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Greenhouse Gas (ghg) Emission Reductions Due to Anaerobic Digestion of Dairy Manure

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Abstract. *Livestock agriculture is a source of greenhouse gas (ghg) emissions in the U.S., and emits one of the most potent greenhouse gases – methane (CH_4). Through manure anaerobic digestion technology, a portion of these emissions can be mitigated. The Association of State Energy Research and Technology Transfer Institutions (ASERTTI) protocol, released in 2007, is being used by Cornell University to monitor seven on-production farm anaerobic digesters (ADs) in New York State. Among many other requirements, this protocol recommends to use the EPA Climate Leaders methodology to quantify ghg emission reductions attributed to the anaerobic digester (AD) systems being monitored.*

One full year's worth of digester performance data, including biogas production, quality, composition and utilization, has been collected and analyzed for the first two AD systems to complete the one-year monitoring study. Results from the monitoring study were used in this paper to quantify CH_4 and carbon dioxide (CO_2) emission reductions on a TCO_2e basis (metric tonnes of CO_2 equivalents), for these two farms. As part of the ASERTTI protocol, potential ghg reductions between conventional methods of manure storage and anaerobic digestion offset projects in NYS were analyzed. The calculated reductions quantified the ability of each digester system to mitigate ghg emissions when compared to baseline practices.

Several of the collaborating farms undergoing monitoring participated in carbon credit trading, and received payment based on the amount of ghgs reduced by the AD system. This paper presents results of ghg reductions based on different reduction calculation methodologies including: California Climate Action Registry (CCAR), Regional Greenhouse Gas Initiative (RGGI), and EPA Climate Leaders, as well as avoided emissions from reduced fossil-fuel generated electricity estimated by Power Profiler.

The average emission reduction estimate for the farm co-digesting manure with other organic wastes was 4,548 TCO_2e/year, and the manure-only farm digester resulted in 4,193 TCO_2e/year. For the farm using co-digestion, the emission reductions equaled the removal of 0.8 cars from the road for every 1 cow on the farm, which was very close to the emission reductions for the manure-only digester, which equaled 0.7 cars removed from the road for every 1 cow on the farm.

Keywords. Greenhouse gases, carbon credits, anaerobic digestion, dairy, manure treatment

Introduction

Considering the entire chain that supplies fluid milk to the consumer, milk production and associated on-farm practices are responsible for the largest component – 59% – of greenhouse gas (ghg) emissions (Innovation Center, 2008). Utilization of an anaerobic digester (AD) to treat manure can lead to significant reductions in the emission of ghgs (U.S. EPA, 2008) by:

1. capturing methane (CH_4) gas and combusting it, resulting in the emission of a less potent ghg – carbon dioxide (CO_2)
2. displacing fossil fuel-derived energy needs.

Determining ghg emission reductions is part of a larger AD monitoring study taking place in New York State, following a protocol released in 2007 by the Association of State Energy Research and Technology Transfer Institutions (ASERTTI, 2007). The objective of monitoring ADs in NYS using this protocol is to provide:

(1) developers with a standard approach for quantifying the performance of their systems and supporting claims that will receive general acceptance as credible, and

(2) third parties with the same approach for independent performance evaluations (ASERTTI, 2007).

Following this protocol will allow for comparisons of similar and different types of systems based on directly comparable and unbiased information (ASERTTI, 2007). The ASERTTI protocol suggests one methodology to calculate the reduction in ghgs attributed to the AD offset project and associated gas combustion system. However, several methodologies exist for this purpose and an analysis of the approach of each methodology is presented in this paper.

Background

All ghg offsets are put on an equivalent basis of 1 metric tonne of carbon dioxide equivalents, and the units to denote this are "TCO_2e". A CO_2 equivalent puts other ghgs on an equivalent basis with CO_2 since other gases, like CH_4, are more potent in terms of their affect on the atmosphere (Carbon Zero, 2009). The concept of a global warming potential (GWP) was developed to compare the ability of each ghg to trap heat in the atmosphere relative to the baseline gas CO_2. The definition of a GWP for a particular greenhouse gas is the ratio of heat trapped by one unit mass of the greenhouse gas to that of one unit mass of CO_2 over a specified time period (U.S. EPA, 2006). An overview and discussion of each of the carbon trading markets is provided below.

The carbon trading market is in its infancy in the United States, as compared to other countries around the world. The most notable carbon trading markets currently in existence in North America are: Chicago Climate Exchange (CCX), Regional Greenhouse Gas Initiative (RGGI), and the California Climate Action Registry (CCAR). Each of these markets has their own methodology for calculating emission reductions. The U.S. Environmental Protection Agency (EPA) also has a methodology titled "*Climate Leaders Greenhouse Gas Inventory Protocol Offset Project Methodology*" specifically developed to calculate reductions for projects managing manure with biogas recovery systems (U.S. EPA, 2008). This methodology was developed in order to serve as a standard for the industry, but has not yet proved to gain widespread use (Penque and Belcher, 2009).

Climate Leaders

Although the EPA Climate Leaders methodology is not widely used at this time to calculate ghg emission reductions, some industry leaders believe this may become the standard method for calculating reductions, as the U.S. transitions into a national Cap and Trade system (Penque/Belcher, 2009). This methodology calculates emission reductions by taking the difference between the baseline emissions and the project-related emissions, and also takes into account the potential ghg leakage from the project. The emission baseline for a manure management methane collection and combustion project is the manure management system in place prior to the project (U.S. EPA, 2008). Project-related emissions are emissions that occurred after the project was completed and the operation was monitored. Leakage is defined as an increase in ghg emissions or decrease in sequestration caused by the project but not accounted for within the project boundary (U.S. EPA, 2008). In our calculations, we interpreted leakage in the project to include the on-farm importation of organic substrates for co-digestion. The EPA Climate Leaders methodology uses a factor of 21 for the GWP of CH_4. Lastly, the Climate Leaders methodology may yield comparatively low emission reductions for projects in cold climates, due to the procedure used to calculate volatile solids (VS) degradation in the baseline scenario.

RGGI

RGGI has not been widely adopted as a methodology to verify emission reductions, mainly because of the initially low prices per metric tonne of CO_2e developed by the market. RGGI calculates emission reductions simply by determining the baseline CH_4 emissions and then subtracting any transportation-related emissions for conveyance of manure or other organic waste from off-site for co-digestion. The methodology states, “The emissions baseline shall represent the potential emissions of the methane that would have been produced in a baseline scenario under uncontrolled anaerobic storage conditions and released directly to the atmosphere in the absence of the offset project" (RGGI model rule, 2007). The RGGI methodology uses a factor of 23 for the GWP of CH_4.

CCAR

CCAR is currently the most stringent standard recognized for verifying emission reductions, and the credits are currently worth more than on the other carbon trading markets. The CCAR methodology calculates emission reductions by taking the lesser value of the CH_4 destroyed by the offset project (anaerobic digester) and the difference between the baseline emissions and the project-related emissions. The methodology states, "In the case that the total ex-post quantity of metered and destroyed methane is less than the modeled methane reductions, the metered quantity of destroyed methane will replace the modeled methane reductions" (CCAR, 2008). The CCAR methodology uses a factor of 21 for the GWP of CH_4. This methodology may yield comparatively higher baseline emissions for projects in colder climates, due to the procedure used to estimate VS degradation in the long-term storage. The CCAR methodology for calculating ghg emission reductions results in comparatively conservative values when compared with the other methodology calculations (Penque and Belcher, 2009).

Methodology summary

The ASERTTI protocol states that the EPA Climate Leaders methodology should be used to calculate ghg emission reductions. The protocol also recommends the use of the EPA developed *Power Profiler* (USEPA, 2009), which calculates the avoided emissions by using renewable electricity produced on-farm rather than purchasing fossil fuel-generated electricity. The three methodologies compared in this paper are RGGI, CCAR, and EPA Climate Leaders, and the reduction results from *Power Profiler* are presented as well.

Farm Information

Of the seven digester systems monitored using the ASERTTI protocol, the two that had completed one year of data collection were selected to compare emission reductions. The first farm, Patterson Farms in Auburn, NY, co-digested dairy manure, cheese whey and onions in their AD, installed to reduce odor emissions from their pre-existing slurry storage. Complete information about Patterson Farms is available from "*Anaerobic Digestion at Patterson Farms, Inc.: Case Study* (Gooch and Pronto, 2008a)."

During the monitoring period (3/2008 to 3/2009), there were an average of 902 lactating cows and 372 heifers on-farm, which equates to 1,073 lactating cow equivalents on a volatile solids basis (LCE_{VS}). A LCE_{VS} unit puts all cow groups on a VS based equivalent scale of a lactating cow (Gooch et al., 2009). The biogas produced was combusted in a 200-kW engine-generator set and excess was flared. Patterson Farms traded their carbon credits on CCX (Gooch and Pronto, 2008a).

The second farm, New Hope View Farm in Homer, NY, is a manure only AD. The farm was started in 2000 with the AD included as part of the green-site dairy project, as the primary manure treatment strategy. Therefore, it was assumed the baseline manure management practice would have been a slurry storage, since it was the dominant practice in the area. Complete information about New Hope View Farm is available from "*Anaerobic Digestion at New Hope View Farm, Inc.: Case Study* (Gooch and Pronto, 2008b)."

During the monitoring period (4/2008 to 4/2009), there were on average 1,053 lactating cows and no heifers on-farm, which equates to 1,053 LCE_{VS} supplying manure to the AD. Biogas produced was combusted in a 70-kW microturbine, a 1.5 million Btu boiler, and excess was flared. The farm did not participate in carbon trading (Gooch and Pronto, 2008b).

Data Collection

Data used in the emission reduction calculations was collected through adherence to the ASERTTI protocol, and each method of data collection is described here in detail. Biogas production data was obtained through biweekly readings of ROOTS® brand gas flow meters (Models 3M175, 5M175, and 11M175) and one Fox® brand gas flow meter (Model FT2) placed at each biogas flow location. Where there was already gas flow monitoring equipment in place, it was removed for testing and calibration and if necessary, cleaned, repaired, or replaced. The set-up for calibration of the ROOTS® gas flow meters, which were already in-place on each of the participating farms, using the Model 5 ROOTS® Prover, is shown in Figure 1.

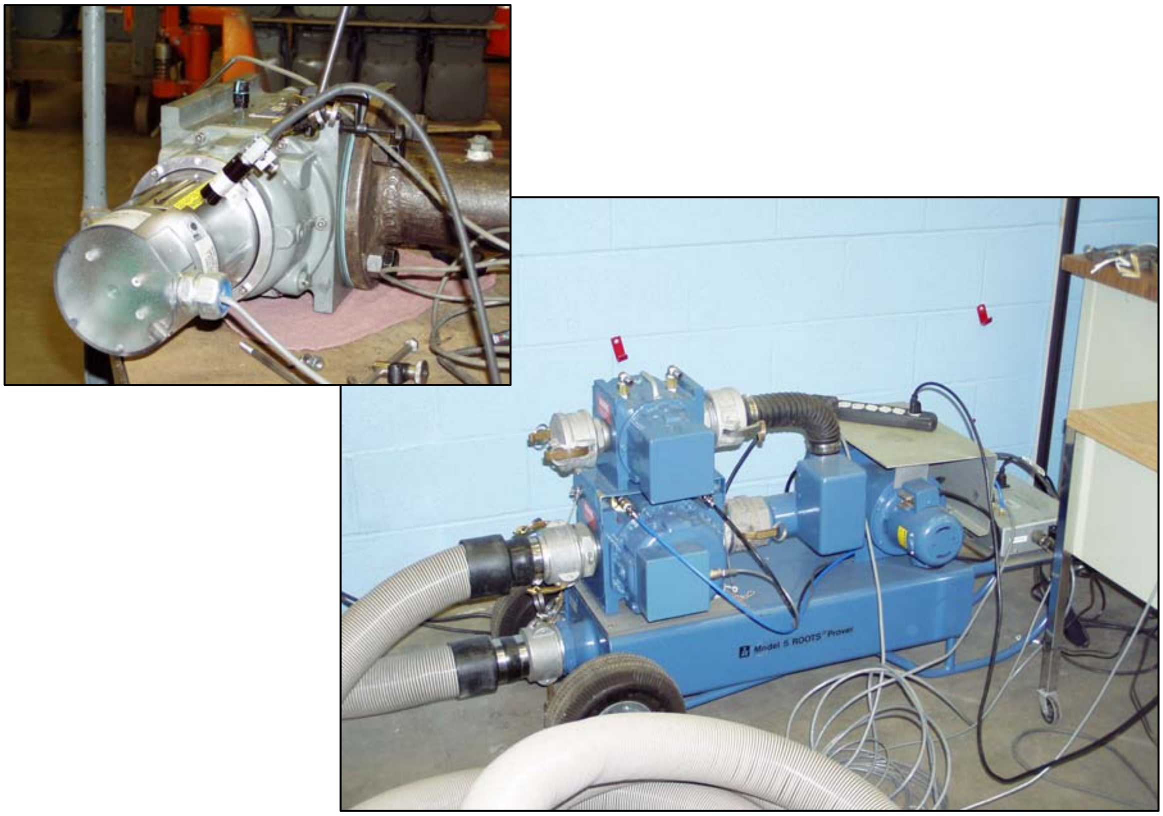

Figure 1. ROOTS® Prover set-up

Methane concentration in the biogas was calculated using a simple subtraction method (Equation 1).

Equation 1: $\left[CH_4\right] = 100 - \left[CO_2\right]$

Carbon dioxide concentration was determined using Sensidyne Precision Gas Detector Tubes in the range of 0-50% (Model #: 126UH). Gas testing was performed on-site biweekly and in triplicate. Equipment used to measure CO_2 concentration is shown in Figure 2.

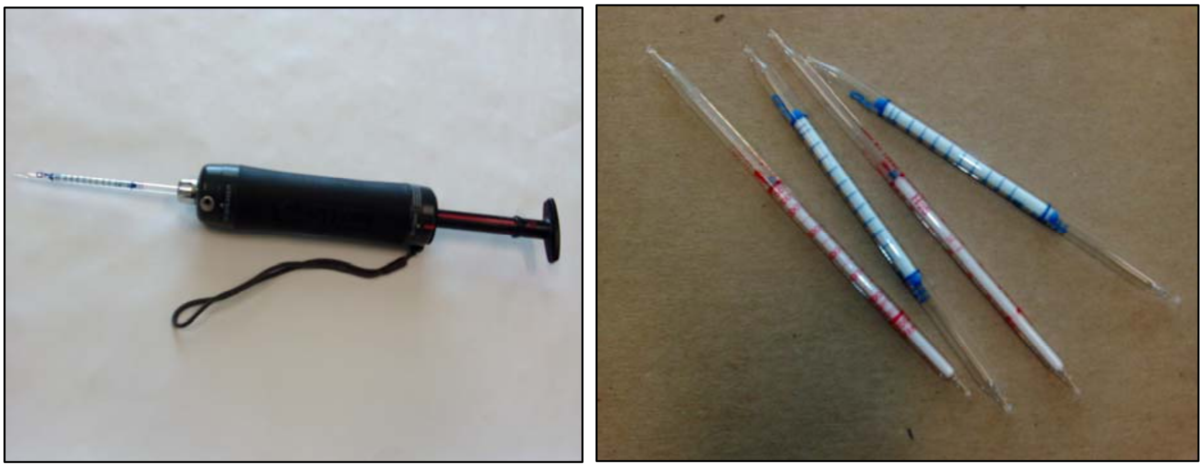

Figure 2. Biogas concentration analysis equipment

The type of influent to the digester was tracked by the farm on a daily basis using a project-generated log to collect information on the type and quantity of material. Influent volumes at New Hope View Farm were determined using a mechanical counter (Model: Redington 1-4615) installed on the piston pump that transferred material to the digester, as shown in Figure 3. At Patterson Farm, a time clock (Model: Redington 722-0004) was installed on the centrifugal pump that transferred influent to the digester, as shown in Figure 4. Pump calibration tests were performed on the influent pump at each farm to determine the flow rate of the pump under normal operating conditions. Details of the test set-ups and results can be found in the paper *"Pump Performance Tests as a Method of Determining Influent Mass Flows to Dairy Farm Anaerobic Digesters" (Pronto and Gooch, 2008).*

Figure 3. Mechanical counter used to track digester influent volume, installed at New Hope View Farm

Figure 4. Patterson Farm time clock, installed to track digester influent volume.

Counter and time clock readings were recorded on a biweekly basis and also noted on a daily basis by the farms. Electrical energy (kWh) readings were taken from the utility meters on a biweekly basis.

Lastly, VS content of the AD influent was determined through biweekly sampling and subsequent lab analysis performed in triplicate. One liter grab samples were taken over a one hour period to fill a five-gallon bucket during each sampling event, and the resulting five-gallons were aggressively agitated using a paint mixer affixed to a drill. A one liter sub-sample was then collected from the agitated bucket, preserved on ice, then sent to Certified Environmental Services laboratory (Syracuse, NY) for analysis.

Data collected at Patterson Farms following the ASERTTI protocol and used in emission reductions verification is shown in Table 1.

Table 1. Patterson Farms data used in emission reduction calculations

Average biogas volume produced	244,247 ft^3/d (n=26)
Average biogas use	Engine: 106,204 ft^3/d (n=26) Flare: 138,042 ft^3/d (n=26)
Average methane concentration	60% (n=27)
Average influent volume	650,962 lbs manure and food waste combined / day (n=26)
Average VS content of influent	6.12% (n=30)
Total electrical energy displaced over 1 year	1,207,804 kWh

Data collected at New Hope View Farm following the ASERTTI protocol and used in emission reductions verification is shown in Table 2.

Table 2. New Hope View Farm data used in emission reduction calculations

Average biogas volume produced	81,822 ft^3/d (n=25)
Average biogas use	Turbine: 7,720 ft^3/d (n=25) Boiler: 30,213 ft^3/d (n=25) Flare: 43,888 ft^3/d (n=25)
Average methane concentration	58% (n=26)
Average influent volume	302,812 lbs manure / day (n=26)
Total electrical energy displaced over 1 year[1]	118,828 kWh
Average VS content of influent	8.78% (n=30)

[1]microturbine was not operating for 8 of 12 months of monitoring

Results

Patterson Farms

Transportation emissions associated with Patterson Farms' acceptance of off-site organic material for co-digestion, were accounted for by the RGGI methodology, but as previously indicated, were added by the authors in the CCAR and EPA Climate Leaders methodologies. We felt these emissions should be also be accounted for, as in fact, they occurred as part of the project. Thus, we performed two calculations that are included in the results for these methodologies – one estimation including off-farm organic substrate related transportation emissions and one estimation not accounting for these emissions. The final results for each methodology are presented in Table 3.

Table 3. Patterson Farms emission reduction calculation results

	(TCO_2e/year)
EPA Climate Leaders	4,534
EPA Climate Leaders (including transportation of food waste for co-digestion)	4,112
RGGI	5,143
CCAR	3,194
CCAR (including transportation of food waste for co-digestion)	2,778
Average[1] of 3 methodologies	4,011
Power Profiler	536
Average of 3 methodologies and Power Profiler	4,548
Average/LCE_{VS}[2]	4

[1]Average using Climate Leaders and CCAR (with transportation of food waste for co-digestion)
[2]LCE_{VS} – lactating cow equivalent on a VS basis

The emission reduction calculation results for Patterson Farms varied from 2,778 TCO_2e/year to 5,143 TCO_2e/year. With a difference of more than 2,000 TCO_2e/year, this has significant implications for the credit trading value of the farm's emission reductions. The 536 TCO_2e/year estimated by using *Power Profiler* would be added to each of the other estimated reductions, since none of the methodologies account for emission reductions associated with avoided fossil fuel-generated electricity purchases.

New Hope View Farm

The emission reduction estimations for New Hope View Farm ranged from 3,718 TCO_2e/year to 4,985 TCO_2e/year, a smaller range in comparison to Patterson Farms. The 53 TCO_2e/year estimated by using *Power Profiler* was added to each of the other reduction estimates, as in the case of the previous farm. The Power Profiler results would have been significantly higher if the farm's microturbine would have operated more frequently during the one year monitoring period. No adjustments were necessary for New Hope View Farm, since there is no inclusion of off-site organic substrates. The final results for each methodology for New Hope View Farm are presented in Table 4.

Table 4. New Hope View Farm emission reduction calculation results

	(TCO_2e/year)
EPA Climate Leaders	4,985
RGGI	3,718
CCAR	3,718
Average of 3 methodologies	4,140
Power Profiler	53
Average of 3 methodologies and Power Profiler	4,193
Average/LCE_{VS}[1]	4

[1]LCE_{VS} – lactating cow equivalent on a VS basis

Discussion

The average value of all methodologies (EPA Climate Leaders, RGGI, and CCAR) plus the reductions estimated by *Power Profiler*, for each of the two digester systems analyzed, is shown in Table 5. It is increasingly popular to put emission reductions of all forms on an equivalent of number of cars removed from the road. This value is shown in Table 5 for each farm, based on the EPA estimate that a typical passenger vehicle emits 5.5 TCO_2e/year (U.S. EPA, 2005). It is helpful to see the effects on a per-cow basis, thus, the number of cars removed for each LCE is also shown in the table.

Table 5. Comparison of farm emission reduction data

	New Hope View Farm	Patterson Farms
Average reduction estimation	4,193 TCO_2e/year	4,548 TCO_2e/year
Equivalent # cars removed from road	762 cars	827 cars
# cars removed/LCE	0.72	0.77

Also interesting to note is the economic effect of each methodology's outcome. An estimate of the gross annual offset payment according to each methodology by farm is shown in Table 6. Instead of using a value from one of the carbon trading markets, the March 2009 carbon value of $5.20/tonne CO_2e from the Voluntary Carbon Index was used (New Carbon Finance, 2009). This value represents an average of all the markets in North America at that time that traded voluntarily reduced ghg emissions. Also shown in Table 6 are the average offset payments, and the average offset payment per LCE. Because each reduction calculation method results in a different estimation of ghg reductions, the offset payment amount is affected. New Hope View Farm could have received from $19,335 per year to $25,922 per year, while Patterson Farm could have received from $14,447 per year to $26,743 per year. It is important to note that there are several costs associated with verifying and trading carbon credits and that only the gross market values are presented in the tables.

Table 6. Offset gross market value ($) for each methodology for both farms using $5.20/TCO_2e$

	New Hope View Farm offset payment ($)	Patterson Farm offset payment ($)
EPA Climate Leaders	25,922	23,577
EPA Climate Leaders (including transportation of food waste for co-digestion)	--	21,384
RGGI	19,335	26,743
CCAR	19,336	16,609
CCAR (including transportation of food waste for co-digestion)	--	14,447
Average[1] of 3 methodologies	21,531	20,858
Power Profiler	274	2,790
Average of 3 methodologies and Power Profiler	21,805	23,648
Offset payment/LCE (accounting for food waste)	20.71	22.04

[1]Average using Climate Leaders and CCAR (with transportation of food waste for co-digestion)

Conclusion

Each of the three methodologies utilized result in different emission reduction calculation results for both farms. An additional method, Power Profiler, was used specifically to calculate the avoided emissions from using power produced on-farm. It is evident from these results that a comprehensive, uniform method of calculating ghg emission reductions should be developed in order to allow farms employing on-farm renewable energy generation equal revenue-producing potential. Related, the associated carbon credit revenues, shown here to vary widely, can significantly affect per-cow basis economics for participating farms. Additional work is needed to determine the appropriate boundary to accurately incorporate the effect of transporting off-farm organic substrates for additional biogas-producing potential.

Revenue from ghg offset projects has the potential to make AD projects more attractive economically, and more viable for farms to implement, if the value of carbon credits significantly increases in the future. However, a uniform standard of calculating the offsets should be developed as the transition is made to a carbon-based economy with a national Cap and Trade program, where the implications for emission reductions will only become more significant.

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