

An Analysis of the Tradeoffs between Policy Instruments to Induce Dairy Producers in California to Participate in a Centralized Digester

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Abstract

Tradeoff between different utility rates and policy intervention to induce dairy producer to join a regional digester are studied. Results demonstrate that a regional digester for the dairy industry in California is feasible given the digester receives \$0.05 per kWh and government intervention or \$0.0925 per kWh with no intervention.

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California's Dairy Industry

Over the years dairymen have strived to increase operational size to reduce cost in order to maintain competitiveness in the industry. This search for economies of scale has been in juxtaposition to the increasing suburban pressures that are growing around the dairies in many states. This alternative use of land to accommodate development has forced dairy producers in many areas to increase intensity of production to gain these economies of scale, resulting in more manure concentrated in a smaller area.

One of the states that have to cope with manure concentrated in a small area is California. California had almost 1.7 million dairy cows in 2003 (CASS, 2003). These cows were utilized by California producers to generate approximately four billion dollars in revenue and 35.4 billion pounds of milk production. These dairies have generated a large amount of manure approximated at thirty million metric tons in 2003.² Eighty-seven percent of the dairy cows in California are located on farms of five hundred or more cows with a heavy concentration in eight counties of California—Fresno, Kings, Merced, Riverside, San Bernardino, San Joaquin, Stanislaus, and Tulare (USDA Census, 2002). These counties account for approximately eighty-four percent of the dairy cows in the state.

Technology exists for dairy producers to capture methane from the manure of their cows and turn it into energy. There are many issues producers must contend with when they want to turn manure into an energy resource. An operation may be too small to generate enough manure to make it profitable to utilize manure to produce energy or biogas. A dairy may not want to take on the extra management responsibility of adopting a technology that will produce energy from their manure. A producer may generate more power from their technology than her farm

² This estimate was derived using a conversion factor developed by Nennich *et al.* (2003). They believe that the amount of manure produced is related to milk production rather than the size of the cow. They propose that one kilogram of milk equates to 1.89 kilograms of manure generated.

can utilize on-site because they have a large operation. This implies that a dairy may need to sell some of the excess power or biogas they generate. It is possible that these producers will not be able to sell enough power to generate the economies of scale necessary to turn a profit because they have insufficient scale to bargain with the local utilities.

While some preliminary research has been conducted examining the feasibility of a regional digester to handle some of the effluent issues related to dairy operations, a more extensive examination is needed. This project provides an analysis of the feasibility of regional digesters in California for handling dairy manure, focusing specifically on the Central Valley. Differing regional digester business models are examined under different policy considerations to determine under what conditions it is feasible to operate a regional digester in the Central Valley.

The rest of this report is broken-up into the following sections. The next section provides an overview of what has been written regarding regional digesters. The third section examines the methodology used for studying the implications of different policy instruments. The fourth section provides key results for the differing policy options considered for this paper. The last section provides summary and conclusions.

Regional Digester Studies

There have been a few reports that have chronicled the operation of centralized digesters. Hjort-Gregersen (2002) and Hjort-Gregersen, Nielsen, and Raven (2002) report the financial aspects of a centralized biogas facility in Denmark. Recent research conducted by Bartram and Barbour (2004) examined the environmental benefits from a regional digester utilizing dairy manure in California's Chino Basin. This facility produces over 680,000 cubic feet of biogas per day, which equates to a facility that can produce approximately 1.5 megawatts (MW) of capacity

of power production (IEUA, 2005a, 2005b, and 2006). The Port of Tillamook in Oregon is another well documented effort at energy creation from a centralized digester. DeVore (2006) and Thompson (2001) provide more details on this operation. This operation was developed to handle manure from approximately 4,000 cows.

There have been a few studies in the grey literature that have examined the feasibility of running a centralized anaerobic digester. Environmental Resource Group (2003) evaluated the development of regional and on-farm digesters for dairy waste manure for King County, Washington. A Wisconsin cost-benefit study found centralized anaerobic digesters could work for northeast Wisconsin with 25,000 cows on 250 farms spread over nine counties that produce over 300 million gallons of manure annually (Kubsch, 2003). A Vermont study by Bennett (2004) examined a centralized digester that sold heat and power to the local prison from the electrical generation process.

Model and Methods

This study examines the feasibility of operating centralized regional digesters in California's Central Valley under different policy scenarios to examine what electricity prices would induce dairy producers to participate in a regional digester. This area represents approximately 1.2 million milking cows out of the 1.7 million dairy cows in the state. A data set of California dairies was acquired from a private vendor. This data set contained 660 dairies representing approximately 1.12 million cows which were transformed into geospatial data.

There were thirty-two different scenarios investigated in this study which were based upon eight differing funding options and participation rates for the four regional digester systems. These funding options had four possible areas of deviation—loan rate, participation rate, capital borrowed, and public funding. Table 1 gives an overview of these options.

Table 1. Funding Options and Participation Rates for Four Regional Digester Systems.

Scenarios	Anaerobic Digester Engine Size			
	Loan Rate	Participation Rate	Capital Borrowed	Public Funding
Scenario A	9%	50%	65%	No
Scenario B	9%	100%	100%	No
Scenario C	5%	100%	100%	No
Scenario D	5%	100%	100%	Yes
Scenario E	9%	75%	65%	No
Scenario F	9%	100%	65%	No
Scenario G	9%	75%	100%	No
Scenario H	9%	50%	100%	No

Scenario A could be considered a purely private model where the regional digester must come up with 35% collateral on the capital purchased and borrow money at a 9% interest rate. Under this model it is assumed that the digester will only be able to convince half of the eligible dairies to participate in the regional digester. There is no public funding possible.

The purely public model is listed as Scenario D. Under this scenario, the state requires 100% participation of dairies in the regional digester. The state lends the regional digester money at a 5% interest rate up to 100% of the capital cost.³ The state also subsidizes the transportation of the manure from the dairies to the regional digester up to the minimum of transportation cost or net social benefits from having the digester.⁴

The other six options can be considered variations of Scenario A and D. The other participation rate that was examined was 75%. Scenarios E and F are variations of the purely public model with different participation rates, while Scenarios G and H is where the government assists with getting a low cost loan for the digester.

³ One way of looking at a regional digester as a purely public entity is to assume that it has access to a 100% loan at a 5% interest rate. This would be similar to the state government acquiring the money necessary for the project by floating a bond initiative.

⁴ Public funding is given by the state government in the form of trucking services necessary to transport the manure as a recycling service. Hence, the regional digester would pay the government a sum equal to the difference between the cost of transportation and the value of the net social benefits.

To investigate these scenarios, simulation techniques were utilized to estimate the feasibility of running a centralized digester at one of approximately 650 sites in the Central Valley. Feasibility is defined as a regional digester that has a positive NPV (NPV) at a 10% discount rate over a fifteen year time horizon with a positive yearly net social benefit. The discount rate and the time horizon used in this study come from Jewell, *et al.* (1997).

The simulation was broken-up into two stages. In the first stage, configurations were chosen that could provide the appropriate number of cows for the digester being examined. The second stage took these configurations that were identified as applicable (cow numbers sufficient within ten miles) and entered each of them into a regional digester business model. Each scenario was examined at electricity prices ranging between \$0.04 up to \$0.10 per kWh at \$0.0025 intervals. The upper limit of \$0.10 per kWh was used because there is little evidence in the literature that any operational digester in the US is receiving a higher price for its electricity.

To make the analysis tractable, a base case manure handling system was developed for comparison purposes and for calculating the net social benefits. This base system has the following characteristics. Each dairy operation currently has its own uncovered lagoon for manure storage. The manure from the dairy cows is flushed twice a day using an average of 70 gallons per cow per day (Schultz, 2000). The manure is left in the lagoon until the producer is able to spread it onto a nearby field.

The systems examined in this report are centralized systems that take undigested manure from local dairies to a facility where an anaerobic digester is located. These systems are assumed to operate 90% of the calendar year, where the other 10% of the time is allocated to maintenance. Each of these regional systems was built from USEPA's AGSTAR model. Information on this model can be found in EPA (2003, 2006a, and 2006b).

There were four centralized anaerobic digesters examined in this study which were based on the amount of electricity they could generate—1.5 MW, 1.6 MW, 4.2 MW, and 10 MW. The 1.6 MW facility was assumed to use a flush manure management system and was the closest business model to the base situation. The other three facilities assume participating dairymen were currently or would change over to a manure scrape system. The centralized digester system developed assumed that the digester would be located on one of the participating dairies' site to capture the full market value of the electricity generated by the operation.⁵ Each of these four systems was developed to change dynamically to meet the requirements of the number of milking cows it will be servicing.

The 1.6 MW system is designed to handle manure generated from 7,300 to 11,450 milking cows. The lower limit to this system is based on the number of cows that could generate at least 1 MW of power.⁶ This system generates between 20 to 31 tons of compost a day that can be sold. The 1.5 MW system is designed to handle between 9,000 to 10,600 milking cows. In addition to the electricity, the digested solids removed from the digester create between 27 to 32 tons of compost per day. The 4.2 MW facility is designed to handle between 20,600 and 27,500 milking cows. It has a lower power generation ability to produce 3.17 MW of power. This system produces between 61 to 82 tons of compost per day. The final system examined was built to generate a net output of 10 MW of electricity. This system has the ability of handling manure from as low as 48,600 milking cows up to 63,500. At the lower end of its usage, it can generate 8.4 MW. The solids from this system can produce 574 to 757 tons of compost per day.

⁵ Normally, producers are required by the power company to sell their electricity at wholesale rather than retail rates.

⁶ One MW of power generation seems to be the minimum production that the public utilities would prefer to handle. The reader should not infer that the power companies will not handle facilities below 1 MW, just that they prefer to handle larger facilities so they can better manage the load on the electrical grid.

Given that the base case dairy is assumed to be operating a flush manure handling system, each dairy that decides to participate in the 1.5, 4.2, or 10 MW systems must convert their manure handling system to a scrape system. Once converted, each dairy uses a manure collection system that scrapes the fresh manure and urine from the freestall floors and transports it to a centrally-located complete mixed digester system for manure treatment.

One of the major cost components of the centralized digester systems is the capital equipment necessary for operation. Table 2 shows the major capital equipment needed for each regional anaerobic digester facility along with their associated costs. Since each facility is dynamically changing in the simulation due to the number of cows, each of these tables reports the per unit capital cost for each piece of equipment.

Table 2. Cost per Unit of Capital Equipment Installed for Each Anaerobic Digester System.

Equipment	Cost per Unit			Unit
	1.5 Megawatts	4.2 Megawatts	10 Megawatts	
Digester Tanks	\$ 932,500	\$ 932,500	\$ 932,500	per tank
Tank Foundations	\$ 125,000	\$ 125,000	\$ 125,000	per digester
Generator Set	\$ 750,000			per 1000 KW
Gas Handling, Generator Sets	\$ 390,625			per 1000 KW
Turbine Generator		\$ 524,000	\$ 524,000	per 1000 KW
Gas Compression		\$ 200,000	\$ 400,000	per 4.2 system
Gas Handling		\$ 200,000	\$ 200,000	per 1000 KW
Electrical Interconnect	\$ 100,000	\$ 100,000	\$ 100,000	per 1000 KW
Manure Collection	\$ 48,000	\$ 48,000	\$ 48,000	per 1000 KW
Solids Separator	\$ 200,000	\$ 400,000	\$ 1,000,000	per system
1.6 Megawatts System				
Equipment	Cost per Unit			Unit
Lagoon Excavation	\$ 1.50			per cubic yard
Lagoon Cover, installed	\$ 1.00			per sq. ft
Generator Set	\$ 850,000.00			per 1000 KW
Gas Handling, Generator Sets	\$ 500,000.00			per 1000 KW
Electrical Interconnect	\$ 60,000.00			per engine
Manure Collection	\$ 48,000.00			per 1000 KW
Solids Separator	\$ 200,000.00			per system

Each of these systems has a 30% engineering cost added to the sub-total of the capital cost. A trailer used for administrative purposes for each of these operations is expected to cost \$20,000, while land is being valued at \$4,000 per acre. The facility capable of producing 1.6 MW needs approximately eight to twelve acres of land. The facilities capable of producing 1.5, 4.2, and 10 MW are estimated to use respectively two, three, and five acres of land.

An amortized payment was developed that would payoff the capital equipment over fifteen years which is the estimated useful life of this equipment. The amount borrowed and the interest rate used for the capital loan are built into the simulation model.

Following Jewell *et al.* (1997), the yearly operation and maintenance cost on the generator is estimated at \$0.015 per kWh. The yearly centralized digester administrative costs were estimated at \$124,084 per year. This cost is allocated to hiring one bookkeeper at a cost of \$16.56 per hour, and one manager to oversee the whole operation at a cost of 29.74 per hour. Both of these costs were taken from the Bureau of Labor Statistics National Compensation Survey database for June 2005 for workers in the Visalia area.

The key component of this study is the transportation of dairy manure from each of the participating dairies to the regional digester. There are two options that can be considered for the transportation method. The manure can be piped from the dairies to the regional digester through a sewer system or it can be transported by trucks. Evidence by Ghafoori, Flynn, and Feddes (2005), and Krich *et al.* (2005) suggest that a piping system for manure is prohibitively high. Hence, truck transportation was used for hauling the manure to the centralized digester.

The transportation model built for this study revolves around the amount of manure that must be hauled to the centralized digester. This quantity of manure determines which size digester is appropriate, as well as, the number of drivers, number of trucks, the operational costs

of moving the manure, *etc.* To develop an estimate of how much it costs to transport the manure to the centralized digester, an estimation of the quantity of effluent and how far it travels is necessary. Using the GIS data acquired for this project, concentric circles were drawn around the location chosen for the regional digester in half-mile increments up to ten miles away from the center dairy. This central dairy was assumed to have the regional digester located on its farm. Define $D_{i,j}$ as the distance in miles that concentric circle i is away from regional digester j . This provided over 13,840 possible configurations to investigate. After deleting the scenarios that were not feasible based on the requirements of the varying digesters, 7,962 possible scenarios/configurations were examined.⁷

A simplifying assumption used for this study was that each dairy participating in the regional digester is assigned to the nearest outer concentric circle.^{8,9} Define $N_{i,j}$ to be the number of cows located within the i^{th} concentric circle around the j^{th} dairy for $i = \{ 0.5n \mid n=0, 1, 2, \dots, 20 \}$ and $j = 1, 2, \dots, 650$. Hence, the number of cows allocated to any concentric circle $C_{i,j} = PR*(N_{i,j} - N_{i-0.5,j})$ for $i = \{ 0.5n \mid n = 1, 2, \dots, 20 \}$ where PR is the participation rate used in the simulation. The j^{th} dairy that has the regional digester is defined as $C_{0,j}$ which is equal to $N_{0,j}$.

Once $C_{i,j}$ has been found, an estimation can be made how much effluent is located within a certain circumference of the dairy and how much it will cost to transport that manure to the centralized digester. For the 1.6 MW system, the amount of captured effluent generated per cow per day is equal to approximately 84 gallons which implies a yearly production of manure per

⁷ A configuration was deleted if it could not obtain enough cows to sustain one of the four systems examined in this study or if it provided too many cows for the digester to handle given a particular participation rate.

⁸ This assumption is not to imply that each dairy is being placed at the same point on the concentric circle. It is only a method for assigning the distances. It is reasonable to assume that dairies could be scattered anywhere on the concentric circle.

⁹ Placing all dairies on the outer concentric circle is meant to compensate for dairies that cannot drive directly to the regional digester. A more conservative estimate would have been to multiply each distance by $2\sqrt{2}$. This assumes that the transportation route follows a right triangle from the regional digester. This assumption would be very

cow for this system of 30,660 gallons. For the 1.5, 4.2, and 10 MW systems, only 12 gallons of captured effluent is gathered per cow per day.¹⁰ This equates to each cow producing 7,665 gallons of manure per year. The amount of effluent $M_{i,j}$ generated yearly that is estimated for each concentric circle i located around dairy j is equal to $30,660 \cdot C_{i,j}$ for the 1.6 MW facility and $7,665 \cdot C_{i,j}$ for the other regional digesters. The total amount of manure transported to the regional digester j is defined as $TM_j = \sum_i M_{i,j}$.

To transport the manure, it is assumed that a tanker truck is used with a vacuum system attached to the truck.¹¹ Once the manure has been digested at the facility, it is trucked back to one of the cooperating dairies.¹² The truck used for this study is estimated to carry 4,000 gallons of effluent per trip and has a capital cost of \$130,000. This truck was estimated to have a seven year life which equates to a yearly cost of \$25,898. Following Jewell *et al.* (1997), a maintenance cost of \$0.50 per mile was assumed. The trucks were estimated to get 6.5 miles per gallon of fuel with a fuel cost of 3.50 per gallon. The wage rate and benefits for the truck operator were estimated at \$22.10 per hour. This wage rate was derived from the Bureau of Labor Studies' National Compensation Survey estimate of wages for truck drivers in 2005. A

stringent. A brief analysis was conducted using this measure of distance and it was found that the results were not considerably changed. Hence, the results from using this stronger criterion will not be reported.

¹⁰ According to Brugger and Dorsey (2006), a cow typically consumes approximately 21 gallons of water a day. Out of this amount about a third of the fluids go to the cow for milk production and its general needs. The rest of the liquid comes out in the form of urine and manure. It is assumed in this model that approximately 83% of the effluent is captured in the scrape systems and 98% of the effluent and waste water is captured in the flush system. Brugger and Dorsey (2006) also explain that approximately 7.5 gallons of water per cow per day is used to clean out the milking barns and the scrape system. It is assumed that these 7.5 gallons is kept separate from the primary manure that is collected through scraping. This leftover water goes into a separate lagoon where it sits until it is spread onto a field. This is an important assumption because if this water is allowed to be collected with the rest of the manure, then the amount of manure slurry that must be transported and digested must increase by over 50%.

¹¹ This ensures that each dairy does not need its own pumping system and centralizes all maintenance issues at the regional digester. Two major reasons cited for the failure of many of the facilities from the late seventies and early eighties were a lack of expertise in maintenance and lack of regular maintenance.

¹² Since many dairies in the Central Valley use dairy manure as a fertilizer for their crops, it was assumed that the digested manure would be hauled back to the dairies. Otherwise, these dairies may be giving-up a valuable resource for free, which is unlikely to happen.

decision rule was built into the model to determine whether to pay overtime at 1.5 times the person's wages or to hire another employee.

T_{ij} is defined as the number of trips needed yearly for hauling the manure from concentric circle i to the j^{th} regional digester, where $T_{ij} = M_{ij} / 4000$ gallons. The number of drivers needed is found by examining how long each trip will take for each concentric circle. This time is dependent on the time needed to load and unload digested and undigested manure which is estimated to take 0.6 hours for each trip.¹³ The time is also dependent upon the time it takes to travel to and from each dairy. The total roundtrip time TD_{ij} that the truck must travel from concentric circle i to regional digester j is defined as $TD_{ij} = 2 * D_{ij} / 30$ mph.¹⁴ The amount of laborers L_{ij} needed to drive the trucks from concentric circle i to the j^{th} regional digester is defined as $L_{ij} = ((TD_{ij} + 0.6) * T_{ij}) / 1872$ hrs.¹⁵ The total number of drivers TL_j needed to transport the manure to regional digester j is defined as $TL_j = \sum_i L_{ij}$.

This study focused on two products to be sold—electricity and compost for fertilizer. The primary revenue source for each digester is electricity. An on-farm rate and off-farm rate were used for each system. The price used for the on-farm rate was \$0.13 per kWh, which is the retail rate that is charged by Southern California Edison (CEC, 2004).¹⁶ The off-farm rate is the

¹³ Jewell *et al.* estimated that a facility that has less than 500 cows should take approximately 0.5 hours for loading and unloading the digested and undigested manure (1997). For dairies over 500 cows, they estimate the time needed at 0.6 hours per trip. To stay on the conservative side, it is assumed in this study that all dairies take 0.6 hours. Out of the original 689 dairies in the data set acquired for this study, only fourteen were below 500 cows.

¹⁴ This assumption is more likely to hold for larger facilities in comparison to smaller facilities. You would expect with smaller regional digesters that the average distance traveled to each of the participating dairies is shorter than the average distance traveled to each of the participating dairies for a larger regional digester. With shorter distances traveled, you would expect that the truck will have less distance to pick-up speed. The rate of thirty miles per hour was a modification of Jewell *et al.* (1997) estimate of thirty-five miles per hour average. There were no studies found that examines average rate of speed and average distance needed to be traveled.

¹⁵ Jewell *et al.* (1997) estimate that a person who works an 8 hour shift will only be available to work an effective 7.2 hours per day. This implies that a single laborer can work only 1872 hours per year.

¹⁶ The rates charged to agricultural operations ranged from 9.54 cents per kWh from the Sacramento Municipal Utility District (SMUD) up to 19.75 cents per kWh from Pacific Gas and Electric (PG&E). If the regional digester is located in PG&E's district, the revenue stream would be better for the regional digester. Southern California Edison was used as a conservative estimate of this revenue source.

rate the regional digester receives by the utility company. These rates were fluctuated from \$0.04 per kWh up to 0.10 per kWh at \$0.0025 increments by the simulation process.

Another source of revenue comes from the compost. This compost is derived from the solids that cannot enter the anaerobic digester process. It was assumed that the solids could be turned into fertilizer and sold for a net value of \$5.00 per ton. This value is consistent with estimates done by Terre-Source, LLC (2003), Devore (2006), and Liu, Shumway, and Myers-Collins(2003).¹⁷

To estimate the net social benefit from operating a regional anaerobic digester, social costs and benefits were calculated off the base system that was proposed above and are calculated on a marginal basis. There were three social benefits and four social costs that were examined related to operating a regional digester over the status quo. The benefits estimated came from a reduction of methane gas being release into the atmosphere from the existing lagoon systems, a reduction in odor, and an improvement in local water quality. The social costs came primarily from the transportation of the manure from the dairies to the regional digesters. These costs were associated with an increase in carbon dioxide, carbon monoxide, nitrogen oxide, and other reactive organic gases.

The first benefit comes from the decrease in methane released into the atmosphere from the standard lagoon being used for storage. The estimated value of this was taken from Chicago Climate Exchange Carbon Instrument Financial Contracts and is valued at approximately \$4.50 per ton of carbon equivalent as of June 2006. The second benefit is a reduction in odor and flies associated with lagoons. Using Bennet (2004), a value of \$10.00 per cow was used as an estimate of the benefit. The final benefit comes from an improvement in water quality. Using

Chaudry (2003) estimate for what people are willing to pay for desalinated water, a value of \$1.50 per thousand gallons of captured effluent was used.¹⁸

There are four primary pollutants that can be associated with trucking manure to a regional anaerobic digester. To estimate the social costs that come from trucking the manure, the 2002 Emissions Factor Model (EMFAC 2002) was used to develop the technical coefficients for using diesel trucks to haul the manure (CARB, 2003). EMFAC 2002 estimates that 0.895 grams of carbon monoxide, 6.32 grams of nitrogen oxide, 1,334.68 grams of carbon dioxide, and 0.007 grams of methane equivalent is given off per mile of transportation. The total amount of each of these pollutants is found by multiplying the yearly amount of miles driven for all the trucks combined by the corresponding pollution value estimated by the EMFAC 2002 program.

Using the Chicago Climate Exchange, carbon dioxide emissions was set to \$4.50 per ton, while methane production was valued at \$94.50 per ton. Carbon monoxide was valued at \$27.00 per ton by using an estimate done by Indala (2004). Using Farrell (2004), nitrogen oxide was valued at \$1,000 per ton. After the social benefits and costs were given a yearly value, the net social benefit was derived by adding together all of the social benefits and then subtracting the value of each of the social costs.

Results

Table 3 provides the minimum price per kWh necessary to produce a positive NPV per cow for each of the thirty-two simulated scenarios. The results represent the most feasible of the feasible solutions. The lowest possible price necessary for a regional digester to be feasible is \$0.04 per

¹⁷ Liu, Shumway, and Myers-Collins estimated the profit from composting for 8,000 cows. They found that a cubic yard of composted dairy waste brought in a profit of \$3.58 per cubic yard. Using the fact that there are 1,127 lbs. in a cubic yard, this gives a net profit from selling compost at \$6.35 per ton.

¹⁸ The reason to use the amount of captured effluent that comes directly from the cow is to take away a potential bias from the 1.6 megawatt facility which uses 70 gallons of flush water per cow per day. This system would have a much larger benefit due to its usage of more water.

kWh. This price is based on the 10 MW facility getting public funding to offset transportation costs. Except for Scenarios C and H, this facility has a pricing advantage over the other digesters examined which demonstrates that there are economies of scale that exist for the larger facilities.

Table 3. Minimum Price per kWh Needed to Produce a Positive and \$100 (in parenthesis) NPV per Cow under Differing Assumptions for a Centralized Digester

Scenarios	Anaerobic Digester Engine Size			
	1.6 MW (Flush)	1.5 MW (Scrape)	4.2 MW (Scrape)	10 MW (Scrape)
Scenario A: Loan Rate: 9%; Participation Rate: 50% Capital Borrowed: 65%; Public Funding: No	7.50 ¢	8.00 ¢ (10.00 ¢)	8.50 ¢ (9.75 ¢)	8.25 ¢ (9.25 ¢)
Scenario B: Loan Rate: 9%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	10.00 ¢	8.00 ¢ (9.75 ¢)	8.00 ¢ (9.25 ¢)	7.50 ¢ (8.50 ¢)
Scenario C: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	8.50 ¢	5.75 ¢ (7.50 ¢)	6.50 ¢ (7.75 ¢)	6.25 ¢ (7.25 ¢)
Scenario D: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: Yes	6.00 ¢	4.50 ¢ (6.25 ¢)	4.50 ¢ (5.75 ¢)	4.00 ¢ (5.00 ¢)
Scenario E: Loan Rate: 9%; Participation Rate: 75% Capital Borrowed: 65%; Public Funding: No	9.00 ¢	8.25 ¢ (10.00 ¢)	8.00 ¢ (9.25 ¢)	7.75 ¢ (8.75 ¢)
Scenario F: Loan Rate: 9%; Participation Rate: 100% Capital Borrowed: 65%; Public Funding: No	> 10.00 ¢*	8.25 ¢ (10.00 ¢)	8.25 ¢ (9.50 ¢)	7.50 ¢ (8.75 ¢)
Scenario G: Loan Rate: 9%; Participation Rate: 75% Capital Borrowed: 100%; Public Funding: No	8.75 ¢	8.00 ¢ (9.75 ¢)	8.00 ¢ (9.25 ¢)	7.50 ¢ (8.75 ¢)
Scenario H: Loan Rate: 9%; Participation Rate: 50% Capital Borrowed: 100%; Public Funding: No	7.50 ¢	8.00 ¢ (9.75 ¢)	8.25 ¢ (9.50 ¢)	8.00 ¢ (9.25 ¢)

* For this case, a price greater than 10 ¢ per kWh is necessary to obtain a positive NPV.

The regional digester that needs the highest electricity price to be feasible is the 1.6 MW facility. The only scenarios when this system has a pricing advantage over the other systems are when the participation rate is 50%—Scenarios A and H.¹⁹ This result is occurring due to the high transportation cost of trucking the manure that has a high relative water content.

Examining scenarios A and D in the Table 6 shows what kind of effect public participation can make in enhancing the feasibility of a regional digester. For the 10 MW facility, having public support drops the price necessary for operation by \$0.0425 per kWh. The smallest drop that occurs is with the facility producing 1.6 MW, which only decreases the

¹⁹ Since each facility was designed to handle a certain amount of cows, some configurations with cows closer to the regional digester were discarded because they would have provided too many cows for the digester. Using a 50% participation rate allows these configurations to not be discarded, allowing a closer source of manure.

electricity price by \$0.015 per kWh necessary for the regional digester to become feasible. These results provide an interesting policy dilemma for the state government if it wants to encourage regional digesters. Should the state compel utility companies to pay a higher price to regional digesters as a policy matter? Or, should the state provide financial support to the regional digesters directly using some form of subsidization scheme? This answer will rely on how well the utility company can justify that the price it pays is a reasonable price.

For the systems that rely on dairies that use scrape systems, a positive NPV would be enough to induce dairies to participate in a regional digester. For those systems that are not currently using a scrape system, an extra incentive will be necessary to induce these dairies to participate in the regional digester. Since most dairies in the Central Valley have manure management systems that rely on flush manure management practices, they will need to expend some capital to change from flush to scrape systems. Since no data was found on what this cost would be, an estimate was provided by the Agricultural Engineer utilized for this project. He believes that on average it would take approximately \$100 per cow to make the change over.²⁰

The numbers in parenthesis in Table 3 represent the minimum price per kWh needed to generate at least an average \$100 per cow of NPV. Since the facility producing 1.6 MW of electricity was built around each dairy using a flush system, it was left out of these results because no incentive is needed. The facility producing 10 MW has the lowest minimum price needed at \$0.05 per kWh. This result occurs under scenario D where the public support is the highest. To obtain the extra \$100 per cow in NPV for this scenario, an increase of \$0.01 per kWh is necessary. This is also true for Scenario A. The facility capable of producing 10 MW

²⁰ It should be noted that this \$100 per cow has to cover two primary expenses. The first expense is the fixed capital cost necessary to change the system from a flush system to a scrape system. The second expense is related to the potentially higher labor costs associated with manure management based on a scrape system. Also dairies have the

has a pricing advantage over the smaller regional digesters demonstrating that economies of scale are occurring.

Comparing the facility capable of producing 10 MW to the 1.6 MW in Table 3 shows the importance of the participation rate. The reason these two should be compared is based on two reasons. First, it is expected that the facility producing 10 MW, which brings in \$100 per cow in NPV, is going to transfer that \$100 per cow to the dairy operator to changeover to a scrape system. This would imply that the net gain for the regional digester would turn to a small positive number, if not a breakeven amount, making it comparable to the facility capable of producing 1.6 MW. The second reason to compare these two facilities is because the 10 MW facility represents the most economically efficient in relationship to the other systems relying upon scrape manure management systems. As the participation rate increases, the 10 MW facility has a pricing advantage over the system that relies on flush manure management systems.

Given the evidence in the literature, \$0.10 per kWh is the maximum price that digesters are able to get from the public utility companies they sell their power to. Table 4 provides a look at the maximum NPV per cow if this price could be achieved. The facility capable of producing 10 MW of electricity dominates all other regional digesters examined in this study in generating the highest NPV. If you subtract out \$100 per cow for this facility, it still dominates the facility capable of producing 1.6 MW for participation rates greater than 50%.

The maximum amount of NPV that can be achieved for each cow is \$561.10, which occurs in Scenario D. The worse maximum NPV achievable for the regional digester capable of producing 10 MW is \$173.87, which occurs in the purely private model with a 50% participation rate. This would imply that the most feasible regional digester that is based on the purely private

opportunity to offset some costs of technical change by applying for state or federal funding, such as EQIP program funds.

model could compensate dairy operators up to \$173 per cow to change from a flush manure management system to a scrape manure management system and still maintain a positive NPV.

Table 4. Maximum NPV per Cow Given a \$0.10 Price per KWH under Differing Assumptions for a Centralized Digester in the Central Valley.

Scenarios	Anaerobic Digester Engine Size			
	1.6 MW (Flush)	1.5 MW (Scrape)	4.2 MW (Scrape)	10 MW (Scrape)
Scenario A: Loan Rate: 9%; Participation Rate: 50% Capital Borrowed: 65%; Public Funding: No	\$135.82	\$113.99	\$131.62	\$173.87
Scenario B: Loan Rate: 9%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	\$7.56	\$120.22	\$161.29	\$244.21
Scenario C: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	\$93.90	\$244.50	\$276.35	\$353.06
Scenario D: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: Yes	\$230.75	\$317.18	\$439.80	\$561.10
Scenario E: Loan Rate: 9%; Participation Rate: 75% Capital Borrowed: 65%; Public Funding: No	\$63.57	\$112.47	\$167.10	\$216.91
Scenario F: Loan Rate: 9%; Participation Rate: 100% Capital Borrowed: 65%; Public Funding: No	\$0.00*	\$108.58	\$150.51	\$234.02
Scenario G: Loan Rate: 9%; Participation Rate: 75% Capital Borrowed: 100%; Public Funding: No	\$71.71	\$123.96	\$177.13	\$227.06
Scenario H: Loan Rate: 9%; Participation Rate: 50% Capital Borrowed: 100%; Public Funding: No	\$144.01	\$125.40	\$142.62	\$184.14

* This particular scenario had no positive NPVs.

At \$0.10 per kWh, all three regional digesters provide a NPV greater than \$100 per cow under Scenarios A through H. This implies that if the regional digester can get this price for its electricity, it should still end up with a positive NPV after compensating the dairies to changeover to scrape systems. For the 1.6 MW facility, not all of the scenarios are giving a NPV greater than \$100 per cow. Only scenarios A, D, and H provide \$100 per cow. Scenario F for the facility relying on flush manure management systems does not provide a positive NPV at a price of \$0.10 per kWh. The best case scenario for this system is when the participation rate is low or public funding is used to offset transportation costs.²¹

²¹ This result is again an anomaly of the model. What causes this result is the scenarios with lower participation rates for hauling manure shorter distances.

Larger facilities appear to be more profitable on a per cow basis in comparison to smaller facilities. The 4.2 MW facility has a greater NPV per cow than the 1.5 MW facility under all eight funding/participation scenarios. Both of these facilities are dominated by 10 MW facility. This demonstrates that a subset of dairies in the Central Valley are close enough together that the increase efficiency in electricity generation outweighs the travel needed to get the manure to the facility. Further examination of the 10 MW facility shows that NPV is increasing with participation rate.

Summary, Conclusions, and Future Research

The goal of this study was to examine the tradeoff between different utility rates and policy intervention to induce dairy producer to come together under a regional centralized digester. To examine this issue, four regional digester business models were examined using GIS data and simulation techniques. There were three types of policies examined. The first policy examined what would happen if the regional digester received a subsidized loan for its capital equipment. The second policy examined was a subsidy given to the regional digester that offset the transportation cost of the manure to the centralized digester. This subsidy was based on the net value of the social benefits achieved from having a regional digester. The third policy examined was where the government requires all dairies to participate in the regional digester. A stylized model was given for developing the cost of transporting manure from the participating dairies to the regional digester.

It was shown that government intervention through a subsidized capital loan, a government payment for the positive net social benefit, and a requirement for all dairies to participate in the regional digester can reduce the price necessary to make a regional digester feasible by \$0.0425 per kWh in comparison to a purely public operation. This study also showed that economies of scale exist for regional digesters to become larger. The most feasible regional

digester examined was the 10 MW facility. This facility had the highest NPV for each scenario investigated. This system had a price per kWh that fluctuated from \$0.05 to \$0.0925 after compensating producers to change over to a scrape manure management system.

Results from this study demonstrate that a regional digester for the dairy industry in Central Valley of California can be feasible given that the digester can obtain \$0.05 per kWh and heavy government intervention or receive \$0.0925 per kWh with no government intervention. Since evidence suggests that electricity companies are unlikely to pay \$0.0925 per kWh necessary for a private regional digester to be feasible, it should be expected that if California wants regional digesters for the dairy industry, then some form of government intervention will be necessary to induce producers to come together as a regional digester.

There is much research left to be conducted regarding the feasibility of regional centralized digesters. While this study examined operating regional digesters based on dairy manure as the only input, review of the literature suggests that many anaerobic digesters operate using many different types of agricultural waste. There is a need for a study that provides an overarching vision for agricultural waste utilization that takes all types of agricultural waste and turns it into some form of usable energy like gas or electricity.

This study assumed that the regional digester would be located on a dairy operation due to efficiency gains in transportation and a gain in revenue due to sales that could occur for the dairy that the centralized digester is located. An analysis of locating the digester away from the dairy may prove fruitful.

This study looked at facilities that could produce up to 10 MW of power. Having shown that larger facilities are more profitable per cow over the smaller facilities begs the question how much larger the facility could get before the transportation cost starts to dominate the effect of

increased efficiency. Further analysis should be conducted to define the most profitable size regional digester.

A major assumption of this study is that it would take \$100 per cow to induce a dairy producer using a flush manure management system to changeover to a scrape manure management system. Further study is necessary to develop the necessary inducement for producers to make the changeover.

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