester scenario suggests that the digester would be competitive with many nonfarm investments. The most important single contributor to the base digester's NPV was tipping fees, followed in turn by electricity, grants, and substrates. The carbon market and fiber sales also added to the NPV, but the negative economic impact of trucked-in manure more than offset the contribution of electricity generation. If additional manure can be transported in a pipeline, transportation costs could be minimized.

## Sensitivity Analysis of Particular Scenario Alternatives

A sensitivity analysis of the base digester scenario examined the impacts of alternative discount rates, depreciation period, power generation, herd size, fiber sales, and carbon trading conditions on NPV, IRR, and MIRR. These results are discussed below.

### *Discount Rate*

The real discount rate used for the NPV calculations was 4.0%, which is similar to historical rates of return on farm equity. It is higher than the actual real interest on the digester's loan. The sensitivity of the NPV to discount rate was analyzed with two alternative scenarios, one with a lower (3.0%) and another with a higher (5.0%) real discount rate. The lower discount rate used in Scenario 8 increased the NPV by more than \$200,000 but decreased the MIRR by 0.6% because the rate of return on reinvestments was lower. The higher discount rate used in Scenario 9 reduced the NPV by nearly \$180,000 and increased the MIRR by 0.5%.

### *Physical Depreciation Period*

The life of the base digester was estimated to be twenty years (US-EPA, 2007). The digester is a concrete structure and physically should last well beyond twenty years. Sensitivity to this conservative assumption was tested with a thirty-year physical depreciation period assumption in Scenario 10. While the NPV increased by nearly \$600,000, the IRR increased by only 0.5% and the MIRR decreased by 1.1%.

### *Power Generation*

Since the base digester includes several co-products, Scenario 11 excludes electrical generation for comparative purposes. Biogas produced in the digester is piped into a reciprocating engine, retrofitted for natural gas combustion. The maximum generator capacity is rated at 285 kWh. Since the investment in generation equipment would not be needed, it is also excluded. While the investment remains feasible, the NPV drops by more than \$1 million, the IRR by 10.7%, and the MIRR by 3.5%.

### *Herd Size*

To determine the effects of operating the digester at near capacity with manure produced on the farm, Scenario 12 represented a 1,300-cow herd. With a maximum capacity of 1,500 cows, a reasonable operational upper limit is 1,300 cows, assuming accurate sizing of engine/generator sets to handle the inflow of manure/substrates. This operational limit allows the digester to accommodate fluctuations in influent flows from management practices and weather. The larger amount of manure in this scenario increased the production of electricity, carbon credits, and fiber proportional to the increase in manure. The additional cattle provided enough gas to run the generator at nearly 100% capacity, but it was insufficient to compensate fully for lost electricity generation and tipping fees from

substrates. This scenario decreased NPV by more than \$100,000, IRR by 0.7%, and MIRR by 0.3% relative to the base digester. This result is in line with the earlier U.S. EPA (2004) study that showed positive net income for a manure only digester given appropriate electrical sales pricing and proper digester sizing. In addition, it helps explain the increased adoption rate for digesters over the last few years, as even without co-digestion, data shows strong economic potential for dairy manure digester projects given certain thresholds. Finally, it suggests that digesters installed with excess capacity can more than make up for the smaller amount of manure if they can add substrates.

### *Potential Fiber Markets*

In addition to use as bedding, digested fiber could be sold to firms that use fiber in value-added markets such as potting amendments. In the base digester scenario, most of the fiber was used as a bedding substitute on the dairy, and a small portion (15%) was sold for soil amendments. As bedding is the lower-value alternative, sales of the separated fiber are preferred. Early tests by WSU suggest it can substitute for peat moss, but this market for the fiber is new and underdeveloped. It will take empirical evidence of a reliable supply and consistent quality, as well as marketing and industry education, for the price of digested fiber to reach a level comparable to peat moss.

Without established markets, fiber sales by the dairy running the test-bed digester were unpredictable. Fiber from the digester was sold for \$13.50 per cubic yard, but sales varied. Scenario 13 considered the possibility that all of the digested fiber, not just 15%, could be sold at \$13.50 per cubic yard. This scenario increased estimated NPV by nearly \$50,000, IRR by 0.7%, and MIRR by 0.1%. Scenario 14 anticipated development of a potting medium market for the fiber, allowing for all the fiber to be sold at a modestly higher price of \$20/yd<sup>3</sup>. This increased NPV by nearly \$250,000, IRR by 2.7%, and MIRR by 0.6% relative to the base digester. This higher price is still considerably lower than the price of imported peat moss. However, marketing the fiber as a peat substitute will require a concerted technological and marketing effort to develop a reliable, high-quality product.

### *Carbon Credit Trading*

The first carbon credit option, Scenario 15, considered the impact of cutting the carbon trading brokerage fees for trading on the CCX from 50% of the traded value to 25%. This decrease in trading commission is comparable to changes that occurred in sulfur dioxide trading commissions in the early 1990's (Joskow et al., 1998). Reduced trading commissions increased the NPV by \$95,000, IRR by 0.9% and MIRR by 0.2%.

The final possibility, Scenario 16, considered how the digester owner would benefit by having access to the European carbon markets (ECX). The difference between the NPV value of the base digester scenario and the ECX trading scenario was substantial because the ECX price was so much higher than the CCX price. NPV gains

approached \$800,000, IRR increased by 7.4%, and MIRR increased by 1.7%. These are the largest increases in financial measures of any individual option examined in the sensitivity analysis.

While the future of voluntary U.S. carbon markets is uncertain, several state and local governments are taking action in lieu of the federal government's failure to act (Bang et al., 2007). State actions to cap carbon emissions should increase the carbon trading market. Yet, without a homogenous federal policy imposing emissions caps, it is uncertain how stable the emerging market will be and whether prices will reach ECX levels.

### **Conclusions and Inferences for Decision Making**

- Proper sizing of a digester is vitally important, as over-sizing beyond reasonable engineering precautions can induce artificially high capital costs compared to revenue, particularly if the digester is digesting only manure. Sizing becomes less of an issue with co-digestion.
- Community digesters relying on the transport of liquid manure by truck will be severely hampered in their economic viability as even at minimal transport distances studied in this project, fuel, labor, and equipment costs overwhelmed any additional revenues from the increased electrical sales. Piping manure might be an option for neighboring dairies.
- The alternative power generation scenario documented the importance of electricity as a source of revenue. Although the base digester would be economically feasible without generating power, electricity prices are important and warrant attention both by those considering investment in digester technology and by policy makers. Because of the way public utilities are regulated, additional legislation may be required to align the goals of utilities with those of small generators of green electricity.
- The only scenarios that made the investment infeasible were those in which no substrates were received or in which no tipping fees were received for the substrates.
- One implication of the strong role of co-digestion and tipping fees is that geographic placement of the digester can be important in order to take full advantage of potential co-product markets. A comparison of the scenarios that consider power generation and tipping fee receipts reveals that, while important, the emphasis on electrical generation may even be a secondary concern to establishing relationships with food processors. It is important to note that demand for organic-rich waste solids could grow in the future as alternative energy markets develop, diminishing tipping fees and greatly impacting assumed economics of the project. These conditions are beginning to exist in certain areas of Europe that are intensively using anaerobic digesters and co-digestion.
- Co-digestion of food wastes diverts nutrients and energy currently dumped in landfills, creating additional environmental benefits. Our economic analysis considered only private costs of co-digestion, but the social value of

- avoided landfill use may be higher than the private cost. In addition, there is a potential for added carbon credits for diverting substrates from a landfill.
- Because of their high nutrient content, substrates have the potential to exacerbate existing nutrient management problems for dairies, but nutrient extraction technologies currently in development through CFF may address these concerns. If these products are fully developed, digestion could redistribute nutrients in a manner that is optimal for the dairy farm, crop farms, and society in general. This could prove to be a critical link in assuring economic feasibility of digesters and sustainable waste management practices. Neither the potential on-farm value of beneficial nutrients nor the costs of disposing of excess nutrients were explicitly assessed in our analysis because these costs are farm specific.
  - Development of other co-product markets could greatly improve the economic feasibility of digesters for a large audience of potential owners. Revenues from carbon credits, revenues from fiber sales, and/or cost savings from on-farm use of digested fiber can provide important supplemental income to digester owners. Each can be enhanced by public policy to promote investment in digestion technology as a holistic approach to renewable energy and sustainable food production.
  - Several promising future developments could improve digester economics significantly. For example, GHG emissions reduction policies could result in carbon credit prices approaching those of the European carbon market. Investment in research and development could enhance the quality and value of the digested fiber product for organic uses. And as world energy markets fluctuate, there may be increased interest in scrubbing the gas for sale to gas companies or for use as a transportation fuel. However, there is also reason to be cautious about these future projections. Renewable energy issues were hyped in the 1970s and 1980s but then retreated from the public consciousness for more than a decade. While a decline of interest in alternative fuels would not be advisable, the economics of digester operations and adoption under harsh market conditions should be considered. Too much emphasis on “best case” scenarios could prove economically disastrous for adopters of digestion technology.

### Key Project References Related to Chapter

The majority of the work presented in this chapter has been previously published as:

- Bishop, C. and Shumway, C.R., 2009. The economics of dairy anaerobic digestion with co-product marketing *Review of Agricultural Economics*, 31(3) 394-410.
- Frear, C., Liao, W., Ewing, T., Chen, S., 2009. Evaluation of co-digestion at a commercial dairy anaerobic digester *Bioresource Technology*, Submitted.

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