ESTIMATING FARM SIZE REQUIRED TO ECONOMICALLY JUSTIFY ANAEROBIC DIGESTION ON SMALL DAIRY FARMS

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INTRODUCTION

The benefits of anaerobic digestion (AD) of dairy manure vary from economic (reduced power costs/income from excess electricity/heat), to environmental (reduced greenhouse gas emissions, better control over field application of digestate) to social (through reduced odor during storage and application). However to realize these benefits economically, is the true challenge of AD, and a part of the reason for the slow adoption rate in the US, particularly when compared to European countries such as Germany and Denmark. According to the EPA there are currently approximately 131 dairy farm based anaerobic digesters with cogeneration operating in the United States (AgSTAR, 2012). In Germany alone there are more than 3,000 on-farm biogas plants. In the US, the average herd size is 150 lactating cows, whereas in Germany it is 50. Clearly there must be a reason for why anaerobic digestion has not flourished in the US as it has in Europe.

Anaerobic digestion of dairy manure continues the digestion process started in the cow and produces biogas. This biogas can be used to fuel a boiler to produce heat, fuel an engine-generator set to produce electricity and heat, scrubbed and used as a natural gas replacement, or even just flared off. Depending on the size of the system the engine-generator may represent one-third to one-half the capital cost. Estimates of capital costs for various systems can vary greatly depending on the type of system selected and the size of herd it is designed for. AgSTAR estimates of capital costs on a per cow basis for larger farms indicate costs at the 500-cow level of approximately $1,500 per cow for plug flow systems and $1,100 per cow for complete mix systems (AgSTAR 2012). However, analyzing existing small farm data (farms 100 to 250 cows) prices can vary from $1,000 up to $2,800 per cow. With such a significant capital investment, it is key that the revenue and benefits of the digester are capable of at least paying down capital costs.

Revenue is a major difference between the United States and Europe. Feed in tariff pricing is a common tool used worldwide to encourage renewable energy production. Under this strategy long-term contracts guaranteeing a premium price for renewable power are signed with a producer. Rates vary greatly from jurisdiction to jurisdiction and depend on the priority put on a particular form of power generation. Feed in tariff programs in Ontario, Canada are $0.195 per kWh for farm biogas-based energy for projects under 100 kW and $0.185 for projects over 100 kW, whereas solar power sources can get up to $0.802 per kWh under certain circumstances (Ontario Power Authority, 2012). Currently the feed in tariff rate for electricity produced from biogas is 0.215 Euro ($0.31 USD) per kWh in Germany.

In the Northeastern United states, Vermont provides a feed-in-tariff for AD based energy of $0.16 per kWh. Many states don't have a feed in tariff, though they may encourage AD based energy through net metering laws. Under net metering laws surplus energy is put onto the grid, and can be withdrawn at times when production may not meet demand. Typically however, any surplus energy at the end of the year is only paid out to the farmer at wholesale rates, which may be as low as $0.05 per kWh.

Another contributor to the revenue of European digesters are the carbon credits associated with the destruction of methane. When manure is spread on a field with plenty of aeration it decomposes aerobically and little methane is produced. However in manure storages such as pits or lagoons, the conditions are often anaerobic under which methane can be formed. According to the US EPA, (2006) methane is 21 times more potent that CO_2 as a greenhouse gas, and so manure storage systems can represent a large source of greenhouse gases. Carbon credits are monies paid to a project for their reduction in CO_2 emissions from pre project levels. Through this trading, industries that emit too much CO_2, or it is too expensive for them to meet emissions reductions, can "reduce" their emissions through offsets trading. The company that needs to reduce emissions can pay a different company to reduce their CO_2 footprint through implementing emissions reducing strategies. For farms with existing manure storage systems capturing this methane either through a cover or AD system, and then destruction of the methane either through flaring or burning in an engine generator set or boiler, reduces the methane emissions relative to not having a system and it is this difference (pre project emissions minus post project emissions) that can then be sold.

On the European Carbon Credit market these reductions have relatively recently been worth 16.5 euro ($24) per metric ton (though currently the carbon market has dropped substantially due to the economic difficulties in Greece and an influx of approved offset projects (Carbon Capitalist, 2012). Anaerobic digestion systems can lead to a carbon credit offset amount of approximately 2.5 metric tons of CO_2 per cow per year, or $60 per year per cow at the $24 per metric ton carbon credit pricing. Carbon markets in the US are still uncertain with the Chicago Climate Change (CCX) reaching a peak of $7.50 per metric ton in 2008, and ceasing operations in 2010 with a value of only $0.05 to $0.10 per metric ton. California is implementing a new cap and trade market exchange to reach its greenhouse gas emission targets that could help projects throughout the country.

To further maximize biogas production, many digesters in Europe and the US co-digest additional materials; from food processing and other organic waste, to crops grown specifically for use in the digester. Co-digestion represents an excellent opportunity to help the bottom line of digesters if in addition to increased biogas yield, a “tipping fee” comparable to what a waste stream producer would pay at a landfill, is paid to the digester.

Tipping fees can vary greatly depending on the availability of digestible material. Increased transportation costs of material will result in a lower realized fee. Another complication is ensuring long-term availability of the material. The difficulty in signing long-term supply contracts for co-digestion materials makes planning for their use difficult. The increased value of biogas in Europe encourages diverting organic waste streams to digesters.

The definition of small farm varies greatly depending on the region of the country considered. The average herd size of 120 dairy cows, is certainly very small when compared to the sizes of farms that presently have operating AD systems. Due to economies of scale it has generally been easier for larger operations to justify AD systems. The circumstances of each farm will can vary greatly, affecting the feasibility of constructing an AD system. Location can also affect the costs associated with hooking into the grid for energy sales, and proximity to organic wastes for co-digestion. Beyond economics there are other hurdles to small dairy AD, such as:

- The time required to operate and maintain the additional systems
- The barn style (tie-stall and stanchion may not be suitable for manure collection)
- The availability of smaller scale equipment (mixers, engine generators) biogas cleanup
- permitting and local regulation compliance
- air quality standards

The goal of this paper is to present a cost-benefit analysis of the effects of benefits pricing on small farm AD coupled with power generation. A firm understanding of the costs and potential benefits of AD systems is key to making informed decisions on individual projects, and on a larger scale, the policies that regulate and encourage them. In order to achieve the goal of this paper, the following objectives were developed and implemented.

Objectives:

1. To develop a model to estimate the surplus electricity, carbon credit and co-digestion incomes possible based on farm size (number of dairy cows.)
2. To use the model to estimate farm size necessary to break even under varying capital cost and benefit pricing scenarios.

THE MODEL

The starting point of the model is the number of lactating cows. From this population a default herd size for animals contributing to manure production was estimated based on common ratios of dry cows and heifers to lactating cows found on typical farms (17 dry cows for every 100 lactating cows and 80 heifers for every 100 lactating cows). From the herd size and make-up, the volume of manure produced and the volatile solids loading was estimated using standard values (ASAE. 2005). Herd population also serves as one of the inputs to estimating the carbon credits available to the farm following digester installation. The volatile solids loading rate serves as the basis for predicting co-digestion capacity, biogas production, and electricity production.

Co-digestion

For the purposes of the model the capacity of the system to accept additional organic materials to co-digest, was based on the volatile solids loading rate of the manure. Small farm digesters are ideally as low maintenance as possible which makes high co-digestion rates difficult. Co-digestion can require considerable effort into monitoring both the flow of materials into the digester and the health of the digester itself; a task that may be onerous for a small farm with a limited workforce. For this reason the volatile solids loading rate as a percentage of the volatile solids of the manure was limited to 25% (i.e. one quarter of the volatile solids can be from co-digested material).

The material used as an example was cheese whey, but the model could be easily adapted to incorporate other materials. Based on the fraction of volatile solids for co-digestion a volume or mass of co-digestion material was estimated based on the density and volatile solids content of the particular material.

Electrical generation and consumption

The biogas production of the digester was estimated based on the volatile solids loading rate from the manure and any co-digested materials. The volatile solids loading rate used to estimate biogas production assuming standard values for digestibility (Jewell, 2005).

Electricity generation was modeled by taking the estimated biogas production and assuming it was used in an engine-generator set, with a capacity factor of 0.95. Conversion efficiencies for a range of generator set sizes (20 to 250 kW) were averaged and used to estimate and develop a ratio of biogas consumed to power produced. This ratio was used to give an estimate of the required size of engine-generator set required as well as the yearly power generation.

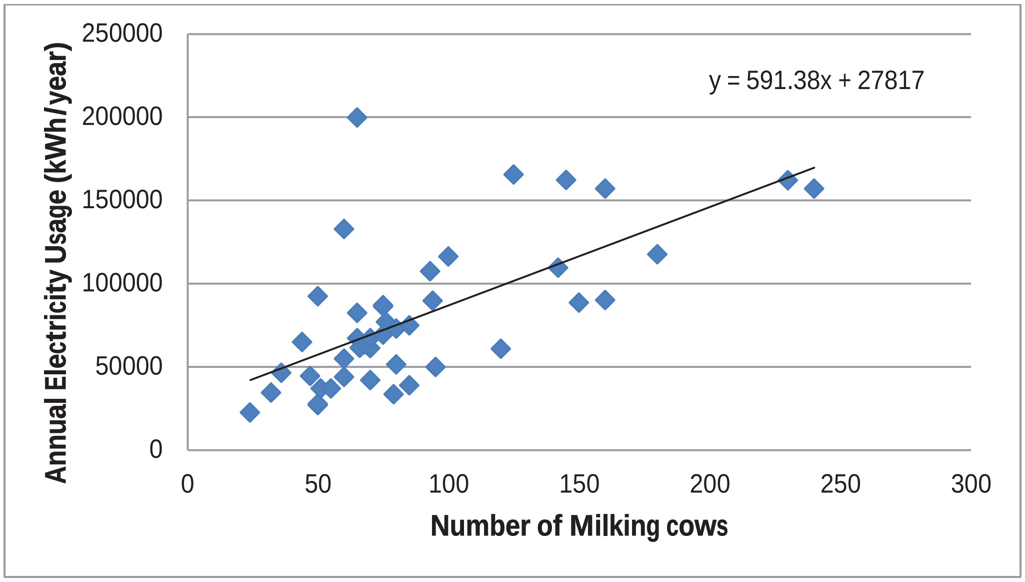
To estimate the surplus electricity generated as a function of farm size, energy audit data from 45 small farms (ranging in size from 24 to 240 cows), was analyzed (Petersen, 2011). This dataset contained yearly energy use and herd information necessary to develop a relation (Figure 1) between farm size and energy usage on a small farm scale. In addition, 10% of the output of the generator was assumed to contribute to operating the digester itself (parasitic load).

A net metering situation was assumed such that power available for the grid was the total power generated, minus that required for on farm (and digester) use, on an annual basis. The benefit of electricity generation was then assumed to be the avoided cost of power purchasing plus the sale of any surplus power.

Carbon credits

The amount of carbon credits available was estimated using the Excel workbook developed by the Climate Action Reserve (2008). The data required for the workbook used assumed values for NY, for farms with existing manure storage and the same assumed herd information used to estimate biogas production. Default values for lactating, heifer and dry cows were taken from the provided table information, along with the performance of the biogas containment system. The results of this worksheet provided the yearly avoided CO_2e in metric tons.

Figure 1: Annual Electricity Usage as a function of Dairy Cow number



MODEL VARIABLES

The purpose of the model is to investigate what effects incentives such as feed in tariff rates, carbon credits, and tipping fees could have on the financial viability of a digester system. By varying these benefit prices in a number of scenarios it is possible to see how important they are relative to one another. By including capital and maintenance costs in a cost benefit analysis it is then possible to examine under what scenarios digesters with accompanying power generation could be viable.

Varying Energy Price

The range of electricity price analyzed in the model goes from the basic wholesale price of $0.05 per kWh, to the feed in tariff rates seen in Europe at $0.31 per kWh. An intermediate value of $0.16 as available in Vermont is also analyzed. A further important consideration is the purchase price of electricity. Avoided purchased power is an important benefit in engine generator economics. To simplify the analysis for this paper an avoided purchase price of $0.10 per kWh was used for all scenarios.

Varying Carbon Credit Price

Carbon prices have been in turmoil lately, however this uncertainty could change once the economic crisis resolves and/or the new Californian initiative begins. For this paper, carbon credit pricing of $0 (no carbon credit value) to $20 with an intermediate value of $10 per metric ton CO_2e were investigated.

Varying Tipping Fee

For this paper, cheese whey was assumed to have a value of $0.05 or $0.10 per gallon which represents a typical price currently received, and a higher than average price. Additional scenarios assumed no tipping fee for the co-digestate to evaluate the effect of increased biogas alone on the economics. Two levels of co-digestion were considered for this paper; a lower level where 10% of the volatile solids are from co-digestion and a higher level where the 25% are from co-digestion (the condition of no co-digestion was also examined).

Varying Capital Costs

The capital cost of digester systems is generally cited as a major roadblock to their adoption on farms both large and particularly small (Gloy and Dressler, 2010). Economies of scale favor larger projects both through reduced per cow expenses and the ability to devote specialized labor to operation and maintenance.

To examine the cost of capital costs on small farm digester feasibility two levels of capital cost were investigated for this paper. Capital costs were expressed on a per cow basis and were assumed to include both the construction of the digester and purchase/installation of the engine generator. Many analyses consider the benefits of using separated solids for bedding; however this option was left out of the analysis for this paper as solids separated from raw manure can also be used for bedding. For the analysis it was assumed that the installed cost of the generator set was $1,000 per kW which is an approximate rule of thumb (Weeks, 2012.) The balance of the capital cost was assumed to consist of the digester and other expenses associated with the project and to have a lifespan of 20 years. The engine generator set costs were depreciated over a 7-year lifespan. Lost opportunity cost was assumed to be 8%.

The per cow capital costs examined for this paper were $1,500, and $3,000 per cow. $1,500 per cow represents a low cost for a small farm digester with an engine-generator set and would most likely require some subsidization. A higher value is $3,000 per cow for small farm systems with an engine-generator set and mixing. These system cost levels were based on reviewing the project costs of the limited number of small farm digesters both with and without cogeneration of power, and were selected to span the likely average capital cost of a small farm AD project.

Maintenance Costs

Maintenance costs were estimated based both on the quantity of power generated, as well as a fixed percentage of the initial capital cost. For the purposes of this analysis it was assumed that no gas cleanup equipment was installed to reduce the concentration of H_2S in the biogas. High concentrations of H_2S shorten the lifespan of biogas equipment and as such the maintenance costs are higher. Maintenance costs have been estimated to be in the range of $0.015 to 0.020 per kWh generated (Martin 2009). Assuming no gas cleanup, $0.02 per kWh was used.

General maintenance on the digester pumps/mixers and other equipment was estimated as 5% of the initial capital cost.

RESULTS

This analysis was focused on small farms and determining what level of benefit pricing would allow them to cover the substantial capital cost investment. To answer this question a total annual cost/benefit economic analysis was performed. The sum of the annual cost savings and revenue were subtracted from the total costs to own and operate the system expressed on an annual basis. A positive value means that the system is a net economic liability to own and operate while a negative value means that the system probably is an economic benefit, but further analysis would be needed to determine its true economic benefit to the farm.

Thirty milking cows was selected as the lower limit to this analysis. The manure from a herd of this size could potentially power a 10 kW engine generator set with co-digestion. A generator set of this size designed to run on biogas may not be currently available (such systems typically start at 20kW) however, some smaller farms have utilized modified internal combustion engines to run on the biogas they produce. The upper limit for this analysis was set at 250 milking cows.

The various scenarios of benefit pricing values and initial capital cost level were input into the model, and the number of cows necessary to offset the costs from the benefits was solved for (Tables 1 and 2.) A negative value (shown in parenthesis) indicates the system is likely an economic benefit to the farm. All values are expressed on a per cow basis.

In many cases there was no solution in which the combination of benefit pricing would offset the capital and maintenance costs (this was the case in most of the scenarios with a capital cost of $3,000 per cow) and so only the scenarios with a neutral or net benefit are shown in the tables. Similarly under some scenarios even the lower limit farm size of 30 milking cows was capable of offsetting the costs.

At a per cow capital cost of $3,000 it is clear that all three benefit strategies play an important part of offsetting the capital costs. Under no scenario at this capital level was a surplus power sale price of $0.05 per kWh feasible. Only at a level of $0.16 or $0.31per kWh did any scenario break even. Further, only scenarios that also featured a tipping fee and/or some level of Carbon Credit valuation showed a neutral or net benefit. The best options at this capital level are high usage of co-digestion (25% of the VS from co-digestables) coupled with a tipping fee. Including a carbon credit valuation dramatically reduced the size of farm necessary to break even.

Table 1. Annual cost/benefit analysis of benefit pricing scenarios resulting in a net benefit with an initial capital cost of $1,500 per cow.

		Yearly per Cow Expenses		Yearly per Cow Benefits				
				Electricity				
Scenario	Cow #	Capital	Maint	Avoided cost	Sold	CC	TF	Total Annual Cost/ Benefit
$0.31/kWh, no CC, no CD	254	$122	$14	$77	$60	$0	$0	($0)
$0.31/kWh, $10 CC, no CD	91	$122	$14	$87	$29	$21	$0	($0)
$0.31/kWh, $20 CC, no CD	53	$122	$14	$96	($1)	$42	$0	($0)
$0.05/kWh, no CC, 10% VS $0.05 TF	30	$123	$16	$106	($12)	$0	$44	($0)
$0.16/kWh, no CC, 10% VS $0.05 TF	30	$123	$16	$106	($12)	$0	$44	($0)
$0.31/kWh, no CC, 10% VS $0.05 TF	30	$123	$16	$106	($12)	$0	$44	($0)
$0.05/kWh, $10 CC, 10% VS $0.05 TF	30	$123	$16	$106	($12)	$21	$44	($19)
$0.16/kWh, $10 CC, 10% VS $0.05 TF	30	$123	$16	$106	($12)	$21	$44	($19)
$0.31/kWh, $10 CC, 10% VS $0.05 TF	30	$123	$16	$106	($12)	$21	$44	($19)
$0.05/kWh, $20 CC, 10% VS $0.05 TF	30	$123	$16	$106	($12)	$42	$44	($40)
$0.16/kWh, $20 CC, 10% VS $0.05 TF	30	$123	$16	$106	($12)	$42	$44	($40)
$0.31/kWh, $20 CC, 10% VS $0.05 TF	30	$123	$16	$106	($12)	$42	$44	($40)
$0.05/kWh, no CC, 25% VS $0.05 TF	30	$125	$18	$118	$1	$0	$110	($86)
$0.16/kWh, no CC, 25% VS $0.05 TF	30	$125	$18	$118	$3	$0	$110	($88)
$0.31/kWh, no CC, 25% VS $0.05 TF	30	$125	$18	$118	$6	$0	$110	($92)
$0.05/kWh, $10 CC, 25% VS $0.05 TF	30	$125	$18	$118	$1	$21	$110	($107)
$0.16/kWh, $10 CC, 25% VS $0.05 TF	30	$125	$18	$118	$3	$21	$110	($110)
$0.31/kWh, $10 CC, 25% VS $0.05 TF	30	$125	$18	$118	$6	$21	$110	($113)
$0.05/kWh, $20 CC, 25% VS $0.05 TF	30	$125	$18	$118	$1	$42	$110	($129)
$0.16/kWh, $20 CC, 25% VS $0.05 TF	30	$125	$18	$118	$3	$42	$110	($131)
$0.31/kWh, $20 CC, 25% VS $0.05 TF	30	$125	$18	$118	$6	$42	$110	($134)
$0.31/kWh, no CC, 10% VS no TF	76	$123	$16	$90	$50	$0	$0	($0)
$0.16/kWh, $10 CC, 10% VS no TF	100	$123	$16	$85	$33	$21	$0	($0)
$0.31/kWh, $10 CC, 10% VS no TF	49	$123	$16	$100	$18	$21	$0	($0)
$0.16/kWh, $20 CC, 10% VS no TF	32	$123	$16	$105	($9)	$42	$0	($0)
$0.31/kWh, $20 CC, 10% VS no TF	32	$123	$16	$105	($9)	$42	$0	($0)
$0.16/kWh, no CC, 25% VS no TF	129	$125	$18	$82	$61	$0	$0	($0)
$0.31/kWh, no CC, 25% VS no TF	37	$125	$18	$110	$33	$0	$0	($0)
$0.16/kWh, $10 CC, 25% VS no TF	31	$125	$18	$116	$6	$21	$0	($0)
$0.31/kWh, $10 CC, 25% VS no TF	30	$125	$18	$118	$6	$21	$0	($3)
$0.05/kWh, $20 CC, 25% VS no TF	30	$125	$18	$118	$1	$42	$0	($19)
$0.16/kWh, $20 CC, 25% VS no TF	30	$125	$18	$118	$3	$42	$0	($21)
$0.31/kWh, $20 CC, 25% VS no TF	30	$125	$18	$118	$6	$42	$0	($24)

*** CC = Carbon Credit, TF = Tipping Fee**

Table 2. Annual Cost/Benefit analysis of Benefit Pricing Scenarios Resulting in a Net Benefit with an Initial Capital Cost of $3,000 per cow.

		Yearly per Cow Expenses		Yearly per Cow Benefits				
				Electricity				
Scenario	Cow #	Capital	Maint	Avoided cost	Sold	CC	TF	Total Annual Cost/ Benefit
$0.31/kWh, $20 CC, 10% VS $0.05 TF	235	$236	$16	$77	$88	$42	$44	($0)
$0.16/kWh, no CC, 25% VS $0.05 TF	221	$237	$18	$78	$68	$0	$110	($0)
$0.31/kWh, no CC, 25% VS $0.05 TF	39	$237	$18	$107	$40	$0	$110	($2)
$0.16/kWh, $10 CC, 25% VS $0.05 TF	34	$237	$18	$112	$13	$21	$110	($0)
$0.31/kWh, $10 CC, 25% VS $0.05 TF	30	$237	$18	$118	$6	$21	$110	($0)
$0.16/kWh, $20 CC, 25% VS $0.05 TF	30	$237	$18	$118	$3	$42	$110	($18)
$0.31/kWh, $20 CC, 25% VS $0.05 TF	30	$237	$18	$118	$6	$42	$110	($21)
$0.31/kWh, $20 CC, 25% VS no TF	254	$237	$18	$77	$134	$42	$0	$2

*** CC = Carbon Credit, TF = Tipping Fee**

The situation is quite different when the capital cost per cow is $1,500. Many more scenarios are break even. Under this cost regime every scenario that featured $0.31/kWh power broke even. Low (and high) power sale price scenarios with other benefits often broke even at the lowest farm size, but this is due to the fact that at this farm size there is no surplus power to sell (the farm has to purchase additional power) and so the sale price does not come into play. This illustrates the point that selling to the grid is often not enough to justify a digester and some other means of taking advantage of the surplus energy needs to be employed.

Another clear result from this analysis is the importance of capital cost. The cost of carrying a large initial capital investment is a significant challenge, particularly with a small farm system. To examine the effect of how the initial capital cost affects the net benefit of the systems, the intial capital cost was varied from $500 to $3,000 per cow with optimistically achievable values for Feed in Tariffs, Carbon Credit pricing, and Tipping fees (Table 3) as well as the scenario of no feed in tariffs, or carbon credit market, with surplus power sold at the price it would be purchased for ($0.1 per kWh), and moderate co-digestion (%10 VS from cheese whey) with a tipping fee of $0.05 per gallon (Table 4).

The results shown in Tables 3 and 4 indicate that keeping capital costs below $1,500 is key to achieving a net benefit as at this level even the smallest farms almost showed a net benefit (net cost of $2 per cow per year) with very attainable tipping fee prices. The results also show that the benefit of tipping fees and reduced capital alone is more important for small farms than a feed in tariff, as for all the scenarios with a net benefit, no surplus power is sold to the grid (so feed in tariff rates do not come into play.) The avoided cost of purchased power is however a major advantage, indicating that small farms would benefit most from sizing an engine generator set to meet their net on farm needs, rather than aiming to sell power to the grid.

Table 3. Annual Cost/Benefit analysis of Capital Cost effect with Benefit values of $0.16 per kWh for power, $10 per tonne Carbon Credit, and co-digestion with 10% of the VS from off-farm cheese whey and a tipping fee of $0.05 per gallon.

Capital Cost ($/cow)	Cow #	Yearly per Cow Expenses Capital	Maint	Yearly per Cow Benefits Electricity Avoided cost	Sold	CC	TF	Total Annual Cost/ Benefit
500	30	$48	$16	$106	($12)	$21	$44	($94)
1,000	30	$86	$16	$106	($12)	$21	$44	($57)
1,500	30	$123	$16	$106	($12)	$21	$44	($19)
2,000	57	$161	$16	$96	$16	$21	$44	($0)
2,500	254	$198	$16	$77	$46	$21	$44	$26
3,000	254	$236	$16	$77	$46	$21	$44	$64

*** CC = Carbon Credit, TF = Tipping Fee**

Table 4. Annual Cost/Benefit analysis of Capital Cost effect with Benefit values of $0.10 per kWh for power, $0 per tonne Carbon Credit, and co-digestion with 10% of the VS from off-farm cheese whey and a tipping fee of $0.05 per gallon.

Capital Cost ($/cow)	Cow #	Yearly per Cow Expenses Capital	Maint	Yearly per Cow Benefits Electricity Avoided cost	Sold	CC	TF	Total Annual Cost/ Benefit
500	30	$48	$16	$106	($12)	$0	$44	($73)
1,000	30	$86	$16	$106	($12)	$0	$44	($36)
1,500	30	$123	$16	$106	($12)	$0	$44	$2
2,000	254	$161	$16	$77	$29	$0	$44	$27
2,500	254	$198	$16	$77	$29	$0	$44	$65
3,000	254	$236	$16	$77	$29	$0	$44	$102

*** CC = Carbon Credit, TF = Tipping Fee**

Grant programs to reduce the burden and risk to small (and large) farms are one option that has been used. The effect of grant support on the annual cost/benefit, for a 125 cow dairy is presented in Table 5. The capital costs for a 125 cow dairy (125 cows represents the approximate average size herd in the US in 2010) were estimated by averaging the capital costs for three existing small farm anaerobic digesters with associated engine-generator sets (Klavon 2011). The percentage of the total capital cost of $2,700 per cow paid by the farm was then varied from 100% down to 30% and the annual cost/benefit calculated. Benefits assumed surplus power was sold at the purchase rate of $0.10 per kWh, no Carbon Credit revenues, and tipping fees of $0.05 per gallon for cheese whey making up 10% of the Volatile solids digested.

Table 5. Annual Cost/Benefit Analysis of the Effect of % Grant Support with Benefit Values of $0.10 per kWh for power, $0 per tonne Carbon Credit, and Co-Digestion with 10% of the VS from off-farm cheese whey and a tipping fee of $0.05 per gallon, for a 125 cow dairy farm with a Capital Cost of $2,700 per cow.

		Yearly per Cow Expenses		Yearly per Cow Benefits			
				Electricity			Total Annual Cost/ Benefit
Capital Cost % Borne by Farm	Cow #	Capital	Maint	Avoided cost	Sold	TF	
100% ($2,700 per cow)	125	$213	$16	$82	$23	$44	$80
90% ($2,430 per cow)	125	$193	$16	$82	$23	$44	$59
80% ($2,160 per cow)	125	$173	$16	$82	$23	$44	$39
70% ($1,890 per cow)	125	$153	$16	$82	$23	$44	$19
60% ($1,620 per cow)	125	$132	$16	$82	$23	$44	($1)
50% ($1,350 per cow)	125	$112	$16	$82	$23	$44	($22)
40% ($1,080 per cow)	125	$92	$16	$82	$23	$44	($42)
30% ($810 per cow)	125	$72	$16	$82	$23	$44	($62)

***TF = Tipping Fee**

The calculations show that with a grant covering 40% of the capital cost, the project is probably an economic benefit. A 40% grant on a total capital cost of $2,700 per cow and 125 cows, is $135,000.

DISCUSSION

It is clear from the results that financing small farm AD can be difficult depending on the incentive programs available to a farmer. Even with relatively generous programs it may take several benefit programs in concert to justify AD at the small farm level. It is also clear that avoided costs of purchasing power is a significant benefit, and that the sale of surplus power even with a generous feed in tariff may not be worth it.

The initial capital cost of digester systems is a significant hurdle to their further adoption and strategic policy will need to be enacted to allow small farms to participate in AD. Keeping the capital costs below $1,500 per cow whether through grant programs or improved low cost designs would likely be preferable to relying on feed in tariff and carbon credit programs where the benefits pricing may be variable or short lived.

Another consideration when deciding on whether to pursue AD on a small farm, is the valuation of non-monetary benefits such as improved flexibility in field application and odor reduction. These can be very significant reasons for installing and AD system particularly if a small farm is located near encroaching residential areas. The net cost of an AD system could be a means of assigning value to odor reduction.

The model will continue to be developed to answer further questions, and increase the scope of the analyses it can be used for. The model will be expanded to provide an estimate of the AD system capital costs based on a line item estimate of costs for digester components and construction and engine generator pricing. This estimator will include actual costs and sizes of equipment and make use of average site development, engineering and labor costs developed from similarly sized projects. Though every project situation will be different, an approximate estimation based on average values will be of use in determining how policy decisions could affect the adoption of small farm AD.

Similarly, for power production estimation, actual available generator sizes (and prices) will be used. Any excess biogas produced beyond what that size generator can use (and the next size up could use) would then be flared and not used for power generation. This technique will more closely match real world production of power from biogas and the associated costs of doing so.

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