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Best Management Practices for Designing and Operating a Biogas Recovery System under a Time-of-Use Net-Metering Program: A Focus on Electricity Revenue Generation from Two California Dairies

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Abstract:

Utilizing information from two dairies in California, this paper develops a model for examining best management practices for designing and operating an anaerobic digester under the situation of a time-of-use net metering contract. It is argued that optimal decision making requires that multiple enterprise budgets should be developed that account for the different prices that can be received for producing at different times of the day for power that is consumed on-farm or net metered to the local utility. Furthermore, it is argued that while many anaerobic digesters are developed based on engineering efficiency, it would be better under differential pricing if they were built around the idea of maximizing profits, i.e., engineering efficiency is not synonymous with profit maximization.

Key Words: anaerobic digesters, time-of-use, net metering, dairy, best management practices, electricity generation, differential pricing

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Background

AgSTAR, which is a joint effort by the US EPA and USDA, is a program developed to encourage livestock producers whose operations create methane emissions to adopt biogas recovery systems/anaerobic digesters (http://www.epa.gov/agstar/about-us/index.html). This program, along with grant programs that exist at the federal and state levels, have had success encouraging producers to adopt anaerobic digestion systems. Lusk (1998) reports that there were 28 operational digesters in 1997 and found at the time a high failure rate. According to the 2010 *US Anaerobic Digester Status Report* developed by the US EPA, there are currently 157 anaerobic digesters operational across the country, which represent approximately a five-fold increase. Many of these digesters have received large grants for their initial capital costs to encourage them to adopt anaerobic digestion technology.

One of the major sources of revenue for anaerobic digesters comes from selling power to the local public utility. The contracts by these utility companies take many forms. They can be as simple as a power purchase agreement where the utility buys all the power at one particular rate, or much more complex where the producer gets different rates depending on whether power produced on-farm is consumed on-farm or sold to the public utility through a net metering program. The level of complexity increases further when there are different rates that occur for different parts of the day and/or year, sometimes known as time-of-use pricing.

California's two major public utility companies, which service many dairy producers in the state, have very complex contracts for purchasing power from anaerobic digesters. These contracts revolve around a net metering program that takes into account time-of-use. Net-metering was written into the Energy Policy Act of 2005 (US GPO, 2005). Guerrero et al. (2010) has defined net metering as "an incentive, which allows consumers to offset their cost of consuming

electricity by banking, or essentially storing, excess energy produced until needed for consumption" (p. 284). Hence a dairy producer operating an anaerobic digester who produces more electricity than he is able to consume at a given point in time can transfer that electricity to the local utility and obtain that electricity at a later date to offset excess demand periods for electricity.[1]

California has a very uneven demand for power throughout the year. In the summer period, peak demand can put a sizable strain on the power grid. In order to provide incentive for consumers to better manage their power consumption, several utility companies provide a time-of-use rate schedule. Time-of-use rate schedules provide differential pricing based on the time of day, part of the week, and part of the year. These rate schedules can save consumers money if they have the ability to shift their power usage from peak usage times to non-peak usage times. The public utilities in the state have a myriad of different rate schedules that define peak and non-peak periods. For example, one of California's major public utility companies, PG&E, has its peak hours between noon and 6:00 p.m. in the months between May and October under one time-of-use contract (PG&E, 2007). This peak period is valid Monday through Friday except on certain holidays. In the winter months (November to April) under this same contract, PG&E has a partial-peak period that runs from 8:30 a.m. to 9:30 p.m. Monday through Friday. [2] Each period has its own rate associated with it. Southern California Edison, another major public utility in California has its own rate schedules and definition of peak and non-peak periods which can be different than PG&E.

[1] When electricity is net metered, it is not necessarily the actual kilowatts that are being banked but rather the value of the kilowatts. Hence, a producer is not necessarily able to put a kilowatt on the grid and later get that full kilowatt back. Hence, the power company is charging the producer for the storage of electricity.

[2] In terms of winter, the partial peak period represents the period that has the highest rate of the season.

The nuances of net metering contracts can be shown to have implications on the design and operation of anaerobic digesters. Adding in time-of-use further complicates the decision on design and operations. Unfortunately, it appears from a review of the literature that these nuances are not well understood or taken into account in many studies. Many anaerobic digesters appear to be built around engineering efficiency rather than economic efficiency. This can lead to economically viable anaerobic digesters being abandoned by producers because they do not appear to be profitable. In some cases these digesters were designed not to be as profitable as they could have been given a better understanding of how differential pricing affects revenue of the digester operation. Hence, many of the studies in the economics and business literature focus on examining the feasibility of new revenue sources or on policy questions to induce producers to adopt anaerobic digesters.

The purpose of this paper is to fill an important gap in the anaerobic digester literature. It is meant to derive a set of best management practices when designing and operating a methane digester when there is differential pricing, specifically time-of-use pricing. It highlights how important it is to understand the implications revenue has on design and operation of the digester. There are two primary objectives of this paper. The first is to develop an electricity revenue model for anaerobic digester operations that use a time-of-use net metering program. Objective two of the paper is to provide a set of best management practices when designing and operating an anaerobic digester that operates in a time-of-use net-metering environment.

Past Studies

There have been many different avenues of research regarding anaerobic digestion and the generation of power. The two primary disciplines that have studies anaerobic digesters are engineering and economics. Many studies on the agricultural engineering side have focused on

the technical nature of the design of digesters (Lusk, 1998; Wilkie, 2005; Martin et al., 2003), but some have also examined feasibility of certain systems (Martin, 2008;Yiridoe, Gordon, and Brown, 2009; Bailey et al., 2008). Studies on the economic side have focused on many different avenues including policy questions, feasibility studies, and revenue generation. This section primarily focuses on what studies have been done in the economic literature on anaerobic digestion.

Bishop and Shumway (2009) utilize two years of data from an operational anaerobic digester in Washington State to analyze the feasibility of operating the digester with multiple revenue sources. These main sources of revenue include electricity generation from the burning of methane from the digestion process, tipping fees from accepting off-farm food waste to be fed to the digester, digested fiber used to offset bedding expenses for the cows, and income received from trading carbon credits on the Chicago Climate Exchange. To analyze the effects of these different revenue sources, they evaluate multiple scenarios using three economic performance indicator—net present value, internal rate of return, and a modified internal rate of return. They find that power generation and bedding cost offsets alone are not enough to make the digester feasible. With the addition of the other revenue sources, the investment in anaerobic digestion can be feasible and make sense as an investment.

Lazarus and Rudstrom (2007) utilize information gathered from an operational digester in Minnesota to examine how it can contribute to the bottom line of a dairy farm. They analyze the level of impact subsidies from the government and utility companies would have on the profitability of the dairy. While the farm the authors investigated was profitable, they find that at the time of the study the current electricity prices were not enough to induce other producers to take on the investment of anaerobic digesters without subsidies or significant benefits that go

beyond electricity sales. The reason the case study farm was profitable was because it received heavy subsidies on the initial capital investment. In the authors' summary, they state "the size of the anaerobic digesters on livestock farms is determined by expected amount of manure production" (p. 362). This paper argues that amount of manure is only one component in the decision on developing the appropriate size of the digester.

Leuer, Hyde, and Richard (2008) developed a stochastic capital budgeting model to investigate how net metering policies and carbon credits affect the profitability of Pennsylvania dairy farms that might employ anaerobic digesters. The focus of their research was to examine the cost versus the benefits of adding a new source of benefit/revenue. The benefits they examined were avoided electricity from utilizing the power generated on-farm, electricity sold to the local utility, savings from the cost of purchasing bedding, sales of the separated solids that have been composted, carbon credits, and renewable energy credits. They examine three different dairy herd sizes—500, 1,000, and 2,000 cows. They were able to show a positive correlation between profitability and size. They also were able to demonstrate that net metering programs and selling carbon credits had a positive effect on the net present value of the project, but the magnitude of the gains was not enough to take an unprofitable situation to a profitable one. From this last finding, they argued that current policies regarding carbon credits and net metering were not enough to encourage producers to adopt anaerobic digester technologies.

Morris, Jorgenson, and Snellings (2010) focus their study on the acceptance of food waste to the anaerobic digester system. They attempt to quantify the environmental impacts of a select group of dairy farms accepting food waste rather than the waste ending up in the local landfill. They estimate that their business model of utilizing food waste for the anaerobic digesters would reduce greenhouse gas emissions by 50% over the option of letting that waste go to the landfill.

Stokes, Rajagopalan, and Stefanou (2008) take a view that an anaerobic digester can be viewed as an investment that has a large upfront capital cost and an uncertain value stream to the adopter. Given this view, they examine the adoption of an anaerobic digester through the lens of a real options framework. Utilizing this framework, the authors employ a capital budgeting model to a 500-cow dairy farm. They find that significant subsidization of the capital expenses is required to induce dairy producers to move forward with investing in anaerobic digestion technology.

Gloy and Dressler (2010) investigate the barriers to adopting anaerobic digestion technologies. They focus on why lenders/investors may be reluctant to finance anaerobic digesters. The authors identify four primary reasons why lenders might be reluctant to finance digesters. The first reason pertains to the price of electricity being volatile over the life of the digester. Asset specificity is a second reason for the reluctance. Since much of the asset investment in a digester cannot be easily salvaged, considerable risk exists in recuperating funds that were lent. A third reason for reluctance in lending is that access to output markets can be challenging due to the logistics involved with interconnecting the outputs , i.e., gas and/or electricity production, to the local utility. It is argued that a fourth reason lenders may be reluctant to loan money for an anaerobic digester system is the uncertainty that exists in the policy and regulatory realm. The authors posit several solutions to these barriers including better information gathering and sharing of current working systems, further development of government loan programs, and a development of a set of established policies that minimize the regulatory and pricing uncertainty that occurs with operating an anaerobic digestion enterprise.

Gebrezgabher, Meuwissen, and Oude Lansink (2010) examined what it would cost for the dairy industry in their country to become energy neutral. Their focus was to see what it would take to

achieve energy neutrality through the production of biogas. They utilized data from 23 farms producing biogas in the Netherlands and tested several different business models. They found that it would take substantial subsidies from the government for the dairy industry to be energy-neutral.

Gloy (2010) attempts to estimate a supply curve of carbon dioxide offsets that could come from anaerobic digesters. He finds that to obtain widespread adoption of anaerobic digester systems by dairy producers across the US, there needs to be "relatively" high offset prices. He estimates that it would take a price of $5 per ton to obtain an 11% reduction of 2005 levels of methane production from manure storage. To achieve an 80% reduction, prices would have to be increase seven-fold to $35 per ton.

Key and Sneeringer (2011) developed a model to incorporate how various different government policies affect the profitability of anaerobic digesters as well as meet certain policy goals. Specifically, they examined policies related to government cost sharing, electricity pricing, and carbon offset markets. The policy goals they examined were related to energy production, greenhouse gas emissions, digester adoption rate, and renewable energy generation. Expectedly, they find that particular policies do a better job on particular goals than other policies, i.e., there does not appear to be a silver bullet policy to attain all goals efficiently.

Morris, Jorgenson, and Snellings (2010) focus their study on the acceptance of food waste to the anaerobic digester system. They attempt to quantify the environmental impacts of a select group of dairy farms accepting food waste rather than the waste ending up in the local landfill. The estimate that their business model of utilizing food waste for the anaerobic digesters would reduce greenhouse gas emissions by 50% over the option of letting that waste go to the landfill.

The common theme amongst these papers is trying to make anaerobic digesters more feasible. Many of the articles utilize as there base assumption that the producer receives a single rate for power production. A few of the articles take into account that the digesters may get an on-farm rate and an off-farm rate for their power production. None of the articles really examine how differential pricing affects the design and operation of the digesters.

Modeling a Time-of-Use Net Metering Contract[3]

Data has been collected from two operational anaerobic digesters located in California. This data runs the gamut from operational technical coefficients to economic outcomes from each of the operations. Revenue models presented below are from the billing statements and an examination of the contracts the dairies have with their local utility. These billing statements were used to derive the components that make up the operations revenue that is related to operating a digester.

Time-of-use net metering contracts have many nuances and implications for the design and operation of anaerobic digesters in comparison to a power purchase agreement that buys and sells all electricity at a single rate. At a single rate, it makes economic sense to design the digester from an engineering efficiency perspective. Unfortunately, many digesters if not most, receive differential pricing because some of the power is used on-farm getting "full" retail rate, while the rest is sold to the local utility.[4] Since time-of-use contracts have differential pricing, design implications exist regarding storage of gas and oversizing the power generating engine. Daily operating implications regarding when to operate the digester also exist. To understand

[3] There are many different time-of-use net metering contracts that exists. The model built for this study has been built in as general means as possible, but are still primarily based on the two dairies that are being used as the basis of this study. Hence, this model may not be completely general for all time-of-use net metering contracts.
[4] It will be demonstrated later that even on-farm consumption of power produced on-farm may not be receiving the full retail rate that the producer pays for power.

these implications, it is important to understand both the decision on when to produce and the rate that is received for producing in any particular time period.

With time-of-use contracts, it is important to understand that the rate a producer gets for power production is different in different parts of the day. Taking into account the stipulations of net metering, the economic rate that the producer receives is dependent upon whether the power is generated and used on-farm or if the power is transferred to the power grid under the terms of the net metering contract. Hence, power production must be categorized not only by the billing cycle and season, it must also take into consideration a block of time during the day that is under a particular rate and whether the power is consumed directly on-farm or if the power is being transferred to the electric grid for net metering. Define $kWh_{on\text{-}farm,\ tsb}$ as the kilowatt-hours generated during a particular block of time, t, for a particular season, s, and billing cycle b that is consumed directly on-farm and is not net-metered to the electric grid.[5] Furthermore, $kWh_{off\text{-}farm,\ tsb}$ can be defined as the kilowatt-hours generated during a particular block of time, t, for a particular season, s, and billing cycle b that is net-metered to the electric grid. Hence, total power production (TPP_{sb}) for season s and billing cycle b can be defined as:

$$TPP_{sb} = \sum_{t=1}^{n}(kWh_{on-farm,tsb} + kWh_{off-farm,tsb}) \ ,$$

where n represent the total number of different rates during a particular day for season s and billing cycle b.[6]

Revenue generation from an anaerobic digester is not like the typical revenue you would receive from an operation on a farm. For a typical operation, the producer is provided a payment for the

[5] Note that kWh_{tsb} represents the total power generated in a particular billing cycle that fell under a current rate.
[6] In the case of PG&E for the dairy being examined, n would be 2 in the summer months representing peak and non-peak times. In the winter months, n would be 2 representing the partial peak time and the non-peak time. PG&E have some time-of-use contracts that have n that is greater than 2.

products that he sells. The revenue generation from an anaerobic digester is not as direct because the revenue generation is really in the form of a reduced energy bill for the farm operations.[7] Hence, the price that the producer receives from electricity production comes in the form of what rate or portion thereof the producer is paying for at the time the electricity is being produced, i.e., the price received is actually the cost/rate the producer pays for electricity consumption.

There are several major components that make-up the rate a producer is charged for electricity consumption on a time-of-use net metering contract for the utilities being examined in this study—a service charge, a demand charge, and an energy charge. The first component is related to having the electrical hook-up services. Define SC_{sb} as the service charge that is billed to the producer in billing period b for season s. This charge could be a flat charge for the month or a daily charge that is summed up over every day that the meter is being used. In essence, this charge exists just to have the service. In either case, flat charge or daily charge, the only way to avoid this cost is to not have the meter.[8] Hence, it could be argued that this charge is a cost of being part of a net-metering program and should not be considered as part of the price the producer receives for his power generation.[9]

[7] It has been observed by the researcher of this paper that this form of revenue is very difficult for the producer to understand. Hence, most dairies that the researcher has come across do not have a firm grasp of how much revenue is actually being generated by the anaerobic digester.

[8] Avoiding this cost would imply that the producer is not participating in a net metering plan. Another potential implication is that power production is being completely consumed on-farm.

[9] This argument has a potential implication on all those studies that have relied upon average utility rates of a particular region as the actual price that a dairy producer would receive if he operated a digester. Utilizing average published utility rates is overstating the true price the producer receives for his electricity production.

An important factor to understand with net-metering is the load that can be generated on the meter that the anaerobic digester is attached to at any given time.[10] This load dictates whether power is valued at the on-farm rate or the off-farm rate. If the power generation of the anaerobic digester is below the load, then the electricity generated is valued at the on-farm rate. Power generation that is above load is valued at the net-metered rate. Define the load, L_{tsb}, as the amount of demand measured in kilowatts an operation has in time period t, season s, in billing cycle b from all the electrical demands from the operation that are attached to the particular meter that has the anaerobic digester generator. Define the maximum load, ML_{sb}, as the maximum load that occurs in a billing cycle in a particular season, i.e., $ML_{sb}(kWh_{on\text{-}farm,\ tsb}) = Max(L_{tsb} - g(kWh_{on\text{-}farm,\ tsb}))$ across all t where the function g( ) converts kilowatt-hours into a measurement of kilowatts. ML_{sb} is measured in terms of kilowatts.

The second main component in the electricity bill of a time-of-use net metering customer is the demand charge. The demand charge is more variable than the service charge and is a function of the load that is being demanded. In terms of the contract being examined for this study, this charge is based on the maximum kilowatts that are demanded in the billing cycle, i.e., ML_{sb}. Hence, demand charges can be affected by how much power is being generated by the digester operation at any particular time period. The closer the generator can match load, the smaller this charge. By defining the load rate as r_l, which is the rate charged on the maximum load per month in terms of kilowatts, then the demand charge DC_{tsb} is defined as

$$DC_{tsb}(kWh_{on\text{-}farm,\ tsb}) = r_l * ML_{sb}.$$

These demand charges can be a substantial portion of the electricity bill.

[10] The load represents the total amount of power demand that is coming from the production facility that is attached to the meter that the anaerobic digester is attached.

Typically, one of the largest contributing factor to the electricity bill for a time-of-use net metering customer is the energy charge. This component will be defined as EC_{tsb} where t, s, b represent the time block, the season, and the billing cycle respectively. The energy charge is broken-up into many components, but can be summarized into three main areas. The first component is the transmission and distribution charges, TDC_{tsb}. The second component is the generation charge, GC_{tsb}. The third component is miscellaneous charges, MC_{tsb}.[11] The energy charge is heavily influential on the rate a producer receives for the power he generates. If the power is consumed on-farm, the producer is able to recoup the whole energy charge. Define the price that the producer receives for power produced and consumed on farm as $r_{on\text{-}farm,\ tsb}$, where

$$r_{on\text{-}farm,\ tsb} = TDC_{tsb} + GC_{tsb} + MC_{tsb}.$$

Any excess power that is net metered to the public utility, which will be defined as $r_{off\text{-}farm,\ tsb}$, is valued at only the generation component of the energy charge, i.e., $r_{on\text{-}farm,\ tsb} = GC_{tsb}$. Hence, the value of the power consumed on-farm from the digester can be much more valuable than the power net metered to the grid, i.e., $r_{on\text{-}farm,\ tsb} > r_{off\text{-}farm,\ tsb}$.

An interesting aspect of net metering is that it only allows you to receive revenue up to the cost of the total demand the producer has for power under a particular contract cycle. Any excess power generated by the producer that goes beyond the total power usage of the farm is forfeited to the utility company. Power consumption of the farm does not have to be limited only to the meter that the digester is attached to. The contracts investigated in this study allowed for other meters on the producers operation to be calculated as the total power consumption that could be offset by net metering.

[11] Some of the charges that fall under these miscellaneous charges include: a nuclear decommission charge, a bond charge that was voted by the people of California in a referendum, and public purpose program charge.

Assume that the producer who is planning to adopt an anaerobic digester is mainly focused on optimizing their return from energy generation.[12] When a producer is deciding to invest in anaerobic technologies, they have a couple of components that affect the revenue generating capacity of the digester system--the generator and the gas storage capacity.

The first major component is the generator. The size of this component is one factor that dictates the total kilowatt hours that can be generated on any given day. It shall be assumed that the capital cost of the generator, GENC(kW) is increasing with the size of the kilowatts (kW) that the generator can produce at any given time. It is assumed that GENC(kW) takes into account the capital costs that are directly associated with the type of generator that is selected.[13] One of the major variable costs that are related to the generator are the operational and maintenance costs. These operational costs for any month and season, GENOC(kW,h_{sb}), are increasing based on the number of hours (h_{sb}) the generator is operating where h_{sb} is a function of TPP_{sb}. Hence, operational costs can be reduced if kilowatts generated per hour is maximized.

Another component that dictates the amount of electricity that can be generated is storage. Increased storage capacity allows for shifting gas production from one time period to another which potentially allows for greater electricity production in periods that have higher rates. The storage capacity and the generation capability of the electrical generator for the digester are interlinked. Storage is not just linked to the generators ability to use the gas from storage, it is also a function of the gas production from the system. The gas production turns out to be a function of the number of cows that produce manure for digester. Storage costs, SC(kW), are

[12] There are many papers mentioned above that have discussed other sources of income including tipping fees, off-set bedding costs, heat recapture which is used to off-set propane costs for heating water on the dairy, among other sources of income. This paper is focusing purely on electricity generation and the optimal decisions primarily because the dairies being studied only

[13] For example, if a hydrogen sulfide scrubber is required for the generator to operate within regulations or efficient from an engineering standpoint, it is being assumed that this is absorbed in the cost of the generator.

based on the kW the generator is able to handle. These costs are assumed to be increasing in terms of kW.

There are many other capital costs, which will be defined as CC, that makeup the initial cost of setting up the digester outside the cost of storage and the cost of the generator. For this model, it will be assumed that these costs are fixed and not directly applicable to the major decisions on design and operation of the digester. This assumption may not be too farfetched because outside of the capital cost for the generator and the storage, most other capital costs are standard across systems.[14] It is assumed that the producer has already decided upon the digester system he would like to employ.[15]

The purpose of this model is to examine the design implications and the operating implications of an anaerobic digester that is in a time-of-use net metering contract. The operating implications can be developed from the short-run profit maximization problem the producer faces, while the design principles come from the long-run maximization problem. In the short-run, the producer has to decide on $kWh_{\text{on-farm, tsb}}$ and $kWh_{\text{off-farm, tsb}}$ for each time period t, in season s, for each billing cycle b.[16] Hence, the short-run profit maximization problem $SR\pi_{sb}$ for the producer can be represented as:

$$Max \sum_{t=1}^{n} \left(\{ r_{\text{on-farm,tsb}} * kWh_{on-farm,tsb} + r_{\text{off-farm,tsb}} * kWh_{off-farm,tsb} \right)$$

[14] For example, the cost of the piping to get the manure to the digester is roughly the same under different storage and generator configurations for a particular type of digester.

[15] There are three primary digester systems that are utilized for anaerobic digesters. They are plug-flow systems, covered lagoons, and complete mix systems. This model assumes that the decision has been made on what type of system the producer would like to employ. In many respects, this system is dictated by the environment the producer is working in. This environment may revolve around the type of milking production system the producer has, the regulatory environment, the availability of funds for capital costs, etc.

[16] The short-run in this case is defined by each billing cycle in each season.

- $DC_{tsb}(kWh_{on\text{-}farm,\ tsb})$ - GENOC(kW,h_{sb})

w.r.t. $\{kWh_{on-farm,tsb}, kWh_{off-farm,tsb}: t = 1,2,..,n\}$

s.t. $g\left(kWh_{on-farm,tsb}\right) \leq L_{tsb}$

$h_{sb} = v(TPP_{sb})$,

where the function v( ) maps the total kilowatt hours produced to a number of hours the generator has operated in the billing cycle for the season. Note that the variable for kW is fixed in the short-run and is given by the design decision on how much the electric generator is able to produce.

Long-run profit maximization for the dairy producer is focused on maximizing the net present value of the short-run profits given the decision variables of kW size of the generator and cost of the storage capacity. Long-run profits, LRπ, can be defined as:

Max -GENC(kW) - SC(kW) + $\sum_{s\in S}\sum_{b\in B} NPV(\pi_{sb}(kWh_{on-farm,tsb}, kWh_{off-farm,tsb}))$

w.r.t. kW, $kWh_{on\text{-}farm,\ tsb}$, $kWh_{off\text{-}farm,\ tsb}$,

where S represents all the seasons the generator will be operable, B represents all the billing cycles that the generator will be operable, and NPV( ) is the net present value operator that brings future profitability into the present.

Discussion of Best Management Practices from the Time-of-Use Net Metering Model

When an operator of an anaerobic digester gets a single rate for power production, then the design of the system should be based on engineering efficiency and the digester should always be in operation except for regularly scheduled maintenance. Under time-of-use net metering

contracts these principles are not necessarily a given. The results of the model are not just constrained to time-of-use contracting. They also hold if the producer gets a different price based on whether the produced power is consumed on-farm or if it is sold to the utility company under a net metering contract.

The two digesters examined in this study were both developed from an engineering efficiency standpoint. The driving factor in designing these digesters was to develop the systems to handle all of the manure generated from the dairy cows in the most technically efficient manner. One of the major assumptions made was that the digester needed to operate at a continuous level throughout the day and night. Under time-of-use contracts where there are higher prices during peak periods of the day, then continuous operation may not be profit maximizing. Depending on the initial start-up cost of storage and bringing in an oversized electrical generator, it may be feasible to maximize profits by only operating during the peak hours of the day or to produce power for only on-farm consumption. This leaves an added benefit of being able to do maintenance on the machinery on scheduled down time during the day. Another cost savings can come from needing less maintenance costs. Manufacturers recommend that you do maintenance after a certain amount of hours of operation. Since you are running the generator fewer hours than if it was running continuously, you could reduce the maintenance cost considerably.

A consideration in the design process is to make sure that the on-farm load is as high as it can be on the meter the digester is attached. The anaerobic digester should be put on the same meter with the highest possible load. This will assist in maximizing the on-farm revenue generation possibility. Another implication is that there is enough load built into the net metering contract to absorb the excess production capacity of the electrical generator. For the particular operation

examined in this study, the net metering contract allowed the producer to combined consumption from any other meters on the farm.[17] Since there was no cost to adding meters to the contract, it would have been best to add all meters to maximize the load that can be net-metered against. If there is a cost to adding extra meters, add only the meters that the net metered value is greater than the cost of adding the meter to the contract. While the dairies can get the net metered value for other meters on their property, they will not capture the full retail rate because the net metering program only gives the generation portion of the rate and not the other portions of the rate. This can be a substantial reduction in the value of the electricity generated.

Typically, producers view there digester operations as another revenue source for their dairy operations. This is true for the dairies that were the basis of the model for this research. A producer who wants to maximize profits should think of his dairy operation as a separate enterprise from his anaerobic digester operation. This implies that he should develop an enterprise budget for his anaerobic digester enterprise. With time-of-use net metering, a single enterprise budget is not enough. An enterprise budget should be built for each revenue time period and each rate rather than just having one enterprise budget for the digester system. Hence the base unit of the enterprise budget should be time period of production and where the power is "sold", i.e., on-farm or net metered, rather than how it is typically done in the literature which is based on a per cow or per herd basis. In the case of the farms for this study, they should have an enterprise budget for peak period operations and non-peak operations for both on-farm consumption of production and power generation that is net metered. Multiple enterprise budgets based on the time period will allow the producer decide if it makes sense to produce.

[17] It was discovered by the researcher that the producer who is the reference for this study did not have enough load from other meters to absorb all of the excess capacity under his current contract, even though he had enough total load on-farm to do so. This discovery led to the producer adding more meters to the program.

For instance, it is possible that the non-peak period revenue that is net metered may not cover the operating and maintenance expense for producing that power. This would imply that it would be better to shutdown the generator rather than produce power beyond on-farm usage during non peak rates.

When developing these multiple enterprise budgets, special consideration needs to be given to the demand charges. When an anaerobic digester is not operational, then the demand charges increase. These demand charges can be minimized if the dairy matches its production of power with its demand for power. Obviously, if the digester is shutdown, these demand charges will increase. It has been the experience of this researcher that given the time period that demand charges are measured under, the generator to the digester will be shut down for one reason or another.[18] In reality, it may not be possible to get demand charges to zero. Hence, there is a balancing act that occurs with minimizing the demand charges constrained by maximizing the revenue by only producing in the highest revenue time periods. It is the belief of this researcher that more effort should be spent on maximizing the revenue then minimizing the demand charges.

Once the dairy producer gets beyond thinking about the anaerobic digester as just a revenue component to their dairy enterprise, he might find it beneficial to adjust his dairy operation to maximize the profits from the anaerobic digester operation. A best management practice for designing the digester system would be to consider the dairy operation and the digester operation as two separate enterprises. This implies that a reconsideration of the size of the dairy enterprise

[18] The measurement for the purposes of demand charges is over the entire billing cycle. Hence a producer who wants to minimize demand charges would have to make sure that the generator was matching load on the meter for the whole billing cycle which is approximately 30 days. This may be an impossible task for a dairy operator to achieve given the mechanical limitations of the generator as well as the time demands on the producer to manage the dairy operation.

or its practices may be necessary to optimize the long-run profit. In essence, the digester enterprise could be economically optimized if the dairy enterprise could be changed. It is conjectured by this researcher that most dairy producers and/or the people selling the digester systems would take this into consideration.

Maintenance should be regularly scheduled and occur when the revenue generation from operating the digester is the smallest. In the case of running only during peak hours, this scheduled maintenance should be during the downtime. If the digester needs to run continuously, then scheduled maintenance should occur when the power is worth the least. This implies that some of the scheduled maintenance should occur outside typical maintenance hours that might occur on the farm depending on the season.

Concluding Remarks

This study developed a model for how revenue is generated for an anaerobic digester that operates under a time-of-use net metering contract. The basis of this model were to dairies in California that have operating anaerobic digesters. Billing statements and net metering contracts were reviewed and analyzed to develop the model.

This article demonstrated how time-of-use contracts under net-metering terms can have an effect on the design and operation of anaerobic digesters. When studying the alternatives for digesters under this differential pricing regime, it is not necessarily appropriate to build the digester based around engineering efficiency. It is important to take into account how revenue is specifically generated. Hence, what may appear to be a system that is not efficient from an engineering standpoint, may be efficient from a economic standpoint. A system with storage capacity that can handle a much larger amount of gas than that which is produced on a continuous basis may

be economically optimal. Furthermore, it may make sense to put an oversized electrical generator that can handle enough gas to only produce during peak hours and is idle for the rest of the day.

This article argues that the anaerobic digester should be viewed as its own enterprise, rather than a revenue source for the dairy enterprise. Furthermore, under time-of-use net metering contracts, there may be several enterprise budgets that are developed for each different time period and whether the power is consumed on-farm or net metered. Most previous studies attempt to develop the enterprise budgets with a base unit of a cow or herd. It is argued that putting the base unit of your anaerobic digester on a per cow basis will hinder the producers ability to make decisions that maximize profits. It is also argued that enterprise budgets based on time of production generation may show that it may not be beneficial to net meter some power because the operation and maintenance costs are greater than the revenue that would be received. This would never be recognized from an enterprise budget that was based on a per cow or herd basis.

An implication of the service charge is that there is no way to avoid it. It is a cost of doing business to utilize net metering. Since this is the case, the part of the rate that is from the service charge cannot be allocated as part of the cost savings from producing and consuming the power on-farm. This service charge is a component in the total average rate that is published by utility companies. This implies that those studies in the literature that utilize an average published utility rate for their simulations maybe overestimating the value that producers are receiving for power generation from their anaerobic digesters. Depending on the utility company, this may be negligible or significant. This article suggests caution when utilizing average published rates.

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