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An Analysis of the Feasibility of Anaerobic Digestion on Small-Scale Dairies in Utah

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AN ANALYSIS OF THE FEASIBILITY OF ANAEROBIC
DIGESTION ON SMALL-SCALE DAIRIES IN UTAH

by

Steven Chans Lund

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ABSTRACT

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by

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Utah State University, 2016

Major Professor: Dr. DeeVon Bailey
Department: Applied Economics

The purpose of this study was to analyze the feasibility of implementing anaerobic digester systems on small-scale dairy farms (i.e., 210 cows) in the state of Utah. The specific objectives of the study were the following:

1. Examine the potential economic benefits of different products produced from anaerobic digestion.
2. Examine the benefits of codigestion on a dairy farm and artisan cheese plant operation.
3. Examine the potential social and environmental benefits received from anaerobic digestion.
4. Analyze the strengths and weaknesses of using anaerobic digestion as a means to managing dairy waste.

This study proceeds with a literature review of the history and science of anaerobic digestion, the dairy industry, other studies on the feasibility of anaerobic digestion and the need for sustainable agriculture. Methods used to determine the feasibility of adopting anaerobic digestion on small-scale dairy farms in Utah include creating enterprise budgets, analyzing future cash flows, estimating the net present value, estimating the internal rate of return and performing sensitivity analyses. Results show that adopting anaerobic digestion on small-scale dairy farms can be feasible when subsidies are provided for the initial investment cost. The feasibility is improved when coproducts from anaerobic digestion are marketed correctly. Small-scale dairy farms that produce artisan cheese have a higher probability of adopting anaerobic digestion successfully due to the whey byproduct of cheese production.

(143 Pages)

PUBLIC ABSTRACT

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With an ever increasing concern for the environment, different methods of managing organic waste on dairy farms have been explored and analyzed. Anaerobic digestion has long been a popular method of managing organic waste. Its popularity stems from the potential to decrease greenhouse gases, improve air quality and provide a source of additional revenue for the farm. Problems with implementing anaerobic digestion arise from high failure rates, high start-up costs and continuous maintenance and equipment replacement.

Subsidies for the initial investment and improved technology have increased the possibility of large-scale dairy farms to adopt anaerobic digestion. Due to economies of scale large-scale dairy farms are more able to adopt anaerobic digestion, but small-scale dairies struggle to finance the investment, maintain the digester system and provide sufficient organic waste to continuously feed the microorganisms inside the digester system. The increasing impact of urbanization greatly impacts the demand for anaerobic digestion on small-scale farms to mitigate the negative effects of organic waste produced by dairy farms.

Dr. Conly Hansen at Utah State University suggested we use an IBR digester model to analyze the feasibility of adopting anaerobic digestion on small-scale farms.

The IBR digester system is more conducive to small-scale dairies located in regions with varying temperature (i.e., Utah), and may be the solution to mitigate the negative effects of organic farm waste. Dr. Donald McMahon also suggested we analyze the potential of implementing a digester on a dairy farm that produces artisan cheese. We predicted that this would improve the feasibility due to the need to dispose of whey from the cheese production.

To determine the feasibility of implementing a digester system on a small-scale dairy farm the net present value and the internal rate of return were calculated to estimate the success of the investment. These financial measures were calculated from equipment price quotes, estimations from the literature review and from using estimated annual receipts and costs for a dairy farm, artisan cheese plant and anaerobic digester system. The feasibility also depends on the success of marketing the products produced from the digester system and the farmer's participation in incentive programs for digester systems. The products produced vary from electricity to waste disposal services, and marketing an array of diverse products and services is important to the success of the digester system. The feasibility determined by this study was estimated using generalized assumptions from various sources and should be analyzed by individual operations to determine specific farm feasibility.

ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION, MOTIVATION, AND OBJECTIVES

The motivation for this thesis lies in the continuing increase in environmental regulations related to waste management, unsightly farms, and the pollution of water, air, and land through agricultural practices. These regulations require additional costs be incurred to be compliant or will result in increasing penalties and fines for non-compliant agricultural firms. In either case, environmental regulation affects the sustainability of agriculture and food production.

This thesis focuses on the use of anaerobic digester systems on small-scale dairy farms as a means to manage waste, to improve the appearance of farms and to reduce pollution. Meeting these three objectives may make dairy farmers more sustainable economically, socially and environmentally. One potential option to increase the profitability of small-scale dairy farms is to implement a value-adding component to dairy production, specific to this thesis is converting milk to cheese through artisanal methods.

Various regions of the world may have strict definitions of artisan food production. Other regions may require the food production to be done by a skilled person, with specific ingredients and in a certain way. Some believe a universal definition should be created and regulated so as to protect cultural and traditional food production (Domínguez-López et al. 2011). For this paper the definition used for artisan production is food (e.g. cheese) that is produced by a craftsman in a traditional way instead of by industrial methods. Artisan dairies are smaller in scale and produce a finished product (e.g. cheese) from raw materials obtained through on-farm production.

Whey is a waste product created in cheese production. It adds another component to the waste management of the operation and another potential benefit of using an anaerobic digester system. The major forms of waste on a dairy farm include manure, bedding, whey from dairy processing (if the dairy engages in cheese making) or any other spoiled or unused food product produced by the dairy. With the exception of biosolids and animal manures, organic waste management in the United States is regulated at the state level.

The United States Environmental Protection Agency (US EPA) is a federal government agency that regulates manure and wastewater generated by Confined Animal Feed Operations (CAFOs)[1] to ensure they are in compliance with the Clean Water Act[2]. The objective of the Clean Water Act is to reduce and prevent water pollution. Wastewater disposal is regulated through the Clean Water Act to ensure the quality of water available for all living organisms (US EPA 2015c). Polluted water from agricultural operations has the potential to kill fish and cause eutrophication and toxic algal blooms affecting all states that are connected by common waterways.

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[1] CAFOs are dairy operations with 700 or more cows confined on site, or an operation that disposes of waste water in a ditch, stream or waterway (USDA NRCS n.d.).

[2] Clean Water Act establishes standards to keep US waster free of pollution (US EPA 2015c).

The correct management of waste is essential for compliance with EPA regulations and fulfilling the requirements of sustainability. Ensuring that waste storage facilities on dairy farms are well maintained and that the system for land application of manure is efficient will help mitigate the economic, social, and environmental problems associated with dairy farming. Correct waste management techniques should also improve the public perception of agricultural production and also decrease the possibility of water pollution, but this may not be sufficient to make an operation sustainable if there is not economic benefit.

Using an Anaerobic Digester in Waste Management

A mature 1,400 lb. dairy cow that is lactating can generate as much as 112 lbs. of manure per day. Of the 112 lbs. an average of 75% is expected to be recoverable. Recoverable manure is defined by the USDA Natural Resource Conservation Service (NRCS) as "the amount of manure deposited in confinement that can feasibly be collected and utilized" (USDA NRCS 1995). Thus, the scale of waste management on American dairy farms that typically have several hundred to even several thousand cows is an important consideration. Science has been applied to try to find the best way to manage the substantial amount of waste associated with dairy production. Anaerobic digesters may be one method that can provide significant assistance to this waste management problem, especially for large-scale producers.

Organic waste, such as manure, naturally degrades. If this degradation process occurs with oxygen, the waste is degraded under aerobic conditions. If organic waste is broken down without oxygen, it is degraded under anaerobic conditions. Anaerobic degradation occurs as microorganisms feed on and digest organic waste and release methane, carbon dioxide and other trace compounds such as hydrogen sulfide. Anaerobic digestion can be accelerated in a mechanical anaerobic digester system, and the resulting methane can be sequestered from the digestion process in the form of biogas. This biogas can then be used to fuel electric generators or boilers to create electricity or heat. If the biogas is further processed the methane can be separated from the remaining carbon dioxide and other trace elements. This purification process allows the methane to be used to fuel vehicles or introduced into a public pipeline to be bought and used by the public. Scrubbed biogas or biomethane is also not as damaging to combustion engines used for electric generators. If biogas is purified, the lifetime of combustion engines for electric generators may be extended by several years.

Any organic waste that does not contain lignin (woody plants) can be used effectively as feedstock[3] for anaerobic digester systems. Manure and energy crops such as sugar beet and corn are often the primary feedstock used in anaerobic digester systems, but the use of additional feedstock such as waste frying oil in codigester systems can increase the biogas production without dramatically increasing residual solids in the effluent (Cave 2013). Anaerobic digester systems provide not only a means to mitigate animal waste but also food waste. The FAO reported that as of 2011 "one-

[3] Feedstock is the organic matter that is fed to the microorganisms, digested and converted to biogas.

third of food produced for human consumption is lost or wasted globally." They estimate that the per capita waste by consumers in Europe and North America is 95-115 kg per year (FAO 2011). Anaerobic digester systems provide a way to convert energy wasted in the form of food to energy that can be used on the farm.

Need to Use Resources Efficiently for Sustainability

The increasing population of the world creates with it the need for improved efficiency of the use of resources used to satisfy the unlimited wants and needs of people. Terms such as "energy crisis" and "food crisis" are used to describe the potential shortage of two resources needed to sustain life. Concerns relating to the depletion of food and energy resources has given rise to government programs, regulations and subsidies created with the intention of fostering sustainable methods of processing and using scarce resources. Innovation and technology from both the public and private sector continue to improve methods for extracting, harnessing and processing energy and food resources so as to reduce and reuse waste and improve sustainability.

By reducing waste and making environmentally-responsible production more profitable, food production becomes more sustainable socially, environmentally and economically. The 2011 edition of the United States Code defines sustainable agriculture as production that satisfies the food and fiber needs of the consumer while using resources natural resources efficiently. Using natural resources efficiently includes integrating natural biological cycles and controls and enhancing the environmental quality. The farm must also be economically viable and meet the financial needs of the farmer and somehow improve society (US Government Printing Office 2011). The US EPA states that sustainable production is based on the fact that the natural environment provides everything we need to survive. Therefore "productive harmony" between humans and nature must be achieved. This is done by accounting for social, environmental and economic factors of production, so that natural resources will be widely available for future generations (US EPA 2015d).

Food resources range from heirloom to genetically-modified and energy resources from nuclear to renewable. Each genre can make different arguments for its contribution to sustainability. The endeavors to create sustainable agriculture have been given terms such as permaculture and organic when speaking of agriculture methods. With regards to economics, terms such as corporate social responsibility, triple-bottom line, and creating shared value are often used. Regardless of the discipline used to study and classify agricultural sustainability, producers are consistently concerned about their own financial bottom line and usually focus business efforts on reducing costs and hedging risk. Being able to utilize waste as an energy source efficiently has been a topic of interest for many years, but the production of energy from waste often creates additional costs without the ability to increase revenue sufficiently to profit from these renewable investments. If all three pillars of sustainability (social, environmental and economic) are not realized, then disputes arise about which is more important and regulations are put into place as an attempt to provide balance and improve sustainability.

Different Approaches to Food and Energy Issues

Worldwide food and energy concerns are addressed and handled differently by different countries through political solutions, and individual countries are generally driven to seek sustainable solutions for food and energy concerns. That is, most countries are concerned about producing food and energy responsibly, but the resource bases and politics of countries are different often resulting in different approaches to achieving these goals. The US has addressed food issues primarily through the lens of reducing costs and increasing production. This has been achieved primarily through methods such as increasing agricultural yields through genetically-modified organisms (GMOs) and taking advantage of economies of scale through increased farm size and thus becoming more efficient. The US also provides large amounts of subsidies to farmers for specific crops to help protect against economic losses.

On the other hand, the European Union (EU) with its relatively high energy costs and small farms has focused more on environmental regulations to drive their subsidies to farmers in the hope of preserving the resources used to produce the food needed for many years to come. The EU has done this by providing subsidies through the Common Agricultural Policy (CAP) to promote sustainability in food, water and land. These regulations and subsidies have made the EU one of the leaders in biogas production due to the increased feasibility from subsidies and the carbon credit exchange.

Both the EU and the US have created regulations that directly connect food and energy concerns. The US has encouraged ethanol production, which has greatly increased the amount of corn produced in the US, and the EU has improved the feasibility of biogas production through anaerobic digestion. Whatever the means, it is evident that the energy sector and the food sector have become intertwined in an attempt to provide sustainability.

The extent to which the US subsidizes anaerobic digester systems will greatly affect the feasibility of implementing anaerobic digester systems on small-scale dairies (<250 cows). Whatever the methods and foci of sustainability, governments, the World Bank and the United Nations place high priority on agricultural regulations and subsidies to reduce food and water scarcity. The World Bank and the Food and Agriculture Organization of the United Nations (FAO) predict a need for a 50% and 70% increase in food production by 2050, respectively (World Bank 2015; Food and Agriculture Organization of the United Nations 2009). This increase in food need motivates the implementation of sustainable practices.

A Changing Dairy Industry in the US and Purpose for this Study

Urbanization and the relocation of the majority of the dairy production to the western states of the US have begun to push small-scale dairy operations out of business due to water, land, odor and visual pollution in neighborhoods. Urban encroachment has often become a challenge for small dairies (especially in Utah) where areas were once populated numerous by small family dairies are becoming surrounded by houses and other non-agricultural activities. This urbanization has pushed dairy production from areas of increasing population, such as New York and Pennsylvania, to the western US where there is more open space and less urban pressure. However, the westward movement of US dairies may not be the best solution to situating the American dairy industry. Droughts are more common in the southwestern states and increased urbanization of western states has increased the demand for water for non-agricultural uses. The lack of water potentially limits the growth of the dairy industry in the western US. This increases the need for small family run dairies to maintain profitability and continue localized production despite urbanization.

Anaerobic digester systems offer a means to mitigate these social and environmental problems associated with agriculture, but more specifically agricultural production where a large number of animals are clustered such as is the case with dairy operations. Large-scale dairy operations are large enough that they rarely encounter problems with urbanization due to the fact that the majority of the surrounding land is owned by the producer and will likely not be sold to housing developers that will urbanize the area.

There have also been many studies done on the economic viability of anaerobic digester systems implemented on large-scale dairies, and it is much more likely that the large-scale operations will be able to be profitable with the anaerobic digester systems than would be small-scale operations. The purpose of this research project is not to determine whether anaerobic digester systems can be successfully implemented on large-scale dairies. There is already a plethora of literature that argues the likelihood of anaerobic digester systems being profitable on large-scale dairies. It is also less probable that large-scale dairies are under the same pressures as small-scale dairies to manage waste to mitigate the concerns of non-agricultural neighbors (e.g., odor) in the case of increasing urbanization.

In 2012 there were more than 47,000 dairies in the United States and 86% of them had less than 200 cows with the average herd size being 187 cows (Dairy Management Incorporated n.d.). In 2014, the USDA Economic Research Service reported that there were nine states that had more than 300,000 cows each and of those nine, five are in the top ten most populated states of the US (USDA ERS 2014; US Census Bureau 2014). The demand for economic and sustainable waste management is high due to urban encroachment and an increasing demand for food. The purpose of this research is to investigate the economic viability of anaerobic digester systems for small-scale dairies by evaluating the externalities of agriculture and food production, the start-up cost of anaerobic digester systems for small-scale production, and the possible sources of revenue for digester systems.

Anaerobic digester systems that convert manure, sludge or food to biogas are an option for producers to possibly reduce energy costs and hedge their risk through diversification through selling residual byproducts from the energy conversion process. It also provides a way to remove harmful and unpleasant aspects of agriculture that could potentially cause lawsuits and detrimental penalties and fines. If enough energy is produced to reduce fuel and energy costs, then anaerobic digesters may provide enough economic value to pay for the necessary equipment for a digester. If so, producers can become more financially sustainable and increase the social and environmental sustainability of their production. If enough residual byproducts from the digester can be sold as fertilizer, then revenues may also be increased to a point that profit is created from the production of fertilizer by the digester. If revenues are not high enough, then subsidies will need to be made available to encourage social and environmental sustainability.

Diversification through product proliferation by the dairy may be very helpful in hedging a producer’s risk, but it can also require additional time away from the primary production activity (producing milk) and stretch the producer’s time and energy too thinly between the different enterprises of the operation. Small- and medium-sized producers rarely use anaerobic digester systems because the amount of waste produced does not provide a high enough economic return from reducing energy costs or increasing revenues by selling residual solids as fertilizer. It is more common to have small- and medium-sized producers haul waste to a larger centralized producer to be digested and incur the cost of disposal.

The other option is to use the waste as fertilizer on crops, but there is often not enough cropland available for the amount of waste produced, especially due to urbanization around small and medium enterprises. Upon converting waste to energy, a useful resource is created which adds value and expands the options of waste utilization. Centralized digester systems allow several local agriculture producers to dispose of waste and other industries such as restaurants, bakeries, breweries and slaughterhouses to dispose of organic waste. This organic waste from food production also increases the amount of methane produced per unit of feedstock put into the digester.

Anaerobic digester systems provide a way to reduce the carbon footprint of landfills by reducing the amount of waste that flows into them. In 2007, food waste made up nearly 20% of the total waste sent to the landfill each year in the US. Yard trimmings increase the percentage by 7% decreasing the total landfill usage by 25%. In 2007, over 30 million tons of food waste was sent to US landfills. The EPA argues that one of the benefits of using food waste (such as whey from an artisan cheese-producing dairy) as a feedstock for anaerobic digestion systems is that food waste has three times the methane production potential as biosolids and 15 times the methane production as cattle manure. The effluent from food waste also provides high quality fertilizer (US EPA n.d.).

Anaerobic digester systems are not new technology, and they have a bad reputation for failure among dairy farmers in the United States. There are, however, aspects of digester systems that have been improved to be more efficient and cost effective than before. Most farmers, especially dairy farmers, are aware of the capabilities of a typical digester system. Many farmers find the technology very attractive, and recognize the benefits of being able to produce in a way that is more cost efficient and sustainable. However, many producers may be too risk averse to invest in digester systems because of the initial high capital costs needed to initially implement this technology in agriculture. After the close of the Chicago Climate Exchange in 2010 revenues from carbon credits have changed. Revenues from carbon credits are often used to enhance the profitability of anaerobic digestion. Now farmers must apply and be accepted to offset carbon credits. Without the ease of receiving income from a carbon credit exchange similar to what the EU has and additional subsidies from the government, risk averse US farmers may be deterred from implementing digester systems and attempting to market additional byproducts from the digester systems. In the US there is little incentive to encourage small-scale farmers to use the technology. The costs typically exceed the benefits for small-scale farmers.

The most attractive revenue source of anaerobic digester systems comes from the ability to provide the renewable source of electricity that provides social and environmental sustainability to agriculture. However, social and environmental sustainability will not make a business sustainable without a source of economic sustainability, and they will not allow a producer to provide for her/his family needs. Regulations that threaten farm sustainability with financial penalties or taxes for social and environmental harm may be one approach to incentivize producers to introduce digester systems in their operations. It may, however, merely put producers out of business and raise food prices due to exorbitant penalties and unachievable regulation. Another way to incentivize farmers may be to reward them for emission reduction or provide subsidies that can cover enough of the initial capital investment to make it attractive for producers to use anaerobic digester systems as a means to mitigate waste and greenhouse gas emissions.

The funding for subsidies and incentives will need to come from somewhere. Sourcing this amount of money may have repercussions that increase fuel costs, food costs or taxes. The amount of money that can be sourced from the public to subsidize agriculture waste management systems such as anaerobic digestion may represent the social and environmental cost of implementing sustainable practices. However, incentives from the public sector have the potential to negatively impact the sustainability of other farming aspects such as fuel cost, product demand and taxes paid. Another option would be to possibly find investment funding through venture capitalists, non-government organizations, research and development funds or independent investors.

Even with funding from subsidies or private investors, digester systems may not be used by highly risk-averse producers because of their high failure rate and low salvage value. The components of digester systems are very specialized to biogas production and are not very adaptable to anything other than biogas production. They require continual maintenance and management after installation for them to provide returns that outweigh the cost of investment. Digester systems also require farmers to become educated in a new enterprise. Digester systems may only require 30 minutes to an hour a day to determine if the system is working as it is designed to work and ensure the microorganisms are healthy. However, if there is a problem the farmer must be willing to stop farming and work on the waste management system for that amount of time.

The farmer must also be willing to learn and understand all of the incentive programs she/he is involved with that are a potential revenue source. The primary incentive program involves the ability to receive revenue for generating electricity. It is therefore important that the farmer understands the energy industry and what is happening with utility prices and other potential revenue streams for energy. The incentive programs such as carbon offsets and renewable energy credits require application, paperwork and compliance with the standards of the program. There is the possibility that these programs will be terminated similar to what happened to the carbon credit exchange through the Chicago Climate Exchange. The farmer must be willing to understand these programs in order to participate, evolve and find new programs if those used as a source of revenue disappear. These incentive programs are what provide economic value to the digester systems and if lost will cause it to be economically infeasible as an investment.

Farmers must also understand the other revenue sources from coproducts (e.g. fiber sales and tipping fees[4]). If the farmer sells fiber to off-farm sources, then she/he will need to understand the market and how to best sell the product. If the farmer

[4] A tipping fee is charged by a landfill to customers that dispose of waste (Waste Management 2015).

provides an organic waste disposal site, then she/he will need to understand the regulations involved with disposal sites and how to market the service. Farmers may not find enough value in digester systems to outweigh the risk of them failing.

Centralized digester systems may be one method to make biogas production more appealing to farmers that are highly risk-averse and unwilling to learn how to operate, manage and maintain digester systems. Due to the increase in education needed, the attention needed to be paid to additional revenue sources and potential maintenance and labor to make a digester system feasible, it may not be prudent to allot a mere 30 minutes to an hour per day to the management of the digester system. The farmer may decide it is necessary to employ at least one other person to manage to affairs of the digester system. The success of the digester would be the primary focus of the digester system manager to ensure that the investment is used wisely.

Research Objective

The objective of this research is to determine the economic feasibility of implementing an anaerobic digester system on a small-scale dairy of 210 cows in the US. Similar research has been done on larger-scale dairies using capital budgets and other tools provided by the USDA.

Even though there is a considerable amount of research done on the feasibility of digester systems, there are many different results. It is therefore important to realize that these discrepancies in the results show the difficulty in estimating the economic returns to investing in an anaerobic digestion system.

A careful evaluation of equipment costs, operating costs and potential revenues is important. The variables that can affect the estimate are biogas energy yield, on-farm energy use, grid electricity price, net metering electricity price, co-digestion feedstock availability, and capital and operating costs (Enahoro and Gloy 2008). It is also important to consider that past studies either do not directly describe the effects of implementing digester systems on smaller dairies, or they show that it is not feasible without subsidization.

This research paper is considering the additional potential revenue streams and a new digester system provided by Dr. Conly Hansen at Utah State University to improve the feasibility of digester systems. It is the purpose of this paper to determine whether the value given to the waste is sufficient to outweigh the cost of energy conversion. It is also the purpose of this research paper to analyze the economic viability of a small-scale anaerobic digester system designed by Dr. Conly Hansen on dairy farms of 250 cows or less, primarily artisan farms that have waste management issues with manure as well as whey.

In order to determine the economic feasibility of an anaerobic digester system, enterprise budgets are created for three different enterprises within an artisan farm. These budgets are for an artisan dairy farm that makes cheese and sells raw milk. One budget is specifically for the milk production on the dairy. The second budget is for the cheese production and agrotourism involved in the artisan aspect of the farm. The third budget is for the anaerobic digester system and includes start-up costs. A cash flow analysis is conducted to determine the payback period, net present value (NPV) and internal rate of return (IRR). The cash flow analysis is used as a tool to help dairy farmers determine the economic feasibility of an anaerobic digester system.

CHAPTER II

LITERATURE REVIEW

An anaerobic digester system is an investment that may help create food and energy sustainability from a social and environmental perspective, but does it provide financial sustainability to medium and small-scale milk producers? With increasing regulations being placed on agricultural and food production, anaerobic digester systems are a potential means to mitigate and manage waste and odor. In so doing, they may provide sustainability to producers who are being pressed by increasing urbanization near their agricultural enterprises.

Energy Production and Market Share

Different energy sources are considered more sustainable and renewable at a faster rate than others, but these sources of energy may not be economical in terms of being able to cover more than their costs. Analyzing renewable and green energy alternatives more closely may reveal that the components used to capture renewable energy are made from components that are actually scarcer and less renewable than fossil fuels.

The efficiency of alternative energy sources also may be so poor that the energy needed to generate them may create such a large carbon footprint that it might end up destroying large amounts of biodiversity to produce only small amounts of energy. Renewable energy sources may also produce large amounts of visual pollution due to the large footprint needed to produce sufficient amounts of energy from alternative sources. An example of this may be wind turbines placed in the Tehachapi Pass in California, which has more than 5,000 wind turbines that blanket the hills and change the ecology, especially with regards to animals that fly. This combined with another 10,000 wind turbines in Altamont and San Gorgonio Pass makes up 1% of California's electricity. Though visual pollution is a matter of opinion, there are regulations in some regions that attempt to mitigate the amount of visual pollution from renewable energy sources. For example, a national park may not be an acceptable place for thousands of turbines. Most developers will take visual pollution into consideration when developing wind farms in domestic areas (Conserve Energy Future n.d.).

Biofuels show potential as a sustainable renewable energy source through creating energy out of waste, but the use of crops to produce energy may be counterproductive as far as addressing the need to produce more food for the world's growing population. As the global population increases, more land will be needed to provide sufficient amounts of food to meet demand. Choosing to use crops as an energy source instead of a food source may be a short-lived endeavor because doing so reduces the amount of farmable land devoted to food production at a time when the population is increasing. The cost of capturing energy from alternative sources, the footprint of the equipment used for alternative energy production, and the potential visual pollution resulting from alternative energy production need to be taken into consideration when determining the economic viability and the overall sustainability of implementing anaerobic digester systems, especially when implemented in residential areas.

Fossil fuels are one of the most efficient energy sources currently available. It could be said that fossil fuel is the energy source preferred by the majority of consumers due to its continued worldwide use in spite of environmental warnings and concerns tied to the use of fossil fuels used to produce energy. According to the International Energy Agency (IEA), in 2013 81% of the total primary energy supply in the world was generated by fossil fuels. In 2012, the percent of total energy consumption generated by fossil fuels was 66% (IEA 2014). Fossil fuel is the most common energy source used in agriculture in the US, and the demand for fossil fuels used in the generation of energy is fairly inelastic.

Farming practices have evolved in a way that products cannot easily be harvested nor taken to market without the use of fossil fuels. Neoclassical supply and demand laws demonstrate that the demand for fossil fuels is still high enough to outweigh warnings and concerns about greenhouse gas (GHG) emissions caused by the burning of fossil fuels.

The availability of fossil fuels varies from region to region and greatly affects the price of energy and the choice of energy sources. In remote areas, or areas that have low availability, fossil fuels may not be the most economic choice to generate energy. This was the case in Europe after World War II and in remote parts of Asia where biogas became a popular energy resource for heating and cooking. Currently, the depletion of available fossil fuel reserves is a major concern and may also increase the demand for biogas if nuclear energy is deemed too dangerous.

Fossil fuel scarcity has increased as a result of environmental regulations which limit the locations fossil fuels can be extracted (e.g. areas designated as “Wilderness” and offshore production). New technologies, such as enhanced oil recovery techniques such as fracking, have increased the ability to extract oil efficiently and completely, increasing the supply of fossil fuels but also increasing the speed at which they are being depleted. Some of the new technologies such as fracking increase the controversy with regards to the health of the environment. As technology improves, fossil fuel supply increases and prices decrease or remain the same depending on demand. Improvements in mining technology and fuel efficiency will prolong the need to transition from fossil fuels to renewable energy as a primary energy source unless environmental issues become more of a priority.

As fossil fuels become more scarce, the cost of petroleum-based products increases and new forms of energy will need to be developed and used. However, the restructuring that will have to occur to transition from petroleum-dominated energy to renewable energy will take time and will be expensive (Timmons, Harris and Roach 2014). Converting farm equipment, such as tractors and other implements, to be fueled by energy sources other than fossil fuels will be expensive and could cause problems in food production. Anaerobic digester systems offer a potential solution to problems arising from such an energy source transition. After biogas is purified into biomethane, it can be used as an alternate energy source to fossil fuels and, if used to fuel equipment, would require small adjustments to tractors and other implements.

Nuclear energy is the most efficient energy source, but consumers are very cautious and concerned about the use of nuclear energy despite reassurances from nuclear energy advocates and scientists. The IEA records that only 9.7% of the total primary energy supply is from a nuclear source (IEA 2014). Despite the many advantages to using nuclear energy, the fear produced as a result of nuclear accidents such as Chernobyl and Fukushima deter the use of nuclear energy. Fear also reduces the potential for using nuclear energy as a sustainable source of energy until its negative psychological and environmental factors are outweighed by demand. Nuclear energy may produce inexpensive energy, but it creates nuclear waste that is difficult to dispose. In contrast, anaerobic digestion produces energy from waste and offers a sustainable way for farmers to produce energy on site.

Renewable energy sources produce energy from resources that are replenished on a human timescale. They include hydraulics, biofuels and waste, geothermal, solar and wind. Renewable energy sources are clearly beneficial to farmers in remote areas and in situations where low amounts of energy are needed. Renewable energy has the opposite psychological problem for consumers as nuclear energy. Psychologically renewable energy is appealing to most people because it seems to imply limitless amounts of energy that should be fairly inexpensive because it is perpetually generated by nature. However, the equipment used to capture energy from renewable sources is expensive and the energy generated may be neither reliable nor available on demand. For example, solar-based renewable energy requires sunlight which is not available at night.

The storage capacity for renewable energy tends to be less than for other energy sources and the carbon footprint of energy capture and storage equipment is larger for renewable energy than for other energy sources. The IEA reports that 9.3% of the total primary energy supply is renewable energy, which is almost equal to that of nuclear (IEA 2014). Renewable energy often requires subsidies to make it economically feasible and has its greatest value in reducing negative externalities and improving the environment.

Renewable energy produces less GHG emissions than fossil fuels and is considered to be an environmentally-friendly energy source. Biofuels, especially produced from organic waste, have a significant potential as a renewable energy source but are capital intensive and expensive in terms of the equipment needed to be purchased and operated to convert organic waste into usable energy. Of the renewable energy sources biofuels made up 5.3% in 2013. In 2012, biofuels and waste made up 12.4% of final worldwide energy consumption (IEA 2014).

The maintenance and labor required to keep digester systems working is often too expensive or time consuming to continually be used by small and medium-sized enterprises that can neither afford to hire a separate manager for the biogas portion of the business nor take advantage of benefits achieved through economies of scale. In other words, significant economies of scale exist in generating energy using digester systems and this draws into question the scale needed to make installing a digester system economically viable on dairy farms.

History of Anaerobic Digestion

Anaerobic digestion occurs naturally when there is an absence of oxygen and it has been around since the microorganisms that digest and degrade organic waste came into existence. Biogas was first identified by Jan Baptita Van Helmont in the 17^{th} century as emanating from decaying organic matter and was researched throughout the 18^{th} and 19^{th} century before the first anaerobic digestion plant was developed and used near the end of the 19^{th} century. It was at that point that an anaerobic digester system was developed in Exeter, England to fuel streetlamps with biogas from sewage.

Anaerobic digestion has been used and researched widely in India and China for agricultural purposes and as a source of energy in remote locations. India and China especially focused on small and medium-sized digester systems that could be used by individual households for generating household energy. Anaerobic digester systems became very popular in Europe during and after World War II when energy sources were scarce and demand was high (Lusk 1998).

Today biogas production from co-digester systems and centralized digester systems is still very common in Europe with 6,800 digester systems producing electricity in Germany alone (United Kingdom 2011). The US initially focused on using anaerobic digester systems as a waste management system for municipal solid waste. However, by the 1970s the US began looking at digester systems as a means to manage farm-based waste.

Due to urban encroachment, digester systems were implemented in the US as a means to mitigate odor and pollution from livestock manure. Digester systems became a popular option not only to mitigate pollution but also to generate renewable electricity during this time. Even though digester systems overall had about a 50% failure rate and farm-based digester systems had about a 66% failure rate, Lusk argues that this high failure rate is probably no better or no worse than other energy technologies ranging from synthetic fuels to other renewables that received government support during the energy crises of the 1970s (Lusk 1998).

The Science of Anaerobic Digester Systems

Anaerobic digestion and aerobic digestion decompose organic waste. Organic waste is, generally speaking, anything that was once alive but has become a bi-product of some production process (e.g., manure, sawdust, etc.). The main difference between anaerobic digestion and aerobic digestion is the absence of oxygen in anaerobic digestion. When the feedstock, or influent, is introduced into the controlled environment, where the microorganisms live, it begins to degrade as the bacteria digest it. It is first broken down into simple organic acids and then converted into biogas. These microorganisms are sensitive to the pH level and the temperature of the microclimate within the digester system tanks. Balancing the ratio of carbon to nitrogen will yield optimum health of microorganisms. Limiting factors for biogas production are the type of waste, concentration of waste, temperature of waste, toxic materials, pH, hydraulic retention time (time that a soluble compound remains in a constructed bioreactor), solids retention time (average time the activated-sludge solids are in the system), ratio of food to microorganisms, rate of digester loading, and the rate at which toxic end products are removed (Burke 2001).

Biogas is made up primarily of methane, but it also contains carbon dioxide, water vapor, ammonia and hydrogen sulfide. Biogas is often used in power generators to produce electricity, or it can be used as a fuel source in a boiler or furnace. These other components of biogas are often removed through a process called “scrubbing” to purify the biogas to be 98% methane and to make it more compatible for combustion engines and pipeline introduction to the public (Lazarus and Rudstrom 2007). Scrubbing increases the lifetime of the engine and could increase the viability of anaerobic digestion systems on small-scale operations. Being able to use biomethane to fuel equipment creates self-reliant farm production by reducing the farmer’s dependency on outside sources of farm inputs.

Anaerobic digester systems can be used to manage waste for various organic materials. Potential regulations that require homes, restaurants and food processors to separate organic waste from inorganic waste, similar to regulations in Europe, could change the public perception of waste management about converting organic waste to a source of energy. Examples of alternative feedstock for digester microbes include domestic organic waste (e.g., eggshells, flowers, fruit, coffee filters and leftovers), plant waste (i.e., grass clippings, leaves, not wood), communal sewage sludge (must be decontaminated for phosphor, nitrate and heavy metals), manure, energy crops and industrial food waste (i.e., food waste from food and meat production).

Organic waste containing large amounts a lignin, such as woody materials, requires a lot of time for the microorganisms to digest. Consequently, waste containing large amounts of lignin is typically not suitable to use in anaerobic digester systems due to the sensitivity of the microorganisms and the longer throughput time. Lignin will not degrade well during anaerobic digestion. Lignin is found in cow manure in higher quantities than other livestock manures such as swine or poultry. The large percentage of lignin in cow manure is another reason why other manures, and especially other food wastes, produce more biogas per volume of effluent produced than does cow manure. Table 1 shows the percentage of lignin found in cow manure (Stafford, Hawkes and Horton 1980). Diluting cow manure with other organic wastes that have lower concentrations of lignin will improve the efficiency of anaerobic digestion but may change the pH resulting in increased monitoring to ensure the health of the microorganisms.

Table 1. Composition of Manure Volatile Solids

COMPONENT	% DRY MATTER
ETHER EXTRACT	2.6
CELLULOSE	31
HEMICELLULOSE	12
LIGNIN	12.2
STARCH	12.5
CRUDE PROTEIN	12.5
AMMONIA	0.5
ACIDS	0.1
VOLATILE SOLIDS TOTAL	83

Source: Stafford, Hawkes and Horton (1980).

Different management techniques such as co-digestion and centralized digester systems can either improve or diminish the efficiency of digester system production. Co-digestion combines different types of organic wastes to the commonly used feedstock such as manure and energy crops. The additional organic waste can make a significant impact on biogas production while skewing the ratio of biogas to effluent in favor of biogas. European digester systems have found that co-digestion, specifically with slurry and energy crops, made digester systems more economically viable (Cave 2013). This is due to a lower percentage of lignin and higher amounts of energy contained in undigested food, feed and organic matter. Due to the higher amount of lignin than other manures and wastes, diluting cow manure with water or other organic waste products can help “reduce the concentration of certain constituents … that inhibit anaerobic decomposition” (Burke 2001).

The ability to introduce whey from cheese production should improve the efficiency of the digester system in producing energy. Probiopol provides ranges of biogas production that can be achieved by using other forms of organic waste. Potential biogas production of manure can range from 25 cubic meters per metric tonne to 36 cubic meters per metric tonne. The maximum potential for whey is 55 cubic meters per metric tonne. Waste from plants can range from 75 cubic meters per metric tonne to 110 cubic meters per metric tonne. Food waste can range from 120 cubic meters per metric tonne and 220 cubic meters per metric tonne. Grease and oils range from 400 cubic meters per metric tonne and 600 cubic meters per metric tonne (Probiopol 2015). One Mcf is equal to 28.32 cubic meters or 10 therms and one ton is equal to .91 metric tonnes.

Centralized anaerobic digestion (CAD) systems offer the potential to increase the amount of production and revenue from digester systems by accepting organic waste from sources outside of the farm and from other local farms by charging tipping fees. It provides a means to implement co-digestion and aid in diluting lignin and provides higher methane producing feedstock. CAD systems require more attention and management because of the sensitivity of the microorganisms. If there is too much dilution or toxic feedstock introduced from outside sources, the microorganisms will be negatively affected and potentially die. A dairy located near an urban center may find this alternative appealing due to potentially being able to source waste from an increased number of restaurants and industries seeking ways to dispose of organic waste than would be the case for dairies in remote locations (Cave 2013).

Types of Microorganisms

Microorganisms used for biogas production are living organisms and therefore sensitive to the temperature and pH of the environment in the anaerobic digester tanks. This is largely influenced by the waste they are given for feedstock to convert to biogas. The microorganisms are adaptable, but these variables need to be taken into consideration in order to keep the microorganisms alive. There are different temperature ranges for microorganisms used in anaerobic digester systems. The different ranges are thermophilic, mesophilic and psychrophilic, which operate from 50 degrees Celsius to 60 degrees Celsius, 35 degrees Celsius to 40 degrees Celsius and 15 degrees Celsius to 24 degrees Celsius respectively.

Thermophilic microorganisms require higher energy inputs than the other two microorganisms to maintain their relatively high temperature. In a system using thermophilic microorganisms, the microorganisms are less able to adapt to the environment but have higher pathogen removal effectiveness than the other two systems. Systems using thermophilic microorganisms also have the fastest throughput time of 3 – 5 days. This means that waste can be fully processed in this amount of time. Systems using mesophilic organisms are not as sensitive to environmental changes within the tank such as temperature or pH as thermophilic organisms. Systems using mesophilic organisms have a throughput time of 15 – 20 days. Systems using psychrophilic microorganisms have even longer throughput times than thermophilic and mesophilic microorganisms but are more adaptable to changes in temperature and pH.

According to Biogas Energy Inc. (n.d.), the most reliable strain of microorganisms for biogas production are the mesophilic digesters. Anaerobic digestion of agri-food waste has the potential to reduce odor, pathogen levels in manure and GHG emissions on the farm. It also improves the value of the manure as fertilizer because of the odor and pathogen reduction. Anaerobic digestion produces renewable energy from organic waste such as food byproducts, spoiled food or unused food (Canada 2007).

Types of Digester Systems

The three primary types of anaerobic digester systems are 1) the covered lagoon system, 2) the complete-mix system and 3) the plug-flow system. There are other types of digester systems, but the three primary systems mentioned here are the ones most commonly found in previous economic studies about digester systems. One other type of digester will be explained here because it is the type used for this analysis.

The covered lagoon system is the simplest type of anaerobic digester and is not heated, so it is only a viable option for warmer climates. The other two systems are more expensive than covered lagoons but are more efficient at producing energy. The plug-flow and the complete-mix systems are both heated and insulated, so they are better options for cold climates than covered lagoons (Lee and Sumner 2014). Selecting the correct digester system is important to the success of the investment. Each type has pros and cons and the appropriate type of digester depends on the climate, livestock operation size and existing manure management. It is also important to consider the amount of money the farmer is willing to invest and the coproducts she/he wants to include in the revenue stream.

In a covered lagoon system, there are two lagoons used in the process of biogas production. This is a passive system that has slower throughput time and the fertilizer nutrients are not recovered quickly because the fiber is retained for a longer amount of time than in other systems (Hamilton 2012). There are two lagoons in this system that are used to capture the biogas. The first lagoon is where the microorganisms consume the feedstock and generate biogas. The second lagoon is where the effluent is stored (Lee and Sumner 2014).

The covered lagoon system is typically used to manage waste from flush systems and has a higher percentage of water mixed with the manure than the other systems. The percent of total solids for covered lagoon systems ranges from 0.5 to 2 percent. Because this type of digester is not heated, it would most likely use psychrophilic bacteria due to their ability to adapt to ambient temperatures. Due to the longer throughput time this type of system needs compared other systems, is not as conducive to generating electricity and in some cases may only be used for heat production. Larger covered lagoon systems in hotter climates may have the potential to generate enough biogas to justify the use of a generator to produce electricity.

A plug-flow system can use both mesophilic and thermophilic bacteria because the biogas production occurs in a tank that is heated and insulated as manure flows from one end to the other. The throughput time is shorter than the covered lagoon system, and this type of system is more conducive to electric energy generation. The covered lagoon uses manure that is heavily diluted, but the plug flow functions best with manure that is thick, and it requires low amounts of mixing. The percent of total solids for plug-flow systems ranges from 11 to 14 percent.

Complete-mix systems use both mesophilic and thermophilic bacteria because the biogas production occurs in a tank that is heated and insulated. This type of system requires that the manure be mixed continually within the tank so that the solids do not settle. The manure is mixed with an agitator and requires some of the energy produced from the system to facilitate the mixing. The percent of total solids for complete-mix systems ranges from 3 to 10 percent (Penn State University n.d.). Both the complete-mix and plug-flow system are low rate systems where influent displaces effluent, including the microorganisms. Some of the microorganisms can be recycled and returned to the digester system after they leave with the effluent.

A fourth type of system is a suspended media system. There are different types of suspended media systems, but the system used for this analysis is the induced blanket reactor (IBR) system. The percent solids for IBR systems range from 6 to 12 percent. This is a high rate system and microorganisms remain in the system (Hamilton 2012).

The IBR is mentioned because it is the type of digester system that will be used to estimate costs and revenues for the analysis of this thesis. Information on the specific IBR system is provided by Dr. Conly Hansen at Utah State University. The IBR system provides benefits that make it attractive to small-scale farmers. It has a smaller physical footprint than other systems which is very beneficial in areas suffering from urban encroachment. The smaller footprint also reduces the opportunity cost of using the land for other farm production. The IBR system is designed for small-scale dairies in areas with varying climates such as Utah. (Hansen 2015).

Local Food Production

The FAO reports that in 2013 agriculture production increased worldwide over the previous year (FAOstat 2013). This increase in production is important because it shows an improvement in the world's ability to supply food for its increasing population. However, there are only limited amounts of land and as population continues to grow, more of the land is used to produce food at the same time more land is needed to provide housing for the increasing population. The FAO predicts a world population of over 9 billion persons by 2050 that will require food and shelter. If food and shelter are not provided political unrest in both developing and developed countries will occur (FAO n.d.).

The United Nations (UN) Committee on Economic, Social and Cultural Rights states that food and nutrition security is a human right and that every person should have physical and economic access to adequate food (FAO n.d.). Being able to meet the nutritional needs of every person will require that city designers and managers take into consideration the food system for cities as cities encroach on rural developments where food is produced. Urban and rural authorities will need to work together to create sustainable food systems that promote localized food systems and the perpetual existence of agriculture despite urban encroachment (FAO n.d.).

One of the problems with urban encroachment is that it encourages food production to be outsourced to other regions and countries thus reducing the production of food in the immediate area. Food availability has rarely been perceived as a problem in the past with regard to urban planning because most have taken for granted that food would always be available in local supermarkets regardless of how large the city became.

As populations increase and food scarcity increases, food prices are also expected to increase. Globalization has caused many developed countries to rely more heavily on developing but poorer countries to supply much of the food they consume. This places a lot of strain on developing countries to not only supply enough for their needs but also the needs of other countries. This occurs especially when developed countries continue to lose agricultural ground to urbanization. Unless buying local becomes more of a priority this problem will be exacerbated as developing countries also experience an increase in urban encroachment.

There has been an increased emphasis in developed countries on buying local food products and to increase food sustainability despite expanding urbanization. The USDA, Economic Research Service (ERS) reports that in 2012 local food sales were an estimated US $6.1 billion. The USDA defines local food as “food for human consumption sold via direct-to-consumer (DTC) and intermediate marketing channels.” Even though this definition does not give a specific distance the US Congress in the 2008 Food, Conservation, and Energy Act specifies that it cannot exceed "400 miles from the origin, or within the state in which it is produced." DTC marketing channels include farmers' markets, on-farm stores and pick-your-own operations and make up 20% of local food sales. Sales from these food sources increased by 32% between 2002 and 2007 but decreased by 1% between 2007 and 2012.

Small-scale farms that have less than $75,000 in annual gross cash farm income represent 85% of all the farms producing for local food markets in the US. However, these small-scale farms only represent 13% of all local food sales (USDA ERS 2015). Despite their low percentage of local food sales, the majority of US farms are small-scale farms and many are at risk of going out of existence due to urban encroachment. Though this may not have a large economic effect on the amount of local food sales, urbanization is more likely to occur around smaller producers than large producers. Without a means to mitigate unpleasant smells and pollution associated with dairy farms, the majority of the local dairy food producers are at risk of going out of business and decreasing the amount of local dairy products produced.

Urbanization and the loss of small farming operations also reduces the farm culture that many consumers associate with local products which could possibly reduce the incentive for consumers to pursue buying local food products. Artisan dairies that strive to maintain an appearance that would contribute to a farming culture near urban areas will struggle to persist in urbanized areas.

Sustainability

Many believe that in order to be sustainable, agriculture practices that use scarce resources efficiently and produce in an environmentally-friendly way are needed. There must be a focus on economic, social and environmental health, and the triple-bottom-line focus should be the goal of every stakeholder in the supply chain. The FAO recommends that agriculture production begin a transition from fossil fuel-based inputs to renewable energy sources. This may help ensure sustainability as fossil fuel reservoirs are depleted and might contribute to food being affordable as fossil fuel prices increase. It may also improve the profitability of agriculture enterprises by reducing the costs of production (FAO n.d.). Renewable energy, especially from biomass and organic waste, can reduce the demand for fossil fuels in agriculture and improve sustainability by transitioning production from a linear process to a cyclical process that better mimics an effective ecosystem (Sullivan 2003).

During the last 75 years, the US dairy industry has made many changes and advances. Improved breeding practices have increased milk yield and farm efficiency so that producers are supplying more milk with fewer cows. As mentioned previously, there has been a shift away from many small-scale farms to fewer large-scale farms. This is due to business management decisions related to economies of scale, new production technologies and urban encroachment that has pushed dairy producers to adjust the allocation of resources used. These structural changes in the dairy industry have improved many aspects of milk production and the economic viability of the dairy industry in the US. However, an economically-viable enterprise does not necessarily represent a sustainable industry. Many experts are concerned that the economic improvements in the American dairy industry do not equate to a sustainable industry. According to von Keyserlingk et al. (2013), experts are concerned that many of the strengths that have made dairy production more economically viable “lack the resilience to adapt to changing social and environmental landscapes” (5405) and are therefore not sustainable.

The dairy industry has been under scrutiny for several years due to the amount of GHG emissions produced from the CAFO that large dairy represent. Though efficiency in milk production has improved dramatically, the growing population has increased the demand for dairy products driving an increase in CAFOs. Fewer dairies use grazing practices, especially in the US, than was the case in decades past and waste management issues have increased as a result. Further problems arise as urbanization decreases the amount of land available for agriculture and increases the concentration of herds on smaller parcels of land. As farmers struggle to mitigate issues with urban encroachment, the dairy industry has begun to relocate to states that have more land available for agriculture. Western states such as California and Idaho have seen an increase in herd sizes due to this relocation.

Though many western US states have land available, these states are also experiencing the effects of urbanization. One problem that many of the western states have faced in recent years is drought conditions coupled with an increasing human population that demands water be redistributed away from the agriculture sector to urban needs. Urban encroachment requires a reallocation of water to supply domestic households and water in the southwestern states is often in short supply (von Keyserlingk et al. 2013). Digester systems also require water and this needs to be accounted for before deciding to implement anaerobic digestion as a means to mitigate risk. This is also a valid argument for using whey with manure as a feedstock due to the high water content in whey. Introducing whey will provide enough water to the digester system to eliminate the need for additional water from outside the system. The importance of water conservation in the southwestern states often creates problems between household users and the agriculture sector. As a result, it becomes even more important to regulate the use of water as a scarce resource and to protect against pollution from CAFO waste. This creates an issue regarding the viability of dairy farms due to social and environmental issues in Utah.

Utah has also experienced an increase in average dairy herd size and a decrease in dairy farm numbers. As housing developments are built around dairy farms, generational farms go out of business for a number of reasons. The construction of housing developments increases the value of the adjacent land to the point that it is more beneficial to sell portions of the farm, or all of the farm, than mitigate the social and environmental issues associated with continuing to operate the farm in its current location. If just portions of the farm are sold, then herd concentrations increase and cause more potential problems regarding social and environmental issues. If the entire farm is sold, then the option for consumers to buy local products is reduced and food system sustainability decreases.

Keeping in mind that a profitable farm is not necessarily a sustainable farm, but a sustainable farm is an economically successful farm, the benefits of digester systems on dairy farms can be evaluated. Benefits such as GHG reduction through pollution mitigation and pathogen and weed seed reduction in manure applied to the land improve the environmental portion of sustainability. It also improves the economic viability of the farm by reducing the cost of herbicides used to fight weed infestations. Liquid from the effluent is relatively clean and can be used for flushing and irrigation, and nonpoint source pollution is reduced thus improving water conservation. Benefits such as odor and fly reduction in developed neighborhoods provide social benefits. This improves sustainability by providing more self-reliance to communities that can buy locally and have sustainable community food systems. Implementing sustainable practices can increase the value of the farm, and if products are marketed correctly, increase the value of its food products. There is potential to improve sustainable practices through on-farm anaerobic digestion, especially for artisan farms and other farmers participating in direct marketing.

Though sustainable agriculture does not necessarily receive a certification such as an “organic” certification from the USDA, there is potential for farmers to demand a premium for their food products as a result of implementing sustainable practices. Depending on the marketing channels used and the education consumers receive from producers, sustainable practices can differentiate products enough that a premium will be paid by consumers similar to that paid for “organic” certified food. There are many similarities in “organic” and sustainable production, and some sustainable producers may seek to become “certified organic,” but there are also some differences. For example, sustainable producers only minimize synthetic fertilizers used, and “organic” producers are not permitted to use synthetic fertilizers. From a different perspective, there are practices that make sustainable farming different and at times more environmentally-conscientious than “organic” farming. For example, the emphasis on reducing fossil fuel inputs and increasing renewable energy inputs is a strong driving force in sustainable agriculture but is not measured in an “organic” certification (Keating and Jacobsen 2012).

To determine whether agricultural production is sustainable or not there has to be some method of observing and measuring sustainability. Social and environmental aspects of sustainability are often the focus of certification criteria for certifiers such as The Rainforest Alliance, the USDA and Fair Trade. However, these certifying bodies typically only focus on social and environmental issues, and very few provide economic criteria to measure overall sustainability. The Appropriate Technology Transfer for Rural Areas (ATTRA) provides a checklist of possible criteria that can be used to determine sustainability found in Table 2. Though there are criteria that may not be applicable to every producer, the checklist may be beneficial to producers seeking to implement anaerobic digester systems on a small-scale or artisan dairy farms in order to become more sustainable.

Table 2. Sustainability Checklist

Economic Sustainability
The family savings or net worth is consistently increasing
The family debt is consistently decreasing
The farm enterprises are consistently profitable from year to year
Purchase of off-farm feed and fertilizer is decreasing
Reliance on government payments is decreasing
Social Sustainability
The farm supports other businesses and families in the community
Dollars circulate within the local economy
The number of rural families is increasing or holding steady
Young people take over their parents' farms and continue farming
College graduates return to the community after graduation
Environmental Sustainability
There is no bare ground
Clean water flows in the farm's ditches and streams
Wildlife is abundant
Fish are prolific in streams that flow through the farm
The farm landscape is diverse in vegetation

Source: Sullivan (2003).

The criteria used to determine economic sustainability listed above in Table 2 can all be used to help determine the need for an anaerobic digester system on a small-scale or artisan dairy farm to create overall sustainability. The criteria under the social aspects are key indicators of the need for anaerobic digestion on a farm. Anaerobic digester systems can help farms support others in the community and circulate dollars within the local economy by providing a place for members of the community to dispose of organic waste for a tipping fee. It can also provide a source of fertilizer for local community members to purchase. It improves the possibility of the number of rural families increasing by mitigating problems associated with agricultural production in the proximity of urbanization such as odor, appearance and pollution. Being able to mitigate these problems also improves the likelihood that the farm will remain for future posterity to inherit despite urban encroachment. On-farm anaerobic digestion also improves the environmental sustainability of farms by decreasing the potential for water and land pollution. This increases the possibility that wildlife will be seen on the farm and improves the aesthetic appearance of the farm.

Creating a sustainable community food system in the US could be important to supply adequate food and nutrition to US citizens in the future. Food sustainability will reduce the possibility of political instability. It will provide economic strength to the agriculture sector. Sustainable food systems also conserve aspects of American culture (family farming) and family legacies. The Agricultural Sustainability Institute (ASI) of the University of California, Davis (UC Davis) defines sustainable community food systems as a network of food production and disposal that improves the environment, economy and social health of local areas. This especially includes the production that occurs on family farms and the marketing channels used to sell goods. The ASI of UC Davis argues the importance of creating local jobs through agriculture and improving the living conditions around farms (UC Davis ASI n.d.). Anaerobic digester systems implemented on small-scale and artisan dairies can play a large role in creating sustainable community food systems in rural America by managing not only production waste but also consumer waste.

Social and Environmental Costs

Negative externalities reduce the sustainability of dairy farms by impacting the social and environmental components of a sustainable operation. This can also potentially impact the economic viability of a sustainable operation if fines are imposed or monetary compensation is demanded through lawsuits against dairies because of their potential negative externalities. Determining a cost for negative externalities is difficult, but can be estimated by determining the cost of continuing to produce when social and environmental fines are imposed on producers that do not comply with standards and regulations.

In 2004, Tegtmeier and Duffy did a study estimating the cost of negative externalities related to livestock production and determined an industry-wide externality cost for livestock producers to be US $166.7 million. This cost of negative externalities is only for damages to air resources and is based on a price of US $0.98 per tonne of carbon dioxide equivalents (CO_2e)[5]. Other studies similar to this have been done in various countries including New Zealand. It is noted that as the price of CO_2e increases, the demand for waste mitigation practices may increase to prevent the problem rather than having producers merely pay to clean up the problem after the fact

[5] Carbon dioxide equivalent is base measurement used to compare greenhouse gases. It is based on their global warming potential (US EPA 2015a).

(Foote and Joy 2014). This may include an increased demand for more anaerobic digester systems to help farmers comply with standards and to also benefit from carbon offset programs.

It is difficult to determine an actual cost of CO_2e per producer. The amount of CO_2e produced by a small artisan cheese producer may be negligible, but a fine associated with an increased cost of CO_2e may also impact small-scale producers and potentially lower their risk aversion to adopting waste management systems that decrease the emissions of CO_2e.

Anaerobic digester systems use methane that is produced from the consumption of organic feedstock by microorganisms. The methane, or biogas, is used to generate heat or electricity through combustion. The combustion of methane produces carbon dioxide which is also a GHG. However, carbon dioxide is a GHG that is not as detrimental to the environment as methane. Methane is capable of absorbing more radiative energy inside the atmosphere than is CO_2. Though methane has a shorter lifetime in the atmosphere than CO_2, it has an impact 25 times greater than CO_2. The radiative absorption and the lifetime of an emitted gas are what determine the severity of a GHG. Over a 100-year time period, methane has a Global Warming Potential[6] of between 28 and 36 times greater severity of damage than CO_2 (US EPA 2015b).

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[6] Global Warming Potential is a measure of the severity of a greenhouse gas. It is based off of 1 ton of carbon dioxide over a 100 year time period (US EPA 2015b).

Anaerobic digester systems are valuable to agriculture producers if they take advantage of programs that incentivize the reduction of CO_2e.

Another consideration is determining the sustainability of the farm and the value of adopting anaerobic digestion based on avoiding potential lawsuits arising as a result of pollution, pathogen infestation and odors caused by the farm operation. This potential increases as residential neighborhoods are developed around livestock producers.

Dairy farms and cheese plants impacted by urban encroachment have a higher risk of lawsuits than those not close to residential neighborhoods. A list of claims awarded because of agricultural nuisance lawsuits ranges from US $12,100 to $50,000,000 between the years of 1991 to 2007 (Keske 2009). None of these lawsuits were against dairy producers and the size of the operations involved as defendants varies, but the producers were sued for not mitigating wastes that are similar to what dairy farms emit. Examining the lawsuits is not helpful in determining the legitimate cost of externalities, but they represent a potential risk for dairy farmers near urban areas. Keske argues that though these awards from lawsuits are based on individual cases, they provide some insight into the potential economic problems that could diminish the sustainability of a dairy farm if the issue of negative externalities is not considered and dealt with by the farmer. It is also noted that not all of these lawsuits were against producers impacted by urban encroachment. However, urban encroachment increases the risk of having lawsuits from odor and flies filed against farmers. Using anaerobic digestion as a waste management method provides a way to mitigate the risk of lawsuits and several other problems that threaten the sustainability of dairy farms in Utah.

Digester systems provide a means for urban authorities and planners to cooperate with farmers to mitigate the effects externalities on residents who live close to dairy farms. This will improve the sustainability of not only the dairy producer but of the community. In order to determine whether anaerobic digestion of dairy waste truly provides sustainability, the economic feasibility and viability of anaerobic digesters on small to medium-sized dairy farms needs to be evaluated. Taking into account the three pillars of the triple bottom line, economic, environmental and social, will help producers and city planners determine the need for a digester system to mitigate organic waste issues in Utah.

Enterprise and Capital Budgets

One of the tools used to help measure potential economic performance is an enterprise budget. An enterprise budget is used to estimate the annual costs and returns of a specific enterprise to help make investment and management decisions. Enterprise budgets are often based off of price and quantity demanded assumptions. Enterprise budgets show the expected profit if all of the goods are sold at a specific price. Enterprise budgets are representative and do not necessarily reflect costs and returns for a specific operations (Agricultural Marketing Resource Center 2014).

Capital budgets help predict the success of a capital investment. Estimating the NPV and the IRR are financial methods associated with capital budgeting and can be used to predict the potential success of implementing anaerobic digestion. Capital budgets make assumptions about the lifetime, discount rate and growth rate of the investment. In order to estimate net cash flows for the capital budget, assumptions are also made about future inflows and outflows of cash over a given period of time.

Another analytical tool that can be used to help determine the feasibility of using anaerobic digestion to manage organic waste is the FarmWare program (Conservation Technology Information Center n.d.). It is a program provided by AgSTAR and is often referenced in the literature as a resource to estimate the feasibility of anaerobic digester systems. AgSTAR is used in this analysis as a benchmark to compare results estimated by many other researchers. However, the financial estimates are often not equal, and the estimates from AgSTAR often predict better financial performance than other studies (Enahoro and Gloy 2008).

Researchers often note the importance of economies of scale when estimating the potential success of investments in anaerobic digestion. Economies of scale are important in the production of biogas, and describe in part why larger operations benefit from improved net revenues when anaerobic digesters are used as compared to smaller operation. Based on several different case studies, the minimum size threshold for an anaerobic digester system to be feasible for a dairy typically ranges from 500 to 1,000 cows (Lee and Sumner 2014). The majority of the case studies and estimates from other studies reflect dairies large enough to meet this threshold, and the other studies that have considered smaller dairies estimate that it is not profitable without a higher price per CO_2e. Capital costs for dairies of with herd sizes between 100 and 250 cows have varying costs per cow and are expected to have higher costs per cow than dairies with herd sizes over 500. By keeping the capital cost per cow below US $1,500 more small-scale dairies are capable of adopting anaerobic digestion feasibly. This can be achieved through low cost designs or through subsidies (Shelford 2012).

Coproducts and Revenue Streams

Revenue estimates for anaerobic digestion are driven primarily by the price of electricity, but studies have also shown that an increased carbon price improves the feasibility of investing in anaerobic digester systems. The Cap and Trade program in the US determines a limit for the amount of GHG that can be emitted without penalty. If a company estimates that it will exceed that limit, it can offset the amount of GHG it emits by trading with an entity that is reducing GHG through methods such as anaerobic digestion of dairy waste (US EPA 2009). There are two different types of carbon offset markets in the US. There are voluntary offset markets where individuals voluntarily participate in reducing GHG. The Chicago Climate Exchange helped facilitate this type of market before its close in 2010. The other market is the compliance market. This is in conjunction with the cap-and-trade regulations in different regions of the US. The RGGI was the first to implement a compliance market in the US (Key and Sneeringer 2011).

The Chicago Climate Exchange allowed people in North America to trade CO_2e from 2003 to 2010. It was owned by Intercontinental Exchange (ICE) and stopped carbon credit trading in 2011. When the carbon credits ceased to be traded, ICE provided a way for people in North America to receive compensation for carbon offsets by registering with the Chicago Climate Exchange Offsets Registry Program (Intercontinental Exchange n.d.). In 2008 Regional Greenhouse Gas Initiative (RGGI) started providing a way to counteract carbon emissions through the purchase of carbon offsets. These groups, along with others, certify the trading of offsets to comply with cap-and-trade regulations (Natural Resource Defense Council 2014).

Cap-and-trade is a regulatory method that places a cap on the amount of GHGs produced by various sources. Sources that wish to offset the amount of GHGs produced can trade CO_2e with other sources that reduce GHGs through practices such as green energy production. Producing energy through anaerobic digestion reduces GHG emissions and provides a means to increase revenue by participating in the offset programs. Based on the auction results from the California Cap-and-Trade Program in August 2015, the auction settlement price for carbon offsets is US $12.52. This auction is held by the California Air Resources Board and Québec's Minitère du Développment Durable, de l'Enviornnement et de la Lutte contre les changements climatiques (California Environmental Protection Agency 2015).

The price of carbon offsets can make a significant difference in determining the feasibility of implementing anaerobic digestion. This is because the price of carbon offsets can influence the decision of small-scale farms to implement anaerobic digestion to manage waste and help reduce GHGs or not. Using the NPV to determine the feasibility of investment, a carbon price of US \$13 per tonne of CO_2e makes it possible for dairies with more than 544 cows to be profitable according to Key and Sneeringer (2011). A carbon price of US \$26 per tonne of CO_2e lowers the feasibility range to 265 dairy cows. This does not mean that every dairy will be profitable at these prices but that dairies with this sized inventory have an improved probability of feasibly implementing anaerobic digestion (Key and Sneeringer 2011). Gloy (2011) makes the argument that even though the US EPA claims that a price of US \$8 per tonne of CO_2e is a breakeven price for implementing a plug flow digester system, the adoption of anaerobic digestion needs to be analyzed case by case.

Manning and Hadrich (2015) provide similar results as Key and Sneeringer (2011) regarding the price of CO_2e, but they also point out that the cost of enrolling in offset programs also deters participation in the carbon offsets market by adopting anaerobic digestion. They state that the price per tonne of CO_2e minus the cost of enrolling in the program is the social cost of carbon, and this cost must be high enough to motivate a higher percentage of dairies to adopt anaerobic digestion. Other possible revenue sources such as tipping fees, fiber sales and alternative energy sales also increase the possibility of adopting anaerobic digestion as a means to mitigate waste management depending on the size of the dairy, efficiency of the system and the available market for coproducts.

Biomethane is an alternative energy source that can be produced from anaerobic digestion. It is biogas that has been purified sufficiently to be introduced into the grid via a natural gas pipeline. There are three different prices associated with natural gas: the wellhead price, the city-gate price and the commercial price. A dairy would typically be paid the commercial price. Though natural gas prices may be higher than electricity prices, the equipment cost to generate natural gas may make it so it is not feasible for dairies especially for a small-scale digester system.

Biomethane production from animal manure is more common in Europe than in the US and cost estimates from previous studies are based on European biomethane facilities. These facilities are large-scale dairies ranging from 1,500 cows to 27,000 cows. The capital cost presented here is based on the smallest dairy operation and is estimated to be US $500,000. The additional operation and maintenance cost is estimated to be US $5.02 per Mcf (Krich et al. 2005). Adopting biomethane production on a 210-cow dairy many not be feasible due to the lack of economies of scale, and the cost of capital may be overestimated because of a lack of information and adoption in the US.

Bishop and Shumway (2009) analyze the sensitivity of the NPV, the IRR and the modified internal rate of return (MIRR) with different coproducts. The coproducts provide additional revenue but additional costs too. Some do not provide substantial benefit to the anaerobic digester enterprise. In this analysis fiber sales, tipping fees and carbon credits are the coproducts expected to benefit the enterprise the most. Tipping fees increase the NPV more than the other coproducts (Bishop and Shumway 2009). Tipping fees are beneficial to the enterprise for a couple of reasons. They increase revenue, improve the energy levels of the feedstock and decrease the probability of having insufficient feedstock. If the quantity of manure is insufficient to continually provide feed for the microorganisms, they will die and the anaerobic digester system will fail. A small-scale artisan cheese dairy may have problems providing sufficient feedstock without taking on off-farm organic waste when the dairies own cows are being pasture fed thus reducing the amount of manure generated by the dairy itself. Fiber generated by the digester system is sold as either livestock bedding or fertilizer. Fiber is often used by the dairy to offset their own bedding costs or to fertilize crops. It can also be sold to off-farm sources as fertilizer. Landfills often sell compost from decomposed organic waste. Fiber sales from the farm can be treated similarly and are valued at US $13.50 per cubic yard by Bishop and Shumway (2009).

For a 750-cow dairy with a grant for 38% of the cost of capital, the tax credit, the fiber sales, the tipping fees and the carbon offsets make the adoption of a digester system feasible. Implementing the sale of these coproducts provides a NPV of US $1,375,371 and an IRR of 20% for the investment. This estimation is with a 4 percent discount rate (Bishop and Shumway 2009).

Lee and Sumner (2014) note that it is difficult to determine a discount rate for investing in an anaerobic digestion system, especially for one that does not meet the minimum dairy size threshold. The literature usually assumes a discount rate range from 3 percent to 10 percent. As the minimum threshold is approached, the discount rate should be increased to reflect a riskier investment that is unable to take advantage of economies of scale and has a high failure rate. Enahoro and Gloy (2008) estimate a discount rate of 10 percent, which may be appropriate due to the lack of information available on initial capital investment, predicted biogas production, expected lifetime of equipment, future utility prices, operating costs, carbon offset price and the continuance of incentive programs. For a dairy smaller than 250 cows, a discount rate higher than 10% is more probable given the estimates from the literature are based on larger-scale operations and often reflect higher CO_2e prices.

Labor Requirement

Labor is not specified in all of the literature about anaerobic digesters, and estimated labor requirements range from 30 minutes a day to full-time employees dedicated to monitoring and maintaining the digester system. AgSTAR estimates 30 minutes per day are needed to take care of monitoring the system and perform minor maintenance, an additional 30 minutes per day needed to load the digester and an additional 20 minutes per day was estimated to be needed to handle inquiries. Labor was estimated to cost US $20 per hour (Lazarus and Rudstrom 2007). AgSTAR estimates that 30 minutes per day are required at a cost of US $60 per hour for a 9,000-cow dairy (McDonald 2012). Stokes, Rajagopalan and Stefanou (2008) estimate that about 30 minutes per day are needed to monitor, repair and maintain the digester system and recommend a cost of US $12 per hour for labor for a 500-cow dairy. Dvorak and Frear (2012) estimate an annual salary of US $20,000 for labor or US $10 per cow.

The Kettle Butte Dairy in Roberts, Idaho employs three full-time people to monitor and maintain its digester system on its 5,000-cow dairy. In a personal interview with Guillermo Llamas, he suggested that 30 minutes per day is an unreasonable estimate for labor to monitor and maintain the digester system and recommended that more time be allocated to monitoring and maintenance (Llamas 2015). Premium Farm in Wheatland, Wyoming suggests 40 hours per week are necessary to maintain their digesters. Employees in charge of maintaining the digester system are paid US $8.76 per hour plus housing (Keske 2009).

Estimating the amount of labor needed for a digester system is difficult. Labor time and compensation have a wide range of estimates in the literature. It is especially difficult to estimate labor requirements for an anaerobic digester for a small-scale operation due to the lack of coverage in the literature. Scaling estimates based on a per cow cost may provide the best estimate. However, most estimates are not based on herd size. The estimate of 30 minutes per day is used for herd sizes ranging from 500 to 9,000 cows. Having a digester capable of generating additional revenue sources other than electricity will require more time and labor, but the additional revenue sources are estimated to have a positive impact on the overall profitability and sustainability of the operation.

Including off-farm organic waste for feedstock, especially waste with high volatile solid content, will increase the reliability of consistent biogas production. Including additional waste will increase labor costs to manage the organic waste disposal and associated tipping fees, but additional time and labor will also be needed to obtain additional sources of off-farm organic waste to prevent failure of the digester system and the death of the microorganisms when feedstock is low. This can include organic waste from local restaurants, food processors and abattoirs (Enahoro and Gloy 2008).

Increasing revenue through other revenue streams increases the difficulty of estimating labor time and compensation due to additional requirements such as marketing, education for incentive programs and time. Because of the high failure rate for anaerobic digester systems, accurate labor estimates are important to determine the feasibility of implementing anaerobic digestion. Labor is one of the few operating expenses associated with anaerobic digester systems and has a lot of weight in terms of predicting the profitability of a system. Underestimating labor time and compensation will encourage unwise investment and potentially increase the failure rate of anaerobic digesters and dairies.

Subsidies and Grants

In a study by Manning and Hadrich (2015), subsidies for anaerobic digester systems are reported to range from 14.03 percent to 70.59 percent of the initial cost for various sizes of farms and different types of digester systems. They argue that a balance is required when subsidizing anaerobic digester systems. The social and environmental benefits associated with anaerobic digesters are important, but because of the potential financial benefits it is not necessary to subsidize the entire investment. The subsidy program needs to do more than simply transfer money from taxpayers to farmers, and this can be done by basing the percentage of the initial cost covered by subsidy on the number of cows on the farm (Manning and Hadrich 2015).

Stokes, Rajagopalan and Stefanou (2008) discuss the potential insufficiency of using NPV to determine the feasibility of anaerobic digestion due to a lack of confidence in estimated revenue streams and cost estimates. Numerous uncertainties about the revenue streams and costs make adopting anaerobic digestion riskier and more difficult to determine its feasibility. The uncertainty of coproduct supply and the value from anaerobic digestion and the uncertainty of the lifetime of incentive program make predicting future cash flows difficult and variable. It is suggested that the NPV is a useful tool to estimate feasibility but that flaws resulting from coproduct and operating cost uncertainty require real option theory to be used to help analyze the feasibility of the investment (Stokes, Rajagopalan and Stefanou 2008).

Real option theory is used to estimate the value of the producer's option to delay investing. This adds additional barriers to the producer's decision to invest in anaerobic digestion and should be accounted for in the value of subsidies and grants provided (Stokes, Rajagopalan and Stefanou 2008). By accounting for the value of the option to delay investment the decision to invest is influenced by more than just the expected cash flows and the discount rate. Cash flows that are volatile due to uncertainty, similar to those associated with anaerobic digestion, can produce contradicting NPV results depending on the year. Taking into account the time value of money by calculating the NPV may not be a sufficient decision rule for adopting anaerobic digestion if the farmer gains more by waiting to invest. This may be the case regardless of whether or not a positive NPV is estimated (Damodaran 2012). This adds to the difficulty of attempting to estimate the feasibility for small-scale dairies and the subsidy level required.

If the value associated with the option to delay investment is considered to be relevant, then additional revenue may be required to encourage farmers to invest in anaerobic digestion. The amount needed to subsidize the value in the option to delayed investment depends on the price per kWh for surplus energy (Stokes, Rajagopalan and Stefanou 2008). Developing an appropriate subsidy amount will help foster the desired social and environmental benefits but will also encourage anaerobic digestion investors to be more proactive in making the investment profitable.

CHAPTER III

METHODOLOGY

Description of the Integration of the Three Enterprises

The three separate enterprises used for the analysis of dairy waste management via anaerobic digestion are 1) the small-scale dairy (milking) activity, 2) the artisan cheese production activity and 3) the anaerobic digester system. From the literature review, one can see that it is common for analyses to consider either the anaerobic digester system or the artisan cheese plant as part of the dairy enterprise, but not the dairy, cheese, and digester operations to be considered together. For this analysis, each of the three enterprises is first analyzed separately to determine its individual profitability as well as its potential to improve farm profitability when combined and integrated with the other activities or operations.

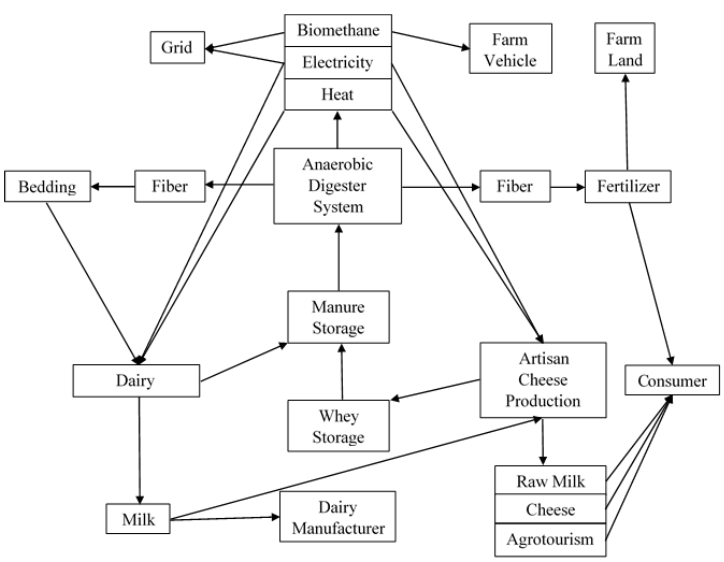

Figure 1. Integrated Enterprise Layout

The separate enterprises are initially treated as separate enterprises instead of an additional capital investment (separate enterprise analysis rather than partial budgeting). By separating and identifying these receipts and costs the labor required for each enterprise is identified and can then be allocated more readily from the general labor pool available to the farm. This assists in identifying and capturing the true cost (both capital and operational costs) of the enterprise as part of the integrated dairy operation.

As is typically the case in economic analysis, assumptions are made to simplify the analysis and provide a model that can be used more generally by farmers to determine the possibility of profitably implementing anaerobic digester systems on small-scale farms. After the three enterprises are analyzed separately, the cash flows from the separate enterprises are added together to determine a cash flow for the entire integrated operation.

The dairy considered as the basis for this analysis is currently operational allowing for the assumptions and results of the analysis to be confirmed against the actual operation. The dairy provides milk for the artisan cheese processing plant. Waste from cheese production, primarily whey, is placed in storage and then sent to the anaerobic digester system where it becomes feedstock for the microorganisms to produce biogas and digested fiber. Waste from the dairy, primarily manure, is placed in a storage pit and then is sent to the anaerobic digester system along with the waste from the cheese production to be used as feedstock by the microorganisms to produce biogas and digested fiber. If organic waste is accepted from off-farm locations, then it is storage and then sent to the anaerobic digester system along with the waste from cheese and milk production to produce biogas and digested fiber. The biogas that is produced is either used as fuel to generate electricity from a generator(s), as fuel for a boiler to create heat and/or goes through additional refining (scrubbing) to produce biomethane. Biomethane production requires additional equipment to be able to scrub the biogas. If electricity is generated, then it is used either on-farm or sold back to the electrical grid to be used by the general public. If heat is generated from the boiler, then it can be used to heat on-farm facilities or the owner's house. If biomethane is produced, then it can be used by vehicles that have been converted to use compressed natural gas, or it can be sold and injected into a pipeline to be used as natural gas by the general public.

Table 3. Labor Requirements for the Integrated Operation (US Dollars)

	QUANTITY	HRS/WEEK	PAY
DAIRY			
OWNER	1	40	$25
HIRED	2	30	$12
ARTISAN CHEESE			
OWNER	1	40	$25
CHEESE MAKER	1	Salary	$45,000
HIRED	2	30	$12
HIRED	15	20	$7.25
ANAEROBIC DIGESTER			
OWNER	2	0.5	$25
HIRED	1	25	$12

Source: Painter, Gray and Norell (2012); Bouma, Durham and Meunier-Goddik (2014); Kohler and Kohler (2015).

Dairy Model

The costs and returns for the dairy operation that were used in the analysis (Table 4) are based on a 2014 enterprise budget for a dairy operation developed by the University of Idaho. This enterprise budget was chosen because it models a small-scale dairy of 210 cows. By necessity, an enterprise budget makes many assumptions and is only representative of dairy operations of that size or, in other words, it does not represent the process and production of a specific farm. It was decided to use an enterprise budget so that somewhat generalizable results would be generated that would be potentially used and adapted after modification by individual farmers according to their own estimated costs of production and production techniques.

Another reason for using an enterprise budget instead of a specific farm is to maintain the confidentiality of the practices used by individual farmers by not revealing too much about specific costs, returns, and production practices. A Utah dairy farmer was interviewed to provide general information about how to adjust the enterprise budget to reflect a dairy that produces milk that is used in an artisan cheese production activity. Changes that were made include price updates for products sold and costs that are incurred, amounts of milk produced per cow and a few minor changes related to feed.

In order to appeal to certain market segments, artisan cheese often gains value by making milk production reflect an artisanal practice. This can be achieved by implementing feeding practices such as pasture feeding and reducing or eliminating corn from feed due to genetically modified organisms and other negative perceptions held by certain groups of consumers about corn-fed livestock.

Fixed Assets Required for the Dairy Explained

It is assumed that the dairy is already in operation and that existing fixed assets currently carry no debt. Fixed assets include such things as real estate and equipment and while they are assumed to not require debt payment they are depreciated to represent the cost of using the asset because the asset will eventually need to be replaced for the operation to be on-gong. Ownership costs are estimated by Painter, Gray and Norell (2012) from the University of Idaho in their dairy budget and only minor changes were made to reflect current market prices for livestock. There is no capital investment needed for the dairy except to upgrade and replace equipment as needed.

Labor Required for the Dairy Explained

It is assumed that two able-bodied adults are partners in the operation and that the labor availability of each partner does not exceed 41 hours per week though this may be underestimated. Labor is assumed to be allocated equally between the dairy and cheese production activities. One hour each week is spent on the anaerobic digester system. Hired labor for the dairy consists of two employees who work 30 hours a week and each. This amount of labor may also be underestimated, but a portion of the dairy labor is performed by the other enterprises (e.g., manure and bedding management). Therefore, the labor on the dairy is reduced to try and account for the integration of the enterprises.

Table 4. Dairy Enterprise Budget for 210 Cow Herd (US dollars)

	Weight Each	Unit	Total Number Or Units	Price or Cost/Unit	Total Value
Gross Receipts					
Milk (Artisan Production)	57.19	cwt	180	$25.00	$257,373.88
Milk	88.91	cwt	180	$17.00	$272,051.76
Bull calves	1.00	head	95	$300.00	$28,350.00
Heifer calves	1.00	head	95	$300.00	$28,350.00
Cull cows	1.00	head	63	$1,500.00	$94,500.00
Total Receipts					**$680,625.64**
Operating Costs					
Alfalfa hay	1	cwt	11,729	$9.00	$105,559.20
Corn silage	0	cwt	25,893	$2.75	$0.00
Grain mix	1	cwt	19,656	$10.00	$196,560.00
Minerals	1	cwt	151	$30.00	$4,536.00
Feeder hay	1	cwt	1,620	$7.50	$12,150.00
Marketing	1	head	210	$69.70	$14,637.00
Supplies	1	head	210	$171.85	$36,088.50
Utilities	1	head	210	$51.44	$10,802.40
Legal and accounting	1	head	210	$13.72	$2,881.20
Bedding	1	Cubic Yards	950	$15.00	$14,250.00
Custom manure management	1	head	210	$20.00	$4,200.00
Replacement heifers	1	head	69	$1,900.00	$131,100.00
Interest on operating capital	1	head	210	$39.07	$8,204.70
State & association charges	1	head	210	$32.94	$6,917.40
Insurance	1	head	210	$17.17	$3,605.70
Veterinary Medicine	1	head	12,774	$1.00	$12,774.30
Miscellaneous	1	head	210	$19.79	$4,155.90
Machinery (fuel, lubrication, repair)	1	$	6,548	$1.00	$6,547.56
Vehicles (fuel, repair)	1	$	3,615	$1.00	$3,615.00
Equipment (repair)	1	$	5,539	$1.00	$5,538.50
Housing and Improvements (repair)	1	$	3,293	$1.00	$3,292.50
Hired Labor		hour	3,120	$12.00	$37,440.00
Owner Labor		hour	2,080	$25.00	$52,000.00
Total Operating Costs					**$676,855.86**
Income Above Operating Costs					**$3,769.78**

Table 4. Continued

	Weight Each	Unit	Total Number Or Units	Price or Cost/Unit	Total Value
Ownership Costs					
Capital Recovery:					
Purchased Livestock	1	$	-	$1.00	$0.00
Housing and Improve.	1	$	19,259	$1.00	$19,259.26
Machinery	1	$	6,955	$1.00	$6,954.65
Equipment	1	$	15,378	$1.00	$15,378.33
Vehicles	1	$	3,310	$1.00	$3,310.24
Interest on Retained Livestock	1	$	270,000	$0.055	$14,850.00
Taxes and Insurance	1	$	1,930	$1.00	$1,929.94
Overhead	1	$	20,000	$1.00	$20,000.00
Total Ownership Costs					**$81,682.42**
Total Costs					**$758,538.28**
Net Income					**($77,912.64)**
Net Income per head					**($371.01)**

Source: Painter, Gray and Norell (2012); Kohler and Kohler (2015).

Other Operating Costs and Receipts for the Dairy Explained

Costs and revenues received represent current market prices except for revenues from milk sold to the artisan cheese plant and prices paid for bedding. These prices are adjusted to represent prices influenced by the other two enterprises. Operating costs and receipts received reflect prices in the year 2015 in Utah and would need to be adjusted for different regions and years.

Milk production is estimated assuming 45 pounds per cow per day for 180 out of the 210 milking cows. This results in 146 hundred weight (14,600 lbs.) of milk being produced by the milking operation per day. In order to adjust the dairy enterprise budget to reflect milk production in an artisanal fashion, corn is not fed and its costs, reflected in the University of Idaho enterprise budget, are removed from the costs incurred for the integrated operation considered here. Milk production is also reduced from that reported in the University of Idaho enterprise budget from 70 pounds per cow per day to 45 pounds per cow per day. This amount of daily milk production better reflects pasture-fed dairy cows than corn-fed cows.

Due to constraints posed by cheese production capability, it is assumed that the artisan cheese production operation is unable to produce cheese from the entire amount of milk produced by the dairy. Therefore 39 percent of the milk goes to cheese production and the remaining milk is sold to a milk manufacturer. The percentage of milk sold to the artisan cheese plant is determined by the capacity of the cheese plant. This volume of milk plays a large role in the profitability of the dairy because the milk price paid by the cheese operation is assumed to be higher than that paid by the milk manufacturer for non-organic milk.

The price paid by the dairy manufacturer closely reflects the national milk price and is not determined by the farmer. By producing cheese, the farmer adds value to the milk produced and can essentially reflect this in the "transfer" price between the dairy and the cheese operation. This price can be higher or lower depending on what enterprise (dairy or cheese operation) the farmer chooses to have a higher cash flow.[7] The transfer price paid to the dairy by the cheese operation is assumed, in this case, to

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[7] Basically, this means that the transfer price could reflect the national milk price paid by the milk manufacturer in which case the dairy will seem less profitable and the cheese operation more profitable. Or, a higher transfer price representing the value of milk in the cheese operation could be charged which would result in a more profitable dairy operation and less profitable cheese operation.

be US $25 per hundred weight instead of the price paid by other dairy manufacturers, US $17 per hundred weight. This is a price ($25/cwt.) that is higher than what would be paid by dairy manufacturers, but is still realistic in that it represents the potential of adding value to a commodity such as milk in the creation of a value-added product (cheese). This price is also justified due to the potential of selling the milk to dairy manufacturers as certified organic if the farmer is willing to comply with the standards for organic milk. The price of organic milk ranges from US $30 – 40 per hundred weight in the US (Natzke 2015). For this study it is assumed that the milk is not certified organic.

Cheese production provides the farmer with diversification. It allows the farmer to adjust the transfer price in whichever direction to reflect the relative value of the milk in either milk production or cheese production based on the manager's (farmer's) own determination. If the farmer desires to direct more money towards the dairy, then a higher transfer price can be charged to the dairy to make it more financially sustainable. By selling a higher percentage of milk to the cheese operation, the dairy will be more profitable. It may be prudent to increase the capacity of the cheese plant to be able to process 100 percent of the milk produced by the dairy.

The total number of calves born equals 90 percent of the number of cows in the herd. The cull rate for cows is estimated to be 30 percent of the herd. To account for transfer costs and pricing in the integrated operation, it is assumed that the dairy includes a charge for the anaerobic digester system to do the custom manure management. Bedding is also “purchased”[8] from the anaerobic digester enterprise. The bedding is purchased at a higher price than the price suggested by the literature review, US $8 per cubic yard of fiber from the anaerobic digester system (Hoard’s Dairyman 2011) or US $36 per head (Bishop and Shumway 2009). The higher transfer cost per cubic yard of bedding is a cost per cubic yard that is similar to that which was being paid by the dairy before receiving digested fiber for bedding. The initial estimated cost of bedding is US $14,490 and the estimated cost of digested fiber for bedding is US $14,250. The digester enterprise includes the costs of cleaning and installing the bedding. The dairy also “purchases” a percentage of the power, heat or biomethane from the digester enterprise if it is not sold back to the grid. The percentage of energy “purchased” by the dairy is the amount of energy not used by the artisan cheese plant. The remainder of the prices and quantities for the dairy enterprise budget were prepared and provided by the University of Idaho.

[8] This means a transfer price/cost is used to connect the two enterprises (dairy and digester) in the integrated operation. Although actual cash does not change hands when the dairy purchases services (manure management) and goods (bedding and power) from the digester enterprise, a reasonable charge or transfer price/cost must be included to reflect the opportunity costs of the digester operation and its value in terms of the services and goods it transfers to the other parts of the integrated operation. The terms “bought” or “purchased” simply reflect that a transfer between segments of the integrated operation takes place and a transfer price/cost is included in the enterprise budgets for this transfer to account for the opportunity costs of the goods and/or services being transferred among the different enterprises.

Artisan Cheese Model

Producing artisan cheese adds value to the milk bought from the dairy and helps the farmer improve profitability. The artisan cheese plant or operation used here represents a larger production size, in terms of volume, than what was included in the literature review. However, the production size selected reflects operations that might be associated with dairy farms that are being affected by urban encroachment in Utah. The issue of urban encroachment on farming operations can be prevalent with family dairy farms that have been owned for generations in the same location. Neighborhoods have been built around them as land is sold and developed. Our sample dairy farm that was used to help estimate prices and quantities for the dairy model is an example of a dairy affected by urban encroachment. Our sample dairy farm is also used to help make generalized assumptions for the artisan cheese model. Other sources of information are also used to estimate appropriate prices and quantities for capital investment, revenue and operating expenses. It is assumed that the artisan cheese project will be financed over a 10-year period.

Fixed Assets Required for Artisan Cheese Explained

Costs for the cheese plant (Table 5) are based on the assumption that there has been a complete startup investment that will depreciate over a 10-year period. The equipment needed for the cheese plant has the capacity to produce 104,926 pounds of cheese per year and is assumed to have been purchased as new. The land required for the cheese operation is one acre and is purchased from the dairy to reflect a separation between the cash-flow for the dairy and the cash-flow for the artisan cheese production. Purchasing the land also reflects the opportunity cost incurred by the dairy by not having one less acre from which to produce.

The cost of the cheese facilities per square foot is assumed to be similar to that of the smaller artisan cheese plant that was discussed in the literature review. The processing and retail facilities for the cheese operation are estimated to cost US $150 per square foot. The total cost of the aging facility is US $26.81 per square foot plus US $24,074 (Bouma, Durham and Meunier-Goddik 2014). The square footage for the cheese plant is estimated to be 4,063 square feet for the processing facility and 7,376 square feet for the aging facility (Bouma 2012). The retail facility is assumed to be the same size as the processing facility. The square footage needed is calculated to be equivalent to the square footage per pound of cheese produced by smaller artisan cheese plants and then scaled to meet square footage needed for 104,926 pounds of cheese per year. The cost of equipment for both raw milk production and cheese production are estimates provided by equipment distributors. The equipment and buildings for the cheese operation are depreciated over 10 years using straight line depreciation with a terminal (salvage) value of 10% of the initial investment.

Table 5. Artisan Cheese Cost of Investment (US dollars)

	Weight Each	Unit	Total Number of Units	Price or Cost/Unit	Total Value
INITIAL INVESTMENT					
Cheese Equipment					
Pasteurizer	1		1	$46,500.00	$46,500.00
COP	1		1	$15,000.00	$15,500.00
Recorder & Thermostat	1		1	$3,500.00	$3,500.00
Air Space Heater	1		1	$1,200.00	$1,200.00
Leak Detect Valve	1		1	$1,300.00	$1,300.00
Cheese Vat 5000lb	1		1	$42,420.00	$42,420.00
Cheese Vat 2000lb	1		1	$25,140.00	$25,140.00
Drain Table	1		1	$1,500.00	$1,500.00
Curd Distributor	1		1	$1,150.00	$1,150.00
Turning Trays	1		1	$125.00	$125.00
Tipping Station	1		1	$2,005.00	$2,005.00
Cheese Bag Trolley	1		1	$2,225.00	$2,225.00
Curd Rake	1		1	$270.00	$270.00
Tower Cheese Strainer	1		1	$525.00	$525.00
Curd Knife	1		1	$995.00	$995.00
Cheddar Mold	1		1	$215.00	$215.00
Cheese Press	1		1	$16,900.00	$16,900.00
Curd Mill	1		1	$16,900.00	$16,900.00
Raw Milk Equipment					
Centrifugal Pump	1	1.5 HP	1	$2,205.00	$2,205.00
Filler Feed Pump Control	1		1	$2,285.00	$2,285.00
Filler/Capper	1	5 Bottles/Min	1	$7,900.00	$7,900.00
Change Sizes	1	.5 gal., qt., pt.	3	$450.00	$1,350.00
Bulk Tank	1	100-300 gal.	1	$4,950.00	$4,950.00
In Table	1		1	$750.00	$750.00
Off Table	1		1	$450.00	$450.00
Building					
Land	1	acre	1	$20,000.00	$20,000.00
Processing	1	square ft.	4,063	$150.00	$609,450.00
Retail Facility	1	square ft.	4,063	$150.00	$609,450.00
Aging Facility	1	square ft.	7,376	$26.81	$221,824.56
Total Initial Investment					**$1,658,984.56**
Cost per Head					**$7,899.93**

Source: Bouma, Durham and Meunier-Goddik (2014); Anco (2015); and Dairy Heritage (2015).

Labor Requirements for the Artisan Cheese Plant

It is assumed that the owner-labor provided by each partner does not exceed 41 hours per week, and that the two owners allocate their time equally between the dairy and the cheese production facilities (Table 6). One partner spends 40 hours at the dairy and the other spends 40 hours at the artisan cheese plant. The remaining half of an hour of labor for each partner is spent with the anaerobic digester system. The cheesemaker is paid an annual salary of US $45,000 (Bouma et al. 2014). Hired labor is paid US $12. Two hired laborers works 30 hours per week each at the cheese plant and the worker. This wage ($12 per hour) is the same hourly wage paid to the dairy workers. There are 15 part-time workers in the cheese operation (retail store, farmers markets, and packaging operation) that are paid minimum wage US $7.25 and will each work 20 hours per week.

Table 6. Artisan Cheese Enterprise Budget (US dollars)

	Weight Each	Unit	Total Number of Units	Price or Cost/Unit	Total Value
Gross Receipts					
Raw Milk	5.7194	cwt	180	$70.00	$72,064.69
Cheese					
Direct Market	50%	lbs	104,926	$13.00	$682,020.20
Wholesale	30%	lbs	104,926	$7.80	$245,527.27
Distributor	20%	lbs	104,926	$3.90	$81,842.42
Other Retail Net Sales	1	$	1	$5,000.00	$5,000.00
Agrotourism	40	People	52	$5.00	$10,400.00
Total Receipts					**$1,096,854.59**
Operating Costs					
Cheese Maker		Salary	1	$45,000.00	$45,000.00
Owner Labor		Hours	2,080	$25.00	$52,000.00
Hired Labor		Hours	3,120	$12.00	$37,440.00
Hired Labor		Hours	15,600	$7.25	$113,100.00
Packaging	1	lbs	104,926	$0.50	$52,463.09
Water Service	1	hcf	10,493	$5.25	$55,086.25
Custom Whey Management	1	$	1	$4,000.00	$4,000.00
Sanitation	1	$	1	$15.47	$15.47
Electricity	1	$	104,926	$0.39	$40,921.21
Propane	1	$	104,926	$0.14	$14,840.38
Marketing	0.03	$	1,096,855		$32,905.64
Farmers' Market Fees		$	52	$60.00	$3,120.00
Distribution	44.444	gal	12	$2.70	$1,440.00
Maintenance	0.01	$	104,926		$1,049.26
Cheese Ingredients	**vats/yr**		**units/vat**	**$/unit**	
Cultures	52	lbs	20,000	$0.008	$8,465.12
Milk	57.19	cwt	180	$25.00	$257,373.88
Rennet	52	lbs	20,000	$0.006	$6,046.51
Salt	52	lbs	20,000	$0.006	$6,046.51
Insurance	1	$	1	$3,605.70	$3,605.70
Property Tax (1%)			0.010	$1,460,724.56	$14,607.25
Depreciation (10 Years @ 10% Salvage of Initial Cost)					$149,308.61
Total Operating Costs					**$898,834.88**
Net Income					**$198,019.70**
Net Income per Head					**$942.95**

Source: Bouma (2012); Curren (2013); Bouma, Durham and Meunier-Goddik (2014); and Kohler and Kohler (2015).

Other Operating Costs and Receipts for the Artisan Cheese Explained

It is assumed that all of the raw milk and cheese produced by the integrated farm is sold, and the number of agrotourists per week is consistent throughout the year. Raw milk sales constituted 10% of the milk that was transferred to the artisan cheese operation. The remainder of the milk produced by the dairy is converted to cheese. The prices for the cheese sold at the retail store varies, but an average is calculated for aged cheese and cheese curd and this is the price used to calculate returns and cash flows in the analysis for the cheese production activity.

There are three different channels through which the cheese is marketed 1) Direct Market, 2) Wholesale and 3) Distributor. It is assumed that all of the cheese will be sold each year and that 50 percent will be sold through direct marketing, 30 percent will be sold through wholesale and 20 percent will be sold through distributor marketing channels. Direct marketing channels include the cheese sold through the on-farm retail store, the farmer's market and the internet. Wholesale channels make high-volume purchases. Packaging costs for high volume purchases are assumed to be the same as the other marketing channels. Distributor marketing channels distribute the cheese to other off-farm retail stores. The cost for packaging cheese is also lumped together for aged cheese and cheese curd (Bouma, Durham and Meunier-Goddik 2014).

It is estimated that 40 people per week visit the farm as agrotourists. Agrotourists receive a tour of the cheese plant, dairy farm and anaerobic digester system. The on-farm retail store provides a source of direct marketing for the cheese, but seeks to attract consumers and supplement receipts through agrotourism and the sale of other off-farm products (e.g., gift baskets and ice cream). The net retail sales from off-farm products is estimated to be US $5,000.

Custom whey management is done through the anaerobic digester system. There was no previous studies in the literature about artisan cheese production that reflect a cheese plant that produces 104,926 pounds of cheese per year. The largest artisan cheese budget found reflects a production size of 60,000 pounds of cheese per year. The cost of custom whey management is a fixed value estimated for the 60,000 pounds of cheese per year. The same cost of custom whey management used to estimate the cost to produce 60,000 pounds of cheese per year will be used to estimate the cost of custom whey management used to estimate the cost to produce 104,926 pounds of cheese per year (Bouma, Durham and Meunier-Goddik 2014).

The budget used to estimate the costs to produce 60,000 pounds of cheese per year is used whenever possible to estimate the cost of producing 104,926 pounds of cheese. However, an enterprise budget estimating the cost of production for a smaller operation is used to estimate the cost of water services. This is due to a lack of detail in information regarding this cost in the budget that estimates the cost to produce 60,000 pounds of cheese per year (Bouma, Durham and Meunier-Goddik 2014). The cost of water services is based off of an estimate for a budget reflecting 2,400 pounds of cheese produced per year. The budget for 2,400 pounds of cheese produced per year estimates the price per one hundred cubic feet (hcf) water to be US $5.25. To produce 2,400 pounds of cheese per year it is estimated that 240 hcf per year will be required, or 10 hcf per pound of cheese per year (Curren 2013). Therefore, it is assumed that 10,493 hcf will be required to produce 104,926 pounds of cheese per year. This potentially removes benefits from economies of scale and may over or underestimate costs.

The distribution distance is estimated to be 800 miles round trip. This distance is chosen because 400 miles is the maximum distance for food to be considered locally produced (USDA ERS 2010). The final assumption made for the artisan cheese production is that the same amount of insurance paid annually for the dairy will be paid for the cheese production.

Anaerobic Digester Model

For purposes of calculating its costs and returns, the anaerobic digester system is assumed to be a separate enterprise from the artisan cheese production and the dairy production (Table 7). The anaerobic digester is a waste management enterprise that provides a waste management service to the dairy and the artisan cheese plant. Along with the service provided, the anaerobic digester provides products that will be sold to the artisan cheese plant and the dairy. There is little current literature covering an anaerobic digester model as small as the one considered here. The literature that is available for similarly-sized anaerobic digesters indicates that, under typical circumstances, an anaerobic digester the size of the one considered in this study is not profitable. However, a new and less expensive digester model as designed by Dr. Conly Hansen at Utah State University is used to represent this enterprise in this study and may yield alternative results to studies of larger digesters that were done in the past. It is assumed that the anaerobic digester system project will be financed over a 20 year period.

Anaerobic Digester SWOT Analysis Explained

A SWOT analysis provides an organized and intuitive view of the internal and external variables that affect the potential success of adopting anaerobic digestion. It helps the farmer analyze the social, environmental and economic consequences of adopting anaerobic digestion before estimating the financial feasibility. The SWOT analysis provides no financial measures. The SWOT analysis organizes the information obtained from the literature review in a table under four categories (i.e., strengths, weaknesses, opportunities and threats) to help the farmer develop a cursory assessment of investing in an anaerobic digester system. This is the first tool used, but it does not determine the feasibility of the project.

Fixed Assets Required for the Anaerobic Digester Explained

The anaerobic digester system considered in this study is a codigestion model that requires enough storage capacity to meet the waste management needs of both whey and manure produced by the cheese operation and dairy, respectively. The IBR model provides tanks that are less expensive than other tanks used by other digester systems. This reduction in the cost for tanks is the primary financial benefit of the IBR digester system when compared to other systems. Five tanks are required if tipping fees are included as a revenue source. If tipping fees are not included, then four tanks are sufficient for an operation of the size considered in this study.

The generators associated with the anaerobic digester need engine replacements every four years, but all of the engines are not replaced simultaneously. Therefore generators work continuously. It is assumed that whey from the cheese plant is always a component of the feedstock fed to the microorganisms of the anaerobic digester. Land is purchased from the dairy because the anaerobic digester system is first analyzed as a separate enterprise from the dairy (Table 7). This cost for the land included in the anaerobic digester's enterprise budget represents the opportunity cost of the dairy forgoing the use of that land for furthering the dairy operations.

It is assumed that the dairy provides any hauling equipment needed for the anaerobic digester enterprise to perform custom manure management and to clean and to install bedding. If biomethane is produced, additional equipment and labor will be required. The equipment cost for a small dairy biogas upgrading plant is estimated to be US $500,000 plus the cost of the storage tanks (Krich et al. 2005). Basic anaerobic digestion equipment costs reflect the estimates of suppliers or were taken from the Minnesota Project. The Minnesota Project was an anaerobic digester economic analysis done for a farm similar in size and equipment to the one considered in this study. The reason the Minnesota Project estimates are not used in their entirety to build the enterprise budget for this study is due to their lack of transparency and detail in the costs reported for the Minnesota Project. All applicable information from the

Minnesota Project that could be used from this study were used to estimate costs. This includes costs for buildings, utility hook up, flare and boiler, tank insulation, construction and plumbing and electrical (Lazarus 2009).

The manure storage pit is an earthen pit. A concrete pit is expensive, but under certain situations concrete pits may be chosen instead of an earthen storage pit. For example, if regulations are implemented to require a concrete pit, or if financial help is provided from sources such as the National Resource Conservation Service (NRCS), or if the owner simply wishes to build a concrete pit, then the added costs for concrete, rebar and additional labor would need to be added to the costs for the manure pit to reflect a concrete pit rather than an earthen pit. The earthen pit is used for this analysis in order to reduce capital costs. Measuring the capital cost per cow and keeping the capital cost per cow near US $1,500 helps to determine the feasibility of adopting anaerobic digestion. By keeping the capital cost per cow near US $1,500 the breakeven potential is improved (Shelford 2012).

The anaerobic digester is depreciated over 20 years using straight-line depreciation. Twenty years is the lifetime of the digester and, according to literature reviewed, this is an acceptable estimate of the time for the digester's useful life. The terminal or salvage value is the price of the land because there will be little or no value left in the equipment, and any value that is left will be difficult to recover through the sale of the equipment for scrap metal.

Table 7. Anaerobic Digester System Cost of Investment (US dollars)

	Weight Each	Unit	Total Number of Units	Price or Cost/Unit	Total Value
Investment Costs					
Digester Tank	1	Tank	5	$12,000.00	$60,000.00
Generator (6kW Inverter)	1	EcoGen Generac	4	$3,799.00	$15,196.00
FAN Separator (32-34% DM)	1	S855HD	1	$44,240.00	$44,240.00
Building Costs	1	Equip. Shelter	1	$36,527.26	$36,527.26
Concrete Pads	1	Cubic Yards	45	$100.00	$4,500.00
Utility Hook Up	1	$	1	$13,282.64	$13,282.64
Flare and Boiler	1	$	1	$14,389.53	$14,389.53
Tank Insulation	1	$	1	$35,420.37	$35,420.37
Construction Labor	1	$	1	$16,603.00	$16,603.00
Plumbing & Electrical Work	1	$	1	$22,137.73	$22,137.73
Agitator	1	$	1	$18,231.40	$18,231.40
Pump	1	DODA AFI 35	1	$7,643.00	$7,643.00
Biomethane Upgrade	0	$	1	$500,000.00	$0.00
Legal Fees		$		$9,645.00	$9,645.00
Miscellaneous	767.00	kWh	365	$0.01	$1,679.73
Land	0.67	Acre	1	$20,000.00	$13,400.00
Pit Excavation & Dirt Work	250	6ft x 100ft x 250ft	1	$95.00	$23,750.00
Manure Storage Pit	0	Cubic Yards	710	$100.00	$0.00
Rebar	0	#5 Rebar	1	$37,800.00	$0.00
Vertical Plastic Whey Storage	1	20,000 gal	1	$19,599.99	$19,599.99
Total Initial Investment					**$356,245.65**
Investment Tax Credit (10%)					**$35,624.57**
Total Cost					**$320,621.09**
Cost per Head					**$1,526.77**

Source: Krich et al. (2005); Bishop and Shumway (2009); Lazarus (2009); FAN (2015); Western States Rebar Fabrication (2015); Generac (2015); Governor's Office of Energy Development (2015); High Tech Manure Handling Equipment (2015); USDA NRCS (2015); Jensen Excavating (2015); Spanjer (2015).

Labor Required for the Anaerobic Digester Explained

It is assumed the custom manure and whey management service provided by the anaerobic digester mitigates all risks associated with on-farm organic wastes. These services are paid for by the dairy and cheese plant enterprises using a transfer price. Any labor needed regarding manure or whey processing is performed by the anaerobic digester enterprise. Any labor needed regarding bedding is also performed by the anaerobic digester enterprise. Labor costs per week are equal to those for the dairy and cheese plant ($12 per hour).

Labor required for the digester system is 20 hours per week if no off-farm[9] organic waste is being received. If off-farm organic waste is accepted an additional 5 hours is needed to accept off-farm organic waste and collect tipping fees. In order to account for the time to monitor and maintain the digester system and manage the revenue stream of coproducts and services (e.g. tipping fees) 25 hours per week are estimated for labor for the digester. Because tipping fees reduce the effects of seasonality and also reduce the potential of failing, 25 hours per week is the time used to estimate hired labor costs. An additional hour is estimated for owner labor costs (Table 8).

Low tipping fees can effect decreased feasibility when additional labor is required for accepting off-farm organic waste. However, accepting off-farm organic waste improves the dependability of feedstock supply and decreases the effects of seasonality. It is assumed that five additional hours are sufficient to meet the demand for organic waste disposal services within the community and part of the supply needs

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[9] The farmer may choose to take waste from other farmers or waste producers and charge them for processing it through the digester.

of the digester system for additional off-farm feedstock. Obtaining off-farm organic waste from restaurants, bakeries and other food producers is also crucial to improve the dependability of the feedstock supply and reducing the effects of seasonality when cows are feeding in the pasture or if cheese production is reduced. Labor time dedicated to collecting tipping fees decreases the feasibility of the digester system because of the low organic waste price in Utah.

It is estimated that the amount of labor required for a digester system for 210 cows is not as much as the amount required for larger dairies used to estimate labor in the literature review. It is assumed that 30 minutes per day is an inadequate amount of labor time to monitor and maintain the digester system, provide the waste management services to the dairy and cheese plant, manage and keep up to date on incentive programs, ensure the amount of carbon that is offset by the digester system is equal to the amount of CO_2e sold and acquire a sufficient amount of feedstock (i.e. off-farm sources) to prevent the failure of the digester system. Allotting 25 hours of labor per week to the digester system will provide sufficient labor time in case of emergencies relating to the digester system. Allotting 25 hours of labor per week to the digester system will also prevent neglect and give proper priority to the welfare of the digester if the dairy and/or cheese plant have simultaneous emergencies or production issues.

Table 8. Anaerobic Digester System Enterprise Budget (US dollars)

	Weight Each	Unit	Total Number of Units	Price or Cost/Unit	Total Value
Gross Receipts					
Net Metering	767	kWh	365	$0.11	$29,955.19
Heat	0	therm	365	$0.95	$0.00
Biomethane (Residential)	0	therm	365	$1.00	$0.00
Bedding (Fiber)	75%	Cubic Yard	1,248	$15.00	$14,040.00
Fertilizer (Fiber)	25%	Cubic Yard	1,248	$15.00	$4,680.00
Custom Manure Mgmt.	1	Head	210	$20.00	$4,200.00
Custom Whey Mgmt.	1	$	1	$4,000.00	$4,000.00
Carbon Offsets	1.44	Tonne CO_2e	210	$12.50	$3,772.13
Tipping Fees (up to 130% Capacity)	1	Cubic Yard	2,500	$3.00	$7,500.00
Prod. Tax Credit (Utah)	767	kWh	365	$0.00	$195.97
Total Receipts					**$68,343.28**
Operating Costs					
Hired Labor	25	Hours	52	$12.00	$15,600.00
Owner Labor		Hours	52	$25.00	$1,300.00
Biomethane Prod.	0	therm	365	$0.50	$0.00
Legal Fees		$		$750.00	$750.00
Other Professional Services		$		$8,011.00	$8,011.00
Miscellaneous	767	kWh	365	$0.00	$559.91
Maintenance (5% of Investment)		$			$17,812.28
Engine Overhaul (Every 4 Years)		Engine	1	$1,500.00	$1,500.00
Property Tax (1%)		$	0.010	$356,246	$3,562.46
Depreciation (20 Years)		$	20		$17,142.28
Total Operating Costs					**$66,237.93**
Net Income					**$2,105.35**
Net Income per head					**$10.03**

Source: Krich et al. (2005); Bishop and Shumway (2009); Lazarus (2009); Gloy (2011); California Environmental Protection Agency (2015); Governor's Office of Energy Development (2015); Rocky Mountain Power (2015); Timpanogas Special Service District (2015); US Energy Information Administration (2015).

Other Operating Costs and Receipts for the Anaerobic Digester Explained

The largest source of revenue for the digester system is the electricity generated through using biogas to fuel generators. It is estimated that 767 kWh per day could be produced by a digester the size of the one considered in this study. If whey is not used as a companion feedstock to manure, then only 697 kWh per day are produced. This would result in an estimated loss in revenues of US $2,700 per year in net metering alone if only manure and not whey is processed by the digester. Not processing whey will also result in a loss of fiber as fertilizer receipts and whey management receipts because less feedstock will be introduced to the digester system. If whey is not used as a companion feedstock to manure, then 182 gallons of additional fresh water per day will also be required for the digester system to function correctly. If whey is not used as a companion feedstock to manure, then an additional US $100 per year will be required for the cost of water. Consequently, for this study it is assumed that whey will always be a companion feedstock to manure in this model.

It is assumed that the anaerobic digester system will collect all the whey and manure from both of the other enterprises (cheese and dairy operations). Both of these organic waste materials (manure and whey) will be used simultaneously as feedstock. It is assumed that the system will run continuously and produce constant amounts of energy (no seasonality) throughout the year.

Bedding produced from digester fiber is sold to the dairy at a higher price as was explained before. To help determine the price the digester enterprise should charge the dairy for bedding, the price of fertilizer was reviewed. The price of fertilizer represents the price that the fiber could be sold for if it was not sold as bedding (opportunity cost). Bishop and Shumway (2009) estimate the value of the fiber at US $13.50 per cubic yard. The price of compost at landfills in Utah is circa US $15 per cubic yard. This is the price used to estimate the value of the fiber for both bedding and fertilizer, and this price is similar to the cost of bedding that was originally estimated by the dairy enterprise budget before digester fiber was considered for bedding.

The original price of bedding in the dairy enterprise budget was nearly US $15.50 per cubic yard. If the digester enterprise sells bedding to the dairy at US $15. The dairy incurs a lower cost of bedding by using fiber from the digester system. The digester enterprise benefits from selling bedding at a price lower than what it could be sold for as fertilizer. By selling fiber as bedding for 90 percent more than what the literature suggests, the digester enterprise is also able to cover the cost of providing the bedding service.

According to the literature review, receiving tipping fees is one of the sources of income that significantly improves the NPV and IRR for an anaerobic digester enterprise. Providing a place for the community to dispose of organic waste has significant potential to generate additional revenue streams and to contribute to the consistency of biogas production. If manure feedstock is reduced seasonally due to cows being on pasture and leaving the manure in the field, then having an off-farm source of feedstock is beneficial to maintain steady biogas production.

This study assumes a steady supply of manure is available. Accepting organic waste disposal increases the amount of green energy produced. One more tank is required for feedstock storage if tipping fees are included in the revenue stream. It is assumed that off-farm organic waste makes up only 30 percent of the feedstock when tipping fees are included. The charge for organic waste is estimated to be US $5.50 per cubic yard (Bishop and Shumway 2009). This price is slightly higher than what is charged for organic waste to be disposed of in Utah.

Tipping fees for organic waste range from US $2 per cubic yards and US $5 per cubic yards for waste smaller than two feet in diameter and greater than two feet in diameter respectively. US $3 per cubic yard is the price used for tipping fees in this model to represent the fees charged in Utah.

Tax credits from government programs and incentives are assumed to be constant over time. There are also two tax credits received from the Utah Governor's Office of Energy Development. The production tax credit pays US $.0035 per kWh per year. This tax credit is available for the first four years of production. To show the effect of the tax credit for the lifetime of the investment, it is spread evenly for 20 years.

The second tax credit is the Investment Tax Credit. It is worth 10 percent of the investment or US $50,000, whichever is less. This tax credit is for commercial installations (Governor's Office of Energy Development n.d.). The termination of net metering, tax credits, renewable energy credits and carbon offsets provided by government programs and incentives would cause the revenue for the waste management enterprise to decrease dramatically. If biomethane is produced by the anaerobic digester on the farm then the cost of operation and maintenance for biomethane is estimated to be US $5.02 per MCF (Krich et al. 2005). This is equal to US $0.11 per therm per day.

NPV, IRR and Sensitivity Analyses Explained

The dairy, artisan cheese and anaerobic digester enterprise budgets (Tables 5, 6 and 8) provide hypothetical annual models of annual costs and returns that can be viewed as a tool to help farmers make decisions about investments. The receipts and expenditures in the enterprise budgets are based on a large number of assumptions but provide data needed for a capital budget. The capital budget is used to determine the NPV, IRR and payback period. It also provides an estimated cash flow (positive or negative) from which the NPV and IRR are calculated for the lifetime of the investment. The sensitivity analysis for the anaerobic digester enterprise provides a chart with a range of NPVs that are based on different discount rates and percentages of the investment that is subsidized.

The NPV is the primary metric used to determine whether an investment should be accepted or rejected. It takes into account the time value of money by analyzing estimated future cash flows and discounting them to the present time. A NPV greater than zero is an acceptable investment but is based on whatever discount rate is used in its calculation. $-C_0$ is the initial investment and C_T is the net cash flow for each year of the lifetime of the investment. V_T is equal to the salvage value of the investment, and *r* is equal to the discount rate. *T* is equal to the planning horizon.

(1) $$NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_T}{(1+r)^T} + \frac{V_T}{(1+r)^T}$$

The IRR is a metric similar to the NPV that is used to determine the feasibility of investments by analyzing its predicted net cash flows. An acceptable IRR is one higher than the discount rate. It must be a rate higher than the discount rate or the NPV of future cash flows will be less than zero. The NPV is the primary metric used to determine the feasibility of the investment because of possible issues that arise with the IRR due to variable discount rates over long-term investments. It is used as a companion metric to the NPV to help measure the feasibility of the investment because it is simple and easy to see the feasibility if the rate is greater than the discount rate. The variables for the IRR equation are the same as those for the NPV equation.

(2) $$0 = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_T}{(1+r)^T} + \frac{V_T}{(1+r)^T}$$

The payback period is reached when an investment has had enough positive net cash flow to breakeven on the investment. An acceptable payback period for this investment (the integrated farming operation considered in this study) would likely range from one to 15 years. The more quickly the payback period is reached, the better the investment.

The percentage of the investment that is subsidized is the measure used in this model to illustrate the effects of social and environmental risk. The subsidy is used to help the farmer finance the initial investment of the project. However, the money used to subsidize the project, whether it is from government entities or non-government entities, has to come from somewhere. It represents money provided by the community through taxes or donations to non-government entities that is used to help struggling or immature enterprises that often provide a social or environmental benefit. Adopting anaerobic digestion is investing in a struggling or immature enterprise in the US that provides social and environmental benefits.

The sensitivity analysis for the discount rate and the subsidy rate provides results for the NPV that vary depending on the discount rate used and the subsidy rate used. It provides flexible results that can be used to help analyze the feasibility of the investment. The sensitivity analysis for the labor and whey management provides net income results for the digester system that vary depending on the labor and whey management. This sensitivity analysis provides flexible results that can be used to help analyze the effects of increased or decreased labor time. It also provides information regarding the potential cost reduction of whey disposal achieved by adopting anaerobic digestion if off-farm disposal methods become more expensive.

For this model it is assumed that there is no value in the option of delaying investment. The farmer is therefore not indifferent to investing or waiting to adopt anaerobic digestion. This assumption is made by assuming that due to regulation or urban encroachment, the farmer is obligated to either adopt anaerobic digestion or cease production. Value in the option of delaying investment increases the amount of subsidy needed to make the adoption of anaerobic digestion feasible.

The value in the option to delay investment in anaerobic digestion arises primarily because of the uncertainty of revenue streams such as the price of electricity, the carbon offset longevity and the availability of feedstock. The uncertainty of revenue streams increases the uncertainty of the value of the investment (Stokes, Rajagopalan and Stefanou 2008).

To account for the uncertainty of the value of the investment in the model uses a range of discount rates to reflect the financial risk farmer undertakes instead of a value for the option to delay investment. This is done to simplify and separate the different components of sustainability (i.e., social, environmental and financial). Social and environmental risks are represented by the subsidy, and the financial risk is represented in the discount rate.

The higher the percentage of initial investment covered by the subsidy is a signal that the social and environmental benefit provided by the enterprise is a high priority for the community. In the sensitivity analysis, a higher financial risk, or discount rate, requires a higher subsidized percentage of investment, social and environmental value for the farmer to be willing to invest in an anaerobic digester system. The recommended subsidy percentage for this model is the lowest percentage that provides a positive NPV for an estimated discount rate.

The discount rate represents the financial risk of an investment. It takes into account the time value of money. It is the rate used to determine the NPV of future cash flows. The higher the discount rate the riskier the investment. The higher the discount rate the higher the IRR must be for the project to be considered feasible. For this analysis, an acceptable discount rate was determined by reviewing the literature and choosing a discount rate used for similar investments. The range of discount rates used by other larger-sized anaerobic digester systems (systems larger than 500-cows and often greater than a 1,000 cows) ranges from three percent to 10 percent (Lee and Sumner 2014).

The success rate of anaerobic digester systems has improved over the last few decades, but most of that improvement has been realized in large-scale operations. In a study published in 2012 and by Klavon et al., small-scale, under 500 cows, anaerobic digesters were analyzed. It was determined that anaerobic digesters may be cost effective but also noted that of the eight digesters examined in the literature review, only 50 percent were successful (Klavon et al. 2013).

The success of the dairy and the cheese plant operations should not be sacrificed to make the anaerobic digester enterprise successful. Money that could be used to improve capacity and efficiency for the dairy and cheese enterprises has value. The opportunity cost of forgoing further investment in these other two enterprises needs to be taken into account when choosing a discount rate for the digester. A discount rate of four percent is considered low even for a large-scale operation. A discount rate greater than 10 percent is more likely given that there is a high failure rate for anaerobic digesters and an even higher failure rate for anaerobic digesters on small-scale operations. A recommended discount rate range for this analysis is from 10-20 percent depending on the risk aversion of the producer. This is not an unreasonable estimated discount rate given the opportunity cost of diverting funds from the other two enterprises, the low annual net cash flow, the failure rate and the high initial investment cost. Real estate investors may estimate discount rates from 10-35 percent depending on the stability of the asset (Kirsch 2013).

Whey Disposal and Labor Sensitivity Analysis Explained

A sensitivity analysis for whey disposal and hired labor for the anaerobic digester is created for two reasons 1) there is a lack of consistency in information regarding the required amount of time for managing the digester system enterprise. The sensitivity analysis provides an array of annual net income results for various amounts of labor. 2) it provides an array of annual net income results if the price of whey disposal increases. If the annual net income of the artisan cheese plant is sufficiently low due to a higher cost of off-farm whey disposal, then the cheese plant no longer adds enough value to the milk produced by the farmer for the farm to be profitable. Potential increases in the cost of off-farm whey disposal may decrease the profitability of the artisan cheese plant unless anaerobic digestion is adopted. The sensitivity analysis helps show the value in adopting anaerobic digestion for on-farm whey disposal.

The Value of Whey Management

The value of on-farm whey management has a variety of benefits for the anaerobic digester (e.g., high energy feedstock), but the value it provides via receipts to the anaerobic digester shows the symbiotic relationship between the digester, dairy and cheese plant. The value of whey management to the anaerobic digester is estimated by calculating the NPV for an investment in anaerobic digestion without receiving a receipt for whey management. In order to obtain an acceptable NPV (i.e., at least zero) for the investment in anaerobic digestion other revenue sources need to increase when there are no receipts for whey management. The receipt for manure management is therefore adjusted to determine an acceptable NPV when receipts for whey management are not received. The increase in the cost for manure management incurred by the dairy is then compared to the price of milk that the dairy must receive to maintain a similar level of annual net income as would be received with a lower cost of manure management. This estimates a price of milk required to compensate for no whey management receipt and achieve an acceptable NPV for the anaerobic digester. Similarly, the increase in cost for manure management incurred by the dairy is compared to the price of cheese that the cheese plant must receive to maintain a similar level of annual net income. The price of cheese is adjusted to compensate for the loss of whey management receipts for the anaerobic digester.

CHAPTER IV

RESULTS

This chapter reports the projected financial feasibility for the anaerobic digester system on a small integrated dairy farm. The financial feasibility of adopting the digester system is reported separately from the dairy operation and the artisan cheese plant. The financial effect of adding the anaerobic digester when integrated with the artisan cheese plant and small-scale dairy is estimated to determine its overall feasibility. Analyzing the strengths and weaknesses of anaerobic digestion with a SWOT analysis gives a cursory overview of the potential success of the investment (Table 9).

Table 9. Anaerobic Digester SWOT Analysis

Strengths	**Weaknesses**
Waste Management	History of High Failure Rate
Diversified Revenue Stream	High Capital Cost
Reduce Odors	Frequent Motor Replacement
Reduce Pollution	Low Annual Net Revenue
Reduce Impact of GHG	Overextension of Resources
Reduce Threat from Regulation	Lack of Expertise
	Seasonality of Feedstock
Opportunities	**Threats**
Improved Social Image	Microorganism/System Failure
Improved Environmental Image	Termination of Incentive Programs
Certifications	Lack of Off-Farm Organic Waste
Continue Farm Legacy & Culture	
Environmentally Conscious Consumer	

The digester system enterprise budget (Table 8) is one tool used to determine the feasibility of adopting an anaerobic digester system by estimating the capital cost per cow on the dairy farm. The target capital cost per cow is US $1,500 according to the Shelford (21012) estimation for target capital cost per cow. A projected cash-flow analysis and capital budget for the digester system is another tool used in conjunction with the enterprise budget to determine the feasibility of the digester system by estimating the payback period for the digester as well as its NPV and IRR.

The cash-flow analyses, based on the enterprise budgets, for the small-scale dairy and the artisan cheese plant presented in this chapter help analyze the benefits of integrating the anaerobic digester system into the farm operation. Results are based on the capital cost per cow for the investment of the anaerobic digester system, the NPV and the IRR. The payback period is also used to analyze if adding the waste management system (i.e., anaerobic digestion) and artisan cheese plant to the dairy increase overall farm profitability.

Dairy Enterprise Budget Results

The net income for the small-scale dairy is US -$77,912.64 per year, or US -$371.01 per cow per year for a 210 cow dairy under the assumed conditions (Table 4). Net income is negative when 61 percent of the milk volume is sold to a dairy manufacturer at a price of US $22 per hundred weight and when 39 percent of the milk volume is used for artisan cheese production at a price of US $25. When the price of milk sold to a dairy manufacturer is US $17 per hundred weight, the dairy must use 76 percent of the milk for artisan cheese production before the net income is positive.

Artisan Cheese Enterprise Budget Results

The results reported in the artisan cheese enterprise budget (Table 6) indicate that, when considered it is the most profitable of the three enterprises (dairy, cheese, and digester) considered in this study (Table 6). Artisan cheese production provides a net income of US $198,019.70 per year, or US $942.95 per cow per year. The cost to adopt this value adding enterprise (cheese plant) is US $1,658,984.56, or US $7,899.93 per cow. This may be one reason farmers are deterred from investing in artisan cheese production.

Artisan cheese production provides increased receipts to the dairy enterprise and reduces the effects of low milk prices paid by dairy manufacturers. The whey produced by the artisan cheese plant provides additional feedstock for the anaerobic digester system and increases the receipts reported for the anaerobic digester enterprise budget (Table 8). The additional feedstock improves the amount of biogas produced and reduces the effect of seasonality on biogas production. This is because manure quantities going through the digester are low when the cows are on pasture (i.e., during summer months). Having whey available for the digester during the months the cows are on pasture helps to maintain production for the digester during those months. The artisan cheese enterprise provides the highest source of net income per year to the farmer of the three enterprises considered and improves the net income per year for the other two enterprises.

Anaerobic Digester Enterprise Budget Results

The net income for the anaerobic digester is US $2,105.35 per year, or US $10.03 per cow per year, when production is optimal and all government incentives are acquired (Table 8). Optimal production refers to when the microorganisms are healthy, the feedstock supply is adequate and the equipment is functioning correctly. Net metering (i.e., electricity) is the best option for biogas use. Converting all biogas produced to electricity provides a positive net income per year. To implement anaerobic digestion as a waste management resource (install a digester), a capital cost of US $320,621.09 is required after subsidies. This is the capital cost after an investment tax credit of US $35,624.57 is given by the State of Utah.

A capital cost of US $320,621.09 equates to a cost of US $1,526.77 per cow for the 210-cow dairy. According the literature, the low cost of the IBR digester system reduces the capital cost sufficiently to meet the target capital cost per head of US $1,500 suggested by Shelford (2012). Meeting the capital cost per head target indicates that adopting the IBR anaerobic digester system is feasible if the other investment measures (i.e., NPV and IRR) indicate acceptable investment results (Table 8).

Labor and Whey Management Sensitivity Analysis

The sensitivity analysis for labor on the digester system and the receipts from custom whey management demonstrate how the annual net income is affected by various amounts of labor and custom whey management receipts. Labor ranges from 1 – 40 hrs., and the receipts for custom whey management range from US $1,000 – 8,000 per year (Table 10). The feasibility of adopting anaerobic digestion improves as the cost of off-farm whey disposal for the cheese plant increases and labor for the anaerobic digester decreases. An increase in off-farm whey disposal improves the feasibility of anaerobic digestion because the cost savings improves due to on-farm waste management. The cost of whey management is reduced by having the anaerobic digester, and the whey received as feedstock for the digester produces more methane per unit than manure from the dairy.

Table 10. Labor per Week and Whey Management Sensitivity Analysis for Digester

		LABOR								
		-70%	**-60%**	**-40%**	**-20%**	**0%**	**20%**	**40%**	**60%**	**70%**
		7.5hrs	**10hrs**	**15hrs**	**20hrs**	**25hrs**	**30hrs**	**35hrs**	**40hrs**	**45hrs**
		$4,680	**$6,240**	**$9,360**	**$12,480**	**$15,600**	**$18,720**	**$21,840**	**$24,960**	**$28,080**
WHEY MANAGEMENT	**$1,000**	$10,025	$8,465	$5,345	$2,225	-$895	-$4,015	-$7,135	-$10,255	-$13,375
	$2,000	$11,025	$9,465	$6,345	$3,225	$105	-$3,015	-$6,135	-$9,255	-$12,375
	$3,000	$12,025	$10,465	$7,345	$4,225	$1,105	-$2,015	-$5,135	-$8,255	-$11,375
	$4,000	$13,025	$11,465	$8,345	$5,225	$2,105	-$1,015	-$4,135	-$7,255	-$10,375
	$5,000	$14,025	$12,465	$9,345	$6,225	$3,105	-$15	-$3,135	-$6,255	-$9,375
	$6,000	$15,025	$13,465	$10,345	$7,225	$4,105	$985	-$2,135	-$5,255	-$8,375
	$7,000	$16,025	$14,465	$11,345	$8,225	$5,105	$1,985	-$1,135	-$4,255	-$7,375
	$8,000	$17,025	$15,465	$12,345	$9,225	$6,105	$2,985	-$135	-$3,255	-$6,375

[a]See Table 8 for estimated net income

Marketing Coproducts

The coproducts that maximize profitability for the digester are net metering (i.e., electricity production), bedding, fertilizer, custom on-farm waste management, carbon offsets and off-farm waste management (i.e., tipping fees). Energy companies are the target market for selling electricity, if they pay the same price for net metered electricity as the price they charge for electricity. The electricity produced is sold back to the grid instead of being used on-farm. Selling electricity back to energy companies allows the farm to remain on the grid and to maintain a working relationship with the energy company. By maintaining this relationship, the farm is able to more readily take advantage of services provided by the energy company.

Coproducts produced from the fiber produced by the anaerobic digester can be sold to nurseries and local gardeners within a 20 to 30-mile radius of the farm. 20 to 30 miles is close to the radius of the Wasatch, Utah and Summit counties in Utah. However, even if no fiber is used on the farm for bedding or fertilizer, there is still not enough produced on the farm to justify selling to a target market outside of the 20 to 30-mile area. Both males and females that garden and are environmentally-conscious are targeted for selling the farm's fertilizer.

It is important that the off-farm organic waste disposal service offered by the integrated farm be marketed effectively. These disposal services provide revenue from the tipping fees but also compete with local landfills and private disposal methods (e.g., burning). So, these fees need to be competitive with these competing activities. The target market for organic disposal services is similar to that for fiber sales. Consumers living within a radius of 20 to 30 miles from where the digester is located should be targeted for disposal services. Both males and females who are environmentally-conscious are targeted. Consumers purchasing the waste services from the farmer would transport their own waste to the where the digester is located and would pay a tipping fee for environmentally-conscious disposal using the anaerobic digester.

Other off-farm organic waste disposal services for food producers will be marketed differently. This target market is represented by food sellers (e.g., restaurants, bakeries and abattoirs) within a 20 to 30 mile radius from the digester system. This target market provides a more reliable supply of organic waste than other sources and the organic waste would be collected by the farmer owning the digester system.

Benefits of Whey Management

Besides providing additional feedstock with a high energy content, the whey management improves the feasibility of the anaerobic digester. Without the receipts from whey management the receipts from manure management need to be at least US $19,088.16 for the unsubsidized digester to achieve an acceptable NPV (Table 11). This is US $14,888.16 more than the estimated cost of manure management of a typical dairy. An acceptable NPV that does not effect a change in annual net income for the other enterprises can also be achieved if the price of artisan milk increases by US $333.74 per hundred weight, or if the price of milk purchased by the dairy manufacturers increases by US $214.70 per hundred. If the artisan cheese plant bears the cost of adopting anaerobic digestion, then cheese prices must increase by US $0.18 per pound for the direct market, wholesale and the distributor. This price is more realistic than the required increase in price of milk, but it does not take into account the loss of high energy feedstock from the whey collected from the cheese plant.

Table 11. Milk and Cheese Prices Needed to Compensate for No Whey Management

COPRODUCT SCENARIO	COST OF MANURE MANAGEMENT FOR ACCEPTALE NPV	DIFFERENCE FROM ESTIMATED COST	COST PER CWT OF ARTISAN MILK	COST PER CWT OF MANUFACTURER MILK	COST PER LB OF CHEESE
W/ ALL COPRODUCTS	$15,088.50[a]	-$10,888.50[b]	$263.81[c]	$169.71[d]	$0.14[e]
W/O WHEY	$19,088.16	-$14,888.16	$333.74	$214.70	$0.18
W/O CARBON OFFSETS	$18,868.50	-$14,668.50	$329.90	$212.23	$0.18
W/O WHEY AND CARBON OFFSETS	$22,868.00	-$18,668.00	$399.83	$257.22	$0.22
W/O WHEY, CARBON OFFSETS AND TIPPING FEES	$25,512.48	-$21,312.48	$446.07	$286.96	$0.24

[a]Price needed for custom manure management to achieve an acceptable NPV with no subsidies
[b]Difference between needed price[a] and estimated price of custom manure management (i.e., US $4,200) (Table 4)
[c]Calculated by dividing the cost of manure management[a] by the estimated amount of milk used by the cheese plant (i.e., 57.19 cwt) (Table 4)
[d]Calculated by dividing the cost of manure management[a] by the estimated amount of milk sold to dairy manufacturers (i.e., 88.91 cwt) (Table 4)
[e]Calculated by dividing the cost of manure management[a] by the estimated amount of cheese sold (i.e., 104,926 lbs.) (Table 6)

Capital Budget and Cash Flow Analysis Results

The NPV and the IRR are estimated using the cash flow analyses. An acceptable investment result for the NPV is a value that is greater than zero. An acceptable investment result for the IRR is a percentage that is greater than or equal to the discount rate. The payback period is also estimated to provide additional information to potential investors to help determine the feasibility of specific operations based on her/ his risk aversion.

Dairy Cash Flow Analysis

Neither the NPV nor the IRR are estimated for the dairy enterprise because it is not considered a new investment and is already operating (Table 12). There is not a need to analyze the feasibility of an investment in the dairy enterprise because the investment has already been made. The NPV and the IRR for the dairy do not provide meaningful information for this study. The cash-flow analysis for the dairy estimates a negative cumulative cash flow for the first 10 years assuming that the price of milk per hundred weight is less than $22. The cumulative cash flow would be even more negative without the high price of milk “sold” to the artisan cheese enterprise (Table 12). The cumulative cash flow for a given period is determined by calculating the difference between the cash flow of the current period and the previous period. The dairy cumulative cash flow is improved by increasing the amount of milk converted to artisan cheese, or by selling the milk as “organic” to a dairy manufacturer. However, the primary focus of this thesis is to determine the feasibility of adopting anaerobic digestion and these results are not analyzed here.

Artisan Cheese Capital Budget and Cash Flow Analysis

The estimated NPV and IRR for the artisan cheese plant investment both indicate that the cheese plant is an acceptable investment under the assumed conditions. The results for the NPV and the IRR are US $580,739 and 39.17%, respectively (Table 13). The NPV is greater than zero, therefore it indicates the cheese operation is an acceptable investment. The discount rate used to estimate the IRR is 10 percent, therefore the IRR also indicates the cheese plant is an acceptable investment. The investment in the cheese plant is assumed to be amortized over a time period of 10 years. The cumulative cash flow for the cheese plant (Table 13) estimates a 3-year payback period.

Table 12. Projected Cash Flow (US dollars) for the 210-Cow Dairy

Year	0	1	2	3	4	5	6	7	8	9	10
Receipts[a]		680,626	701,044	722,076	743,738	766,050	789,032	812,703	837,084	862,196	888,062
Terminal Value											0
Cash Inflow[b]		**680,626**	**701,044**	**722,076**	**743,738**	**766,050**	**789,032**	**812,703**	**837,084**	**862,196**	**888,062**
Down Payment[d]	0										
Labor[a]		89,440	92,123	94,887	97,734	100,666	103,685	106,796	110,000	113,300	116,699
Other Operating Expenses[a]		587,416	605,038	623,189	641,885	661,142	680,976	701,405	722,447	744,121	766,444
Ownership Cost[a]		81,682	84,133	86,657	89,257	91,934	94,692	97,533	100,459	103,473	106,577
Depreciation[g]		0	0	0	0	0	0	0	0	0	0
Interest[h]		0	0	0	0	0	0	0	0	0	0
Principal[h]		0	0	0	0	0	0	0	0	0	0
Taxable Income[i]		-77,913	-80,250	-82,658	-85,137	-87,691	-90,322	-93,032	-95,823	-98,697	-101,658
Income Taxes[j]		0	0	0	0	0	0	0	0	0	0
Net Cash Outflow[b & c]	**0**	**758,538**	**781,294**	**804,733**	**828,875**	**853,742**	**879,354**	**905,734**	**932,906**	**960,894**	**989,720**
Net Cash Flow[e]	**0**	**-77,913**	**-80,250**	**-82,658**	**-85,137**	**-87,691**	**-90,322**	**-93,032**	**-95,823**	**-98,697**	**-101,658**
Cumulative Cash Flow[f]	**0**	**-77,913**	**-158,163**	**-240,820**	**-325,957**	**-413,649**	**-503,971**	**-597,003**	**-692,825**	**-791,523**	**-893,181**

[a]Receipts and costs are obtained from Table 4.
[b]Receipts and costs are estimated with a growth rate of 3%
[c]Net Cash Outflow is determined by adding Labor, Other Operating Expenses, Interest, Principal and Income Taxes
[d]Down payment is 0 because the dairy enterprise is in operation and has no start-up capital cost
[e]Net Cash Flow is determined by subtracting the Net Cash Outflow from the Cash Inflow
[f]Cumulative Cash Flow is determined by adding the Net Cash Flow for the current period to the Cumulative Cash Flow for the previous period
[g]Depreciation is straight line depreciation
[h]A finance rate of 8% is used to determine Interest and Principal
[i]Taxable Income is determined by subtracting Labor, Other Operating Expenses, Depreciation and Interest from the Cash Inflow
[j]Income Taxes are calculated with a 30% tax rate

Anaerobic Digester System Capital Budget and Cash Flow Analysis

The estimated NPV and IRR for the anaerobic digestion as a waste management system indicate that it is not an acceptable investment. The NPV and the IRR are estimated to be US -$65,378 and -5.20%, respectively (Table 14). The NPV is less than zero and therefore unacceptable. The IRR is less than the assumed discount rate of 12 percent and is therefore unacceptable when considered as a stand-alone investment. Though the suggested target capital cost per cow (i.e., US $1,500) is achieved, the investment should not be made unless the investment is even more heavily subsidized by a government or non-government entity. A 12 percent discount rate indicates that an estimated 35 percent of the investment cost must be subsidized before an acceptable NPV and IRR is realized (Table 14). If 30 percent of the investment cost is subsidized, then the estimated NPV and IRR are US $1,356 and 12.39 percent, respectively. The investment for the anaerobic digester is assumed to be amortized over a time period of 20 years.

The cumulative cash-flow with no subsidy for the digester indicates that a payback period is not be achieved during the 20-year lifetime of the equipment and, indeed, has a negative cumulative cash flow that continues throughout the 20 years. This is not an acceptable payback period. With a subsidy of 45 percent of the investment cost (Table 14), the payback period is achieved in six years. A six-year payback period is acceptable if it is less than the maximum payback period desired by the investor. A subsidy of 60 percent of the investment cost for the digester reduces its payback period to three years. This is a much more acceptable payback period and indicates a payback period accepted by more investors with higher risk aversion. The results indicate that requiring an anaerobic digester will greatly reduce the profitability of the entire integrated operation unless significant subsidies are provided to the farmer.

Sensitivity Analysis for an Array of Discount Rates and Subsidy Rates

Levels of risk aversion vary for different investors. This can partially be accounted for in this analysis by using an array of discount rates that reflect different required returns to make an investment. Higher discount rates reflect higher risk aversion while lower discount rates reflect lower risk aversion. For example, investors who consider the adoption of anaerobic digestion to be highly risky may use discount rates higher than 12 percent which, in turn will lead to higher estimates of the subsidy needed to indicate a feasible investment. The reason for this is that a high discount rate results in a lower NPV than if a low discount rate is used. If the NPV is negative (more likely the higher the discount rate used), it suggests that a higher subsidy will be required to entice the investor to invest in the anaerobic digester.

The results provided by the sensitivity analysis based on the NPV indicate that as the discount rate increases the subsidy must increase for the adoption of anaerobic digestion to be feasible (Table 15). The sensitivity analysis is used to estimate the feasibility of the investment at various economic, social and environmental risk levels. If the discount rate in the sensitivity analysis ranges from 4 to 25 percent and a subsidy ranging from 22 to 54 percent is provided, then the anaerobic digester is an acceptable investment because the NPV is positive (Table 15). These results are based on the digester system being a separate entity from the dairy and the artisan cheese plant.

Overall Results for the Three Enterprises

The cumulative net cash flow of the dairy, artisan cheese plant and anaerobic digester system is used to estimate the overall payback period of the integrated farm operation. Tables 15-20 report net cash flow for the different operations (dairy, cheese plant, and digester) as well as the total cash flow for the integrated operation (cash flow added for the three components of the operation). A positive overall cash flow (positive when the cash flows of the three components are added) indicated that the payback period has been achieved. Table 15 reports these results under different levels of subsidies for the anaerobic digester.

The cumulative net cash flow estimates a payback period of nine years for the artisan cheese plant investment and the adoption of an anaerobic digester if there is no subsidy for the digester. The cash flow of the artisan cheese enterprise is large enough that it compensates for the low cash flows of the dairy and digester system enterprises. The overall payback period of the integrated operation is reduced from nine years to eight years with a subsidy for 15 percent of the cost of investment for the digester. The overall payback period of the integrated operation is reduced one year for every 15 percent subsidy increment addition until the 30 percent subsidy range. After a 30 percent subsidy is provided a 30 percent subsidy increment addition is required to

Table 13. Artisan Cheese Projected Cash Flow, NPV and IRR (US dollars) with a 10 percent Discount Rate and an 8 percent Finance Rate

Year	0	1	2	3	4	5	6	7	8	9	10
Receipts[a]		1,096,855	1,129,760	1,163,653	1,198,563	1,234,520	1,271,555	1,309,702	1,348,993	1,389,463	1,431,146
Terminal Value											165,898
Cash Inflows[a]		**1,096,855**	**1,129,760**	**1,163,653**	**1,198,563**	**1,234,520**	**1,271,555**	**1,309,702**	**1,348,993**	**1,389,463**	**1,597,045**
Down Payment[c]	331,797										
Labor[a]		247,540	254,966	262,615	270,494	278,608	286,967	295,576	304,443	313,576	322,984
Other Operating[a] Expenses[a]		501,986	517,046	532,557	548,534	564,990	581,940	599,398	617,380	635,901	654,978
Depreciation[a]		149,309	149,309	149,309	149,309	149,309	149,309	149,309	149,309	149,309	149,309
Interest[a]		106,175	98,846	90,930	82,381	73,149	63,177	52,408	40,778	28,217	14,651
Principal[a]		91,615	98,944	106,860	115,409	124,641	134,613	145,382	157,012	169,573	183,139
Taxable Income[a]		91,845	109,594	128,242	147,845	168,464	190,163	213,011	237,083	262,460	455,123
Income Taxes[a]		27,553	32,878	38,473	44,353	50,539	57,049	63,903	71,125	78,738	136,537
Net Cash Outflow[b]	**331,797**	**974,870**	**1,002,680**	**1,031,435**	**1,061,171**	**1,091,928**	**1,123,745**	**1,156,667**	**1,190,738**	**1,226,005**	**1,312,289**
Net Cash Flow[a]	**-331,797**	**121,985**	**127,080**	**132,218**	**137,391**	**142,592**	**147,810**	**153,035**	**158,255**	**163,457**	**284,756**
Cumulative Cash Flow[a]	**-331,797**	**-209,812**	**-82,732**	**49,486**	**186,877**	**329,469**	**477,279**	**630,314**	**788,569**	**952,026**	**1,236,782**
NPV[d]	**580,739**										
IRR[d]	**39.17%**										

[a]See Table 12 footnotes to know how numbers were calcuated
[b]Receipts and costs are estimated with a growth rate of 3%
[c]Down payment is 20% of the investment
[d]Net present value is calculated assuming a discount rate of 10% and a finance period of 10 years

Table 14. Digester Projected Cash Flow, NPV and IRR (US dollars) with No Subsidy and an 8 percent Finance Rate

Year	0	1	2	3	4	5	6	7	8	9	10
Receipts[a]		68,343	70,394	72,505	74,681	76,921	79,229	81,605	84,054	86,575	89,172
Terminal Value											
Cash Inflows[c]		**68,343**	**70,394**	**72,505**	**74,681**	**76,921**	**79,229**	**81,605**	**84,054**	**86,575**	**89,172**
Down Payment[a]	64,124										
Labor[b]		16,900	17,407	17,929	18,467	19,021	19,592	20,179	20,785	21,408	22,051
Other Operating[b]		32,196	33,162	34,156	35,181	36,236	37,324	38,443	39,597	40,784	42,008
Depreciation[a]		15,361	15,361	15,361	15,361	15,361	15,361	15,361	15,361	15,361	15,361
Interest[a]		20,520	20,071	19,587	19,064	18,499	17,889	17,230	16,519	15,750	14,920
Principal[a]		5,605	6,053	6,538	7,061	7,626	8,236	8,894	9,606	10,375	11,204
Taxable Income[a]		-16,633	-15,607	-14,528	-13,393	-12,197	-10,937	-9,609	-8,208	-6,729	-5,168
Income Taxes		0	0	0	0	0	0	0	0	0	0
Net Cash Outflow[b]	**64,124**	**75,220**	**76,693**	**78,210**	**79,773**	**81,382**	**83,040**	**84,748**	**86,506**	**88,318**	**90,183**
Net Cash Flow[a]	**-64,124**	**-6,877**	**-6,300**	**-5,705**	**-5,092**	**-4,461**	**-3,811**	**-3,142**	**-2,453**	**-1,742**	**-1,011**
Cumulative Cash Flow[a]	**-64,124**	**-71,001**	**-77,301**	**-83,006**	**-88,098**	**-92,560**	**-96,371**	**-99,513**	**-101,966**	**-103,708**	**-104,719**
NPV[d]	**-86,926**										
IRR[d]	**-8.18%**										

Table 14. Continued

Year	11	12	13	14	15	16	17	18	19	20
Receipts	91,848	94,603	97,441	100,364	103,375	106,477	109,671	112,961	116,350	119,840
Terminal Value										$13,400
Cash Inflows	**91,848**	**94,603**	**97,441**	**100,364**	**103,375**	**106,477**	**109,671**	**112,961**	**116,350**	**133,240**
Down Payment										
Labor	22,712	23,394	24,095	24,818	25,563	26,330	27,120	27,933	28,771	29,634
Other Operating	43,268	44,566	45,903	47,280	48,699	50,160	51,665	53,215	54,811	56,455
Depreciation	15,361	15,361	15,361	15,361	15,361	15,361	15,361	15,361	15,361	15,361
Interest	14,024	13,056	12,010	10,881	9,662	8,345	6,922	5,386	3,727	1,935
Principal	12,101	13,069	14,114	15,244	16,463	17,780	19,202	20,739	22,398	24,190
Taxable Income	-3,518	-1,774	71	2,024	4,091	6,281	8,603	11,066	13,680	29,855
Income Taxes	0	0	21	607	1,227	1,884	2,581	3,320	4,104	8,956
Net Cash Outflow	**92,105**	**94,085**	**96,145**	**98,830**	**101,614**	**104,499**	**107,490**	**110,592**	**113,811**	**121,171**
Net Cash Flow	**-258**	**518**	**1,296**	**1,534**	**1,762**	**1,978**	**2,181**	**2,369**	**2,539**	**12,070**
Cumulative Cash Flow	**-104,977**	**-104,459**	**-103,162**	**-101,628**	**-99,866**	**-97,889**	**-95,708**	**-93,339**	**-90,800**	**-78,730**
NPV	**-86,926**									
IRR	**-8.18%**									

[a]See Table 12 footnotes to know how categories were calculated
[b]Receipts and costs are obtained from Table 8
[c]Receipts and expenses are estimated with a growth rate of 3%
[d]See Table 13 footnotes to know how categories were calculated
[d]Net present value is calculated assuming a discount rate of 12%, a subsidy of 0% and a finance period of 20 years

Table 15. Anaerobic Digester System NPV Sensitivity Analysis with Subsidies from 15 percent to 54 percent

DISCOUNT RATE (ECONOMIC RISK LEVEL)	SUBSIDY RATE (SOCIAL & ENVIRONMENTAL RISK)									
NPV[a]	**15%**	**16%**	**17%**	**18%**	**19%**	**20%**	**21%**	**22%**	**23%**	**24%**
4%	(24,501.99)	(20,431.31)	(16,360.64)	(12,289.96)	(8,219.29)	(4,148.61)	(77.94)	3,992.74	8,063.42	12,134.09
5%	(29,466.08)	(25,674.31)	(21,882.55)	(18,090.79)	(14,299.02)	(10,507.26)	(6,715.50)	(2,923.74)	868.03	4,659.79
6%	(33,667.11)	(30,121.00)	(26,574.89)	(23,028.78)	(19,482.67)	(15,936.56)	(12,390.45)	(8,844.34)	(5,298.23)	(1,752.12)
7%	(37,229.90)	(33,900.93)	(30,571.96)	(27,243.00)	(23,914.03)	(20,585.06)	(17,256.09)	(13,927.12)	(10,598.15)	(7,269.18)
8%	(40,257.55)	(37,121.19)	(33,984.83)	(30,848.48)	(27,712.12)	(24,575.76)	(21,439.41)	(18,303.05)	(15,166.69)	(12,030.33)
9%	(42,835.37)	(39,870.46)	(36,905.55)	(33,940.64)	(30,975.73)	(28,010.82)	(25,045.91)	(22,081.00)	(19,116.09)	(16,151.18)
10%	(45,034.19)	(42,222.41)	(39,410.62)	(36,598.83)	(33,787.05)	(30,975.26)	(28,163.48)	(25,351.69)	(22,539.91)	(19,728.12)
11%	(46,912.93)	(44,238.36)	(41,563.79)	(38,889.21)	(36,214.64)	(33,540.07)	(30,865.49)	(28,190.92)	(25,516.35)	(22,841.78)
12%	(48,520.73)	(45,969.51)	(43,418.29)	(40,867.07)	(38,315.84)	(35,764.62)	(33,213.40)	(30,662.18)	(28,110.96)	(25,559.73)
13%	(49,898.68)	(47,458.69)	(45,018.71)	(42,578.73)	(40,138.74)	(37,698.76)	(35,258.77)	(32,818.79)	(30,378.80)	(27,938.82)
14%	(51,081.19)	(48,741.83)	(46,402.47)	(44,063.11)	(41,723.74)	(39,384.38)	(37,045.02)	(34,705.65)	(32,366.29)	(30,026.93)
15%	(52,097.20)	(49,849.12)	(47,601.05)	(45,352.97)	(43,104.90)	(40,856.82)	(38,608.75)	(36,360.67)	(34,112.60)	(31,864.52)
16%	(52,971.02)	(50,806.01)	(48,640.99)	(46,475.98)	(44,310.96)	(42,145.95)	(39,980.93)	(37,815.92)	(35,650.90)	(33,485.88)
17%	(53,723.22)	(51,633.98)	(49,544.75)	(47,455.52)	(45,366.29)	(43,277.06)	(41,187.82)	(39,098.59)	(37,009.36)	(34,920.13)
18%	(54,371.14)	(52,351.24)	(50,331.34)	(48,311.44)	(46,291.54)	(44,271.64)	(42,251.74)	(40,231.84)	(38,211.94)	(36,192.04)
19%	(54,929.52)	(52,973.21)	(51,016.90)	(49,060.60)	(47,104.29)	(45,147.99)	(43,191.68)	(41,235.38)	(39,279.07)	(37,322.76)
20%	(55,410.84)	(53,513.01)	(51,615.18)	(49,717.36)	(47,819.53)	(45,921.71)	(44,023.88)	(42,126.05)	(40,228.23)	(38,330.40)
21%	(55,825.74)	(53,981.82)	(52,137.90)	(50,293.98)	(48,450.06)	(46,606.14)	(44,762.22)	(42,918.30)	(41,074.39)	(39,230.47)
22%	(56,183.29)	(54,389.18)	(52,595.07)	(50,800.96)	(49,006.85)	(47,212.74)	(45,418.63)	(43,624.52)	(41,830.41)	(40,036.30)
23%	(56,491.25)	(54,743.26)	(52,995.28)	(51,247.29)	(49,499.31)	(47,751.32)	(46,003.34)	(44,255.35)	(42,507.37)	(40,759.38)
24%	(56,756.24)	(55,051.06)	(53,345.89)	(51,640.71)	(49,935.53)	(48,230.35)	(46,525.17)	(44,820.00)	(43,114.82)	(41,409.64)
25%	(56,983.96)	(55,318.59)	(53,653.23)	(51,987.86)	(50,322.50)	(48,657.13)	(46,991.77)	(45,326.40)	(43,661.03)	(41,995.67)

Table 15. Continued

DISCOUNT RATE (ECONOMIC RISK LEVEL)	SUBSIDY RATE (SOCIAL & ENVIRONMENTAL RISK)									
NPV[a]	**25%**	**26%**	**27%**	**28%**	**29%**	**30%**	**31%**	**32%**	**33%**	**34%**
4%	16,204.77	20,250.41	24,293.76	28,337.11	32,380.45	36,423.80	40,467.15	44,510.49	48,553.84	52,597.19
5%	8,451.55	12,220.79	15,987.95	19,755.12	23,522.28	27,289.45	31,056.61	34,823.77	38,590.94	42,358.10
6%	1,793.99	5,319.80	8,843.74	12,367.69	15,891.64	19,415.58	22,939.53	26,463.47	29,987.42	33,511.37
7%	(3,940.21)	(629.54)	2,679.44	5,988.42	9,297.40	12,606.38	15,915.37	19,224.35	22,533.33	25,842.31
8%	(8,893.98)	(5,774.14)	(2,655.83)	462.48	3,580.80	6,699.11	9,817.42	12,935.74	16,054.05	19,172.36
9%	(13,186.27)	(10,236.29)	(7,287.69)	(4,339.08)	(1,390.47)	1,558.13	4,506.74	7,455.34	10,403.95	13,352.55
10%	(16,916.34)	(14,118.06)	(11,321.02)	(8,523.98)	(5,726.94)	(2,929.90)	(132.86)	2,664.18	5,461.22	8,258.26
11%	(20,167.20)	(17,504.85)	(14,843.63)	(12,182.41)	(9,521.18)	(6,859.96)	(4,198.73)	(1,537.51)	1,123.71	3,784.94
12%	(23,008.51)	(20,468.37)	(17,929.24)	(15,390.11)	(12,850.98)	(10,311.86)	(7,772.73)	(5,233.60)	(2,694.47)	(155.35)
13%	(25,498.84)	(23,068.90)	(20,639.88)	(18,210.86)	(15,781.85)	(13,352.83)	(10,923.82)	(8,494.80)	(6,065.78)	(3,636.77)
14%	(27,687.56)	(25,357.32)	(23,027.91)	(20,698.50)	(18,369.09)	(16,039.69)	(13,710.28)	(11,380.87)	(9,051.46)	(6,722.05)
15%	(29,616.45)	(27,376.65)	(25,137.62)	(22,898.59)	(20,659.56)	(18,420.53)	(16,181.49)	(13,942.46)	(11,703.43)	(9,464.40)
16%	(31,320.87)	(29,163.38)	(27,006.59)	(24,849.80)	(22,693.00)	(20,536.21)	(18,379.41)	(16,222.62)	(14,065.83)	(11,909.03)
17%	(32,830.90)	(30,748.52)	(28,666.76)	(26,585.01)	(24,503.26)	(22,421.51)	(20,339.76)	(18,258.01)	(16,176.26)	(14,094.51)
18%	(34,172.14)	(32,158.48)	(30,145.39)	(28,132.30)	(26,119.21)	(24,106.12)	(22,093.03)	(20,079.95)	(18,066.86)	(16,053.77)
19%	(35,366.46)	(33,415.84)	(31,465.74)	(29,515.64)	(27,565.55)	(25,615.45)	(23,665.35)	(21,715.25)	(19,765.16)	(17,815.06)
20%	(36,432.58)	(34,539.93)	(32,647.77)	(30,755.61)	(28,863.44)	(26,971.28)	(25,079.12)	(23,186.95)	(21,294.79)	(19,402.63)
21%	(37,386.55)	(35,547.36)	(33,708.61)	(31,869.86)	(30,031.11)	(28,192.36)	(26,353.61)	(24,514.86)	(22,676.11)	(20,837.35)
22%	(38,242.18)	(36,452.40)	(34,663.01)	(32,873.62)	(31,084.23)	(29,294.84)	(27,505.45)	(25,716.06)	(23,926.67)	(22,137.28)
23%	(39,011.39)	(37,267.36)	(35,523.69)	(33,780.02)	(32,036.35)	(30,292.68)	(28,549.01)	(26,805.34)	(25,061.67)	(23,318.00)
24%	(39,704.46)	(38,002.90)	(36,301.67)	(34,600.44)	(32,899.21)	(31,197.98)	(29,496.75)	(27,795.52)	(26,094.29)	(24,393.06)
25%	(40,330.30)	(38,668.25)	(37,006.49)	(35,344.74)	(33,682.99)	(32,021.24)	(30,359.49)	(28,697.74)	(27,035.98)	(25,374.23)

Table 15. Continued

DISCOUNT RATE (ECONOMIC RISK LEVEL)

	SUBSIDY RATE (SOCIAL & ENVIRONMENTAL RISK)									
NPV[a]	**35%**	**36%**	**37%**	**38%**	**39%**	**40%**	**41%**	**42%**	**43%**	**44%**
4%	56,629.48	60,642.59	64,655.70	68,668.80	72,681.91	76,695.02	80,708.13	84,721.23	88,725.15	92,705.06
5%	46,115.22	49,854.91	53,594.59	57,334.28	61,073.96	64,813.65	68,553.33	72,293.02	76,024.27	79,733.50
6%	37,026.18	40,525.13	44,024.08	47,523.03	51,021.98	54,520.94	58,019.89	61,518.84	65,010.05	68,481.03
7%	29,142.98	32,429.20	35,715.43	39,001.66	42,287.89	45,574.11	48,860.34	52,146.57	55,425.68	58,686.21
8%	22,283.10	25,380.68	28,478.26	31,575.84	34,673.42	37,771.00	40,868.58	43,966.16	47,057.20	50,131.14
9%	16,294.25	19,223.95	22,153.65	25,083.34	28,013.04	30,942.74	33,872.44	36,802.14	39,725.81	42,633.75
10%	11,048.99	13,828.77	16,608.56	19,388.34	22,168.12	24,947.90	27,727.68	30,507.47	33,281.70	36,041.44
11%	6,440.40	9,085.86	11,731.32	14,376.78	17,022.24	19,667.70	22,313.16	24,958.62	27,598.97	30,225.95
12%	2,378.51	4,903.23	7,427.95	9,952.66	12,477.38	15,002.09	17,526.81	20,051.52	22,571.52	25,079.20
13%	(1,212.57)	1,203.26	3,619.09	6,034.92	8,450.75	10,866.58	13,282.41	15,698.24	18,109.72	20,509.82
14%	(4,397.06)	(2,079.72)	237.61	2,554.94	4,872.28	7,189.61	9,506.95	11,824.28	14,137.59	16,440.40
15%	(7,229.41)	(5,001.44)	(2,773.48)	(545.51)	1,682.46	3,910.43	6,138.39	8,366.36	10,590.61	12,805.15
16%	(9,755.95)	(7,609.30)	(5,462.65)	(3,316.01)	(1,169.36)	977.29	3,123.94	5,270.58	7,413.79	9,548.01
17%	(12,016.16)	(9,943.72)	(7,871.28)	(5,798.84)	(3,726.40)	(1,653.96)	418.48	2,490.92	4,560.17	6,621.11
18%	(14,043.81)	(12,039.27)	(10,034.74)	(8,030.20)	(6,025.66)	(4,021.13)	(2,016.59)	(12.06)	1,989.53	3,983.41
19%	(15,867.83)	(13,925.60)	(11,983.36)	(10,041.12)	(8,098.89)	(6,156.65)	(4,214.41)	(2,272.17)	(332.67)	1,599.69
20%	(17,513.10)	(15,628.17)	(13,743.23)	(11,858.30)	(9,973.37)	(8,088.43)	(6,203.50)	(4,318.56)	(2,436.16)	(560.39)
21%	(19,001.04)	(17,168.94)	(15,336.84)	(13,504.74)	(11,672.65)	(9,840.55)	(8,008.45)	(6,176.35)	(4,346.61)	(2,523.01)
22%	(20,350.13)	(18,566.87)	(16,783.60)	(15,000.34)	(13,217.08)	(11,433.82)	(9,650.56)	(7,867.29)	(6,086.22)	(4,310.85)
23%	(21,576.40)	(19,838.37)	(18,100.35)	(16,362.33)	(14,624.31)	(12,886.28)	(11,148.26)	(9,410.24)	(7,674.25)	(5,943.56)
24%	(22,693.74)	(20,997.71)	(19,301.69)	(17,605.67)	(15,909.65)	(14,213.63)	(12,517.61)	(10,821.58)	(9,127.45)	(7,438.25)
25%	(23,714.24)	(22,057.29)	(20,400.34)	(18,743.40)	(17,086.45)	(15,429.51)	(13,772.56)	(12,115.62)	(10,460.43)	(8,809.82)

Table 15. Continued

DISCOUNT RATE (ECONOMIC RISK LEVEL)	SOCIAL & ENVIRONMENTAL RISK									
NPV[a]	**45%**	**46%**	**47%**	**48%**	**49%**	**50%**	**51%**	**52%**	**53%**	**54%**
4%	96,684.97	100,664.88	104,644.79	108,624.70	112,604.61	116,573.18	120,516.88	124,460.58	128,404.28	132,347.98
5%	83,442.72	87,151.95	90,861.18	94,570.40	98,279.63	101,978.35	105,654.04	109,329.72	113,005.41	116,681.09
6%	71,952.02	75,423.00	78,893.98	82,364.97	85,835.95	89,297.20	92,737.09	96,176.98	99,616.88	103,056.77
7%	61,946.73	65,207.26	68,467.78	71,728.31	74,988.84	78,240.33	81,472.01	84,703.70	87,935.38	91,167.07
8%	53,205.08	56,279.03	59,352.97	62,426.91	65,500.86	68,566.42	71,613.59	74,660.75	77,707.92	80,755.09
9%	45,541.70	48,449.64	51,357.58	54,265.52	57,173.47	60,073.62	62,956.69	65,839.77	68,722.84	71,605.91
10%	38,801.19	41,560.93	44,320.67	47,080.42	49,840.16	52,592.66	55,329.29	58,065.91	60,802.54	63,539.16
11%	32,852.94	35,479.93	38,106.92	40,733.91	43,360.90	45,981.15	48,586.64	51,192.12	53,797.61	56,403.09
12%	27,586.87	30,094.55	32,602.23	35,109.90	37,617.58	40,118.99	42,606.65	45,094.31	47,581.97	50,069.64
13%	22,909.92	25,310.02	27,710.12	30,110.22	32,510.32	34,904.59	37,286.05	39,667.51	42,048.97	44,430.43
14%	18,743.20	21,046.00	23,348.81	25,651.61	27,954.42	30,251.78	32,537.21	34,822.64	37,108.07	39,393.51
15%	15,019.68	17,234.22	19,448.75	21,663.29	23,877.82	26,087.29	28,285.62	30,483.96	32,682.30	34,880.63
16%	11,682.24	13,816.46	15,950.68	18,084.90	20,219.13	22,348.61	24,467.72	26,586.83	28,705.93	30,825.04
17%	8,682.05	10,742.99	12,803.92	14,864.86	16,925.80	18,982.32	21,029.14	23,075.97	25,122.80	27,169.62
18%	5,977.30	7,971.18	9,965.06	11,958.94	13,952.83	15,942.58	17,923.28	19,903.98	21,884.68	23,865.38
19%	3,532.06	5,464.42	7,396.78	9,329.15	11,261.51	13,190.01	15,110.05	17,030.09	18,950.14	20,870.18
20%	1,315.39	3,191.17	5,066.95	6,942.72	8,818.50	10,690.67	12,554.92	14,419.17	16,283.42	18,147.67
21%	(699.41)	1,124.19	2,947.79	4,771.38	6,594.98	8,415.20	10,228.02	12,040.83	13,853.65	15,666.46
22%	(2,535.48)	(760.11)	1,015.26	2,790.63	4,566.00	6,338.21	8,103.49	9,868.76	11,634.03	13,399.30
23%	(4,212.87)	(2,482.18)	(751.49)	979.20	2,709.89	4,437.62	6,158.85	7,880.08	9,601.31	11,322.54
24%	(5,749.04)	(4,059.84)	(2,370.63)	(681.43)	1,007.78	2,694.20	4,374.54	6,054.88	7,735.22	9,415.56
25%	(7,159.22)	(5,508.62)	(3,858.01)	(2,207.41)	(556.80)	1,091.20	2,733.49	4,375.78	6,018.06	7,660.35

[a]Net present value is calculated assuming a finance period of 20 years

reduce the overall payback period one year.

The impact of the anaerobic digester system on the payback period is very low compared to the impact of the dairy and the artisan cheese production enterprises. Implementing the production of artisan cheese reduces the economic risk of adopting anaerobic digestion and improves the net profit of the overall operation. Without the additional cash flow from the artisan cheese enterprise, the cumulative net cash flow of the dairy and the anaerobic digester is never positive when milk prices are US $17 per hundred weight. At this price for milk, a subsidy of 100 percent of the cost of investment for an anaerobic digester system is not even sufficient to generate a positive cumulative net cash flow without the production of artisan cheese.

Table 16. Total Projected Cumulative Net Cash Flow with No Subsidy (US dollars)

Year	0	1	2	3	4	5	6	7	8	9	10
Cumulative Cash Flow											
Dairy[a]	0.00	(77,912.64)	(158,162.65)	(240,820.17)	(325,957.41)	(413,648.77)	(503,970.87)	(597,002.64)	(692,825.35)	(791,522.75)	(893,181.07)
Artisan Cheese[b]	(331,796.91)	(209,812.10)	(82,732.16)	49,485.83	186,877.28	329,469.15	477,278.98	630,313.72	788,568.60	952,025.76	1,236,781.77
Digester[c]	(64,124.22)	(71,001.36)	(77,301.07)	(83,006.04)	(88,098.40)	(92,559.80)	(96,371.30)	(99,513.39)	(101,966.01)	(103,708.46)	(104,719.44)
Cumulative Net Cash Flow[d]	(395,921.13)	(358,726.10)	(318,195.89)	(274,340.38)	(227,178.54)	(176,739.42)	(123,063.19)	(66,202.30)	(6,222.76)	56,794.55	238,881.26

[a]Cumulative Cash Flow from Table 12
[b]Cumulative Cash Flow from Table 13
[c]Cumulative Cash Flow from Table 14
[d]Cumulative Net Cash Flow determined by the adding cumulative cash flows for the Dairy, Artisan Cheese and Digester

Table 17. Total Projected Cumulative Net Cash Flow with 15 percent Subsidy (US dollars)

Year	0	1	2	3	4	5	6	7	8	9	10
Cumulative Cash Flow[a]											
Dairy	0.00	(77,912.64)	(158,162.65)	(240,820.17)	(325,957.41)	(413,648.77)	(503,970.87)	(597,002.64)	(692,825.35)	(791,522.75)	(893,181.07)
Artisan Cheese	(331,796.91)	(209,812.10)	(82,732.16)	49,485.83	186,877.28	329,469.15	477,278.98	630,313.72	788,568.60	952,025.76	1,236,781.77
Digester System	(54,505.58)	(57,464.01)	(59,845.01)	(61,631.26)	(62,804.91)	(63,347.59)	(63,240.37)	(62,463.75)	(60,997.65)	(58,821.38)	(55,913.65)
Cumulative Net Cash Flow	(386,302.50)	(345,188.75)	(300,739.82)	(252,965.60)	(201,885.05)	(147,527.21)	(89,932.26)	(29,152.66)	34,745.60	101,681.63	287,687.05

[a]See Table 16 for origin of numbers

Table 18. Total Projected Cumulative Net Cash Flow with 30 percent Subsidy (US dollars)

Year	0	1	2	3	4	5	6	7	8	9	10
Cumulative Cash Flow[a]											
Dairy	0.00	(77,912.64)	(158,162.65)	(240,820.17)	(325,957.41)	(413,648.77)	(503,970.87)	(597,002.64)	(692,825.35)	(791,522.75)	(893,181.07)
Artisan Cheese	(331,796.91)	(209,812.10)	(82,732.16)	49,485.83	186,877.28	329,469.15	477,278.98	630,313.72	788,568.60	952,025.76	1,236,781.77
Digester System	(44,886.95)	(43,926.66)	(42,388.95)	(40,256.48)	(37,511.41)	(34,135.38)	(30,109.44)	(25,414.10)	(20,029.29)	(13,934.31)	(7,107.86)
Cumulative Net Cash Flow	(376,683.86)	(331,651.40)	(283,283.76)	(231,590.82)	(176,591.55)	(118,315.00)	(56,801.33)	7,896.98	75,713.96	146,568.70	336,492.84

[a]See Table 16 for origin of numbers

Table 19. Total Projected Cumulative Net Cash Flow with 45 percent Subsidy (US dollars)

Year	0	1	2	3	4	5	6	7	8	9	10
Cumulative Cash Flow[a]											
Dairy	0.00	(77,912.64)	(158,162.65)	(240,820.17)	(325,957.41)	(413,648.77)	(503,970.87)	(597,002.64)	(692,825.35)	(791,522.75)	(893,181.07)
Artisan Cheese	(331,796.91)	(209,812.10)	(82,732.16)	49,485.83	186,877.28	329,469.15	477,278.98	630,313.72	788,568.60	952,025.76	1,236,781.77
Digester System	(35,268.32)	(30,389.31)	(24,932.88)	(18,881.70)	(12,217.92)	(4,923.16)	3,021.49	11,635.54	20,939.07	30,845.18	41,126.38
Cumulative Net Cash Flow	(367,065.23)	(318,114.05)	(265,827.70)	(210,216.04)	(151,298.05)	(89,102.79)	(23,670.41)	44,946.63	116,682.32	191,348.19	384,727.08

[a]See Table 16 for origin of numbers

Table 20. Total Projected Cumulative Net Cash Flow with 60 percent Subsidy (US dollars)

Year	0	1	2	3	4	5	6	7	8	9	10
Cumulative Cash Flow[a]											
Dairy	0.00	(77,912.64)	(158,162.65)	(240,820.17)	(325,957.41)	(413,648.77)	(503,970.87)	(597,002.64)	(692,825.35)	(791,522.75)	(893,181.07)
Artisan Cheese	(331,796.91)	(209,812.10)	(82,732.16)	49,485.83	186,877.28	329,469.15	477,278.98	630,313.72	788,568.60	952,025.76	1,236,781.77
Digester System	(25,649.69)	(16,851.97)	(7,476.82)	2,493.08	13,075.58	24,289.05	36,152.42	48,466.33	61,177.50	74,293.56	87,822.06
Cumulative Net Cash Flow	(357,446.60)	(304,576.71)	(248,371.63)	(188,841.26)	(126,004.56)	(59,890.57)	9,460.52	81,777.42	156,920.75	234,796.58	431,422.76

[a]See Table 16 for origin of numbers

Table 21. Total Projected Cumulative Net Cash Flow with 85 percent Subsidy (US dollars)

Year	0	1	2	3	4	5	6	7	8	9	10
Cumulative Cash Flow[a]											
Dairy	0.00	(77,912.64)	(158,162.65)	(240,820.17)	(325,957.41)	(413,648.77)	(503,970.87)	(597,002.64)	(692,825.35)	(791,522.75)	(893,181.07)
Artisan Cheese	(331,796.91)	(209,812.10)	(82,732.16)	49,485.83	186,877.28	329,469.15	477,278.98	630,313.72	788,568.60	952,025.76	1,236,781.77
Digester System	(9,618.63)	5,467.70	20,938.05	36,802.93	53,073.10	69,759.53	86,873.44	104,426.27	122,429.73	140,895.71	159,836.38
Cumulative Net Cash Flow	(341,415.54)	(282,257.04)	(219,956.77)	(154,531.41)	(86,007.04)	(14,420.09)	60,181.54	137,737.36	218,172.98	301,398.73	503,437.08

[a]See Table 16 for origin of numbers

CHAPTER V

CONCLUSIONS

Results reported for the investment analysis indicate that adopting anaerobic digestion for waste management on a dairy farm with an artisan cheese plant is feasible if sufficient subsidies for the investment are provided. The investment in an anaerobic digester provides some security against potential financial risks faced by farmers operating in the urban fringe such as reducing the possibility of fees and tariffs the farm might need to pay due to lawsuits, regulations and pollution. Protection against potential financial risks is not measured in the annual net income or projected cash flows reported in the results chapter. But the reduced risks inherent in having an anaerobic digester can increase the economic sustainability of the farm. An investment in an anaerobic digester contributes very little to the farming operation in terms of directly increasing its profits, but having an anaerobic digester likely contributes largely with respect to improving the sustainability of the farm by providing social and environmental benefits.

The amount of profit earned as a result of incorporating the digester system enterprise depends largely on the coproducts chosen to be produced and sold as well as funds that can be obtained through participation in incentive programs. It is important that the coproducts not used on the farm to produce electricity, bedding or other products but rather are marketed and sold. Otherwise, the probability of the investment being feasible is reduced. The majority of the coproducts can be used on the farm as bedding, fertilizer and energy, but any unused inventory beyond this must be sold off-farm. There is not space for inventory to accumulate on the farm, and profit margins are too small for the digester system to not take advantage of every possible revenue stream (i.e., selling products off-farm).

The seasonality associated with the on-farm manure supply increases the need for off-farm organic waste and on-farm whey supply to keep the digester operating efficiently during the course of the year. Small-scale dairies near large cities and/or resorts have the advantage of more restaurants and other food producers in the local area that need to dispose of organic waste than dairies located in more isolated areas. Relationships with reliable feedstock suppliers such as local restaurants need to be cultivated to obtain a consistent and constant supply of organic material from these sources so that the potential of digester system failure is reduced. Contracts may be necessary to secure the supply of additional organic waste to reduce volatility in the feedstock supply. Though an acceptable NPV for adopting anaerobic digestion without receipts for whey management can be achieved by increasing the price per pound of cheese by only US $0.18, the whey from whey management provides a high energy content feedstock that improves the amount of energy produced through anaerobic digestion and reduces the effects of seasonality.

Carbon offsets are sold at an auction to consumers who wish to offset the amount of GHG emissions they produce. The digester enterprise is responsible for registering for the auction and meeting the amount of carbon offsets needed by the consumers. The small-scale dairy does not produce a large amount of carbon offsets compared to other green energy projects. But, a steady stream and sufficient amount of carbon offsets produced will be attractive to carbon credit buyers and will improve the sustainability of the digester system if the farmer sells carbon credits. The employees of the digester system must remain up-to-date on carbon offset regulations and other potential market changes (e.g., program termination). Any entity producing more GHG than regulations permit or that produces more GHG than is morally acceptable in the mind of the entity represents the target market for carbon offsets.

Selecting the right products to produce, use and sell will improve net income and ultimately the feasibility of the anaerobic digester system enterprise. However, the digester system is not feasible on its own unless milk prices are at least US $24 per hundred weight. Milk prices are volatile and are rarely at US $24 per hundred weight or higher. However, the adoption of an anaerobic digestion system should not be determined based on the potential price of milk. Small-scale dairies that produce artisan cheese have sufficient cumulative cash flow to remain profitable while adopting an unsubsidized anaerobic digester system, but this does not reflect a wise investment. An investment in unsubsidized anaerobic digestion reduces the economic sustainability of an integrated, small-scale dairy and artisan cheese production.

An investment in an anaerobic digester should only be made when the investment analysis indicates an acceptable investment for an individual farm. The conditions for investment should be: 1) the estimated annual net income should be positive and 2) the capital cost of the investment per cow should be approximately US $1,500. It is estimated that the IBR digester system minimizes the capital cost per cow sufficiently to meet the US $1,500 target. The IRR should be equal to or greater than the discount rate determined by the investor. The payback period should be within an acceptable amount of time as determined by the investor. The NPV is the analysis tool used in this analysis and the NPV should be greater than US $0.

The adoption of anaerobic digestion on dairy farms with 210 cows is feasible under an appropriate set of conditions outlined in the results chapter. This includes considering the level of risk aversion the farmer has. Higher risk aversion suggests the purchase of an anaerobic digester is risker than if the farmer has a low level of risk aversion.

Small-scale dairy farmers in Utah (i.e., 210 cows) should not adopt anaerobic digestion as a means of managing waste unless an appropriate investment subsidy is available or unless policies and regulations in Utah mandate circumstances that require the implementation of anaerobic digestion for waste management. It is also possible that the pressures of urban encroachment and neighboring residents will force the adoption of anaerobic digestion to avoid lawsuits. In either case, the small-scale farmers buying anaerobic digesters will not be profitable unless substantial subsidies are made available for adopting the digester.

The pressures of urban encroachment on dairy farmers are eased when the community shares in the cost of urban encroachment through appropriate subsidies that reflect the cost of reducing the negative externalities of dairy farming by the use of anaerobic digesters. Adopting anaerobic digestion due to urbanization pressures is done at the discretion of the farmer. The adoption of anaerobic digestion should not occur unless economic conditions are created through subsidization for the digester system to be feasible independently of the cumulative cash flows of the dairy and the artisan cheese production operations of an integrated farm operation.

The adoption of anaerobic digestion can improve the sustainability of the farm. The farm's economic sustainability is improved through coproduct revenue streams. The farm's economic sustainability is also improved through reducing the risk of fees and tariffs from potential lawsuits and negative policies and regulations.

Anaerobic digester systems improve the social and environmental sustainability of the farm by reducing the negative externalities caused by agriculture, primarily when a farm, in this case a dairy farm, is located in close proximity to an urban area. It does this by improving the social acceptability of farms through reducing odors and also reducing the quantity of waste stored on the farm. It provides a socially acceptable method of waste management, decreases air pollution (e.g., GHG) and decreases the probability of water pollution. If the cost of making the farm more socially and environmentally sustainability is not shared with the community, then the farm will suffer from urban encroachment and the probability of the farm's failure is increased.

If the community wishes to maintain small-scale dairy farming as part of the landscape, it will need to consider subsidizing the adoption of an anaerobic digester for such farms. However, the level of subsidies should be determined on a case-by-case basis. The subsidy should be adjusted to a level that does not entirely remove all financial responsibilities from the farmer but at the same time also makes the investment feasible for small-scale farmers. The level of subsidy should be determined by the level of financial risk a particular operation can accept and the level of pressure from urban encroachment. The subsidy level is influenced by the size of the farm, especially small-scale production, due to the economies of scale these operation lack but which are essential to the financial viability of unsubsidized anaerobic digesters.

Farmers and community officials must work together to determine the amount of compensation needed to ease the pressures of urban encroachment on dairy farms and to prevent the loss of the culture and tradition that farming provides to communities in Utah. By subsidizing the investment of anaerobic digester system by at least 35 percent of their initial investment cost, the sustainability of small-scale dairy farms in close proximity to urban areas in Utah will be improved.

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