

Clustering of Independent Dairy Operators for Generation of Bio-Renewable Energy: A Feasibility Analysis

Report prepared for the California Institute for the Study of Specialty Crops

Sean Hurley
James Ahern
Douglas Williams*

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*Sean Hurley is an Assistant Professor, James Ahern is a Professor in the Department of Agribusiness at the California Polytechnic State University—San Luis Obispo, and Douglas Williams is a retired Professor from the Bio-Resource and Agricultural Engineering Department at the California Polytechnic State University—San Luis Obispo. Funding for this project has been made available by the Governor’s Buy California Initiative, the California Department of Food and Agriculture (“CDFA”) and the U.S. Department of Agriculture (“USDA”). The content of this publication does not necessarily reflect the views or policies of CDFFA or USDA, nor does any mention of trade names, commercial products and organizations imply endorsement of them by CDFFA or USDA.

EXECUTIVE SUMMARY

The Issue

According to the California Agricultural Statistical Service (CASS), California had almost 1.7 million dairy cows in 2003. These cows generated approximately four billion dollars in revenue, making the California Dairy industry the largest agricultural commodity in the state. These California dairies are estimated to have produced roughly thirty million metric tons of manure in 2003. According to the 2002 USDA census, eighty-seven percent of the dairy cows in California are located on farms of five hundred or more cows. Furthermore, the dairy industry is heavily concentrated in eight counties of California. This high concentration of dairies in the state implies that the manure from these cows is also highly concentrated in these same areas.

In 2003, the United States Environmental Protection Agency (EPA) released a significant revision to regulations of confined animal feeding operations (CAFO). Effluent guidelines and limitations were further laid out in this revision. According to EPA documents, a farm that has seven hundred or more mature dairy cows is considered a large CAFO and is required to obtain permits from EPA. These new regulations will require these dairies to have a manure management plan approved by the EPA. These new regulations are putting pressure on dairy producers to better manage the handling and disposal of the manure generated from these operations.

With the heavy concentration of cows on dairies in California, this new legislation could have a considerable effect on these producers. While some producers have enough farmable acreage to handle the manure generated by their operations, others may not. Additionally, these dairies are coming under increasing pressure to control not only the disposal of the manure but also the gaseous emissions from manure and its storage. For many years, effluent from a dairy operation has been used directly to fertilize crops if the producer had the land available. With the advent of the new EPA regulations, producers may begin to perceive manure more as a waste disposal problem rather than a resource prior to the regulations. These new regulations imply a need for a better solution to this issue.

This project provided an in-depth analysis of the financial feasibility of regional anaerobic digesters in California which capture methane from dairy manure produced from cows in the state. The emphasis of this project is placed on examining the feasibility of these multi-farm centralized digesters in the Central Valley.

Centralized Anaerobic Digesters Examined

There were four anaerobic digestion systems investigated in this project for developing a centralized digester. The first system examined a 1.6 megawatts facility that used a covered lagoon system to capture methane that is used to generate electricity. This system was reliant upon the participating dairies using flush manure management systems. Systems two, three, and four assumed that the dairies converted their operations from flush systems to scrape systems and participated in centralized digesters that were capable of producing up to 1.5 megawatts, 4.2 megawatts, and 10 megawatts of power. These three systems used a complete mix system to

capture the methane that is then converted to electricity. All four systems sold manure compost along with the electricity.

Each of the four systems was investigated under differing assumptions regarding the level of public support received and the level of participation achieved. In total, 32 scenarios were investigated. All the scenarios examined assumed a 15 year time horizon for the capital loans to be paid back.

The first set of scenarios examined purely private investment models and made up twelve of the scenarios investigated. These models assumed that producers would borrow 65% of the capital needed at an interest rate of 9%. Each of these models was investigated at three levels of participation by producers—50%, 75%, and 100%.

The second set of scenarios investigated different public investment models. These models were further categorized into three sets of scenarios. The first set of public scenarios was based on the assumption that producers would borrow 100% of the capital cost at 5% interest rate. This set was examined for the four different systems. Under these scenarios, all producers were required to send their manure to the centralized digester giving a participation rate of 100%.

The next set of scenarios assumed that the government would pay for the transportation cost up to the monetized value of the social benefits for the regional digester. This model also assumes that producers could get a 5% loan for their capital expenditure. This second scenario further assumed a participation rate of 100%.

The final set of public model scenarios provided 100% financing to the producers at a 9% interest rate. The scenarios were examined at three levels of participation—50%, 75%, and 100%. All of these scenarios were investigated using geo-spatial data and simulation techniques to identify the most feasible locations to locate regional digesters. In all three sets of the public investment models, the government would partake in facilitating preferential loan terms through legislation.

Major Findings

Since the majority of the dairies in the Central Valley use a flush manure management system, which is assumed in this study to use 70 gallons of water per cow per day, a centralized digester is generally not feasible using truck transportation. For the operations that were found feasible where dairies maintain flush systems, they relied heavily on locating the anaerobic digester facility near a dairy that has at least 5,800 milking cows and can source out the rest of the cows needed within a 1-mile radius of the digester. This result emphasizes the importance of trucking cost as an impediment to centralized digesters when a flush manure handling system is utilized.

If the government offsets the transportation cost up to the societal benefits of the centralized digester, the smallest dairy that the centralized digester would need to be located at would be 5,800 cows. This is only possible if this dairy can source out 3,600 cows within approximately one-half mile from its operation and receive 9.00 cents per kWh. If the government offered a 100% capital loan at 5% cost of borrowing with a 100% participation rate by producers, the

smallest dairy that could be used as the location for the centralized anaerobic digester would be 6,850 cows assuming the digester could get 10.00 cents per kWh. If the regional digester was located at a dairy with 7,000 and received public money to offset transportation costs, it would be feasible to operate the digester at 6.00 cents per kWh.

Since this 1.6 MW system relies on being located near large dairies (greater than 5,800 cows under the best case scenario), it would not be a viable solution for the state as a whole. In order to induce large dairies to participate in a centralized digester system rather than having each do their own, an incentive scheme that pays the large dairies the marginal value of their cows is needed.

While this study focused on using truck transportation for moving manure to the centralized digester, a piping/sewer system was briefly examined. It was found that there is limited evidence currently available on piping manure to a centralized digester. The evidence in the literature suggests it is not likely a viable solution because it is too costly from a capital standpoint to be feasible.

Table ES1 presents the price per kilowatt-hour (kWh) that will produce at least \$100 per cow of net present value for three different size anaerobic digesters investigated under differing levels of public support. This net present value was examined at a 10% discount rate over a fifteen year investment horizon. The reason for targeting a net present value of \$100 per cow was because it is assumed that this is the minimum amount of money needed to induce a producer to change over from a flush system to a scrape system.

Table ES1: Minimum Price per KWH Needed to Produce a Net Present Value of At Least \$100 per Cow under Differing Assumptions for a Centralized Digester in the Central Valley

Scenarios	Anaerobic Digester Engine Size		
	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	10.00 ¢	9.75 ¢	9.25 ¢
Scenario B: Loan Rate: 9%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	9.75 ¢	9.25 ¢	8.50 ¢
Scenario C: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	7.50 ¢	7.75 ¢	7.25 ¢
Scenario D: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: Yes	6.25 ¢	5.75 ¢	5.00 ¢

Scenario A in Table ES1 is the purely private investment model where the producer must meet conventional loan terms and is only able to solicit participation from approximately 50% of the dairies around it. Under this scenario, a 1.5 megawatt facility could be feasible if it could sell its excess power generated at a price of 10.00 cents per kWh.

Scenario D, the publicly funded scenario, assumes that the government will supply a low cost loan at 5%, require every producer to participate in the system through some sort of regulation, and provide an offset to the transportation cost up to the amount of public benefit from having an

anaerobic digester. The 10 megawatt facility is the most feasible under this scenario with a bottom end price of 5.00 cents per kWh.

Scenarios B and C are gradations of Scenarios A and D that rely on 100% capital financing at two different interest rates. For the facility capable of producing 10 megawatts of power, Scenario C becomes feasible at a price of 7.25 cents per kWh, while scenario B is feasible at a price of 8.50 cents per kWh. Hence, dropping the borrowing rate by four percent decreases the price of electricity by 1.25 cents per kWh to make this operation feasible.

The 10 megawatt facility is the most feasible of the three systems from a price standpoint. The 10 megawatt facility also has the ability to be located in more areas across the state than any of the other systems as well as having the ability to reach further out in terms of transporting the manure to the digester while maintaining feasibility.

While Table ES1 provides information on what price is needed to make each regional digester feasible, Table ES2 provides the highest net present value per cow achievable if the digester can receive 10.00 cents per kWh. This table represents the best case scenario for each size of regional digester. Scenario D, where the public provides support to offset transportation costs, has the highest net present values for each regional digester. The highest net present value achievable occurs at the regional digester that has the capability of producing 10 megawatts of electricity.

Table ES2: Maximum Net Present Value 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

Due to the relatively low cost of water in comparison to labor, producers in the Central Valley apparently have chosen flush dairy systems rather than scrape systems. In this current environment, it is generally infeasible for most dairies to participate in a centralized digester because the cost of transportation is prohibitively high due to the greater volume of water hauled. For those producers who can band together and continue to use a flush system, they will have a lower net present value per cow than the systems that changeover to scrape systems because the transportation of the manure to the centralized digesters is relatively high in comparison to scrape systems.

If producers move over to scrape systems, there are many locations in the state that would make it feasible for producers to participate in a centralized digester assuming they could get a

reasonable price for selling their power to the grid. As the EPA and regional water control boards tightens the constraints on how dairy producers dispose of their manure, producers over time may find that these regulations push them to change their current flush systems to scrape systems to more efficiently manage the disposal of the manure. This would produce an environmental benefit by reducing water consumption by dairies.

The Policy Implications

The results above are heavily dependent upon how the California regulatory environment interacts with these proposed regional digesters. The feasibility of these operations was heavily dependent upon a regulatory environment that is conducive to facilitating the building of these regional digesters. It would not take much in the way of added regulatory costs to make most of the feasible regional digesters in this study infeasible. Hence, if the California state government is interested in facilitating the building of regional digesters, it should consider the following policy recommendations:

- 1) The state government should develop policies to remove any unnecessary barriers for producers to sell their power to the electrical grid. Accompanying this reduction in barriers should be policies that allow producers to get reasonable prices for selling their power to the grid. In many instances found in the literature on the topic of regional digesters, it is not uncommon for producers to receive between 4.00 to 5.00 cents per kWh if they sell their power to the grid. Under this pricing regime, most regional digesters from this study are infeasible.
- 2) For centralized digesters to be successful, there is a need for policies that facilitate the production of these facilities. Three of the major policies the California government could implement are: a) low cost loans to producers who want to develop these facilities, b) fast track permitting that will allow these operations to come on-line more quickly, and c) developing a regulatory environment that does not cause transportation of manure using trucking to become overly cost prohibitive.

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Chapter 1: Introduction

Discussion of 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 (lower average costs) has been in juxtaposition to the increasing suburban pressures that are growing around the dairies in many states, especially in California. 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. This has further resulted in less crop land area available for recycling manure as fertilizer in traditional and environmentally sound ways (Hughes and Wilkie, 2005).

According to the California Agricultural Statistical Service (CASS), California had almost 1.7 million dairy cows in 2003. These cows were utilized by California producers to generate approximately four billion dollars in revenue, making the California dairy industry the largest agricultural commodity in the state. California dairies led the nation in milk production with 35.4 billion pounds. While these dairies have managed a high level of output of milk, they have also generated a large amount of manure. Using a conversion developed by Nennich *et al.*, California dairies are estimated to have produced roughly thirty million metric tons of manure in 2003 (2003).¹

According to the 2002 USDA Census of Agriculture, eighty-seven percent of the dairy cows in California are located on farms of five hundred or more cows. Furthermore, the dairy industry is heavily concentrated in eight counties of California—Fresno, Kings, Merced, Riverside, San Bernardino, San Joaquin, Stanislaus, and Tulare. These eight counties account for approximately eighty-four percent of the dairy cows in the state. This high concentration of dairies in the state implies that the manure from these cows is also highly concentrated in the state. When examining the average number of dairy cows per farm that have over five hundred head of dairy, Stanislaus has the lowest average of the eight counties with nine hundred fifty-eight cows, while

¹ Nennich *et al.* 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 (2003).

Tulare has the highest average with one thousand seven hundred seventy-nine cows (USDA National Agricultural Statistics Service, 2002).

In 2003, the United States Environmental Protection Agency (EPA) released a significant revision to regulations of confined animal feeding operations (CAFO). These regulations focused on defining what operations were considered CAFO's and which operations needed to have waste water pollution permits from EPA. Effluent guidelines and limitations were further laid out in this revision. According to the document, a farm that has seven hundred or more mature dairy cows is considered a large CAFO and is required to obtain EPA permits. These new regulations will require dairies with seven hundred or more cows to have a manure management plan that must be approved by the EPA (EPA, 2004). With the heavy concentration of cows on dairies in California, it appears that this new legislation could have a considerable effect on these producers.

EPA's new regulations of dairies require that producers develop a plan for disposing of their manure. While some producers have enough farmable acreage to handle the manure generated by their operation as a supplement to fertilizer, others do not. Additionally, these dairies are coming under increasing pressure to control not only the disposal of the manure but also the gas emissions from manure storage. The San Joaquin Valley Air Pollution Control District has estimated that each dairy cow emits 19.3 pounds of Volatile Organic Compounds (VOC's) each year, which would rank the cows as the largest polluter in the Valley, exceeding the emissions from light trucks and cars (San Joaquin Valley Air Pollution Control District, 2005).

For many years, effluent from a dairy operation was used to fertilize crops if the producer had the crop land available. To handle this effluent, many dairies invested in lagoon systems to store their manure before they spread it on their crops. If there was any leftover manure that could not be spread on crops, it was viewed as a waste product that needed to be disposed of. With the advent of the new EPA regulations and increasing scrutiny on how manure is applied to the land, producers may begin to perceive manure more as a waste product than a resource prior to the regulation. Even though many dairies are utilizing some of their manure as fertilizer for crops, the new EPA regulations will bring greater scrutiny on how the manure is utilized (e.g.,

application rates) on farm land. This implies a need for a better solution for manure management in the state.

According to the AgStar Handbook, in the late seventies and early eighties, some producers attempted to turn their effluent from their operation into a new resource. A small group adopted technology that turns manure into methane gas and electricity. While some of these dairies were successful, others were not. Those dairies that were successful found that their manure had a new possibility of becoming an income generating resource for them. By converting the manure to methane via anaerobic digestion they found that they could capture these volatile organic compound gases and create a renewable energy source. Over the last thirty years, technology for creating energy and biogas from manure has advanced considerably.

There are many issues producers must contend with when they want to turn manure into an energy resource. Many of these issues can be related to the size of the operation. 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 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. For example, if a dairy producer would like to sell her power to Southern California Edison, she would need to provide evidence of financial stability, an outline of her approach to quality assurance, and evidence that the business has the “management and technical ability” to provide the product she is selling (Southern California Edison, 2006). Many dairies may not have the desire to go through this process.

One answer to all the issues stated above is to develop a regional or centralized digester to handle the manure from many operations. Another answer is to link a group of producers who have digesters on-site to a local business entity that would handle any excess power and/or

digested manure the producer may have. The question that needs to be answered is what method would be most economically feasible and beneficial to all stakeholders involved?

There have been a few attempts to examine whether it would be profitable to link farms together to create power and bio-fuels. Hjort-Gregersen reports the financial aspects of a centralized biogas facility in Denmark (2002). He explains that the biogas plants in Denmark have demonstrated sustainability both from an economic as well as an environmental standpoint. Producers who were involved in these types of facilities found economic gains from manure storage and transportation, and in fertilizer costs. Currently, Denmark has approximately twenty of these centralized biogas plants in operation and hundreds of farm scale biogas plants.

Recent research conducted by Bartram and Barbour examined the environmental benefits from a regional digester utilizing dairy manure in California's Chino Basin (2004). A group of stakeholders, including fourteen dairy operators, have come together to test the concept of operating a regional digester to help control the issues that arise from the heavily concentrated dairy operations in the area. The business model that this project is using is public private partnership run through the Inland Empire Utility Agency. It is estimated by Bartram and Barbour that this project will generate a reduction of the following:

- Sixty-nine tons of methane per year,
- Twenty-two tons per year of nitrous oxide, and
- One hundred seventy-one tons of ammonia per year.

The Issue Examined

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 in-depth analysis of the feasibility of regional digesters in California for handling dairy manure, focusing specifically on the Central Valley. Differing regional digesters business models are examined to determine if it is feasible to operate a regional digester in the Central Valley. An estimate of the environmental benefits is examined

as well as the policy implications of providing incentive for producers to participate in a regional digester system and/or a regional power distribution system.

Objectives of the Research Project

The goal of this project was to examine the feasibility of operating regional anaerobic digesters in California which would handle only dairy manure. To meet this goal, four primary objectives were developed for the study. These objectives were the following:

- ❑ Objective 1: Develop a technical bio-energy system to handle manure from a cluster of dairies for six different scenarios

- ❑ Objective 2: Examine the feasibility and profitability of each regional digester system developed

- ❑ Objective 3: Estimate the potential environmental and social benefits of each system

- ❑ Objective 4: Investigate the policy implication of developing a regional digester

The only objective that was modified as originally written was the first objective. Instead of analyzing six scenarios, thirty-two different scenarios were examined.

The rest of this report is broken-up into the following chapters. Chapter two provides a brief overview of studies conducted on anaerobic digestion. Also presented in this chapter are the policies that have been enacted both by the United States and Europe to support renewable energy like biogas. Chapter three explains the methodology used to investigate the feasibility of anaerobic regional digesters in California. The fourth chapter presents the major results and findings from the study. The final chapter gives a brief summary of the study, its findings, the policy implications, and future research needed.

Chapter 2: Review of Studies on Anaerobic Digestion and Centralized Digesters

Anaerobic Digestion Process

A dairy lagoon that holds manure that is not aerated is a natural environment for biogas (BG) to be produced. Biogas is the result of an anaerobic (without oxygen) process where bacteria feed on organic material. One prime source of this organic material can be found in agricultural waste products like dairy manure. The process converts a range of organic solids to sugars and amino acids, which through fermentation creates volatile fatty acids. These fatty acids through the processes of acidogenesis and methanogenesis produce biogas (Lusk, 1996). These processes require the accumulation of wastes being fed into a digester that produces biogas (about 60% methane-CH₄, 35% CO₂, and 5% other gases), while allowing the reactions to run from 15 to 40 days—their hydraulic retention times in the digester.

The natural production of biogas can be enhanced using technology. There are multiple types of digesters that are used to convert dairy manure to biogas. The three primary types are the covered lagoon system, the complete mix system, and the plug flow system (EPA, 2002). A covered lagoon digester is a digester that places a cover over an earthen basin to capture the gas emanating off the lagoon. This system is best suited for flush type manure management systems that maintain a solid content between 0.5% and 3%. The complete mix digester dumps fresh manure with a solids content between 3% and 10% into a heated tank.² This tank has a pump in it which continuously churns the manure. The plug flow digester is a long heated tank, usually built into the ground and has a gas tight cover over the top of it. Fresh manure with a solid content ranging between 11% and 13% is placed in a heated system on a daily basis. As new manure is pushed through the entrance, digested manure exits the other end of the digester. The plug flow and complete mix systems provide a steady flow of gas throughout the year. Each is also well suited for scrape manure management systems. In warmer climates a covered lagoon will also steadily produce gas. A covered lagoon tends to be the cheapest digester to build, while the complete mix system is usually the most expensive to build.

² Some people will push the solid content up to 12%.

The continuous flow of dairy manure with the natural production of biogas in a typical non-aerated lagoon makes anaerobic digestion a potentially reliable fuel source. To date, most evaluations have found biogas to be a relatively costly source of electrical power in the period up to 2002; subsequently, fossil fuel prices have soared, showing no recess through mid 2006. This has allowed for biogas production as a producer of energy to become a more feasible opportunity. Some governments, Sweden in particular, have viewed cleaned/scrubbed biogas as a relatively cheap source of vehicle fuel and see its greatest value in that arena, as an alternative to fossil fuel.³

Farm Scale Anaerobic Digester Studies

In the US, “farm scale” anaerobic digestion plants have received the most attention, especially in the larger scale dairies in the dairy industry; however, in some European countries (Denmark and Sweden) centralized biogas plants have integrated energy production (combined heating and power-CHP), manure-organic waste treatment, and nutrient redistribution facilities. The last two items have been important primary or secondary issues for various agricultural groups in the US. Germany appears to have accepted anaerobic digesters at the farm scale where they have high numbers of small farm scale biogas plants in operation. The number of these operations continues to grow. Several European countries and the United States have used anaerobic digesters widely and in an intensive mode handling municipal solid waste (MSW) and landfill gas systems capturing methane (Holm-Nielsen and Al Seadi, 1997).

The efforts in the upper Midwest in anaerobic digesters of animal manures are reflected in a paper by Kramer (2004). He reports new operations of anaerobic digesters and also the temporary or permanent closure of five anaerobic digester plants since 2002. Fourteen dairies milking over 22,000 cows (herds ranged from 675 to 3750 head) had anaerobic digester operations in the region, producing approximately 5.5 megawatts of capacity (Kramer, 2004). This did not account for one swine and one duck anaerobic digester operation. Ten of those dairies reported capital cost of development, which totaled over \$5 million. The operations include the well documented Haubenschild (Minnesota) and Gordondale (Wisconsin) Farms.

³ Sweden has few known fossil fuel resources.

Kramer presents the non-market social benefits, but only in discussion where no apparent attempt was made to monetize.

California is the site of one of the earliest (1982) United States experiments with anaerobic digesters, at the 350 cow Langerwerf Dairy in Durham. This facility is one of the oldest facilities in the US. This operation was smaller in size and only utilized the manure production from a single farm with no co-digestion (Riggle, 1996).

California efforts in anaerobic digestion have been expanding. Two well known dairies recently installed flush system lagoon anaerobic digesters in 2005. The Straus Family Creamery (Marin County) is one of these dairies. They sell a branded well known organic milk product produced with less than 300 head of cows and try to emphasize sustainability.

The Joseph Farms (Atwater, Merced County) is a well known cheese producer with one of its dairy locations serving 5000 head for CHP. Joseph Farms continues to improve its methane digester system that generates power for operations. The lagoon digester has a seven acre anaerobic covered lagoon which generates biogas. The gas is scrubbed and then piped to two power generators. One generator produces 300 kWh of electricity and the other produces 400 kWh. The power generated by these two large generators is used to provide electricity for Joseph Farms Cheese Plant. Heat captured from the generators and exhaust is used to heat water for the cheese plant usage, off-setting some of the need for propane to heat boilers. As much as 80% of the power required to operate the cheese plant is supplied by the system (Joseph Farms, 2006).

Regional or Centralized Digester Studies Operating in the United States

California is site of one of the larger centralized digester operations begun in 2001 in San Bernardino County. This operation is run by the Inland Empire Utilities Agency (IEUA) which runs both complete mix and plug flow digesters. This operation currently covers the manure output of 14 dairies with 300 tons wet manure daily and 90 tons of food waste. This facility is producing over 680,000 cubic feet of biogas per day, which equates to a facility that can produce

approximately 1.5 megawatts of capacity of power production (IEUA, 2005a, 2005b, and 2006). All indications are that this operation is running successfully.

IEUA (San Bernardino-Riverside area) on-going experiments with anaerobic digestion reflect application rather than mere feasibility. They report positive results with their operations of multi-dairy scrape and haul system. Their approach is somewhat capital intensive compared to other systems, but their positive initial results, grant support, and revenue sources from other parts of their regional drainage area activities provide the capital and confidence to proceed. The entity (firm) handles several forms of solid waste with charges of reducing the environmental burden of human and agricultural effluents while improving ground water system recharge and avoiding effluent deposition. The number of dairies participating has increased and they claim to handle the effluent of 14,000 head of cattle (IEUA, 2005a, 2005b, and 2006).

The Port of Tillamook (Oregon) is another well documented on-line effort at energy creation from a centralized dairy manure waste anaerobic digester. Tillamook began operations two years in 2003. The Port of Tillamook effort in centralized manure digestion apparently has not been quite as successful financially as IEUA. This system was developed to handle manure from approximately 4,000 cows. Tillamook's biogas output has not been as good and revenues have not quite been sufficient to cover costs. While producing energy, it has had trouble generating sufficient cash flows to cover costs and is seriously addressing those issues. High costs of hauling manure and low revenue value appear to be its greatest nemeses (DeVore, 2006). The Tillamook operation was getting approximately \$0.042 per kWh and \$3 per cubic yard of compost. Their price received for electricity was too low to make the project financially viable long run without other sources of revenue. In order to meet the shortfall, the Tillamook operation has examined charging tipping fees of 80% of the transportation cost to the farmers, attempt to increase the amount they receive for their power generation to approximately \$0.06 per kWh, increase the efficiency of transportation and power generation, and develop a revenue source from selling greenhouse gas credits (DeVore, 2006; Thompson, 2001).

Regional Centralized Digester Feasibility Studies Conducted

King County, Washington (the Enumclaw Plateau-south and slightly east of Seattle-Tacoma urban areas) study evaluated the development of regional and on-farm digesters for dairy waste manure. Their average waste hauling distance was 2.5 miles for their centralized digester. The project was thought to rely upon receiving sufficient returns to solid fertilizer byproducts of anaerobic digestion above the energy production value. The situation was found to favor a centralized digester system. They estimated a roughly \$8 million investment to process the effluent of some 6000 cows, while providing net revenues of slightly over \$1 million annually. This equates to an internal rate of return of 13.8% with an 8.6 year payback period (Environmental Resource Group, 2003). This included generating over 200 acre feet of water clean enough to re-use or enhance water quality and generate nearly 50,000 tons of solid and liquid fertilizer products. Their estimates valued (revenue) from byproducts at four times the energy potential (p. 45-46).⁴

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). Her analysis used electricity valued at \$0.015 per kWh and \$19 per yd³ digestate byproducts value. She found that no project was successful, via positive NPV, until a 10% renewable energy production tax credit was granted. Only 29% of farmers surveyed reported being “highly” or “very highly” interested in such a project.

A Vermont study by Bennett provided a unique twist with a ready market for both heat and power (CHP) generated (2004). This market was driven by the local state prison facility that was willing to purchase the regional digesters’ power and heat produced from the anaerobic digestion process. Bennett looked at many alternative manure handling systems by examining different combinations or sizes of anaerobic digesters seeking the best response. He found that costs of transporting manure seemed to overwhelm the potential. He discovered that when the value of

⁴ It should be noted that this study estimates that the cost to clean-up digested effluent to potable level is \$1.50 per thousand gallons. This cost was estimate given by a salesman of the technology that was being investigated. It is unclear how accurate this number is considering an efficient desalination plant has a similar cost of cleaning

byproducts and social values were added into the valuation of the project, a single centralized digester could be feasible. He found a positive cash flow if 50% of capital costs were paid for through government grants. The single large scrape and haul central digester, costing nearly \$6 million, provided the needed economies of scale and met the prison energy needs best. He evaluated a piping scenario, but found many difficulties related to the effluent's properties and the climate reduced its viability.

Regional/Centralized Digesters in Europe

While anaerobic digestion is not a new technology, the adoption at a commercial scale is relatively new in the United States. Europeans have approximately a ten year lead on Americans in developing this area of on-farm energy production. In 1997, European Union countries were reporting 765 animal manure based biogas plants of all types in twelve of the fifteen member countries; only France, Ireland, and Luxemburg were non-producers. Germany with its 500 smaller farm scale plants had the greatest number of biogas facilities, while the largest producer of energy from biogas was Denmark with forty (half centralized, half farm scale) plants. Sweden was the second largest producing country of biogas at 40% of the Danes production (Holm-Nielsen and Al Seadi, 1997). Methane used as a vehicle fuel has increased six fold in Sweden over a ten year span since 1995 and about 45% of that was from biogas. The potential growth anticipated from farm biogas by the year 2020 is 753 PJ.

By 2004 there were over 2200 agriculture/food based biogas plants in the European Union, which was targeting 10% of fuel use from methane by 2020. Cumulatively there are some 400,000 non-petrol (natural gas/cleaned biogas) vehicles in Europe fueling at over 1,700 stations with hundreds more being built (Jönsson, 2005).

Denmark built its first centralized biogas plant in 1984 at a time when there was pressure to reduce the burden of animal manure on the environment. This pressure led to stricter manure handling regulations being strengthened in 1987. Farmer restrictions on manure storage and time periods of application on crop land were put in place and anaerobic co-digestion was seen as a

seawater to a potable level for this cost. It is unlikely at this time that the cost of upgrading seawater is the same as the cost of upgrading digested effluent to a potable level.

way of managing those problems (Hjort-Gregersen, Nielsen, and Raven, 2002). Twenty years later, a parallel issue to the Denmark experience is developing in the western United States with large dry lot confined animal feeding operations (CAFO).

In Denmark centralized anaerobic digesters for biogas CHP cumulatively produced 1 PJ per year, comparable to all Danish landfill biogas plus 100 sewage plants producing 1 PJ per year also. Sorensen claimed that in 1996 centralized biogas plants no longer required incentives for establishment. This was reflected in 11 more plants in the planning stage, while eighteen of the twenty centralized Danish biogas plants had been built (Sorensen, 1996).

In the wake of the Kyoto Protocol, which requires a limit on greenhouse gas emissions, the European Union has stressed the importance of anaerobic digestion to its constituency (Hjort-Gregersen, Nielsen, and Raven, 2002). This has been a contributing factor to the European Union's push of anaerobic digestion of agricultural waste. Euro trading of greenhouse gasses has driven the market price of \$25 per ton of carbon equivalent in 2005 or more than five times the value quoted at the Chicago Climate Exchange. This reflects the greater maturity of the European market and the compulsion felt by European Union's directives to meet the Kyoto Protocol requirements. However, the United States' disinterest in Kyoto Protocol seems to have set the stage for its industries to not improve renewable energy production forms as compared to the more aggressive approach taken by the European Union.

Policy Devices/Instruments Used by Governing Bodies to Support Biogas from Anaerobic Digestion

In both a policy and production sense many European countries are far ahead of the United States in terms of acceptance of renewable energy activities. European countries have mandatory acceptance of purified biogas (97% methane) or electricity into gas/electric grid systems. Cross industry coordination is important in Europe and mandated by *EU Directive 98/30/EG of 2003*, "The Gas Directive." This directive requires that biogas be allowed full access to the Natural Gas grid, if national specifications are met (in Sweden that means 97% methane minimum).

Europe's power systems are taxed for CO₂ emissions, which is tied to meeting the Kyoto Protocol. Carbon dioxide taxes are used to fund long run renewable energy investment. In 2001, a proposal was floated to increase biogas production ten fold with the thought that capital investment and job creation would outweigh the program's grant subsidies' cost. Capital construction grants are provided to developers of alternative energy systems in the most developed European biogas producing countries. Some countries, for example Austria, have not found biogas production to be very effective or successful and have far fewer incentives; however, Germany is constructing several hundred biogas plants and finds the process a low cost treatment for organic wastes. Denmark, Sweden, and Germany appear to be the leaders in biogas production from agricultural byproducts.

Denmark Policies

Denmark appears to be the leader in Europe for renewable energy where they develop biogas from manure, food wastes, and other biomass, as well as wind energy. Denmark expects to increase biogas production ten fold by 2025 with concurrent reduction in greenhouse gas production. The Danish have set a goal that 9% of energy use will be produced from biogas by 2030. In order to meet this goal, Denmark has developed a policy that requires a set minimum price per kWh for a twenty year horizon for biogas and other renewable energy sources, which is derived from the Danish EEG Act. This act is meant to improve energy supplies, energy independence, and meet Kyoto Protocol requirements of the European Union (Hartman and Ahring, 2005). Danish energy policy issues that have focused on anaerobic digestion include the following:

- Priority purchase of biogas by obligation
- Production grant of 0.056 €/kWh capacity, investment incentive⁵
- Tax exemptions for biogas and anaerobic digester related to heat generation
- Six to nine months of manure storage capacity
- Prohibit organic waste in landfills and tax incineration of waste
- Investment incentives to change plants from fossil fuel to biogas
- Incentives for R&D and pilot plants for biogas

⁵ This is roughly equivalent to \$0.07 per kWh in the United States.

Sweden Policies

Sweden does not have a biogas program per se, rather it has developed many policies between 1998 and 2003 that encourage biogas production from local investment program. Some of the policies that have been conducive to biogas production have been 1) a policy related to reducing landfill burden or reception, 2) biogas tax free for vehicle fuel for ten years, and 3) climate investment programs.

Sweden has a strong tax policy on waste disposal to encourage renewable energy. It has levied effluent taxes on landfill waste, and has taxes for incinerating waste without energy recovery. While Sweden taxes waste that is incinerated for energy, it is at a lower rate than the previous two possibilities. Swedish law (2005) prohibits organic wastes in landfills, which compels alternative handling. Auken believes that this law has allowed Sweden to reduce the amount of organic waste material in landfills to 20% (2005). To put this value into perspective, the city of Seattle has approximately 50% of its organic waste going to landfills.

To further encourage biogas production, Sweden is now using “set aside” land for producing renewable biogas feedstock crops. Sweden has treated digested agricultural waste as a usable soil conditioner/fertilizer whose value was considered crucial to the financial success of anaerobic digesters. Biogas plants in Sweden uses human food wastes, but not human sludge or beef SRM⁶, in thermophillic (55°C) systems to pasteurized the digestate to make it suitable for food crop farming. They also have had a national standard for biogas in vehicles since 2003. Sweden’s has made great strides in biogas production through its R&D program. It is reported that the Bromma biogas plant in Sweden is producing biogas cheaper than gasoline.

Germany Policies

Kottner, with the International Biogas and Bioenergy Centre, finds that agriculture in Germany has the largest potential for biogas production, with a potential of establishing 220,000 biogas plants (2001). This potential would be enough to produce 3% of stationary electrical demand or 11% of natural gas consumption in Germany. He claims that in 2000 Germany had 1250 biogas

⁶ SRM refers to specified risk material byproducts of beef processing. These animal parts are considered a threat to carry BSE.

plants. One of the reasons Germany has been successful establishing biogas plants is because it has a policy that allows a biogas plant to receive a guaranteed minimum price for twenty years.

The minimum price that a biogas facility can receive is based on the amount of electrical output of its digester system. If the biogas is produced from a farm up to 500 kilowatts capacity, the farm can expect to receive a price of 0.102 €/per kWh. A facility that produces between 500 kilowatts to five megawatts receives a guaranteed minimum price of 0.092 €/per kWh. A price of 0.087 €/per kWh is guaranteed for production levels between five and twenty megawatts of capacity.⁷ Also, participants can receive a 30% subsidy of construction costs. Germans are attempting to modularize components, which they believe will bring down costs. This should allow them to maintain their yearly production of biogas plants at approximately 600 per year.

US Policy Vehicles for Anaerobic Digestion

The Energy Bill of 2005 sought to diversify United States energy supply by promoting alternative and renewable energy sources. The bill extended production tax credits for wind, biomass, landfill gas, and other renewable electricity sources. It also offered new incentives to promote clean, renewable geothermal energy, and created a new tax credit for residential solar power systems (Office of the President, 2005). This energy bill was seen by some as insufficient support for renewable energy in favor of greater support for oil and coal sectors (Krathwohl, 2005). The administration thought that by developing these innovative technologies it would stabilize energy and encourage energy use produced domestically. Lesser dependence on foreign sources of energy enhances the use of our own renewable sources of energy, which were targeted for 19% of the bill's production tax credits and \$800 million in development bonds (Office of the President, 2005; Krathwohl, 2005).

Net metering appears to be the most common concession by states and utilities to alternative small scale energy producers in United States and for biogas produced electricity in particular. This policy requires power producers to allow small scale energy producers the ability to hook-up to the grid and receive retail rates for at least a portion of the power that they produce. Under

⁷ At the time this report was written, a euro was worth approximately \$1.28. This would imply that the farms with anaerobic digesters are receiving between \$ 0.11 and \$ 0.13 per kWh.

such systems, biogas producers pay for only net electricity used, but receive no net payments even if merited. Economically, this coerces a “breakeven” or cost avoidance situation at best, thus a lesser incentive in a market economy.

Eighteen American states and the European Union have passed laws targeting 20% sourcing of electricity from renewable fuel sources by 2010 (Bustillo, 2005). Some states are moving forward without federal leadership to reduce greenhouse gasses, including six northeastern states in a “Governors Climate Action Plan” (Hurley, 2005). These states have used the argument that improving climate science indicates that aggressive action is needed to reduce greenhouse gas emissions toward the ultimate goals of stabilizing the earth’s climate and eliminating the negative impacts of climate change (New England Governors/Eastern Canadian Premiers, 2001). Similarly, western United States governors have taken action on air pollution, as exemplified by the Governors of Oregon, California, and Washington pact to reduce fossil fuel use and greenhouse gasses in the environment and their local economies (Kulongoski, 2004; Kulongoski, Locke, and Davis, 2003).

Environmental Quality Incentives Program Funding

The Environmental Quality Incentives Program (EQIP) was enacted in 1996 Farm Bill as a voluntary assistance program for livestock producers in meeting federal and state environmental regulations (Grossman 2006; California NRCS, undated). Congress reauthorized EQIP through 2007 in the 2002 Farm Bill, and also increased authorized funding significantly. Federal financial assistance is available to help livestock producers meet air and water quality requirements of the Clean Air Act and the Clean Water Act, and other environmental laws. USDA's Natural Resources Conservation Service (NRCS) administers the EQIP program. This agency published final regulations for EQIP in May 2003 (Grossman, 2006).

EQIP is intended to help producers meet environmental quality criteria, to provide assistance to install and maintain conservation practices, and to streamline conservation planning and regulatory compliance. EQIP focuses on beneficial, cost effective changes to animal agriculture’s nutrient management problems. The program helps producers to comply with regulatory requirements for soil, water and air quality, wildlife habitat, and surface and ground water conservation. Under NRCS regulations, reduction of various types of non-point source

pollution is first priority, which appears to fit well with anaerobic digestion and planned use of mineralized nutrient digestate or rest product. A second priority is reduction of emissions of regulated air pollutants (Grossman, 2006).

EQIP authorizes one to ten year contracts with producers implementing eligible environmental and conservation practices in exchange for cost-sharing, incentive payments, and technical assistance. Animal waste management facilities, such as anaerobic digesters are included specifically (practice code numbers 365 and 366), as a structural "practice," as are land management practices (including nutrient and manure management), and comprehensive nutrient management (practice code number 590) planning practices. Residue, nutrient, pest, and air quality management effects can affect the amount and rate of incentive payments for a practice (Grossman, 2006).⁸

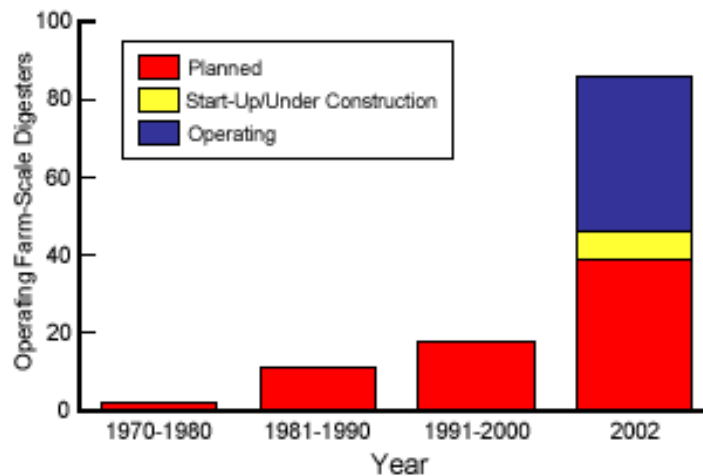
The 2002 Farm Bill made more EQIP money available to livestock producers, and targeted 60% of program funding nationally for environmental livestock production practices. Livestock producers throughout the United States are eligible, and even large facilities may qualify for payments for construction of waste management facilities. A livestock producer whose plan of operation includes an animal waste storage or treatment facility is eligible for cost-share payments if, along with other requirements, that producer develops and implements a comprehensive nutrient management plan (Grossman, 2006).

AgSTAR - US EPA

The AgSTAR Program is a voluntary program jointly sponsored by the United States Environmental Protection Agency, the United States Department of Agriculture, and the United States Department of Energy that encourages the use of methane recovery (biogas) technologies at confined animal feeding operations (CAFO) that manage manure as liquids or slurries. These technologies reduce methane emissions while achieving other environmental benefits.

⁸ Waste storage, treatment, treatment lagoons, and utilization are practice code numbers 313, 629, 359, 633 respectively.

According to the EPA, “the AgSTAR Program has been very successful in encouraging the development and adoption of anaerobic digestion technology (Winter 2006).” Since 1994, the number of operational digester systems has doubled, which has produced significant environmental and energy benefits. Methane emission reduced approximately 124,000 metric tons of carbon dioxide equivalents and annual electricity generation of thirty million kWh. The graph below reveals the growth in on-farm or farm scale anaerobic digester units for biogas recovery technology from animal waste.



Source: EPA AgSTAR Program: Accomplishments (2006)

The AgStar program analysis suggests that over 2000 livestock facilities could effectively utilize anaerobic digestion. In the period between 2004 and 2006, the number of operational digester systems has increased by 30%. EPA states that there are several factors over the past few years influencing the market demand for anaerobic digesters (EPA, Winter 2006). These include:

- “increased technical reliability of anaerobic digesters through the deployment of successful operating systems over the past five years;
- growing concern of farm owners about environmental quality;
- an increasing number of state and federal programs designed to cost share in the development of these systems; and
- the emergence of new state energy policies (such as net metering legislation) designed to expand growth in reliable renewable energy and green power markets (EPA, Winter 2006).”

California Anaerobic Digester Related Policy

On April 11, 2001, the governor of California signed into law Senate Bill 5x, the Dairy Power Production Program. This bill specifically supports biogas production projects in California by allocating \$10 million in grants for either buying down capital expenditure or paying incentives to produce electricity from biogas. These grants are administered by the Western United Resource Development, Inc. (WURD) for the California Energy Commission. The capital buy down grants would pay up to 50% of capital costs (with a maximum of \$2000 per kilowatt capacity). As of 2003, ten projects have been approved for funding and will have an estimated capacity planned of about 1.665 megawatts when fully operational. The buy down provision pays for construction costs as incurred and incentive grants pay after completion. Forty-six out of the forty-seven projects applied for were for on-farm biogas systems. As of June 2003, WURD was considering centralized biogas plant projects, but has identified the high cost of manure transport as a significant barrier.

In September 2000, California Assembly Bill 970 (AB 970) created a self generation program especially for businesses and large institutional customers, which sought “the creation of more energy supply and demand programs (PGE, undated).” By March 2001, the California Public Utilities Commission (CPUC) authorized the Self-Generation Incentive Program (SGIP), which offered financial incentives to utility customers who installed specific “distributed generation facilities” to meet all or a portion of their own energy needs. This program authorized \$112 million to be spent through major electrical suppliers. Participants of this program received one time rebates based on watt generating power capacity of their systems.

AB 1685 signed in 2003 extended the SGIP through 2007. This bill allows micro turbine of internal combustion engines operated on renewable fuels such as “biomass or digester gas” excluding wind power (SGIP Handbook). This bill targeted smaller scale energy production with a maximum size of five megawatts and targeted one megawatt size facilities. By January 2005, California had eleven anaerobic digesters on dairies with about 2.3 megawatts of capacity, which were receiving compensation from this bill.

AB 2228 of 2002, which was made effective in January 2003 (Pilot Net Metering Plan) is a program for new dairies with less than one megawatt of capacity. This program has the language for net metering a cluster of dairies, but the capacity limits should be raised in a separate program and language facilitating the sale of additional power should be added.

Introduction to Private and Social Benefits and Costs of Dairy Manure Anaerobic Digestion

Kahn provides some useful insights to food and agricultural adaptations of benefit-cost analysis (1998). He suggests an important starting point is listing the costs and benefits and an applied relative weighting of importance of each in the larger scheme of the issues. This is important as some important issues may not be able to be measured in dollars either for lack of market or inability to speculate a value for social aspects. The private benefits most often have market aspects. Table 2-1 lists potential benefits and costs that can arise from implementing an anaerobic centralized digester. While this table is not exhaustive, it does highlight some of the major cost and benefits that come from anaerobic digestion.

Table 2-1: Potential Benefits and Costs of Centralized Anaerobic Digestion Systems for Dairy Cow Manure

<u>Potential Benefits</u>	<u>Potential Costs</u>
1. Electricity or natural gas production	1. Construction cost of anaerobic digester
2. Concurrent heat energy collection	2. Operational costs
3. Greenhouse gas reductions	3. Integration into existing energy systems
4. Odor and pest reduction	4. Degraded road quality
5. Water quality improvement	5. Centralized system land acquisition costs
6. Manure byproducts-compost	6. Effluent spills during transportation
7. Environmental particulate matter avoided	7. Environmental particulate matter increases
	8. Permit costs and regulatory oversight

Benefit-Cost Analysis -- Social Benefit of Carbon Dioxide Equivalent Greenhouse Gas Reduction

Implementation of the Clean Water Act has pushed many dairies in California to use lagoons for holding manure. Usage of a lagoon system are implemented by dairy producers to release nutrients at times and rates appropriate to the plant uptake, and meet environmental and soil conditions as currently required under NRCS-EPA resource management plans. While this potentially has a positive effect on ground water, it has a negative effect on air quality. Since lagoons are natural environments for anaerobic digestion, an uncovered lagoon can release greenhouse gasses in the form of methane, which is considered equivalent to twenty-one times

carbon dioxide. Thus methane production is a standard byproduct as the CAFO systems (intensive animal production facilities) attempt to prevent water pollution from excessive release of manure nitrogen and phosphorus into the environment from animal operations (Bartram and Barbour, 2004; Sturtz, 1997).⁹

The EPA's AgStar program provides the basic calculation of the methane gas (thus carbon dioxide equivalents) captured from a closed anaerobic digestion system (EPA, Winter 2006). Two levels of methane capture are emission reduction from gas capture valued at its carbon equivalents (1048-2538 tons depending on the system used) and the reduction of carbon dioxide (526 tons from 500 cow herd regardless of system) from supplanting higher polluting carbon fossil fuels, such as coal or fuel oil, in electrical generation (Miller, 1997; or Spath *et al.*, 2000).¹⁰

Benefit – Reduced Odor and Pest Problems

In southern California, dairy operations have been considered a burden near the urban-rural fringe. This has occurred due to the pest and odor production that occurs with a typical confined dairy operation. In recent years, the Central Valley has increasingly encountered the same problems as population increases in the area, causing the urban fringe to intrude upon the lands next to dairies. As the urban fringe moves closer to dairy operations, an increasing societal benefit develops from a reduction of pest and odor problems. Anaerobic digestion can have a positive effect on reducing these externalities.

There are both private and social benefits that can come from a reduction in odor and pests. Schwart *et al.* contend that digested effluent from an anaerobic digester has virtually no odor, and even after weeks in a secondary lagoon can be retrieved and spread on fields almost without

⁹ Physical scientists inform us that aerobic treatment in a well maintained environment convert the manure effluent to usable mineralized forms as well as anaerobic digestion, but without the conversion to methane and its release into the atmosphere. This requires an adequate set of soil microbes and insects (*e.g.* dung beetles) present to handle these materials.

¹⁰ Plombin cites the combustion of methane as utilizing carbon dioxide formed by plant materials and then broken down during combustion as part of the carbon dioxide recycling, rather than creating additional carbon dioxide release as fossil fuel would (2003). Plombin also suggest that far less (one-third) land surface area is necessary for anaerobic digestion than is required for aerobic breakdown of manure through composting. However, many anaerobic digester facilities will subsequently compost solids separated from liquid portion of manure in anaerobic digestion systems.

odor (2005). The standard double pond or lagoon systems or tank enclosure of complete mix digesters remove most if not all of the nuisance odor potential from dairies.¹¹ It has been shown that insect pests and odors from manure and urine waste can have a detrimental effect to a cow's milk production and laborer work efforts in the work place. The private benefits of an anaerobic digestion system from controlling these externalities will be captured in increased productivity of both the animals and people on the farm. The greater social benefit will accrue to the public through reduced fly pest populations, and an almost complete reduction in odor by the systematic capturing of manure effluent in the enclosed environment of anaerobic digestion (Lusk, 1996, 1998; Wright, undated; Kramer, 2004).¹² Wright also points out that decreased solids will be spread by using anaerobic digestion. Odor control with this technology is estimated to be less costly when compared to aerating lagoons as a method of reducing odor (EPA, 2002).¹³

Related Water Quality Problem Avoidance

Both European and domestic sources have identified the potential for improvements for water quality with anaerobic digestion system handling of dairy manure (Al Seadi, 2000; Nelson and Lamb, 2002; Wright, undated; US EPA, 2002). Nelson and Lamb point out that manure that has been processed in an anaerobic digester has a lower Total Oxygen Demand than manure from a lagoon. Thus, anaerobic digesters help reduce the hazard if a catastrophic spill occurs.

Centralized biogas plants provide "good" possibilities for improved nitrogen utilization from anaerobic digestion of manure given the regulatory atmosphere on permissible amounts of

¹¹ Nuisance is the common-law remedy that applies when a producer's activities interfere unreasonably with another person's use and enjoyment of land, injure life or health, or interfere with public rights. A private nuisance can arise from an "invasion of another's interest in the private use and enjoyment of land." Private nuisance often results from an activity on defendant's land that interferes unreasonably with use of plaintiff's neighboring land. A public nuisance is "an unreasonable interference with a right common to the general public." A public nuisance usually affects a significant number of people; cases are normally brought by a government official or (less often) by an individual with a "special injury" (an injury different in kind from members of the general public). A few recent cases have used the theory of anticipated nuisance to prevent construction of livestock facilities, which would (arguably) cause a nuisance.

¹² Kramer cites the cases of an Illinois hog farm with 8000 head and a Wisconsin dairy with 2800 head that claim success with anaerobic digestion as odor control, which was their primary goal when investing in anaerobic digestion systems (2004). These operations made minimal use of methane as an energy source. In Illinois the system eliminated compliance investigations and complaints from neighbors. Gordondale Farms in Wisconsin reports savings of \$5000 per year for pesticide costs avoided on an 800 cow dairy with anaerobic digestion.

¹³ Ernst, *et al.* use testimonial response of a farmer's anaerobic digester experience as verification of odor reduction. The authors report results from two panel studies of consumers and professionals, which both found odor reduction (1999, p.7).

nitrogen fertilizer applied in agricultural uses. Cornell scientists Gooch and Scott cite the pasteurization aspects of anaerobic digestion if dairy effluent is heated one hour at 70°C and at thermophilic operating temperatures (55°C) controlling bacteria, weed seed, and internal parasites (2006).¹⁴ Anaerobic digestion is reported to greatly reduce the pathogens present in the original manure effluent. Under conventional practices (without anaerobic digestion) where daily spreading of manure occurs, it is not uncommon to find degraded water quality (Bennett, 2004). The pre-heating is also thought to increase methane output.

Many point out the improved properties of digested effluent from an anaerobic digester. Digested effluent carries mineralized forms of soil nutrients, which are then in a form more readily taken up by target crop plants. This can have a benefit of reducing ground water leaching problems assuming that digested manure is spread appropriately (Ribaud, 2003). Ribaud found that water quality problems could be mitigated by increased livestock concentrations of CAFOs if manure were processed at fertilizer, energy, or industrial waste treatment facilities (2003).

The Inland Empire Utilities Agency (San Bernardino County primarily) reports ground water quality enhancement from the removal of over 1100 tons of salts, ammonia, and nitrates in 2002 via their centralized manure digesters (IEUA 2005a,b). IEUA is permitted to recycle water by permit from Regional Water Quality Control Board.

¹⁴ See also North Carolina Solar Center, undated and Nelson and Lamb, 2002.

Chapter 3: Methodology

The purpose of this project was to determine the feasibility of operating a regional anaerobic digester that relies on dairy manure effluent from local dairies in California. For purposes of this project, feasibility is defined as a regional digester that has a positive net present value at a 10% discount rate over a fifteen year time horizon with a positive yearly net social benefit. A fifteen year time horizon was chosen because that is the expected life of the major capital equipment, while the 10% discount rate was chosen to be competitive with the historical long-run returns of the stock market.¹⁵ Both of these values were used in the feasibility study conducted by Jewell *et al.* (1997). To investigate this issue, simulation techniques were utilized to estimate the feasibility of running a centralized digester at one of approximately 650 sites in the Central Valley.

This study focused on examining the feasibility of operating centralized regional digesters in California's Central Valley. This area represents approximately 1.2 million milking cows out of the 1.7 million dairy cows in the state.¹⁶ The reason for focusing on the Central Valley was primarily due to two reasons. The first reason was due to data limitation. To conduct a successful study on feasibility of a regional digester, a minimum of two pieces of data are required—physical locations of the dairies and the number of dairy cows. A data set that meets these two data requirements were acquired from Valley Air Solutions, LLC in Stockton. This data set limited the analysis because it only contained information regarding dairies in the Central Valley.

The second reason that this study focused on the Central Valley is because the other high producing dairy region in the state, the Chino Valley, already has a regional digester in operation. Thus, it was judged that the a hypothetical look at this region would be less valuable than examining the actual information put out by the Inland Empire Utility Agency (IEUA) which operates the regional digester.

¹⁵ While the stock market over the last ten years has exceeded a 10% return, the historical average has hovered around 10%. Hence, this percentage was assumed because it's a more conservative return hurdle.

¹⁶ Initially when this project was first conceived, an examination of regional digesters across the whole state was going to be done.

Simulations and Data Generation

The data set of California dairies acquired from Valley Air Solutions, LLC contained the addresses and the corresponding number of milking cows for over 650 dairies in the Central Valley. This dataset covered 689 dairies representing approximately 1.17 million dairy cows in the Central Valley. Using a geo-coding service and the addresses provided, these dairies were transformed into a geo-spatial dataset. Geo-spatial data is data that is associated with a location on a map in latitude and longitude coordinates. Since some addresses were not able to be geo-coded due to missing information, the final number of dairies that were transformed to geospatial data was 660 dairies representing approximately 1.12 million cows.

Once the dairies were converted to geospatial data, they were put into a GIS database where they were used to generate the distance sets that the dairy effluent would need to travel to a regional digester. To develop the distances that the effluent needed to travel to the “centralized” digester, a single dairy was chosen at a time as the location for a regional digester. 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, which was assumed to have the regional digester located on its farm. By the end of this analysis, every dairy in the data set was associated with a set of dairies that were within a ten mile radius of it and the surface distance that must be traveled to go from the central digester to each dairy within that radius.

A simplifying assumption that was used in calculating the distance to travel to each dairy was that a dairy that fell in between two concentric circles was assigned a travel distance from the outer concentric circle to the regional digester. Diagram A gives a pictorial view of how distance traveled was assigned to each dairy. Since Dairy A is within $\frac{1}{2}$ -mile of the regional digester, it was assigned a roundtrip travel distance of 1 mile. Since Dairies B and C are between the $\frac{1}{2}$ -mile concentric circle and the 1 mile concentric circle, they both were allocated a roundtrip travel distance of 2 miles. Hence, a dairy was assigned a travel distance equal to twice the distance of the closest outer concentric circle. Since the dairy is being allocated to the outer concentric circle, the estimate of distance travel is on the conservative side.

Diagram A: Assignment of Travel Distance from Each Dairy to the Regional Digester

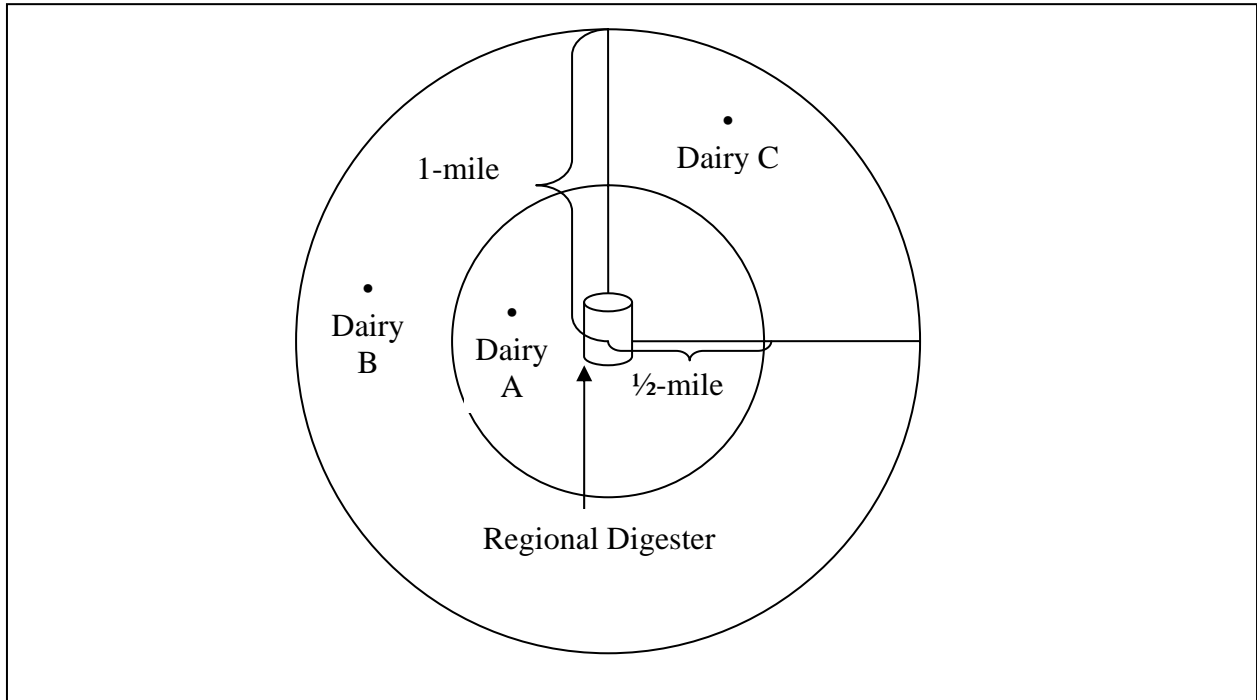


Figure 3-1 provides a look at the map with a single dairy and its corresponding radii up to ten miles for the Central Valley. This figure represents an actual depiction of Diagram A. The dots on each of the figures represent dairies in the Central Valley. The larger the dot is, the more cows the dairy has on its site. The circles represent distances away from the dairy in half mile increments. The farthest circle represents a ten mile radius away from the proposed dairy that will be the site of the centralized digester. This assignment of distance was done for every dairy in the dataset that was geo-coded.

Figure 3-2 shows a map that has all the dairies from this study with the corresponding $\frac{1}{2}$ -mile incremented radii up to ten miles. This map demonstrates how concentrated the dairies are in the Central Valley of California. It also shows that careful planning needs to take place when setting up a regional digester because many of the concentric circles overlap with each other. This implies that regional digesters that are located close to each other may have to compete for dairies to participate in their operation. This could cause problems for regional digesters to operate efficiently. It may be in the regional digester's best interest to sign-up dairies in long-run contracts to ensure the supply of manure needed for efficient operation.

Figure 3-1: A Single Central Valley Dairy with Ten Mile Concentric Circles by 1/2-Mile Increments

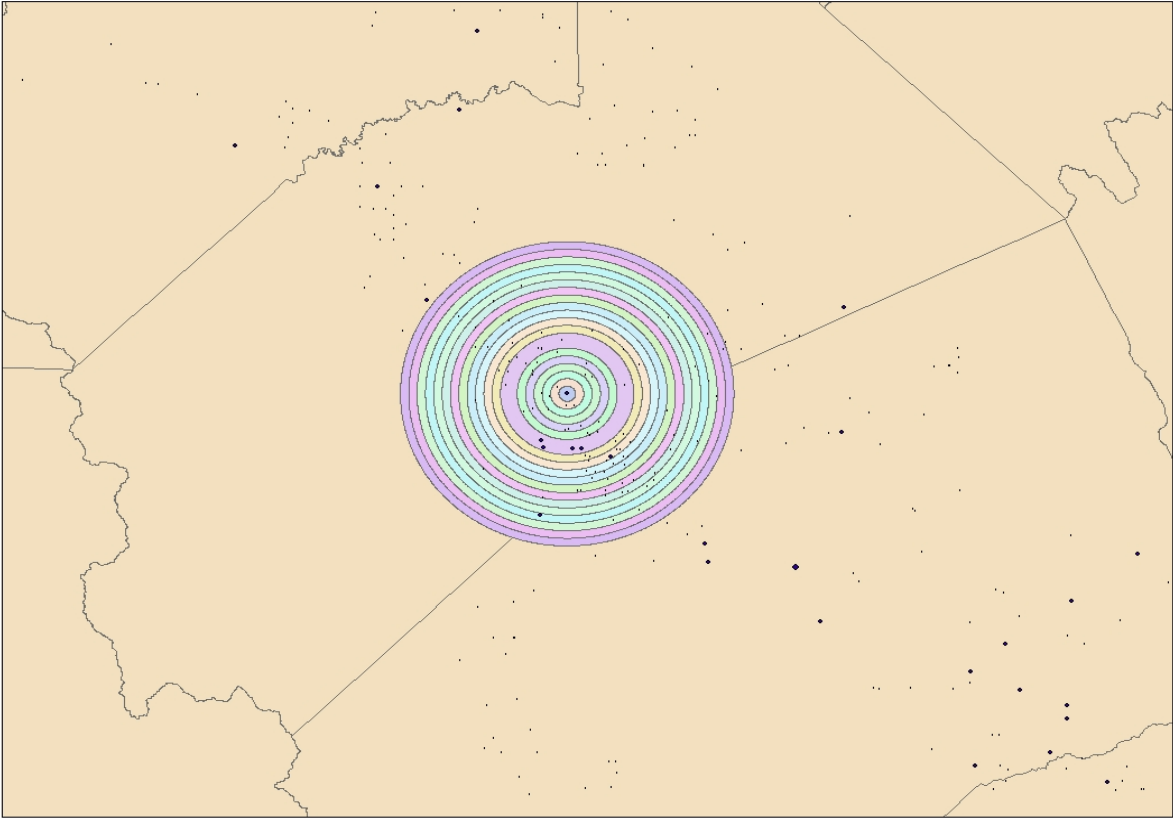
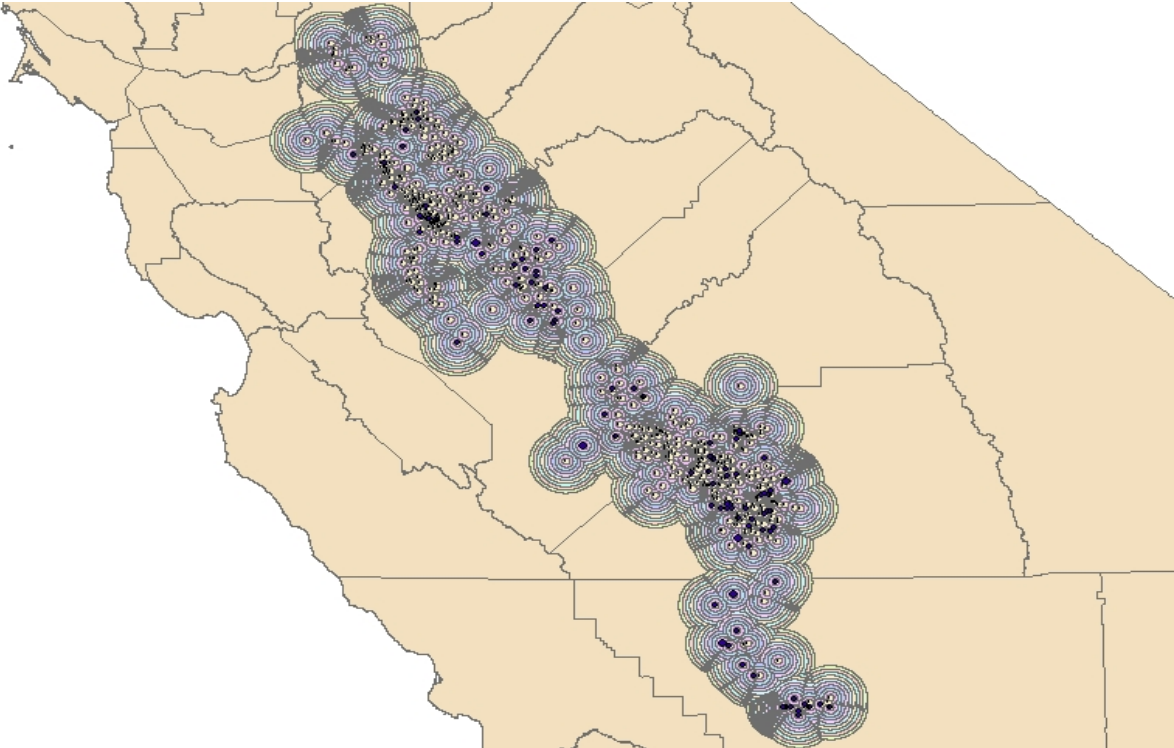


Figure 3-2: Central Valley Dairies with Ten Mile Concentric Circles by 1/2-Mile Increments



After each dairy was assigned a travel distance, the number of cows was counted for each distance. These quantities were then entered into an Excel spreadsheet as a possible scenario to examine for each of the different types of regional digesters under examination. 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 were examined through simulation.¹⁷

The simulation was broken-up into two stages. The first stage of the simulation was used to decide which of the 7,962 configurations could provide the appropriate number of cows for the digester being examined. For example, the facility capable of producing 10 megawatts needs between 48,200 and 63,500 cows to operate. If the scenario could not provide cow numbers in that range, then it was discarded from further analysis for the particular digester under examination. The second stage of the simulation took configurations that were identified as applicable in stage one (cow numbers sufficient within ten miles) and entered each of them into one of four regional digester models. Each applicable scenario was examined at electricity prices ranging between \$0.04 per kWh 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 United States is receiving a higher price for its electricity.

After the simulations were run, all alternatives that had negative net present values with a 10% discount rate over a fifteen year time horizon were discarded. Also discarded were any alternatives that had negative net social benefits. Any dairy that was larger than 9,000 cows was also discarded as a centralized digester because these dairies are large enough to produce one megawatt of power on its own. One megawatt of power seems to be the lower limit of what the public utilities would prefer to be hooked up to the electrical grid without special legislation by the state government.

¹⁷ 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.

Base Case Manure Handling System

To make the analysis in this project tractable, a base case manure handling system was developed for comparison purposes. This base case system is primarily used to develop the net social benefits from having a regional digester. 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. The flush system is considered the base case because approximately two-thirds of the dairies in the state use a flush system; such manure management is the typically employed in the Central Valley. The assumption of 70 gallons per cow was taken from a UC Cooperative extension bulletin (Schultz, 2000). The manure is left in the lagoon until the producer is able to spread it onto a nearby field. These uncovered lagoons are assumed to make no attempts to capture the biogas.

The systems primarily examined in this report are centralized systems that take undigested manure 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. Ninety percent is the lower limit on operation time that is suggested by the USEPA's AGSTAR model, representing an extremely conservative lower estimate of operating efficiency. Any gains in operating efficiency would lead to higher revenue from greater electricity production. While the system is undergoing maintenance, it is assumed that the biogas is flared.

It is assumed that the transportation of manure is done by tanker trucks with a vacuum system attached to the truck. This ensures that each dairy does not need its own pumping system and centralizes all maintenance issues at the regional digester.¹⁸ Once the manure has been digested at the facility, it is trucked back to one of the cooperating dairies. While it was not explicitly assumed in the models examined, there could be sales or some redistribution of manure on these return trips assuming that one dairy has more land to spread manure than the dairy can produce, while another dairy may be short of land for spreading manure. Since the dataset acquired for

¹⁸ One of the biggest advantages to a centralized digester is that it focuses the operation and maintenance of the major capital equipment in one location where specialist are available for upkeep. 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.

this study did not have any information regarding available land and crops grown by dairy, it was not possible to study a redistribution of manure.

The Anaerobic Digesters Examined in this Study

To investigate the feasibility of centralized anaerobic digesters and maintain tractability of the analysis, it was decided to focus on four different plant sizes—1.5 megawatts, 1.6 megawatts, 4.2 megawatts, and 10 megawatts. An assumption for the facility capable of producing 1.6 megawatts was that the manure used to generate power came from manure management systems that used a flush system. A flush manure management system primarily uses water as a method for collection of manure. The flush system washes the manure away from the cows into a lagoon. The other three facilities were based on the assumption that the dairyman whom participated in the system are currently or will change over to a scrape system. A scrape manure handling system relies heavily on labor to collect the manure and place it in some sort of holding facility, although some are mechanized. This scrape system is assumed to keep any wash water used for clean-up separate from the manure that is collected.¹⁹ With the typical flush system, this is not possible. The reason that the centralized digester utilizing dairies with flush systems were capped at 1.6 megawatts is because it becomes prohibitively costly to transport manure effluent from a flush system due to the high concentration of water.

The centralized digester system developed assumed that the digester would be located on one of the participating dairies facilities. The reason to do this is because power generated from the anaerobic digester could be used on the dairy to offset its electrical usage. This would mean that the centralized digester could capture the full market value of the electricity, rather than selling it on the grid at a wholesale cost or less. Each of these four systems was developed with the flexibility to be utilized in the simulations described above. Hence, each system is dynamically changing to meet the requirements of the number of milking cows it will be servicing. This implies that the amount of cows each system can handle, the size of the manure storage, the amount of manure handled, the amount of electricity, and the amount of compost produced must be reported in ranges when describing each digester.

¹⁹ Normally, 5 to 10 gallons per cow per day are used to clean-up the dairy facility after it has been scraped. It is assumed that this wash water is not intermingled with the manure that is scraped.

Centralized Covered Lagoon Dairy Digester Design Capable of producing up to 1.6 Megawatts

This 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 one megawatt of power.²⁰ These cows are assumed to be housed in freestall barns with flush-type manure handling systems. Each dairy where the anaerobic digester is not located collects the flushed manure in a holding pond which is then trucked to a centrally located anaerobic lagoon for manure treatment. The centralized digester has a covered lagoon with a special plastic film that captures the biogas. The generation of electricity is accomplished by piping the biogas from the covered lagoons to one large engine-generator adjacent to the covered lagoon and accessible to a high-voltage power line for electrical export. The electrical output from the generators is rated at approximately 1.6 megawatts, but is assumed to be useful down to one megawatt.

The participating dairies are assumed to continue using an average of 70 gallons of fresh water per cow per day of flush water to remove manure from the freestall barns and dairy parlor. The amount of effluent that is generated from this system ranges from 614,000 gallons to 963,000 gallons per day with approximately 2.1% of total solids in the effluent. The largest potential lagoon that would be needed for this facility has a capacity of 78 million gallons, with the dimensions of 1090 feet long by 410 feet wide by 26 feet deep. The smallest lagoon that would work for this facility can handle 51 million gallons of effluent using a lagoon with the dimensions of 883 feet long by 331 feet wide by 26 feet deep. These lagoons allow for a forty day retention time. As a result of anaerobic digestion, the volatile solids in the manure at each farm are converted to between 408,000 and 640,000 cubic feet of biogas containing 60% methane depending on how many cows are being milked. This biogas has an energy value that ranges from 245 million to 384 million Btu per day, and is converted to electricity in a 1,600 kilowatt engine-generator at each farm. This system generates between 20 to 31 tons of compost a day that can be sold.

²⁰ As was mentioned above, one megawatt 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 one megawatt, just that they prefer to handle larger facilities so they can better manage the load on the electrical grid.

Centralized Complete Mix Dairy Digester Design Capable of Producing 1.5 Megawatts

This system is designed to handle between 9,000 to 10,600 milking cows. This scenario assumes that the milking cows are housed in freestall barns with scrape-type manure handling systems. Given that the base case dairy is assumed to be operating a flush manure handling system, each dairy that decides to participate in this system must convert its 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.

This system consists of a reception tank from which the manure is pumped into two above-ground steel digester tanks with mixing and heating systems that maintain optimal conditions for the anaerobic bacteria at 95 degrees F. These tanks each hold approximately 1.267 million gallons of effluent with each having a dimension of approximately 60 feet diameter by 60 feet depth. Each tank is assumed to not be filled more than 90% of capacity. A total range of 108,000 to 127,000 gallons per day of manure slurry with 12% solids content can be handled by this system.

The two tanks that hold the manure slurry are designed to hold the manure for a twenty day retention time. As a result of anaerobic digestion, the system can generate between 547,000 to 644,000 cubic feet of biogas per day containing 60% methane. This biogas generated from this facility has an energy output between 328 and 387 million Btu per day, which is converted to electricity in a 1.6 megawatt engine-generator. The net output of the system after internal electricity requirements are subtracted ranged from one megawatt up to 1.5 megawatts. In addition to the electricity, the digested solids removed from the digester create between 27 to 32 tons of compost per day. The generation of electricity is accomplished by piping the biogas from the digesters to one large engine-generator adjacent to the digester and accessible to a high-voltage power line for electrical export. This facility could be replicated to produce three megawatts before a new technology can be utilized to gain efficiency in electricity generation.

Centralized Complete Mix Dairy Digester Design Capable of Producing 4.2 Megawatts

The facility capable of producing 4.2 megawatts of electricity is designed to handle between 20,600 milking cows and 27,500 milking cows. It has a lower power generation ability to produce 3.17 megawatts of power. Otherwise, the previous 1.5 megawatts facility could be doubled to produce three megawatts of power. The milking cows are assumed to be housed in freestall barns with scrape-type manure handling systems. 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. This implies that each dairy under the base case assumption that wants to participate in this system would need to changeover to a scrape manure handling system.

The cows that can be handled by the system are estimated to produce between 247,000 gallons to 329,000 gallons of manure effluent per day. This system consists of a reception tank from which the manure is pumped into five to six above-ground steel digester tanks with mixing and heating systems that maintain optimal conditions for the anaerobic bacteria at 95 degrees F. Each tank has approximately 1.267 million gallons of capacity and has the same dimensions as the tanks from the 1.5 megawatts system. Each tank is assumed to use no more than 90% of its capacity. The generation of electricity is accomplished by piping the biogas from the digesters to one large gas turbine generator adjacent to the digester and accessible to a high-voltage power line for electrical export.

The tanks that are part of the complete mix system hold the manure for a twenty day retention time. As a result of anaerobic digestion, this system produces 1.3 million to 1.7 million cubic feet of biogas containing 60% methane depending on how many cows are part of the system. This biogas has an energy value in the range of 763 million to 1 billion Btu per day, and converts to electricity in a 4,800 kilowatt gas turbine-generator. The net output of the system after internal electricity requirements are subtracted is 4,200 kilowatts.²¹ In addition to the electricity, the digested solids removed from the digester have value as compost for use as fertilizer for cropland. This system produces between 61 to 82 tons of compost per day.

²¹ The primary internal use of the electricity is for the digester which uses power to continuously mix the slurry while it is in the holding tank.

Centralized Complete Mix Dairy Digester Design Capable of Producing 10 Megawatts

The final system examined was built to generate a net output of 10 megawatts 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 megawatts. The reason for putting a lower limit of 8.4 megawatts is because the previous system could be doubled. The cows from this facility are assumed to be housed in freestall barns with scrape-type manure handling systems. This implies that dairies that want to participate in this system will need to change the manure management if they do not already meet this requirement. Each dairy uses a manure collection system that scrapes the fresh, undiluted manure from the freestall floors and transports it to a centrally-located complete mixed digester system for manure treatment.

This system consists of a reception tank from which the manure is pumped into eleven to thirteen above-ground steel digester tanks with mixing and heating systems that maintain optimal conditions for the anaerobic bacteria at 95 degrees F. Each tank has a capacity of approximately 1.267 million gallons with dimensions of approximately 60 feet diameter by 60 feet depth. Like the previous two systems, each tank is assumed to be filled to no more than 90% of capacity. The generation of electricity is accomplished by piping the biogas from the digesters to one large gas turbine generation system adjacent to the digester and accessible to a high-voltage power line for electrical export. The optimal net electrical output from the generator is approximately 10 megawatts.

The tanks in this system hold the manure for a twenty day retention time, which result in the production of between 2.9 million to the 3.9 million cubic feet of biogas per day containing 60% methane. This biogas has an energy value that ranges between 1.8 billion to 2.3 billion Btu per day. The maximum net output of the system after internal electricity requirements are subtracted is 10 megawatts. In addition to the electricity, the digested solids removed from the digester have value as compost for use as fertilizer for cropland. These solids can produce 574 to 757 tons of compost per day.

Transportation Model

There are two main methods of transporting dairy manure to a central digester—trucking or pipeline. The method that appears to be utilized the most in practice is truck transportation of the manure (Ghafoori, Flynne, and Feddes, 2005). The main reason trucking is the transportation of choice is that a pipeline has a high capital cost to construct and may have strong public opposition for construction due to the NIMBY (Not In My Backyard) effect. Krich et al. cite estimates of piping cost ranging from \$100,000 to \$250,000 per mile (2005). They explain that this cost is heavily dependent upon number of landowners involved, the terrain that needs to be traversed, and the number of roadways that need to be crossed. Landahl placed the capital cost of piping at \$280,000 per mile (2003).²²

Ghafoori, Flynne, and Feddes examined whether it is more cost effective to use a pipeline to move manure to a central digester or to transport the manure by truck (2005). They find that pipeline costs are heavily dependent upon the scale of manure being moved in comparison to truck transportation which is independent of the scale size. They report that it would take approximately 95,000 cows assuming the use of roughly 30 miles of linear piping before a pipeline is more cost efficient than trucking. Ninety-five thousand cows would equate to a facility that could produce approximately fifteen megawatts. They estimate the operating cost of the pipeline alone to equal approximately \$377,827 per year.²³

For this study, it was decided to examine only truck transportation. This is due primarily to the lack of reliable data that can be used for estimating the cost of a piping system and the lack of evidence that piping manure is the transportation of choice in Europe where centralized digesters have been subsidized by government for many years.

The transportation model built for this study revolves heavily around how much manure needs to be hauled and by what distance. This dictates the number of drivers, number of trucks, the operational costs of moving the manure, etc. As explained above on the simulations that were

²² The original estimate was 150,000 euros per kilometer in October of 2003. Using historical exchange rates for that time period, this was changed over to dollars per mile for comparison purposes.

²³ The actual cost was 441,000 Canadian dollars which was converted to US dollars using the Bank of Canada's exchange rate converter for September 22, 2005.

conducted, concentric circles were placed around the location for the centralized digester at ½-mile increments. Each dairy participating in the regional digester is assigned a distance of two times the nearest outer concentric circle as shown in Diagram A above.²⁴ The purpose of using a factor of two is to account for roundtrip visits based on the assumption that the digested manure is returned to the dairy for spreading on fields.^{25,26} Once each dairy has been assigned to a concentric circle and allocated a distance, all the cows are summed for each concentric circle. Next, the amount of effluent that is generated by the set of cows for each concentric circle is calculated. For the 1.6 megawatts system, the amount of captured effluent generated per cow per day is equal to approximately 84 gallons, while for the 1.5 megawatts, 4.2 megawatts, and 10 megawatts systems, only 12 gallons of captured effluent is gathered per cow per day.²⁷ The amount of effluent that is located at the edge of each concentric circle is equal to the number of cows assigned to that concentric circle times the amount of effluent that is generated per cow per year.

²⁴ 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 perfectly reasonable to assume that dairies could be scattered anywhere on the concentric circle. This would imply that manure hauling efficiency will be affected by how well the dairies are scheduled for manure pick-up and creates the need for a person managing the operations to have knowledge of transportation logistics methods.

²⁵ While it is unrealistic that a dairy would have a driving distance equal to the radius of the concentric circle it is associated with, placing all dairies on the outer concentric circle is meant to compensate for this factor. 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 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.

²⁶ Since many dairies in the Central Valley use dairy manure as a fertilizer for their crops, it was decided for this study 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. There are some dairies that may want to leave the digested manure at the centralized digester because they do not have enough land to spread all the manure produced from their facility. While not modeled in this study, it is recommended that if dairies would like to leave the digested effluent at the regional digester, then they should pay a tipping fee that is equal to the marginal cost of disposal of the manure.

²⁷ According to Brugger and Dorsey, 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 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. For this 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 extremely 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%.

Once the amount of effluent that needs to be hauled from each dairy in a concentric circle is calculated, the next step is to figure out how many trips are needed to haul the manure. To find the number of trips needed for hauling the manure, the total amount of effluent for each concentric circle is divided by the maximum amount that each truck can haul, in this case 4,000 gallons. This gives the amount of trips that are needed to haul the manure from each concentric circle.

Given the number of trips that are needed, the next step is to find the number of drivers that are necessary to haul all the manure. The number of drivers needed is found by examining how long each trip will take for each concentric circle. The length of time needed to haul a load of manure is dependent upon the time to load and unload undigested manure, the time to load and unload digested manure, and the time it takes to travel to and from each dairy. Once the number of drivers for each concentric circle is found, the total number of drivers needed is found by summing up the number of drivers needed for each concentric circle.

To calculate the number of laborers needed for transportation to each concentric circle, two primary items were necessary to calculate. The first was the total travel time necessary for hauling the manure. The time needed to haul the manure for each roundtrip was established by dividing the number of miles driven for each roundtrip by thirty miles per hour which is the assumed average rate of transportation.²⁸ The miles driven for each roundtrip is dependent upon which concentric circle the laborer is traveling to and is equal to twice the radius of the concentric circle. The second item needed to estimate the number of laborers was the amount of unloading and loading time needed. This item is estimated to take 0.6 hours for each trip.²⁹ The

²⁸ 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.* estimate of thirty-five miles per hour average (1997). There were no studies found that examines average rate of speed and average distance needed to be traveled. The authors of this study emphasize that before someone moves forward with developing a regional digester that he/she should do a thorough investigation of what this travel time is. There are many factors that would need to be considered including road conditions, speed limit, number of stop signs/lights, etc.

²⁹ 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.

travel times and the loading/unloading times were calculated for each concentric circle and then summed together.

Once the total amount of time was found for hauling all the manure to and from each dairy, the next step is to calculate the necessary amount of laborers. Following Jewell *et al.*, this total time was divided by 7.2 hours to obtain the number of drivers needed per day (1997).³⁰

Fixed Costs of Operating Each Centralized Digester System

One of the major cost components of the centralized digester systems is the capital equipment necessary for operation. It was explained above the approximate technical layout of each of the anaerobic digesters being studied. To develop a net present value for each system, the capital cost for each system must be established. Table 3-1 shows the major capital equipment needed for each regional anaerobic digester facility. 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. This is because different scales of facilities will require different quantities of capital to efficiently operate.

Each of these systems has a 16% engineering cost added to the sub-total of the capital cost and 14% added to the sub-total for taxes and contingency. Two capital costs which are not considered major equipment is a trailer for administrative support and land set aside to house the trailer, the digesters, and the electrical generators. A trailer for each of these operations is expected to cost \$20,000, while land is being valued at \$4,000 per acre. Each system has a different requirement for the amount of acres necessary for operations. The facility capable of producing 1.6 megawatts needs approximately eight acres of land set aside if it is producing one megawatt of electricity up to twelve acres of land depending if it is running at full capacity. The facilities capable of producing 1.5 megawatts, 4.2 megawatts, and 10 megawatts are estimated to use respectively two, three, and five acres of land.

³⁰ Jewell et al estimate that a person who works an 8 hour shift will only be available to work an effective 7.2 hours per day.

Table 3-1: Major Capital Equipment Installed for Each Anaerobic Digester System and the Cost per Unit of Equipment

1.5 Megawatts System		
Equipment	Cost per Unit	Unit
Digester Tanks	\$ 932,500	per digester tank installed
Tank Foundations	\$ 125,000	per digester
Generator Set	\$ 750,000	per 1000 kilowatt
Gas Handling, Generator Sets	\$ 390,625	per 1000 kilowatt
Electrical Interconnect	\$ 100,000	per 1000 kilowatt
Manure Collection	\$ 48,000	per 1000 kilowatt
Solids Separator	\$ 200,000	per system
4.2 Megawatts System		
Equipment	Cost per Unit	Unit
Digester Tanks	\$ 932,500	per digester tank installed
Tank Foundations	\$ 125,000	per digester
Turbine Generator	\$ 524,000	per 1000 kilowatt
Gas Compression	\$ 200,000	per 4.2 megawatt
Gas Handling	\$ 200,000	per 1000 kilowatt
Electrical Interconnect	\$ 100,000	per 1000 kilowatt
Manure Collection	\$ 48,000	per 1000 KW
Solids Separator	\$ 400,000	per system
10 Megawatts System		
Equipment	Cost per Unit	Unit
Digester Tanks	\$ 932,500	per digester tank installed
Tank Foundations	\$ 125,000	per digester
Turbine Generator	\$ 524,000	per 1000 kilowatt
Gas Compression	\$ 400,000	per 10 megawatt
Gas Handling	\$ 200,000	per 1000 kilowatt
Electrical Interconnect	\$ 100,000	per 1000 kilowatt
Manure Collection	\$ 48,000	per 1000 kilowatt
Solids Separator	\$ 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	\$ 850000.00	per 1000 kilowatt
Gas Handling, Generator Sets	\$ 500000.00	per 1000 kilowatt
Electrical Interconnect	\$ 60,000.00	per engine
Manure Collection	\$ 48,000.00	per 1000 kilowatt
Solids Separator	\$ 200,000.00	per system

Financing Options for the Capital Cost of the Regional Digester

Once the capital cost of each system was developed, an amortized payment was developed that would payoff the capital equipment over fifteen years. This amortized loan payment will be used as a yearly outflow when calculating the net present value of each regional digester. There were two borrowing rates examined for each system—a public rate and a private rate. The public rate assumes that the state government would get involved with financing the loan at a subsidized rate of 5%. The private borrowing rate was assumed to be at 9%. Both rates are assumed to be compounded on a monthly basis.

Another factor investigated with financing was the amount of capital that was needed to be borrowed. If the state government decides to get involved, then the regional digester can borrow up to 100% of the capital cost needed.³¹ If the regional digester decides to get private financing through a commercial lender, then it is assumed that they will only be able to borrow 65% of the capital cost. This private lending model implies that the regional digester will need to come up with 35% of the capital cost to secure the loan.

Administrative, Operating and Maintenance Costs

There are three primary costs that make-up total operating costs for each of the systems investigated in this study. These costs are related to transporting the manure from the dairies to the centralized digester, administering the facility, and the operation and maintenance of the digester and the generator.

The yearly operation and maintenance cost on the generator is estimated at \$0.015 per kWh which was taken from Jewell *et al.* (1997). This cost accounts for the labor needed to manage the generator as well as any spare parts, lubricants, etc. needed to upkeep the generator for its estimated fifteen year life.

The yearly centralized digester administrative costs were estimated at \$124,084 per year. This cost is allocated for hiring one bookkeeper at a cost of \$16.56 per hour, and one manager to

³¹ 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.

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 benefit rate used for each of these people is 34% of gross wages. It is assumed that both administrative personnel work 2,000 hours a year.

Transportation Costs

There are three main components that make-up the cost of transportation. The first major cost is for the purchase of the trucks. There are many different configurations of trucks that can be used for hauling liquid manure. These range from trucks with the tank mounted on them to trucks that haul a trailer that has a tank on it. The trucks that use trailers have an advantage of hauling a greater capacity of manure (usually over 4,000 gallons), but they tend to lack maneuverability and their weight tends to be more damaging to roads. Trucks that have tankers mounted on them have the advantage of maneuverability and are less damaging to roadways, but usually are limited to a holding capacity of 4,000 gallons. The truck that is being used for this study is a truck mounted tanker that has a 4,000 gallon capacity and is estimated to cost \$130,000. This truck is equipped with a vacuum pump. It is assumed that this truck has a seven year useful life and no salvage value. Given a borrowing cost of 10%, each truck is estimated to have a yearly cost of \$25,898. It was assumed that 100% of the money needed for the trucks could be borrowed with no down payment.

Truck operation and maintenance costs are another component of the expenses for transportation. Following Jewell *et al.*, a maintenance cost of \$0.50 per mile was assumed (1997). The trucks were estimated to get 6.5 miles per gallon of fuel with a fuel cost of 3.50 per gallon. It was unclear whether diesel purchased for this facility would be purchased at the agricultural rate or the retail rate. To maintain a conservative estimate, the upper end of the retail rate was chosen at the time of conducting this study.

The biggest expense for transportation was labor costs. A benefit rate of 43% was used on top of a wage of \$15.45 giving the total hourly cost for labor at approximately \$22.10 per hour. The wage rate used in this study came from the Bureau of Labor Studies' National Compensation Survey estimate of wages for truck drivers in 2005. The benefit rate was derived from

Daugovish *et al.* and is meant to cover workers' compensation, payroll taxes, and other benefits (2004).³² The model calculated how many drivers were needed to transport the effluent on a daily basis. This calculation was discussed above.

Rarely was the need for labor a perfect round number. Hence, a decision rule was built into the model to determine whether the regional digester should hire an extra person or to pay overtime at 1.5 times the person's wages. The model was designed to choose the cheapest option.

Basically, if the model required at least two-thirds of a person, then an additional person would be hired; otherwise, it was assumed that the current drivers would work overtime at 1.5 times the total wages.

Revenue Sources

There are many potential products that can be developed from dairy manure that could potentially provide income to the centralized digesters. Some of the products like electricity have a proven track record of generating income, while others do not. This study focused on two products to be sold—electricity and compost for fertilizer.

The primary product sold by each of the systems built for this study is electricity. Two rates were used for each system—an on-farm rate and off-farm rate. Since the regional digester is located on the site of a dairy, it has the ability to sell power to the dairy at approximately the retail price. This is being termed as the on-farm rate. The price used for this rate was \$0.13 per kWh, which is the retail rate that is charged by Southern California Edison (California Energy Commission, 2004).³³ The off-farm rate is the rate the regional digester receives by the utility company. This rate is highly variable in the literature. Hence, when each regional digester was

³² Daugovish *et al.* used a benefit rate of 34% for strawberry growers including worker's compensation which was derived from the state of California Department of Insurance website <http://www.insurance.ca.gov/> (2004). This website has a listing of the rates insurance companies charge for worker's compensation and are effective as of January 2006. To adjust this value to make it relevant to this study, the worker's compensation portion of their estimate was subtracted and the median value of worker's compensation for farm machinery operation, classification 0050, was added back in.

³³ 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.

simulated in this study, rates were fluctuated from \$0.04 per kWh up to 0.10 per kWh at \$0.0025 increments.

A by-product of the anaerobic digestion process is compost that can be used as fertilizer. This compost is derived from the solids that cannot enter the anaerobic digestion process. A report developed by Terre-Source, LLC for King County, Washington examined the feasibility of this option and the value of the compost (2003). They found that they could sell the raw manure for approximately four dollars a ton. If an attempt was made to upgrade the manure to a high value fertilizer, potential cost would run ten to fifteen dollars per ton with a market value of ten to twenty dollars a ton. This would imply that compost manure could have a net value between \$5.00 and \$10.00 per ton. Terre-Source explains that this market may take years to develop and that a potential heavy start-up cost exists that will need to be amortized over the life of the digester.

To simplify matters for this study, it was assumed that the solids that could be turned into fertilizer could be sold for a net value of \$5.00 per ton. This value is close to the bottom end of what Terre-Source, LLC believes composted manure is worth and is close to the value of raw manure. This value is also fairly consistent with what the Port of Tillamook has received for its composted waste. Devore reports that the Port of Tillamook was receiving \$3 per cubic yard of compost (2006). This equates approximately to a \$5.32 per ton rate. An estimate by Liu, Shumway, and Myers-Collins puts composted manure at a net value of \$6.35 per ton (2003).³⁴ Hence, the estimate that is used in this study could be considered a conservative estimate.

There are other sources of revenue that can be generated from anaerobic digestion. It could charge tipping fees to dairy producers or other agricultural entities that need to dispose of their agricultural waste. The anaerobic digester could sell carbon credits on the Chicago Climate Exchange. The heated water that comes off the engine used for generating electricity could be sold to someone who needs it or used on the dairy where the digester is located. Instead of

³⁴ 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.

selling electricity, the biogas could have been cleaned-up and sold as natural gas or used in fuel cell technology. Some of these sources could be extra income to the digester, like the carbon credits, while others would be a replacement of income because a different product is being sold.

A source of income that can be derived from an anaerobic digester is charging tipping fees to users of the facility. A tipping fee will only work if the agricultural producer cannot find a cheaper method of disposing their waste problem. Dairyman in the Central Valley may not have a great problem with manure disposal because agricultural land currently seems to be sufficient to handle animal manure recycling. Although, dry-lot dairies with little cropland, like some of the ones found in the Chino Valley, have fewer options. Devore has found that Oregon dairyman are not used to paying “tipping fees” for disposal of manure waste and apparently have shown reluctance to consider such payments (2006). Since there was no data found that related dairies to land available for spreading digested manure, an assumption was made that the dairies did not have a manure spreading problem. This implies that tipping fees would not be viable.

The European experience has shown that there is potential for tipping fees as a source of revenue for centralized or larger farm scale digesters from food manufacturing and other agricultural wastes. Such inputs enhance methane gas production (Al Seadi, 2000). Since this study only focused on dairy operations and did not have adequate data to analyze whether there are agricultural facilities that have a waste problem, tipping fees for agricultural waste were not examined.

One source of income potential that can be generated from anaerobic digestion is carbon credits. With the signing of the Kyoto Protocol, there has been a developing market for carbon credit trading in the last few years, especially in Europe. In June of 2006, carbon credits were trading for approximately \$4.50 per ton on the Chicago Climate Exchange. To be able to sell carbon credits, an anaerobic digester would have to go through a broker that would certify the level of credits deserved by the operation. The cost of getting this certification is unclear at this point due to the infancy of the market. One company that was investigated was taking over \$2.00 per ton to give the certification. Since the United States has not signed on to the Kyoto Protocol,

which appears to be the main driver in the value of carbon credits, it was decided not to use this as a source of revenue.

Another source of income could come from converting the methane from the digester into biogas to fuel vehicles. *Krich et al.* studied the feasibility of developing biogas as a product from methane digestion from a centralized digester (2005). They found that this market was not viable under the current economic environment primarily because of a lack of marketing infrastructure and the need for public support like subsidies. Since the infrastructure is lacking in California to sustain a regional digester selling biogas for fuel purposes, it was left out of consideration for this project.

Initially biogas production was designed for generating gas energy for use as gas when cleaned of impurities or burned by generator engines to produce electricity. Subsequently, it has been realized that plants could make contributions that solved a range of agriculture, energy, and environmental problems. The electricity generation process produces residual heat, which can also be captured for on-site or industrial uses. Plombin found the potential for waste heat BTU production from biogas electricity generation to be 200,000 €/ year for a 100+ Nm³/hr capacity operation, which is roughly one-sixth of the electricity value (2003). This assumes heat capture is built into the regional digester system and that society can eventually find uses for all the heating power. Consequently, increased attention has been paid to these issues in varying degrees given resource needs and limitations (Al Seadi, 2000). Since there is a lack of data that shows where a market for this product would be in the Central Valley, it was discarded as a revenue source for this study.

An examination was conducted on whether fuel cells were a viable source of generating power from dairy manure. According to a study released by Minott, Scott, and Aldrich, they found that given current technology constraints, this technology is not an economically viable option (2004). A study done in Minnesota on the Haubenschild dairy utilizing hydrogen cell technology also found the technology currently to be infeasible (Feedstuffs, 2005).

Evaluating Net Social Benefits

Krugman states that “economics gives us very good reasons to protect the environment, recognizing that environmental damage is every bit as real a cost as more conventional monetary expenses (2005, p. 296).” With this in mind, an attempt was made to evaluate the primary social costs and benefits of developing a regional digester. 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.³⁵

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 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.

Given the status quo of the base system described above, there are three benefits that are captured from changing over to a regional digester. The first benefit comes from the decrease in methane released into the atmosphere from the standard lagoon being used for storage. This methane is considered to be worth twenty-one times the value of its carbon dioxide equivalent (EPA, 2005). The estimated value of this benefit 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. Hence, the value of one ton of captured methane is worth \$94.50 per ton of methane. It must be emphasized that this market is a very young and thinly traded market and has heavy volatility, but does provide a market estimate of what the reduction in carbon dioxide is worth.

The second benefit from converting to anaerobic digestion is a reduction in odor and flies associated with lagoons. Evidence exists that anaerobic digestion reduces the odor that emanates from a lagoon. Bennet did a feasibility study of a regional digester for dairies in Vermont

(2004). In his study, he used a value of \$10.00 per cow as the value of reduction in odor due to anaerobic digestion. Since no better number was found in the literature for this valuation, this study used this same estimate.

The third benefit from using anaerobic digestion comes from an improvement in water quality. There are two reasons why you might see an improvement in water quality. The first is because you are selling off some of the manure as fertilizer which would normally be spread on the dairy operator's fields. This implies that less of a nutrient load is being spread on the land that could potentially leach into the ground water. The second reason you may get a benefit related to water quality is because the anaerobic digestion process converts the nutrients in dairy manure into a more usable form for plants. Since the manure is in a more usable form, it is expected that the plants will be able to better absorb the nutrients spread on the field, which in turn would mean that it is less likely that the nutrients will get into the ground water. The benefit value used for improved water quality due to anaerobic digestion was \$1.50 per thousand gallons of captured effluent that comes directly from the cow.³⁶ This value was taken from the current cost to clean-up seawater at a desalination plant (Chaudry, 2003). Using the desalination cost represents society's willingness to pay for cleaner water that is usable.

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. EMFAC 2002 was developed by the California Air Resources Board to estimate the pollutants that are emitted by different types of vehicles driven in California. How this report estimates the pollutants is different from Bartram and Barbour, whom estimated the pollutants from trucking manure for the Inland Empire Utilities Agency, because they used a model developed by EPA that is not specific to California (2004).

³⁵ It must be kept in mind that the estimates of the net social benefits are crude estimates due to the focus of this project was on the feasibility of regional digester. Once a particular regional digester system is determined, an in-depth study of the net social benefits would be necessary assuming the public would consider funding these projects.

³⁶ 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.

There are four primary pollutants that can be associated with trucking manure to a regional anaerobic digester. Given the trucks that are being used in this study, 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.³⁷ 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.

The value given to the carbon dioxide emissions is equal to \$4.50 per ton, while the value given to the methane production is \$94.50 per ton. Both values were derived from the Chicago Climate Exchange, which was used to value the benefit of reduced methane used above. Carbon monoxide was valued at \$27.00 per ton. The value of carbon monoxide was taken from research done by Indala who estimated the fuel value of carbon monoxide (2004). He estimates that a kilogram of carbon monoxide is worth \$0.03. Nitrogen oxide was valued at \$1,000 per ton. This value was derived from the lower limit of what Farrell reports as a value for this emission (2005).

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.

The Scenarios Investigated

There were thirty-two different scenarios investigated in this study. These scenarios were based upon eight differing funding options and participation rates for the four regional digester systems built. These funding options had four possible areas of deviation—loan rate, participation rate, capital borrowed, and public funding. Table 3-2 gives an overview of these different funding options examined.

³⁷ The EMFAC 2002 program provides as a default the amount of reactive organic gases (ROG) that come from each mile of travel. There is an option in the model to change the ROG to a methane equivalent, which was used for this study

Table 3-2: Differing Funding Options and Participation Rates for the Four Regional Digester Systems Built

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. The rest of the money needed for the capital is borrowed 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, which could be considered a municipal regional anaerobic digester, is listed as Scenario D. Under this scenario, the state requires 100% participation of dairies in the regional digester. The state floats a 5% bond to cover 100% of the capital cost. 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.³⁸ This scenario is the only one that receives direct public funding.

The other six funding and participation 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 could be considered a public private partnership where the government assists with getting a low cost loan for the digester.

³⁸ One way of thinking about this public funding is that the state government provides the trucking services necessary to transport the manure like a recycling service. Hence, the regional digester would pay the government a sum of money equal to the difference between the cost of transportation and the value of the net social benefits.

Chapter 4: Simulation Results

The last chapter discussed the methodology used for examining the feasibility of operating a regional digester in the Central Valley of California. Feasibility was defined as an operation that had a positive net present value at a 10% discount rate over a fifteen year time horizon with a positive net social benefit. Four different regional digesters were examined under eight possible funding and participation options. Simulation methods were employed to examine different potential locations for the regional digester under different electricity prices that could be obtained. This chapter presents the key results from the simulations of the thirty-two possible scenarios.

There are two necessary conditions needed to make a regional digester a feasible option in the Central Valley of California. A net social benefit is the first necessary condition for a regional digester to be feasible. The second necessary condition to feasibility of a regional digester is the amount of income that could be brought in by the regional digester. The two primary sources of income for the regional digesters modeled in this study were electricity sales and compost sales. Compost sales were assumed to be a secondary product for the digester, while electricity sales were the primary income source. Compost sales were assumed to bring in a net income of \$5.00 per ton. Since the income from electricity is considered the major source of income for the digester, each digester was simulated using different electricity prices it could sell at. These prices ranged from \$0.04 up to \$0.10 per kWh.

Table 4-1 provides the minimum price per kWh necessary to produce a positive net present value 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 kWh. This price is based on the regional digester selected to be the one capable of producing 10 megawatts of electricity while getting public funding to offset transportation costs, Scenario D. Under Scenario D the regional digester would procure a 5% borrowing rate to fund 100% of the capital purchase. Furthermore, the state government would provide financial support up to the cost of net social benefits for transporting the dairy manure from the participating dairies to the regional digester and would require 100% participation by dairies in the immediate area. Except for Scenarios C and H, the facility capable of producing 10

megawatts has a pricing advantage over the other digesters examined in this study. This demonstrates that there are financial advantages that exist by developing larger facilities.

Table 4-1: Minimum Price per kWh Needed to Produce a Positive Net Present Value per Cow 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	7.50 ¢	8.00 ¢	8.50 ¢	8.25 ¢
Scenario B: Loan Rate: 9%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	10.00 ¢	8.00 ¢	8.00 ¢	7.50 ¢
Scenario C: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	8.50 ¢	5.75 ¢	6.50 ¢	6.25 ¢
Scenario D: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: Yes	6.00 ¢	4.50 ¢	4.50 ¢	4.00 ¢
Scenario E: Loan Rate: 9%; Participation Rate: 75% Capital Borrowed: 65%; Public Funding: No	9.00 ¢	8.25 ¢	8.00 ¢	7.75 ¢
Scenario F: Loan Rate: 9%; Participation Rate: 100% Capital Borrowed: 65%; Public Funding: No	> 10.00 ¢*	8.25 ¢	8.25 ¢	7.50 ¢
Scenario G: Loan Rate: 9%; Participation Rate: 75% Capital Borrowed: 100%; Public Funding: No	8.75 ¢	8.00 ¢	8.00 ¢	7.50 ¢
Scenario H: Loan Rate: 9%; Participation Rate: 50% Capital Borrowed: 100%; Public Funding: No	7.50 ¢	8.00 ¢	8.25 ¢	8.00 ¢

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

The regional digester that seems to have the highest minimum electricity cost is the facility capable of producing 1.6 megawatts of electricity, which is based on dairies using a flush manure management system. 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.³⁹ This result is occurring due to the high transportation cost of trucking the manure which is diluted with an estimated 70 gallons per cow per day. These regional digesters are likely to be viable as single dairy operation systems.

Scenario A put forth in this study was meant to simulate a purely private entity operating a regional digester, while Scenario D was used to simulate a public enterprise like a municipality, e.g., Inland Empire Utility Agency. Examining these two scenarios in the table above shows

³⁹ This result is mainly an anomaly of the simulation. Since each facility was designed to handle a certain amount of cows, some of the configuration that had a source of 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; thus, allowing a closer source of manure to be found.

what kind of effect public participation can make in enhancing the feasibility of a regional digester. For the facility capable of producing 10 megawatts, 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 megawatts, which only decreases the 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 probably rely heavily on how well the utility company can justify that the price it pays for the electricity from the regional digester is a reasonable price.

The previous table presented the minimum price necessary to induce a positive net present value for each operation under each funding scenario. For the systems that rely on dairies that use scrape systems, a positive net present value probably would be enough to induce dairies to participate in a regional digester. For those systems that are not currently using a scrape manure management 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 their manure management systems to scrape systems. Since no data could be found on what it may cost to change a dairy system using a flush system to a dairy system using a scrape system, a rough estimate was provided by the Agricultural Engineer on this project. He believes that on average it would take approximately \$100 per cow to make the change over.⁴⁰ For example, if a dairy had 1,000 cows, it is expected that it would cost \$100,000 dollars to compensate the producer to make the change.

⁴⁰ 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. Whether this really will be a new expense will depend on future water regulations for the Central Valley. In order to manage the water quality issues in the Central Valley, it is not difficult to envision EPA developing regulations that will compel dairy operators to better manage water related to their operations. Also, this \$100 per cow assumption does not take into account that dairies have the opportunity to offset some of the cost of the changeover by applying for state or federal funding. One source of funding for this changeover could come from the EQIP program discussed in chapter two.

Given the assumption that it will take on average \$100 per cow of net present value to induce each dairy operator to changeover to a scrape system, Table 4-2 presents the minimum price per kWh needed to generate at least this amount of money per cow. Since the facility producing 1.6 megawatts 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 megawatts 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 net present value for this scenario, an increase of \$0.01 per kWh is necessary. This is also true for Scenario A, which is based on the assumption that the digester is a purely private entity. As with the previous results presented in Table 4-1, the facility capable of producing 10 megawatts has a pricing advantage over the smaller regional digesters.

Table 4-2: Minimum Price per kWh Needed to Produce a Net Present Value of At Least \$100 per Cow under Differing Assumptions for a Centralized Digester in the Central Valley

Scenarios	Anaerobic Digester Engine Size		
	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	10.00 ¢	9.75 ¢	9.25 ¢
Scenario B: Loan Rate: 9%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	9.75 ¢	9.25 ¢	8.50 ¢
Scenario C: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	7.50 ¢	7.75 ¢	7.25 ¢
Scenario D: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: Yes	6.25 ¢	5.75 ¢	5.00 ¢
Scenario E: Loan Rate: 9%; Participation Rate: 75% Capital Borrowed: 65%; Public Funding: No	10.00 ¢	9.25 ¢	8.75 ¢
Scenario F: Loan Rate: 9%; Participation Rate: 100% Capital Borrowed: 65%; Public Funding: No	10.00 ¢	9.50 ¢	8.75 ¢
Scenario G: Loan Rate: 9%; Participation Rate: 75% Capital Borrowed: 100%; Public Funding: No	9.75 ¢	9.25 ¢	8.75 ¢
Scenario H: Loan Rate: 9%; Participation Rate: 50% Capital Borrowed: 100%; Public Funding: No	9.75 ¢	9.50 ¢	9.25 ¢

Comparing the facility capable of producing 10 megawatts in Table 4-2 to the facility capable of producing 1.6 megawatts in Table 4-1 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 megawatts, which brings in \$100 per cow in net present value, 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 megawatts in Table 4-1. The second reason to compare these two facilities is because the facility capable of producing 10 megawatts represents the most economically efficient in relationship to the other systems relying upon scrape manure management systems. As the participation rate increases, the 10 megawatts 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 4-3 provides a look at the maximum net present value per cow if this price could be achieved. The facility capable of producing 10 megawatts of electricity dominates all other regional digesters examined in this study in generating the highest net present values. If you subtract out \$100 per cow for this facility, it still dominates the facility capable of producing 1.6 megawatts for participation rates greater than 50%.

Table 4-3: Maximum Net Present Value 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 net present values.

The maximum amount of net present value that can be achieved for each cow is \$561.10, which occurs in the public funding model, Scenario D. The worst maximum net present value achievable for the regional digester capable of producing 10 megawatts 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 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 net present value.

At \$0.10 per kWh, all three regional digesters provide a net present value 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 net present value after compensating the dairies to changeover to scrape systems. For the facility producing 1.6 megawatts of electricity, not all of the scenarios are giving a net present value 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 net present value at all given a price of electricity 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.⁴¹

Larger facilities appear to be more profitable on a per cow basis in comparison to smaller facilities. The facility capable of producing 4.2 megawatts has a greater net present value per cow than the facility capable of producing 1.5 megawatts under all eight funding/participation scenarios. Both of these facilities are dominated by the facility capable of producing 10 megawatts. 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 examining this facility capable of producing 10 megawatts shows that net present value is increasing with participation rate.

Table 4-4 provides the number of simulations that provide at least \$100 per cow of net present value. Each simulation represented a different electricity price and a different configuration for the dairies that were involved. Under Scenario D, there are over 10,000 possibilities of regional digesters capable of producing 10 megawatts that provide at least \$100 per cow of net present value. Under the purely private model, Scenario A, over 500 simulations provided a net present value greater than \$100 per cow. The facility capable of producing 1.6 megawatts of power had

⁴¹ This result is again an anomaly of the model. What is occurring to make this result true is that the scenarios with lower participation rates are hauling the manure on average a shorter distance.

the fewest simulations covering \$100 per cow. While this facility had only 17 simulations providing \$100 per cow for Scenario D, examining the number of simulations that provide a positive net present value (the number in the table presented in parenthesis) increases to 42.⁴² This is still far below any of the scrape systems and demonstrates that the 1.6 megawatts facility is a less feasible possibility in relationship to the scrape systems under the public funding scenario.

Table 4-4: Number of Simulations that Provide a Net Present Value of At Least \$100 per Cow 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	3 (23)	17	7	529
Scenario B: Loan Rate: 9%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	0 (1)	5	24	2,079
Scenario C: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: No	0 (8)	63	1,020	6,438
Scenario D: Loan Rate: 5%; Participation Rate: 100% Capital Borrowed: 100%; Public Funding: Yes	17 (42)	1,279	6,083	10,846
Scenario E: Loan Rate: 9%; Participation Rate: 75% Capital Borrowed: 65%; Public Funding: No	0 (5)	1	22	1,231
Scenario F: Loan Rate: 9%; Participation Rate: 100% Capital Borrowed: 65%; Public Funding: No	0 (0)	3	15	1,745
Scenario G: Loan Rate: 9%; Participation Rate: 75% Capital Borrowed: 100%; Public Funding: No	0 (6)	3	36	1,511
Scenario H: Loan Rate: 9%; Participation Rate: 50% Capital Borrowed: 100%; Public Funding: No	4 (20)	2	10	754

* The numbers in parenthesis represent the number of simulations that provided a positive net present value.

To this point, results have been presented regarding the minimum price necessary to create a positive net present value per cow and \$100 net present value per cow, the maximum amount per cow that can be achieved by each regional digester given a \$0.10 per kWh price for electricity, and the number of configurations that provide \$100 of net present value per cow. Building off of these results, Table 4-5 presents a summary of the major financial results for the best system built for Scenario D, the publicly funded model. This table presents the number of cows and their distance away from the regional digester. The pro forma project costs, operating costs, trucking costs per kilowatt generated, and three income measures are also presented in this table.

⁴² Since the facility capable of producing 1.6 megawatts does not need to pay any incentive to dairy producers to switch their manure management system, it is appropriate to examine the number of simulations that provide a positive net present value.

The gross income reported in this table is the amount of income received from the sales of electricity and compost. Net income with government subsidy is equal to the gross income added to the government transportation subsidy minus the operating cost. The net income and government subsidy above amortized costs is defined as the previous income mentioned minus the amortization of the capital cost. Trucking cost per kWh and total operating cost per kWh are also presented in this table.

Table 4-5: Selected Simulation Results for Most Feasible Operation at an Electricity Price of \$0.10 per kWh for Scenario D (Publicly Funded Model)

	Anaerobic Digester Engine Size			
	1.6 MW* (Flush)	1.5 MW (Scrape)	4.2 MW (Scrape)	10 MW (Scrape)
Number of Cows Located at the Regional Digester	7000	7000	8,580	6,750
Number of Cows Transported from 0.5 Mile Away from the Digester	0	0	0	4,176
Number of Cows Transported from 1.0 Mile Away from the Digester	2100	2100	0	6,000
Number of Cows Transported from 1.5 Miles Away from the Digester			5,750	7,920
Number of Cows Transported from 2.0 Miles Away from the Digester			7275	0
Number of Cows Transported from 2.5 Miles Away from the Digester			5515	4,500
Number of Cows Transported from 3.0 Miles Away from the Digester				0
Number of Cows Transported from 3.5 Miles Away from the Digester				5,308
Number of Cows Transported from 4.0 Miles Away from the Digester				16,120
Total Number of Cows Serviced by Regional Digester	9,100	9,100	27,120	50,774
Project Capital Cost	\$ 3,726,737	\$ 5,364,712	\$ 14,135,387	\$ 26,216,241
Project Capital Cost per Megawatt	\$ 2,329,211	\$ 3,576,475	\$ 3,365,568	\$ 2,621,624
Amortized Capital Cost	\$ 359,042	\$ 516,849	\$ 1,361,835	\$ 2,525,733
Trucking Cost	\$ 429,398	\$ 86,957	\$ 624,336	\$ 1,564,566
Trucking Cost per kWh	\$ 0.0418	\$ 0.0085	\$ 0.0191	\$ 0.0248
Total Operating Cost	\$ 707,724	\$ 363,702	\$ 1,238,452	\$ 2,635,353
Total Operating Cost per kWh	\$ 0.0688	\$ 0.0357	\$ 0.0379	\$ 0.0418
Trucking Cost as a Percentage of Total Operating Costs	60.67%	23.91%	50.41%	59.37%
Government Trucking Subsidy	\$ 163,732	\$ 86,957	\$ 624,336	\$ 1,388,770
Gross Income	\$ 1,179,109	\$ 1,173,070	\$ 3,544,094	\$ 7,517,910
Net Income with Government Subsidy	\$ 635,117	\$ 896,325	\$ 2,929,979	\$ 6,271,327
Net Income and Government Subsidy Above Amortized Capital Cost	\$ 276,075	\$ 379,476	\$ 1,568,143	\$ 3,745,594
Net Yearly Social Benefits	\$ 163,732	\$ 356,213	\$ 882,342	\$ 1,388,770
Net Present Values	\$ 230.75	\$ 317.18	\$ 439.80	\$ 561.10

Examining Table 4-5 shows that the facility that is capable of producing 1.6 megawatts of power and relies on flush manure management systems has the lowest cost to build at \$3.7 million. It has the cheapest per megawatt cost to build at \$2.31 million dollars per megawatt. A close examination of the three regional digesters that rely on the scrape manure management system shows that the cost per megawatt to build is declining as the facilities get larger. The smallest facility costs \$3.57 million per megawatt, while the largest facility costs only \$2.62 million dollars to build. This would imply that there are cost savings that can be achieved by increasing the size of the operation.

Given a \$0.10 per kWh price for electricity sold to a local utility, Table 4-5 shows that the two smallest facilities source their cows from no further than a mile away from the operation. The two smallest facilities must rely on the same dairies for achieving their highest net present values per cow.⁴³ The facility that is capable of producing 4.2 megawatts of electricity must bring cows from as far away as 2.5 miles from the digester. The largest facility must obtain cows from a minimum distance of 4 miles from the regional digester.⁴⁴

The operating cost for each of these facilities ranges from \$363,000 for the facility capable of producing 1.5 megawatts facility up to \$2.6 million per year for the largest facility. The operating cost and trucking cost per kWh for the regional digesters relying on scrape systems is increasing with the size of the digesters. The facility that relies on dairies utilizing the flush manure management system has the highest per kWh operating cost and trucking cost of the four systems studied. This is due to the high cost of transportation.

Examining the trucking cost as a percentage of operating cost shows that the facility capable of producing 1.6 megawatts of power devotes the highest percentage of operating costs to transportation of the manure at 60.67%. This percentage is slightly higher than the 59.37% that the largest facility is allocating towards trucking cost. At 23.91%, the facility capable of

⁴³ It may be difficult to call these systems regional digesters because they consist of only two operations participating in the system.

⁴⁴ This is not to say that the regional digester is constrained to a 4 mile radius, only that the most profitable facility can source cows from up to 4 miles away. Examining other results from the simulation shows that the facility producing 10 megawatts of electricity can source cows as far as 10 miles away from the facility and still maintain \$100 per cow in net present value.

producing 1.5 megawatts of power had the lowest percentage of its operating cost devoted to transportation of the manure. The facility capable of producing 4.2 megawatts is devoting just over half of its total operating costs to transportation. These results should emphasize the point that transportation of manure is an important cost that must be managed well for a regional digester to remain feasible.

Since this table presents results from Scenario D, the publicly funded option, an examination can be conducted on what each facility will cost the government on a yearly basis. Both the facilities capable of producing 1.6 megawatts and 10 megawatts of electricity need a subsidy that is equal to the total net social benefits. The largest facility has a net social benefit of approximately \$1.4 million which is equal to the subsidy amount provided by the government. The two smaller facilities that rely on scrape systems have a larger net social benefit than the amount needed to subsidize the trucking. This implies that these two regional digesters would still produce a positive net social benefit after being subsidized. This would not be true of the other two facilities because society is taking the benefit it is receiving from the regional digesters and giving the money value of those benefits back to the digester.

There are three different incomes reported in Table 4-5. The most notable finding when examining these numbers is that the gross incomes from the two smallest facilities are nearly equal, but both net income measures are higher for the facility capable of producing 1.5 megawatts. This result provides another highlight of how important transportation costs are to the feasibility of an operation. As would be expected all income measures are increasing as the size of the facilities increase.

While the previous table presented some of the pro forma results for the best regional digesters found under the publicly funded model known as Scenario D, Table 4-6 provides similar results for the purely private model that has a 50% participation rate. This table presents the number of cows and their distance away from the regional digester. In this case, the number of miles needs to increase to seven miles to accommodate the largest facility.

Table 4-6: Selected Simulation Results for Most Feasible Operation at an Electricity Price of \$0.10 per kWh for Scenario A (Purely Private Model)

	Anaerobic Digester Engine Size			
	1.6 MW* (Flush)	1.5 MW (Scrape)	4.2 MW (Scrape)	10 MW (Scrape)
Number of Cows Located at the Regional Digester	7,000	7,000	8,580	7,000
Number of Cows Transported from 0.5 Mile Away from the Digester	0	0	0	0
Number of Cows Transported from 1.0 Mile Away from the Digester	1,050	1,050	0	1,050
Number of Cows Transported from 1.5 Miles Away from the Digester		1,360	2,875	1,360
Number of Cows Transported from 2.0 Miles Away from the Digester			3,638	1,050
Number of Cows Transported from 2.5 Miles Away from the Digester			2,758	2,830
Number of Cows Transported from 3.0 Miles Away from the Digester			3,138	2,410
Number of Cows Transported from 3.5 Miles Away from the Digester				4,235
Number of Cows Transported from 4.0 Miles Away from the Digester				7,495
Number of Cows Transported from 4.5 Miles Away from the Digester				3,910
Number of Cows Transported from 5.0 Miles Away from the Digester				4,448
Number of Cows Transported from 5.5 Miles Away from the Digester				3,758
Number of Cows Transported from 6.0 Miles Away from the Digester				4,835
Number of Cows Transported from 6.5 Miles Away from the Digester				3,010
Number of Cows Transported from 7.0 Miles Away from the Digester				2,792
Total Number of Cows Serviced by Regional Digester	8,050	9,410	20,988	50,182
Project Capital Cost	\$ 3,342,562	\$ 5,440,298	\$ 11,690,221	\$ 26,115,505
Project Capital Cost Per Megawatt	\$ 2,089,101	\$ 3,626,865	\$ 2,783,386	\$ 2,611,551
Amortized Capital Cost	\$ 269,538	\$ 438,696	\$ 942,679	\$ 2,105,909
Trucking Cost	\$ 227,648	\$ 97,419	\$ 424,908	\$ 1,920,712
Trucking Cost per kWh	\$ 0.0250	\$ 0.0093	\$ 0.0168	\$ 0.0308
Total Operating Cost	\$ 488,177	\$ 379,365	\$ 928,216	\$ 2,980,460
Total Operating Cost per kWh	\$ 0.0537	\$ 0.0360	\$ 0.0367	\$ 0.0478
Trucking Cost as a Percentage of Total Operating Costs	46.63%	25.68%	45.78%	64.44%
Gross Income	\$ 1,055,270	\$ 1,209,427	\$ 2,772,022	\$ 7,435,225
Net Income	\$ 567,094	\$ 830,062	\$ 1,843,807	\$ 4,454,764
Net Income Above Amortized Capital Cost	\$ 297,555	\$ 391,365	\$ 901,127	\$ 2,348,855
Net Yearly Social Benefits	\$ 221,730	\$ 362,986	\$ 686,971	\$ 905,692
Net Present Values	\$ 135.82	\$ 113.99	\$ 131.62	\$ 254.43

Also presented in this table are the pro forma project costs, operating costs, trucking costs, and three income measures. The gross income is the amount of income received from the sales of electricity and compost. Net income is equal to the gross income minus the operating cost. This income measure is different than the previous table because Scenario A does not have a subsidy being given to the digester for transportation. The net income above amortized costs is defined as the previous income mentioned minus the amortization of the capital cost. Trucking cost per kWh and total operating cost per kWh are also presented in this table.

Given a \$0.10 per kWh price for electricity, examining the travel distance for each facility shows that the farthest distance needed to source the cows for each facility increased from the public model, Scenario D, except for the digester that relies on the flush manure management system. The facilities capable of producing 1.5 megawatts and 4.2 megawatts had to increase the farthest distance traveled by one-half mile, while the facility capable of producing 10 megawatts needed an extra three miles to obtain the cows necessary. Taking a closer look at the numbers of cows being served by each regional digester and comparing them with the range of cows each facility can handle, all the systems are biased to the lower end of the number of cows they can service.⁴⁵ This would imply that while a movement up in the size of the digester provides some cost advantages, transportation cost drives the number of cows that each facility handles down to its minimum capacity that it can handle. From this result comes a very important policy issue. If the government chooses to subsidize transportation costs, it should expect that regional digesters will run closer to the maximum amount of cows their facilities can manage. On the other hand, if the government decides to push legislation for utility companies to pay an electricity price that is substantial enough to induce a regional digester to operate, then it should expect that the digester will have capital equipment being underutilized from its full potential. It should expect under this policy that there would be more regional digesters, which in turn would keep down the transportation cost per digester.

⁴⁵ While the facilities capable of producing 1.6 and 1.5 megawatts are not at the lowest end of their range of cows they could handle, they are at the lowest point feasible to still be in operation due to the size of the dairies available around each facility modeled.

The capital cost to build each of the facilities ranged from \$3.3 million up to \$26.1 million. Comparing this scenario to the public scenario shows that the capital costs between each facility did not change substantially except for the facility capable of producing 4.2 megawatts. The capital cost of this facility substantially decreased because the amount of cows it services substantially decreased. Under the public model, this facility was servicing over 27,000 cows. The number of cows serviced drops to fewer than 21,000 for the purely private model with the lowest participation rate. The per megawatt cost for this facility decreases to \$2.8 million, which makes the per megawatt cost of this facility closer to the per megawatt cost of the largest facility.

In the previous scenario investigated, the facility relying on flush manure management systems as a source of its cows had the highest transportation cost per kWh and total operating cost per kWh of the four regional digesters examined. Given the purely private scenario, the largest facility has the largest transportation cost per kWh at \$0.0308 per kWh. This effect occurs because the facility capable of producing 1.6 megawatts is transporting fewer cows in this scenario. While the largest facility has the highest per kWh transportation cost, the facility capable of producing 1.6 megawatts still has the highest total operating cost per kWh at \$0.0537 per kWh.

Under the purely private scenario with a 50% participation rate, the percentage of total operating cost devoted to transportation cost decreased substantially for the facility capable of producing 1.6 megawatts. At 46.63%, the percentage of total operating cost devoted to transportation cost is closer to the 4.2 megawatts facility than in the previous scenario where this percentage was closer to the largest facility. The largest facility had the highest percentage of total operating cost expended to transportation at 64.44%, which is a gain of over 5% in absolute terms from the publicly funded scenario discussed previously.

Comparing the two previous tables shows that the bottom line net income (for Scenario D this means net income and government subsidy above amortized capital cost and for Scenario A this means net income above amortized capital cost) increased for the two smaller facilities and decreased for the two larger facilities when moving from the publicly funded model to the purely private model. Even though the two smaller facilities were receiving government subsidies, their

bottom line net income was better when they received no subsidies. This did not equate to a better net present value for the two facilities because the private scenario had to pay 35% of the capital cost before it started operations.

Chapter 5: Summary, Policy Implications, and Future Research

Summary of Key Findings

This report presented results from a study that examined the feasibility of operating regional anaerobic digesters in the Central Valley which only depend on dairy manure as an input to producing revenue generating products. Simulations techniques were utilized to examine over 650 locations in the Central Valley to operate a regional digester. Four different regional digester systems were examined under eight different funding and participation scenarios. Three of these digesters relied upon dairy operators who use scrape manure management system, while one system relied on dairy operators maintaining a flush manure management system.

The feasibility of any regional digester will be contingent on many factors.⁴⁶ The three primary factors affecting feasibility of regional digesters in the Central Valley are: 1) start-up costs and financing, 2) a revenue stream that can provide enough income for a competitive return on capital invested or its opportunity cost, and 3) dairies using a scrape manure management system. All three of these factors can be substituted for each other in some form or another. For example, if favorable financing cannot be secured for the regional digester, then the operation can still maintain its feasibility by having a higher revenue source from higher electricity prices. If a regional digester is meant to rely on dairies using flush manure management systems, then either more favorable financing or greater revenue generation will be necessary to maintain feasibility.

Given prices that have been seen in the literature for electricity generation from anaerobic digestion (\$0.04 to \$0.10 per kWh), this study has shown that regional digesters can be financially feasible in the Central Valley of California when prices are at the upper end for a purely private operation. To be feasible, this operation will need to secure a minimum of \$0.0925 per kWh for the electricity it generates given that it is a purely private entity that can convince 50% of the dairies around the regional digester to participate. This price drops considerably when public funding is provided to offset transportation costs and favorable

⁴⁶ For this study, feasibility was defined as an operation that had a positive net present value at a 10% discount rate over a fifteen year time horizon with a positive net social benefit.

financing is given for start-up costs. If public funding is provided at the value of net social gains, 100% of the dairies around the digester participate, and favorable financing is provided, the price necessary to make a regional digester feasible is a minimum of \$0.05 per kWh of electricity generation. Both of these results are contingent upon producers changing their manure management systems from flush systems to scrape systems and that the facility utilizes the technology that allows it to produce up to 10 megawatts of electricity. In general, the facility capable of producing 10 megawatts has a pricing advantage over the other digesters examined in this study.

This study showed that there are a few feasible regional digesters which rely on flush manure management systems based on the electricity prices found in the literature. But, there are not nearly enough locations in the Central Valley to make this a general feasible operation in the state. The systems normally must source their cows within a mile of their operation. It was discovered that these regional digesters had the highest minimum electricity cost needed to be feasible in comparison to the other facilities examined, which is a result of the high transportation cost.

Given an electricity price of \$0.10 per kWh, the facility capable of producing 10 megawatts dominates all other regional digesters examined in this study in generating the highest net present value. The maximum amount of net present value per cow for this facility ranged from \$561.10 per cow, which occurs in the public funding model, to \$173.87 per cow, which occurs in the purely private model with a 50% participation rate. At \$0.10 per kWh, all three regional digesters based on scrape manure management systems provide a net present value greater than \$100 per cow. Further examining the facility capable of producing 10 megawatts shows that net present value is increasing with participation rate.

The facility capable of producing 1.6 megawatts of power and relies on flush manure management systems has the lowest per megawatt cost to build at \$2.31 million per megawatt. A close examination of the three regional digesters that rely on the scrape manure management system shows that the cost per megawatt to build is declining as the facilities get larger. This

implies that there are economies of scale that can be achieved by increasing the size of the operation.

Policy Implications

The results above are heavily dependent upon how the California regulatory environment interacts with these proposed regional digesters. The feasibility of these operations was heavily dependent upon a regulatory environment that is conducive to facilitating the building of these regional digesters. It would not take much in the way of added regulatory costs to make most of the feasible regional digesters in this study infeasible given an upper end price on electricity sales of \$0.10 per kWh. Hence, if the California state government is interested in facilitating the building of regional digesters, it should consider the following policy recommendations:

1) The state government should develop policies to remove any unnecessary barriers for producers to sell their power to the electrical grid. Accompanying this reduction in barriers should be policies that allow producers to get reasonable prices for selling their power to the grid. In many instances found in the literature on the topic of regional digesters, it is not uncommon for producers to receive between 4.00 to 5.00 cents per kWh if they sell their power to the grid. Under this pricing regime, most regional digesters from this study are infeasible unless the public helps with the funding of the operation either from the capital cost side or the operational cost side.

2) For centralized digesters to be successful there is a need for policies that facilitate the production of these facilities. Three of the major policies the California government could implement are: a) low cost loans to producers who want to develop these facilities, b) fast track permitting that will allow these operations to come on-line more quickly, and c) developing a regulatory environment that does not cause transportation of manure using trucking to become overly cost prohibitive. Careful consideration of each policy needs to be made because this study has shown that a policy can have a considerable effect on the behavior of the operation. This behavior may be counter to what you might expect. For instance, when assistance was

given to the regional digester for transportation of the manure, regional digesters used their capital equipment more efficiently.⁴⁷

Increased participation levels of dairies around the regional digester were shown to improve the feasibility of most operations. Hence, favorable regulations regarding participation may increase participation rates. The government could mandate that if a regional digester is built, then all dairies within its proximity must participate. This type of legislation would probably be infeasible. A more feasible way of inducing producers to participate would be to strengthen the manure application requirements through legislation. This is already occurring with the new CAFO regulations put out by the EPA. The most politically feasible solution to increase participation rate is to provide some sort of financial incentives.

If it is expected that producers will maintain flush systems, it will probably be politically infeasible to have a regulation that requires 100% participation. Since the feasibility of these systems are heavily reliant upon being located next to very large dairies and must locate the needed manure within a one mile radius of the regional digester given current electricity prices, anaerobic digestion at a regional level does not seem to be feasible. If the legislature would like to induce more of these regional digesters to exist and become a statewide solution, heavy subsidization of the regional digesters beyond their net social benefit would be necessary.

For producers to participate in a profitable regional digester, they must convert their manure handling systems to systems that use water very sparingly. This implies that producers who participate in successful regional digesters will need to have a greater labor base to handle the manure. As labor costs increase, producers will be less likely to changeover to a scrape manure management system. Hence, the legislative body should take into consideration that policies like increasing minimum wage can have a detrimental effect on inducing dairy producers to changeover their manure management systems to a scrape system which will affect the feasibility of a regional digester.

⁴⁷ In this case, efficiency is being defined as a regional digester that produces power at the upper level of its productive capacity.

The results found in this study provide an interesting policy dilemma for the state government if it wants to encourage regional digesters.⁴⁸ 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? These two policy questions may not be as diametrically opposed to each other as they first appear. Legislative policy will probably have to balance the political ramifications of these two questions and provide legislation that induces a higher electricity price for regional digesters along with some sort of capital subsidization.

Future Research Needed

While this study only 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. For some regional digesters that were examined in this study, adding other types of agricultural waste may boost the feasibility of centralized digester by providing tipping fees and better methane production. 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 because there would be efficiency gains in transportation of part of the dairy manure needed and sale of power to the dairy the digester is located at. A regional digester, if large enough, could facilitate the redistribution of dairy manure between dairies with a deficit of land to dairies with a surplus of land. This also assumes that the manure can be redistributed across participating dairies that would improve the application from a water quality social benefit aspect. Realistically, there are some dairies in the Central Valley that do not have enough crop land to handle the amount of manure generated by their cows. If the dairies involved in a particular regional digester do not have enough land to apply all of the manure in a manner that does not affect environmental quality in a negative way, then a better method of locating the facility would have to consider the tradeoff in transportation costs by placing the regional digester closer to other agricultural

⁴⁸ By having public support, it was found that the price of electricity that the regional operator needs to be feasible drops by \$0.0425 per kWh for the facility capable of producing 10 megawatts.

facilities that could absorb the excess digested effluent. Another option would be for the regional digester to buy into a technology that would clean the digested effluent to a level where it was disposable.⁴⁹ In either case, the regional digester may need to charge tipping fees to handle the extra costs. This study did not consider locating the regional digester near non-dairy farms that could utilize the dairy manure in a more environmentally efficient way than the dairies. This analysis could be important because it may provide more feasible locations than the ones found in this study.

This study only looked at facilities that could produce up to 10 megawatts 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 find out the most profitable size regional digester. At some point, you would expect that the cost of hauling manure will overtake the efficiency gains achieved by moving to a better technology that could handle more cows.

It was assumed in this study that \$100 per cow would be enough to induce a dairy producer using a flush manure management system to changeover to a scrape manure management system. Since this is primarily an educated guess, further study is necessary to develop the amount of money necessary to induce producers to make the changeover. It is expected that each dairy operator will have a different threshold for making the change in manure management systems. Further study is necessary to develop the relationship between the key attributes of the dairy and the amount of compensation necessary. The cost of labor and its future direction can have a large effect on what this compensation will need to be. A compensation scheme may not be necessary if EPA regulations get stricter on disposal of manure in the future.

Finally, this study did not look at how the profits of the facility would be utilized. The distribution of profits may be an important issue when a producer decides whether they will

⁴⁹ This is not to imply that the digested effluent be brought to the level that would be potable. Rather, it is possible to clean the digested manure to the point where it could be spread on the existing land base without causing environmental degradation.

participate in a regional digester.⁵⁰ Dairy producers who are closer to the centralized digester may want a higher dividend for their participation because the transportation cost on a per cow basis would be less. This could be handled by charging tipping fees to all of the producers based on transportation costs. The optimal tipping fees need examination.

⁵⁰ This assumes that the government does not require 100% participation in the regional digester.

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