THE ECONOMICS OF ANAEROBIC DIGESTION

By

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A thesis submitted in partial fulfillment of
the requirements for the degree of

MASTER OF ARTS IN APPLIED ECONOMICS

WASHINGTON STATE UNIVERSITY
School of Economic Sciences

AUGUST 2007

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of CLARK PAUL BISHOP find it satisfactory and recommend that it be accepted.

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ACKNOWLEDGMENTS

I would like to express my sincere gratitude to the chair of my committee, Dr. C. Richard Shumway, who has given me the opportunity to work on this project and provided me with extraordinary mentoring throughout the duration of my graduate study. His contributions to the success of this project are beyond measure.

I would like to thank Dr. Philip R. Wandschneider for sharing his knowledge of economics and life which benefited my academic and personal growth during my years at WSU. He has been a constant source of inspiration and knowledge for this project.

I am grateful for the support from Dr. Douglas L. Young for his professional contributions to this project and for his wisdom and guidance.

I would like to acknowledge the support I received from the dairy industry that made my research possible. I would specifically like to recognize the assistance I received from Jay Gordon and Bob Naerebout in conducting the survey used in this project. Additionally, I would like to thank Steve VanderHaak for providing me with data and information on his digester.

I would like to recognize the support I received form the School of Economic Sciences and the exceptional staff, especially from Danielle Engelhardt and Ben Weller. I also owe a great deal to Maggie Kettwig for keeping me on track and out of trouble from my first semester at WSU to my last.

Lastly, this project and my education were completed with the steadfast support from my parents, grandparents, and wife. Their ideas, perspectives, and encouragement made this project a success. I am indebted to my wife for her countless revisions and contributions to the development of my thesis.

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Abstract

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August 2007

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This thesis examines the economics of anaerobic digestion technology with specific application to dairy waste management. The economics of digestion technology are considered from both socioeconomic and economic feasibility perspectives. Each perspective is presented as an individual investigation in the second and third chapters of this thesis. These chapters are presented in manuscript format.

The second chapter examines attitudes toward the adoption of this conservation technology on dairy farms. To specify an appropriate dependent variable without a large number of adopters, an ordered probit model is constructed. The empirical analysis uses data from a 2006 survey of Northwest dairy farms. In addition to demographic, structural, and economic variables, the roles of stewardship motives and diffusion typology are explored and found to significantly affect willingness to adopt. The findings do not support conventional hypotheses relating to acreage, herd size, or productivity.

The focus of the third chapter is on an operational digester in Washington State. Using the first two years of physical and financial data from the operational digester, a base scenario is constructed. The analysis focuses on the impact of developing various co-product markets on the digestion system's feasibility. The co-product markets analyzed include electricity, digested

fiber, tipping fees, and carbon credits. The results of the economic analysis show that tipping fees and electricity are key revenue sources for the digester.

Dedication

This thesis is dedicated to my wife Lauren Hubbard
and the former dairy farmers in my family:
my parents Wilbur and Karen Bishop, and
my grandparents Al and Phyllis Sherman.

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CHAPTER 1

This thesis presents two investigations into the adoption of anaerobic digestion technology for dairy applications. The thesis is organized in three chapters. This first chapter introduces anaerobic digestion and the importance of establishing the technology for the dairy industry. The second chapter reports on an investigation of the adoption question from a socioeconomic perspective. Relatively few farms have adopted digestion technology for waste management. The socioeconomic investigation uses an empirical model to determine the significant characteristics of those dairy farmers seriously considering anaerobic digestion. The third chapter describes a feasibility analysis of the digester investment. The analysis is based on an operating digester in Washington State. Using the Washington digester as an operational base scenario, a number of different co-product marketing scenarios are created and compared using common economic indicators.

The perceived importance of anaerobic digestion has been revitalized by increased public awareness regarding the importance of alternative energy sources and greenhouse gas reduction. Further digestion technology addresses both of these societal concerns. Using digestion to facilitate nutrient management is also an important consideration for dairy farmers. In the 2006 survey conducted for this thesis, 45% of the farmers that responded to a question of which digestion benefit is most important for their farm answered that enhanced nutrient management was the most important benefit. The benefits of digestion existed during the inception of the technology in the 1970’s and 1980’s. However, today the environmental benefits of digestion for the dairy industry are increasingly important.

A survey was conducted for this thesis project in the spring of 2006. The survey gathered information on farm manure management practices and farmer perspectives regarding the use of anaerobic digestion technology. In addition to the emphasis on waste management, the survey gathered demographic and structural data for the surveyed dairy farms. The survey was mailed to dairy farmers in Washington, Oregon, and Idaho. The survey was conducted with the support of the Washington State Dairy Federation, the Oregon Dairy Farmers Association, and the Idaho Dairymen's Association. The survey received financial support from Washington State University's Climate Friendly Farming project and from a USDA Conservation Innovation grant. A copy of the survey was mailed once to dairy farms on the supporting agency's mailing lists. A follow up reminder was mailed to non-responders two weeks later, followed by a second copy of the survey. The survey received a 20% response rate overall, a 28% response rate from Washington, 18% from Oregon, and an 8.6% response rate from Idaho.

The survey was intended to gauge interest in dairy digester adoption. The adoption of anaerobic digestion has similarities to the adoption of conservation practices such as no-till farming and water conservation through improved irrigation practices. Conservation studies relating to soil and water management have been studied in a socioeconomic context. Pampel and van Es (1977) were among the first to establish that economic approaches for investigating conservation technologies may need to incorporate methods and theories from other disciplines to fully characterize the adopters of digestion technology. Major advances in the theory of conservation adoption were presented in Ervin and Ervin (1982) and Lynne, Shonkwiler, and Rola (1988). These studies incorporated the multidisciplinary theories of the diffusion of innovations and behavioral psychology as a basis for including variables representing communication channels and altruistic motivators into traditional adoption models. Lynne (1995) has perhaps contributed the most to a formal theory of conservation adoption that operationalizes the theory of multiple utility.[1] Upadhyay et al. (2003) and Rahelizatovo and Gillespie (2004) have made recent empirical contributions to conservation adoption literature. However, the study by Rahelizatovo and Gillespie (2004) is one of the few to have examined conservation adoption decisions other than those related to soil management.

An empirical model similar to those developed in the conservation adoption literature is created to test which factors most effectively characterize potential anaerobic digester adopters. The survey data provide a unique opportunity to study adoption using a stated preference dependent variable. Previous conservation adoption models have been limited to revealed preference variables. However, few dairy farms have adopted anaerobic digestion, thus a revealed preference dependent variable would not contain enough actual adopters to produce valid statistical results. Instead, ordered probit regression is used to estimate a stated preference model, which actually incorporates some revealed preference data in a category comprised of current adopters. Another significant contribution to the conservation adoption literature is the use of a diffusion typology variable and an environmental stewardship variable. These variables are used in an attempt to better reflect the underlying theories of diffusion of innovations and altruistic behavior.

The third chapter addresses the economic feasibility of digester investments. It illustrates the effects of having or lacking access to co-product markets. The digestion investment requires a large fixed capital investment and a large yearly maintenance expense. In order for digesters to be economically feasible, co-products from digestion must be sold to produce consistent revenue streams and outputs must be managed to avoid costly disposal problems. Traditionally, power sales from electric generation have been considered the primary revenue source for digester

[1] See Etzioni (1986) for an exposition about how economics has grappled with morals and altruism.

owners. The feasibility analysis considers tipping fees, carbon credits, and fiber sales as additional co-product markets capable of producing substantial revenues for digester owners. Because these markets are in the early stages of development, forecasts are made about how these markets with develop. The resulting feasibility of the digester investment is judged using net present value and internal rate of return calculations.

If anaerobic digesters are economically feasible in areas where electricity prices are low, it would greatly enhance the environmental and economic sustainability of the dairy industry. Dairy farmers are increasing faced with concerns related to water and air pollution and climate change from waste management. A technology that helps dairy farms cope with changing legal requirement with regards to environmental issues could make farming economically feasible under a wider range of conditions. Moreover, adversarial relationships between environmental groups and dairy farmers may turn into mutually beneficial partnerships. Digestion technology helps bolster the public perception that dairy farmer's are intimately connected with the environment. Digestion technology may go one step further in sustaining agricultural production by integrating already available resources in previously unexplored ways.

The manuscript in the second chapter is a joint publication between Clark Bishop, C. Richard Shumway, and Philip R. Wandschneider. Clark Bishop was responsible for conducting the statistical analysis, authorship, and implementing revisions. Richard Shumway and Philip Wandschneider had extensive input with regard to model specification and data analysis. In addition, both of the co-authors provided input through revisions.

Financial information on the VanderHaak digester was provided by Steve VanderHaak and Andgar Corporation.

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CHAPTER 2

Adoption of Anaerobic Digestion Technology

Introduction

Urban expansion, threats to native salmon populations, higher energy prices, increasing concern over global warming, and the resulting increase in regulatory pressures are encouraging dairy farmers in the Pacific Northwest to consider adopting new technologies for waste management. One technology of national interest for confined animal waste streams is anaerobic digestion. However, early adopters of digestion technology experienced a high rate of failure because of technological problems and financial difficulties. As a result, until recently adoption of digestion technology for dairy applications was low. The renewed interest has been spurred by increased attention to the need for alternative fuels, a surge of public subsidies, and the availability of private funding.

Digestion systems for dairies capture methane produced from the natural degradation of manure waste. Digestion technology optimizes the environment for naturally occurring microorganisms that degrade biomass and, through the process of methanogenesis, create methane (Nyns 1989). Anaerobic digestion is an integrated sustainable conservation technology that contributes to climate, air, and water environmental goals. It is used to mitigate water quality issues by reducing the levels of chemical and biological oxygen demand in discharged agricultural waste (Martin 2005; Meynell 1978). The digestion process also reduces the quantity of harmful pathogens that occur in untreated manure and can pose health risks to humans and animals when mismanaged in proximity to food production and water recreation (Pell 1997; Martin 2005; Meynell 1978).

Anaerobic digestion reduces greenhouse gas emissions through the capture and combustion of methane that would otherwise be released. In terms of greenhouse gas emissions, releasing one ton of methane has the same greenhouse potential as the release of 23 tons of carbon dioxide (Ramaswamy 2001). Burning the captured methane reduces the net greenhouse potential of the gas by exhausting only water and carbon dioxide. This is significant because manure waste management accounts for more than 25% of all agricultural emissions of methane (US EPA 2007). Additionally, burning biogas reduces farm odor. Odor reduction is especially important for farms near urban areas where incentives to reduce odor may include complaints or potential legal action.

The captured methane is generally used as a fuel in modified combustion engines to produce electricity, which is sold or credited to local utilities. Generating electricity from anaerobic digestion is considered net energy efficient (Lewis 1989). Because of the large capital investment, it is generally critical to develop revenue-generating products from digestion operations. However, low electricity rates in the Pacific Northwest (PNW) and the current absence of established markets for digestion co-products creates uncertainty for investing in digestion technology.[2] Further, while utilities generally support renewable energy, farmers trying to sell power produced on the farm may view the utilities as obstacles. Perceived barriers include expensive connection and safety equipment, requirements for costly feasibility studies, and unwillingness to enter into contractual power purchasing agreements. Despite these hurdles, interest in digestion technology appears to be increasing among dairy farmers in the PNW.

Now that digestion technology is receiving renewed attention, the question of who is going to adopt the technology remains. Socioeconomic conservation adoption literature provides an interdisciplinary perspective on conservation practice adoption. The socioeconomic literature

[2] The Pacific Northwest region encompasses Washington, Oregon and Idaho.

is used in this study as a guide to construct and estimate an adoption model that is used to determine the characteristics of potential digestion technology adopters.

The analysis of farmer adoption characteristics will proceed as follows. The data used for the analysis is introduced in the next section. The hypothesis for each independent variable used in the model is developed and relevant literature is cited in the subsequent section. Two variables that represent stewardship motives and diffusion typology are created based on the interdisciplinary approach taken in the conservation adoption literature. A section presenting major findings follows. Interpretation of salient implications of the estimation results, an evaluation of the stewardship motives and diffusion typology, and a look at how future events may shape the adoption of digestion technology are discussed in the penultimate section. The last section concludes.

Data

A survey of dairy farmers in Washington, Oregon, and Idaho conducted in the spring of 2006 provides the data for this study. The survey process included a primary mailing, a reminder postcard, and a second mailing to non-responders. The survey sampled 1,152 dairy operations, and 254 responses were received (22%). Of the total survey responses, 230 (20% of the initial sample) were usable before listwise deletion of observations containing missing values. The response rate was on the low end of previous response rates (13% - 63%) for non-production related dairy adoption surveys (Buttars, Young and Bailey 2006; Winsten, Parsons and Hanson 2000). Given the length and broad scope of the survey, the low-range response rate was expected. Milk prices in the region were down at the time of the survey, which may have dampened the survey response rate as well (Northwest Dairy Association 2007).

The surveyed group was biased towards farms with herd sizes greater than 100 head because of sample protocol design.[3] The survey included questions regarding farm structure, investment considerations, and demographic information. Table 1 presents definitions and basic summary statistics for each variable included in the model.

Theory and Variable Selection

Technology adoption has been studied by the disciplines of communication theory, social psychology, and economics. Communication theory examines adoption through diffusion research, which emphasizes the importance of communication channels in adoption (Rogers 2003). In social psychology, the concept of "attitude" is theorized to be a determinant of behavioral intent which applies to adoption (Ajzen and Fishbein 1980). Economics seeks explanations and predictions of how innovation adoption occurs over time and which groups adopt (Griliches 1957, Stoneman 2002). Economic theory falls short when explaining why producers adopt conservation practices that are not profitable, or fail to adopt practices that are profitable. To explain this behavior, economists look to the aforementioned disciplines; the result is a unique multidisciplinary body of literature examining conservation adoption.

In conservation adoption studies, a technology is featured which improves or protects soil, water, or air quality. In this sense, digestion technology and the other technologies featured in conservation adoption studies are similar. Further, many of the same factors considered in previous conservation adoption studies should apply to anaerobic digestion adoption—including economics, demographics, diffusion activities, and stewardship motives. Nevertheless, much of the existing literature on conservation adoption in agriculture concentrates on conservation

[3] The mean herd size for surveyed farms in the "less than $250,000" gross income category was 84 head, and the mean herd size for farms in the "$250,000 to $500,000" gross income category was 170 head. The economies of scale of digestion technology are such that smaller farms would have a hard time financing a digester unless an emerging technology proves economic for small farms.

tillage and irrigation practices, and relatively little reflects conservation in manure management There are two primary differences between this study and the previous conservation adoption literature: (a) there are additional factors to consider within the dairy industry, and (b) digestion technology does not directly impact the primary farm product, in this case milk production. The first difference requires the inclusion of additional industry-related variables in the model. The second difference does not require specific recognition in the model, but it is a notable difference from studies related to soil and water conservation where the conservation technology directly affects the primary output.

In the remainder of this section, we identify variables used in the model that are derived from the conservation adoption literature and develop hypotheses with regard to their expected signs. The statistical methods used for analysis are then identified.

Dependent Variable

Studying the adoption of digestion technology in the PNW poses a challenge because few farms currently operate digesters. Of the 230 usable responses, only three indicated current digester use and four indicated digesters in planning or construction stages. By comparison to industry figures, five farms are listed by AgSTAR as operating digesters in Washington, Oregon and Idaho (US EPA 2006).[4] Anticipating the lack of sufficient farmers with operating digesters, the survey was designed to examine farmer intentions and considerations as well as actual operator behavior. The dependent variable (CONSIDER) represents interest in adoption using a five-category Likert scale: 1 – not considering adoption, 2 and 3 – minor and some consideration to adoption, 4 – seriously considering adoption, 5 – actual adopter. In the literature, adoption is typically represented in terms of a dichotomous revealed preference variable. Given the small number of farmers currently using digestion, converting the adoption consideration scale into a

[4] AgSTAR is a joint EPA-USDA program that promotes the use of biogas recovery systems (U.S. EPA 2006).

dichotomous variable would result in a small sample problem and limited statistical power. The approach taken here allows for a dependent variable that includes both stated and revealed preferences.

With so few actual adopters, the hypotheses on the explanatory variables are specified in terms of those most likely to adopt. We focus on the marginal effects and characteristics of category 4—farmers seriously considering adoption. This emphasizes stated preferences rather than revealed preferences since the fourth category is not directly analogous to actual adoption. However, it is reasonable to expect that those seriously considering adoption will be more likely to become actual adopters in the future. This assumption is reinforced by the theory of reasoned action put forth by Ajzen and Fishbein (1980). Statistically, by including the categories of less likely adopters (1, 2, and 3) and of actual adopters (5), the model should be well specified for category 4, the more likely adopters.

Independent Variables and Hypothesized Impacts

In most conservation adoption studies, income and size are viewed as positive predictors of adoption activity. Measures of income and size can indicate both the need to do something and the capacity to do it.

Income is frequently measured using a categorical scale because respondents are often more willing to respond to categories than to reveal exact incomes (Lynne, Shonkwiler and Rola 1988; Nowak 1987; Pampel and van Es 1977). We use a continuous measure of gross milk income (GROSS). The income variable GROSS is computed as a linear function of milk production using $14.20/cwt as the price of milk.[5] Using gross income emphasizes scale over financial capacity since operating costs are not deducted (Nowak 1987). Because the capital cost

[5] This was the average price of milk in 2006 for the months of January through August in the PNW. Representing gross income in this manner excludes other sources of income and keeps the focus on revenue from the dairy operation.

of digesters can be prohibitive for smaller farms, it is hypothesized that larger farms are more likely to seriously consider adopting digestion technology.

The amount of available farmland has been an important factor in willingness to adopt conservation practices. It is generally used as an indicator of economic size and the ability to try new innovations (Upadhyay et al. 2003; Nowak 1987). In the case of dairies generally, and anaerobic digestion in particular, acreage takes on a different role because of the relationship between herd size and the amount of land needed for manure disposal. Manure can create environmental and nuisance problems when available farm acreage is insufficient for farm manure handling needs. Hence, a dairy with large acreage is not expected to need digestion technology as much as a farm with fewer acres and a similar herd size. With all else the same, it is hypothesized that total acreage (ACRE) negatively affects willingness to seriously consider adopting digestion technology.

For our study, herd size is a more relevant direct measure of farm size than is acreage. Herd size clearly and directly contributes to the magnitude of the manure management problem for a confined animal operation. Hence, herd size (HERD) is hypothesized to positively influence serious consideration of adoption.

A number of techniques are used in conservation literature to gauge on-farm environmental problems. These techniques include indices and quantitative measurements of potential environmental detriment (Upadhyay et al. 2003; Taylor and Miller 1978; Nowak 1987; Ervin and Ervin 1982). A quantitative gauge of dairy farm impact on the environment would be complicated and require information that is typically unavailable to farmers. For this study, the number of acres with perceived odor and water problems are calculated as a percent of total acreage (ODOR% and WATER%). These variables assume that as manure becomes a problem for a farmer, it is primarily due to water and air quality issues. It is hypothesized that increasing values in ODOR% and WATER% imply an increasing perception of on-farm manure problems, thus positively influencing farmer consideration of digester adoption.

Farms can experience challenges with manure handling that are not directly related to environmental concerns. Farms with flush systems generate a greater volume of waste material which increases on-site storage needs. Some digester configurations provide benefits when recycling flush water. A flush system variable (FLUSH) is included in the model, which is hypothesized to positively influence consideration of digester adoption.

A farmer spending a lot of time managing manure has increased exposure to manure-related issues. A variable for time spent managing manure (MANAGE) is included in the model. It is hypothesized that increased time currently spent managing manure positively influences consideration of digester adoption. This hypothesis assumes that farmers are aware of time saving advances in digestion technology and do not view the labor requirement of digestion technology as a burden.

The final manure problem variable considered is the percent of total land on which manure is applied (MANURE%). It is assumed that applying manure to a large portion of available acreage increases the need to find additional land for manure application or to find alternatives. While alternative scenarios are possible, it is hypothesized that such farms are more likely to consider digester adoption as a substitute for more land.

While it is difficult to measure the trait of innovativeness, it is typically regarded as an important factor when considering adoption of new technology. Milk per cow is sometimes used as a proxy for innovativeness because the more “savvy” producers presumably induce the greatest per cow productivity (e.g., Rahelizatovo and Gillespie 2004). This measure would not account for highly innovative organic operations or farms that innovate in capacities unrelated to output (e.g. cost reducing innovations). We assume that the milk-per-cow variable (MILK/COW) primarily captures innovativeness related to output. Therefore, we hypothesize milk production positively influences consideration of digester adoption.

The length of the farmer's planning horizon is expected to factor into adoption decisions for technologies that require a large capital investment. Planning horizons are internal, subjective states and thus difficult to measure. Adoption studies often use the age of the farmer as a proxy for planning horizon (Featherstone and Goodwin 1993; Upadhyay et al. 2003; Rahelizatovo and Gillespie 2004). It is generally assumed that the older the farmer, the shorter the planning horizon because of the shorter period over which benefits may be realized from an investment. For this study, age is represented by a 10-point categorical scale (AGE) ranging from younger than 30 to older than 70 years. It is hypothesized that age negatively influences consideration of digester adoption.

Retirement plans are related to age. In this analysis, a dichotomous variable (RETIRE) represents a farmer expecting to retire within five years. It is also hypothesized to negatively influence consideration of digester adoption, again based on the shorter time horizon rationale.

Alternatively, a farmer planning to retire might consider a digestion technology in order to preserve the future viability of the farm for an upcoming generation. Several studies recognize the influence of future generations by including appropriate discrete family variables or family size measures (Rahelizatovo and Gillespie 2004; Ervin and Ervin 1982; Featherstone and Goodwin 1993). In this study, a dichotomous variable (INHERIT) represents the prospect of a future generation taking over the dairy operation. It is hypothesized that if another generation plans to take over the dairy, it positively affects consideration of adopting digestion technology.

The number of years (YEARS) the respondent has farmed is conceptually related to the farmer's planning horizon. In a literal sense, the greater the number of years the respondent has farmed, the higher the likelihood the farmer will retire in the near future. Another consideration is that a substantial number of early digester projects failed in the 1980's. A person who was farming two decades ago may be more aware of these failures and could have formed negative opinions about the technology. For this study, it is expected that closeness to retirement and witnessing the failure of early adopters outweigh the experience factor in willingness to adopt digestion technology. Thus, we hypothesize that the number of years of farming negatively influences consideration of digester adoption.

Odor and water problems are exacerbated as urban areas expand into agricultural areas. Soule, Tegene and Wiebe (2000) use urban expansion to "account for the possibility that the farm might be converted to non-agricultural use in the near future" (p. 999). Data from the survey is available regarding the percent of total farm acres within five miles of urban areas (URBAN%). For the same perceived degree of odor problems, it is hypothesized that the reduced planning period caused by urban expansion negatively impacts digester adoption consideration.

Land tenure is a staple in adoption studies (Rahelizatovo and Gillespie 2004, Upadhyay et al. 2003; Lynne, Shonkwiler and Rola 1988; Pampel and van Es 1977). Soule, Tegene and Wiebe (2000) provide an in-depth analysis of how rental arrangements influence the adoption of conservation practices. A farm with primarily rented acres faces an uncertain payoff from a digester because existing rental arrangements may change. It is hypothesized that an increase in percent of rented acres (RENT%) negatively influences consideration of anaerobic digester adoption.

A farmer who wants to expand herd size is expected to consider adopting a digester in order to handle the increased amount of manure from the extra animals. Further, if a farmer wants to expand and there are issues with expansion, such as air and water quality concerns, there will be an even greater incentive to adopt a digester. In this study, these two scenarios are represented respectively by two dichotomous variables EXPANSION_1 (with issues) and EXPANSION_2 (without issues). Both are hypothesized to positively influence consideration of digester adoption.

Higher education levels frequently appear as a characteristic of innovation adopters in diffusion literature (Rogers 2003). The positive influence of education on the decision to adopt is supported by the conservation adoption literature (Upadhyay et al. 2003; Soule, Tegene and Wiebe 2000; Ervin and Ervin 1982; Taylor and Miller 1978). Higher education is expected to broaden personal perspectives regarding the need for conservation (Upadhyay et al. 2003). The categorical education variable (EDUCATION) used in this study ranges from incomplete high school education to the completion of a doctoral program. The education scale is hypothesized to have a positive influence on digester adoption consideration.

The source of household income may affect the decision-making process of the farm. The survey data represents the source of family income using a categorical variable (SOURCE). The first category is for those who farm on the side and receive most of their household income from other sources. Higher categories imply increasing reliance on farming activities for household income. It is hypothesized that farmers receiving more income from the farm are more likely to consider digester adoption because their livelihood depends on continued farming.

In the empirical adoption literature, altruistic and stewardship motives are represented by membership in certain organizations or by attitude scales which directly measure sensitivity towards environmental problems. The exception to this practice is found in the work of Lynne, Shonkwiler and Rola (1988). They utilize methods from social psychology to measure altruistic behavior and employ a survey instrument designed to elicit respondent attitudes in accordance with the social psychological construct of behavioral intentions. While the survey data used in this study does not contain an explicit attitude scale for environmental sensitivity, there are a number of variables that, when considered together, are expected to represent environmental sensitivity. An index (ENVIRO) is created from these variables.[6] It is hypothesized that ENVIRO represents environmental sensitivity and therefore has a positive impact on level of consideration for digester adoption. The creation of this variable is developed in the next section.

Early conservation adoption studies included elements of diffusion theory to explain the adoption timing decision. As described by Everett Rogers, "diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system." (2003, pp. 35). The model of the five stages of adoption put forward by Rogers (2003) is used as a guide in this study to create a variable that represents diffusion theory. Since few of our respondents have adopted digestion technology, few respondents would be considered in the final implementation stage or confirmation stage of adoption theorized by Rogers (Ibid.). Nearly all of the responses to our survey fall within the first three stages of adoption: knowledge (not considering adoption), persuasion (minor or some consideration), and decision (seriously considering adoption). At the knowledge stage, information regarding digestion technology is likely spread primarily through trade journals and similar publications. As farmers cross into the persuasion stage, it is expected that the primary sources of information about the technology shift

[6] The ENVIRO index combines responses to questions regarding the importance of air and water quality in the decision making process, whether or not the respondent is interested in joint ventures for investing in digestion technology, the most important benefit from the adoption of digestion on-farm (including odor management, nutrient management, and community relations), and the most important benefit for the dairy industry (including alternative fuel production, nutrient management, and greenhouse gas reduction).

towards communication with other people in the dairy industry. A farmer in the persuasion stage is also expected to visit a digester in operation. Those who are considering making the decision are expected to use multiple sources of information and also seek out expert advice on digestion technology.

The survey includes several questions concerning respondents' sources of information about digestion technology. The sources include communication with other farmers, trade publications, seeing a digester in operation, and communication with digestion experts. The survey also asks whether the respondent has researched digestion technology extensively, or if this is the first time the respondent has heard of the technology. It is expected that the channels through which farmers have received information about digestion technology could reflect which diffusion stage the farmer is in. Consequently, the set of dichotomous variables regarding sources of information are used in the next section to create a diffusion variable (DIFFUSION) which represents the respondents' stage of diffusion. The diffusion variable is constructed to test the hypothesis that it is positively related to consideration of adopting digestion technology.

Model Specification and Statistical Procedures

Treating the dependent variable CONSIDER as a continuous variable in an ordinary least squares regression would produce biased and inconsistent results. The bias and inconsistency occurs because the true interval spacing between the categories of CONSIDER is unknown. The use of an ordered probit regression allows for uneven interval spacing and is therefore appropriate for this analysis.[7]

[7] The spacing between the category for those seriously considering adoption and the actual adopters is problematic because actual adopters are conceptually different. This is less of an issue of interval spacing than whether or not the fifth category belongs in the same scale with the previous four categories. The use of a generalized ordered probit model was considered because it is more flexible with regard to model restrictions. However, estimation with the generalized model failed to converge, likely due to the small number of observations in category 5.

As in most adoption studies, there are a large number of independent variables in our model (e.g. Rahelizatovo and Gillespie 2004). Given the large number, the likelihood of collinear relationships among some interrelated subsets of variables is high. Although it does not necessarily imply a literal linear dependency, technical multicollinearity could exist because some groups of variables are arithmetically linked.[8] Also, a subset of variables could cumulatively reflect an underlying latent variable while each variable in the subset only imperfectly measures an aspect of the latent variable. This analysis focuses on the resulting coefficient estimates and there significance. Thus, a discussion of the possible presence and implications of multicollinearity follows.

Including all available empirical variables from an interrelated variable subset will likely lead to high multicollinearity and may not even correctly specify the underlying latent variables. In some cases, one proxy variable can capture the key latent variable of interest. In other cases, several of the empirical variables reasonably capture the basic dimensions of the underlying entity. The advantage of using empirical variables over latent factors is that empirical variables can be directly interpreted. However, care must be taken when interpreting the marginal effects of such variables because a particular empirical measure may be a proxy for a dimension of the latent entity rather than truly representing itself.

In this study we encountered both of the above cases. In two situations, we were able to create an index variable to capture the latent object (diffusion and environmental stewardship). They are discussed below. In three others (farm structure, dairy waste management, and farmer planning horizons), a group of empirical variables were found to capture the multiple dimensions of the latent entity. These subsets may form approximate linear functions of one another, yet in each, variables can be dropped or substituted with only minor change to the overall fit and

[8] For example, HERD * MILK/COW * (Milk Price in Survey Period) = GROSS.

magnitudes of the coefficients, which indicates that multicollinearity is not adversely affecting the fitted values in the model. Moreover, the pairwise correlations for the independent variables reveal little significant correlation between the individual variables, thus indicating that the underlying latent variables are not over-specified. Factor analysis and principal components were also explored as alternative methods to handle several subsets of interrelated variables, but these methods provided little benefit.

As noted, the survey provides data on several sources of information that make up the respondents' level of knowledge regarding digestion technology. To properly incorporate diffusion theory, we need a proxy variable to measure diffusion typologies, not individual information sources represented by dichotomous variables. That is, the model uses the information sources as an indicator of diffusion stage rather than variables indicating the impact of information sources directly. In essence, the type and intensity of information use is an indicator of readiness for innovation. To create the diffusion typology indicator, the dichotomous variable for extensive research was regressed on the information source variables and on the number of sources used. Predicted values are estimated from this regression and used as the diffusion typology variable (DIFFUSION) in the adoption model. The regression results for DIFFUSION are presented in Table 2.

A second proxy (index) variable was created to represent stewardship motives. The survey data includes responses to five questions that focus on how important community relations and the environment are to the respondent.[9] In order to effectively use these data, an index variable (ENVIRO) was created from the five questions. A value of zero, one, or two was

[9] The questions include: importance of both water and air quality impacts in the farmer's decision making process; the applicability of joint ventures for the farm; the perceived importance of benefits from digester adoption on the farm level and the dairy industry in general, including nutrient management, alternative fuels and greenhouse gases.

given to specific responses and the resulting values were summed.[10] A larger number for the index suggests that the farmer is more sensitive to the environment and society. Initial investigation into using this variable revealed high multicollinearity with the variables ODOR% and WATER%. It is not surprising that respondents with greater perceived odor and water problems would also be those who are more sensitive to the environment. To overcome the multicollinearity while accounting for the relationship among these variables, the environmental index was regressed on the perceived odor and water problem variables using ordinary least squares. The regression results are presented in Table 3. The predicted values of the index were then entered into the adoption model as an environmental stewardship variable (ENVIROp); ODOR% and WATER% were removed from the set of regressors.

Results

Interpreting marginal effects in the ordered probit model requires separate examination for each category of interest of the dependent variable, CONSIDER. The category for those seriously considering adoption is the most informative for assessing the impact of important adopter characteristics.[11] Therefore, discussion of the results focuses on the marginal effects calculated as $\partial \Pr[\text{CONSIDER} = 4]/\partial x_i$. These effects allow for meaningful interpretation by examining the impact of a unit change in each variable on the predicted probability of adoption for those seriously considering adoption.

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[10] A value of one is applied to the joint venture question if the respondent indicated interest. A value of one is applied if the respondent indicated the use of air and water quality information in their decision making process. A value of two is applied if the respondent answered "definitely yes" to using air and water quality information in their decision making process. A value of one is applied if the respondent indicated the most important benefit from digesters at the farm level to be odor management, nutrient management, or community relations. A value of one is applied if the respondent indicated the most important benefit from digesters at the industry level to be alternative fuel production and nutrient management, or a two was applied if greenhouse gas reduction was indicated as the primary benefit of digestion technology.

[11] The statistical results for category five are hindered by the small number of actual adopters.

The value of x_i used in the partial differentiation also requires careful consideration. If x_i is equal to the sample mean, the value may not represent an actual farm type because the data set is skewed with regard to herd size. To address this issue, two representative farm sizes were chosen. The mean values of farms with herd sizes between 300 and 599 head and the mean values of farms with herd sizes between 600 to 1,999 head are used. This grouping imposes a truncation by excluding the 104 smallest and 21 largest farms from the representative farm mean calculations. Two means are used because the smallest farms are assumed to be the least likely group to adopt, and the largest farms have widely varying incomes, herd sizes, and acreages that would skew the mean calculation. By splitting the sample into two groups and imposing a truncation, the possibility of a few farms dominating and skewing the mean calculation is eliminated. Consequently, two sets of marginal effects are reported for comparison in order to reflect the two size categories, designated as small and large herds. The mean values used for x_i for these groups are reported in the first two columns of Table 5.

For comparison purposes, parameter estimates from the cumulative ordered probit estimation are reported for two models in Table 4. They include the “full” model that formally examines diffusion and stewardship issues and a “base” model that does not. The base model includes variables for the percent of land with perceived odor and water problems and excludes the diffusion and environmental indices. In all other respects, it is identical to the full model.

In addition to the variables already introduced, a quadratic term (ACRE2) was included to capture curvature in the ACRE data with respect to CONSIDER. The parameter on the ACRE2 variable is negative and statistically significant at the 10% level in both models, indicating diminishing contributions to predicted probability for adopting digestion technology from increased farm acreage.[12] An interaction term was also included for age and education (AGEEDU). The interaction term allows for the possibility of on-the-job experience affecting adoption consideration. Presumably a college graduate is prepared with advanced knowledge early in life. However, the person with a lifetime of experience is expected to have advanced understanding of relevant issues and decision making. The variable AGEEDU permits informal education to augment formal education when interpreted with AGE and EDUCATION. The estimated parameter on this variable is negative and statistically significant in both models. The parameter estimates on AGE and EDUCATION are positive and significant in the full model. They are also positive in the base model but only significant for EDUCATION. By including AGEEDU in the models, a set of four extremes with regard to adoption consideration were estimated based on age and education level. The extremes with the highest probability of considering adoption are the young, highly educated group and the older, less educated group. The extremes with lowest probability of considering adoption are the young, less educated group and the older, highly educated age group.

Other variables that are significant in the base model include GROSS, EXPANSION_1, EXPANSION_2, MANAGE, FLUSH, ACRE, HERD, MILK/COW, ODOR%, and WATER%. With the exception of ACRE, HERD, and MILK/COW, the directional impacts of these variables all conform to the hypotheses. The results for HERD, MILK/COW, and ACRE are pursued further in the discussion section. The estimated coefficients on GROSS, EXPANSION_1, EXPANSION_2, MANAGE, FLUSH, ODOR%, and WATER% are all positive. They imply that farms with higher revenues, expansion plans, more time spent managing manure, flush manure systems, or a larger percent of land with odor or water problems

[12] HERD is another variable suspected of having curvature; however, a quadratic term for HERD was not significant in initial estimations.

are more likely to consider digestion technology. The other estimated parameters that are not significant at the 0.10 level also generally conform in sign to the stated hypotheses.

The full model has a higher log likelihood value and a slightly higher Pseudo R^2 value.[13] All estimated coefficients on variables that were significant in the base model are significant in the full model, and none change signs. Both the ENVIRO and DIFFUSION variables are positive and significant, consistent with the conservation adoption literature. The parameter estimates from full model are used for drawing marginal effects and related inferences from the data.

The marginal effects for the full model are presented in Table 5. In columns three and four, the marginal effects are calculated subject to no planned expansion or retirement for small and large herds (i.e., with the dichotomous variables EXPANSION_1, EXPANSION_2, RETIRE, and INHERIT all set to zero). In columns five and six, EXPANSION_1 is set to one, and marginal effects are calculated for small and large herds looking to expand herd size while facing issues with the desired expansion.

For farms not planning expansion or retirement, the signs on each marginal effect are the same as the sign on the estimated coefficient reported in Table 4, but the number of significant effects is considerably smaller than the number of significant parameters. For the marginal effects conditional on small herd means, only EXPANSION_1 and EXPANSION_2 are significant. For those conditional on large herd means, EXPANSION_1, EXPANSION_2, HERD, FLUSH, GROSS, and ENVIROp are significant.

When expansion of the herd is being considered and issues must be faced with the expansion, more marginal effects are statistically significant for both small and large herds. Since farmers planning to expand are more likely to consider adoption of digestion technology,

[13] Pseudo R2 = 1 – (constant-only log likelihood)/(full model log likelihood)

the marginal effects of individual variables are discussed only for such dairies. If all other covariates are constant: a 100-acre increase in farm size increases the predicted probability of adopting anaerobic digestion by 1.7% for small herds and 2.0% for large herds; a 100-head increase in herd size decreases the predicted probability by 3.3% for small herds and 3.9% for large farms; a 10-pound increase in daily milk production per cow decreases the predicted probability by 3.7% and 4.4%; a $100,000 increase in revenue increases the predicted probability by 1.3% and 1.5%; spending the maximum rather than the minimum amount of time managing manure increases the predicted probability by 20.9% and 22.3%; using a flush system to handle all manure increases predicted probability by 20.9% and 22.3% over not using a flush system; the most environmentally sensitive farmer (ENVIROp) increases the predicted probability over the least environmentally sensitive farmer by 20.7% and 23.8%; the farmer at the highest stage of diffusion increases the predicted probability over the farmer at the lowest stage of diffusion by 18.2% and 19.4%.[14] Examining the marginal effects for AGE and EDUCATION in combination with AGEEDU is complicated by the added dimension and the use of categorical instead of continuous values. To simplify the findings, only the marginal effects of a simultaneous positive increase in the AGE and EDUCATION categories are considered. Increasing both by one category increases predicted probability by 16.0% and 18.9%.

The overall probability that the farmer is seriously considering adoption conditional on farm time horizon clearly illustrates the importance of herd expansion on the decision to adopt.[15] The overall probability that the farmer is seriously considering adoption, conditional on no changes in herd size or impending retirement, is 1.7% for the small herd means and 4.1% for the

[14] Minimum to maximum changes are calculated using Long and Freese's prchange command in STATA (2006) rather than the mfx command. The minimum to maximum change emphasizes conditional change rather than unit change.
[15] $Pr[CONSIDER = 4 \mid x_i]$

large herd means. Under herd expansion without issues, the predicted probability of adoption increases over the unchanging herd plan by 9.0% and 14.7% for small and large herds respectively. For a farm looking to expand and expecting complications, the probability of serious adoption consideration goes up by 15.1% and 22.6%. If a farmer expects to retire within five years, even with a younger generation expected to continue farming, the probably that digestion is considered decreases by 0.7% and 1.5% from the unchanging herd scenario. The results suggest that conserving natural resources for future generations may not be as strong a motivator as conserving the financial resources that would be required for investment in anaerobic digestion.

Discussion and Policy Implications

The directional hypotheses presented for the variables ACRE, HERD, and MILK/COW were rejected by the statistical estimation. While it is not clear why those hypotheses were not supported by these data, there are several possible explanations. The hypotheses for ACRE and HERD were need-based; they anticipated that anaerobic digestion appeals to dairy farms with an inadequate land base to support the herd.[16] It is possible that ACRE, HERD, and MILK/COW are accounting for dynamic considerations not identified in the data. For example, farms with inadequate land base to support the herd may consider moving the dairy to a new location. If so, they may expect to have adequate land to support the herd at the new location and be more likely to invest in a move and less likely to invest in a digester at the current location.

Another possible explanation for the unexpected marginal effect of acreage is that large-acreage farms may have more motivation to conserve natural resources because they are

[16] We also explored the use of a "cows per acre variable" which would specifically address nutrient loadings on farms. The findings of importance were not appreciably different.

historically rooted. Consequently, they could be less likely to relocate or cease agricultural operations in the foreseeable future.

The justification for these types of latent effects that enter the model through ACRE, HERD, and MILK/COW are largely subjective. Unfortunately, no questions were included in the survey about farm mobility or historical roots, so these conjectural explanations cannot be tested. What is clear is that these findings suggest a need for greater clarification regarding dairy culture, farm organization, and motivations.

However, one clarification of the impact of increased acreage can be offered. Because of the negative estimated parameter on the quadratic term, ACRE2, the maximum contribution of acreage to predicted probability of seriously considering adoption of digestion technology occurs at 1,850 acres, and the probability of seriously considering adoption decreases above 3,700 acres. Consequently, the largest farms in the sample support the original hypothesis. For most of the farms, the impact of additional acreage may be a reflection of the enhanced ability to finance major investments.

This study follows previous conservation adoption studies by including variables representing stewardship motives. In the literature, empirical testing typically uses proxies such interest group membership to represent stewardship motivation or altruism. Although the variable created from the survey data in this study does not strictly follow the behavioral psychology methodology, it appears to be a better proxy for latent environmental stewardship.

None of the variables used in the creation of ENVIRO directly impacts adoption on its own. Yet, ENVIRO behaves in the manner expected for a variable capturing the latent effect of environmental stewardship on the decision to adopt. Nevertheless, by using the fitted values of ENVIRO regressed on ODOR% and WATER%, the variable is at least partially driven by the perception that others may currently be concerned about air and water pollution created by the dairy. In fact, it is plausible that environmental stewardship can emerge from genuine altruism towards neighbors, future generations, or ecosystems.[17] Alternatively, environmental stewardship may result from concern about what the neighbors might do through political processes or legal action. For practical purposes, the nature of the motives matters less than the behavioral impact.

The diffusion typology variable acknowledges diffusion in context with multiple communication channels and corresponding stages of diffusion. This technique is a significant improvement over widely used simplifications of diffusion theory. Using proxies for diffusion such as knowledge of the problem or education do not formally address the importance of multiple communication channels, nor how the different channels are employed at various stages of diffusion. While the survey data used in this study was not fine-tuned to producing a diffusion variable, the use of the diffusion typology variable is a step towards incorporating diffusion theory into socioeconomic adoption models.

This study has documented several conditions that substantially increase the estimated probability of dairies adopting this integrated sustainable conservation technology that contributes to climate, air, and water environmental goals. However, the adoption of digestion technology could be inadvertently hindered by current public policy regarding alternative fuel development. For example, at the time of the survey in May 2006, milk prices were approximately $11.30 per hundredweight (Northwest Dairy Association 2007). In the first three months of 2007 the price of milk recovered to an average of $14.10 per hundredweight, but dairies are facing increasing financial pressures due to much higher corn prices (Ibid). The rising demand for corn is putatively due to developments in the market for ethanol. This increasing demand for corn, currently subsidized by government programs, could drive up feed prices for

[17] For example, Aldo Leopold's "land ethic".

dairy farmers over the long term. The rising demand for corn creates a negative pecuniary externality to dairy farmers which could result in a negative incentive for the creation of energy through anaerobic digestion. A related example is the incentive to burn wood byproducts to create energy. As wood mills install generation facilities powered by burning mill by-products, an important source of bedding becomes less available to dairy farms. In both cases, one green energy technology could result in reduced adoption of another green energy technology. If farmers face uncertainty with regard to feed and bedding price and availability, the adoption of digestion technology may be less appealing. These examples illustrate the complex interconnections in emerging bioenergy markets. Attention is required at the policy level to ensure that one industry does not bear undue cost as the nation endeavors to become cleaner and more sustainable.

Summary and Conclusions

This study employed an ordered probit model to investigate the characteristics of dairy farmers who may consider adopting anaerobic digestion technology. The use of an ordinal scale for a dependent variable differs from typical adoption studies. By using this ordinal scale and the necessitated ordered probit procedure, this study combines stated and revealed preferences in one empirical model. By using stated preferences, a model is estimated to determine adoption behavior prior to widespread adoption. This expands on previous conservation adoption studies that examine only revealed preferences. In the end, we focus on reporting results from those respondents seriously considering adopting because they are of research and policy interest.

The models used in this analysis were estimated from a data set collected via a survey of 230 Pacific Northwest dairy farms. Particular attention was given to the inclusion of variables that capture the influence of stewardship motives and the process of diffusion. The proxies constructed for stewardship motives and the diffusion typology variable had a significant impact on the decision to adopt digestion technology. This finding supports theories about non-financial motivation (stewardship and altruism) and the importance of communication channels (diffusion theory) in the conservation adoption literature.

This research supports the application of conservation adoption theory to describe which dairies are likely to adopt manure digestion technology. It supports past work showing that adoption decisions are influenced by financial factors such as gross farm income and practical factors such as the farm and manure management situation. Several technical improvements that could be relevant for future studies include the use of a combined stated and revealed preference dependent variable and indices representing diffusion typology and stewardship motivators as regressors.

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TABLE 1

Summary Statistics

Variable	Definition	Unit	Mean	Std. Dev.	n
CONSIDER	Dependent variable, level of adoption consideration for digestion	Categorical, 1 to 5	2.18	1.16	216
ACRE	Total farm acreage	Acre	451.39	617.13	220
ACRE2	$(ACRE)^2$				
HERD	Total herd size	Head	747.24	1,240.66	224
RENT%	Rent as a percent of total acreage	% of Total Acreage	28.28	30.06	220
MANURE%	Land receiving manure application	% of Total Acreage	65.75	31.50	220
URBAN%	Land within five miles of an urban area	% of Total Acreage	56.41	46.18	215
ODOR%	Land with a perceived odor problem	% of Total Acreage	39.25	42.21	212
WATER%	Land with a perceived water problem	% of Total Acreage	47.08	43.38	202
EXPANSION_1	Expansion planned, with issues	1 - Yes, 0 - No	0.19	0.39	226
EXPANSION_2	Expansion planned, without issues	1 - Yes, 0 - No	0.27	0.44	226
MILK/COW	Milk per cow	Hundred Weight	65.96	12.71	224
MANAGE	Time spent managing manure, week	Categorical, 1 to 4	2.03	1.07	218
FLUSH	Manure collected with flush system	%	16.32	32.49	227
LEGAL	Legal action regarding air or water	Categorical, 0 to 2	0.05	0.25	221
AGE	Age of the respondent	Categorical, 1 to 10	5.79	2.00	218
EDUCATION	Highest level of education attained	Categorical, 1 to 7	3.73	1.46	221
RETIRE	Retirement planned in five years	1 - Yes, 0 - No	0.24	0.42	217
INHERIT	Family member continuing to farm	1 - Yes, 0 - No	0.59	0.48	210
YEARS	Respondent years operating the farm	Year	23.39	12.81	219
SOURCE	Primary source of family income	Categorical, 1 to 4	3.44	0.92	211
GROSS	Gross milk income	$100,000	17.89	33.67	227
AGEEDU	AGE * EDUCATION		21.59	11.74	215
ENVIRO	Original Environmental Index	Categorical, 0 to 8	4.78	1.75	166
ENVIROp	Environmental Index as a Function of ODOR% and WATER%	Index	4.74	0.62	195
DIFFUSION	Diffusion variable	Index	0.06	0.12	218

TABLE 2

Regression for Predicting DIFFUSION [a]

Independent Variable	Coefficient	Std. Err.	t	p
INDUSTRY	0.0365	0.0351	1.0400	0.2990
PUBLICATIONS	0.0298	0.0314	0.9500	0.3440
OPERATION	0.0599	0.0359	1.6700	0.0970
EXPERT	0.2238	0.0366	6.1200	0.0000
ADJ-1	-0.0384	0.0279	-1.3700	0.1710
ADJ-2	-0.0364	0.0476	-0.7600	0.4450
ADJ-3	-0.1636	0.0601	-2.7200	0.0070

R^2 = 0.2614 Adj. R^2 = 0.2368

[a] Values of 1 for these dichotomous variable definitions: the dependent variable in the model a binary variable representing those that extensively researched digestion technology; INDUSTRY: discussed digestion technology with other farms or industry people; PUBLICATIONS: read about digestion technology in current trade journals and other publications; OPERATION: saw a digester in operation; EXPERT: digestion technology explained by an expert; ADJ-1,2,3: number of "Yes" answers to INDUSTRY, PUBLICATIONS, OPERATION, and EXPERT.

TABLE 3

Regression for Predicting ENVIROp[b]

Independent Variable	Coefficient	Std. Err.	t	p
ODOR%	0.0093	0.0036	2.60	0.010
WATER%	0.0078	0.0036	2.19	0.030
CONSTANT	3.9880	0.2316	17.22	0.000
$R^2 = 0.1173$		Adj. $R^2 = 0.1047$		

[b] The dependent variable in the

TABLE 4

Base and Full Model Parameter Estimates

Independent Variable	Cumulative Model Parameter Estimates Base Model		Full Model	
ACRE	0.00102	*	0.00074	*
ACRE2	-0.00000025	*	-0.00000020	*
HERD	-0.0015	*	-0.0015	*
RENT%	-0.0048		-0.0045	
MANURE%	0.0041		0.0030	
URBAN%	-0.000381		0.000029	
ODOR%	0.0051	*		
WATER%	0.0052	*		
EXPANSION_1	1.1934	*	1.2086	*
EXPANSION_2	0.7875	*	0.9043	*
MILK/COW	-0.0161	*	-0.0163	*
MANAGE	0.3058	*	0.2911	*
FLUSH	0.0094	*	0.0114	*
LEGAL	0.4995		0.5517	
AGE	0.2682		0.3301	*
EDUCATION	0.4266	*	0.4502	*
RETIRE	-0.4024		-0.3864	
INHERIT	0.3033		0.1829	
YEARS	-0.0093		-0.0107	
SOURCE	0.0678		0.0932	
GROSS	0.0557	*	0.0558	*
AGEEDU	-0.0627	*	-0.0773	*
ENVIROp			0.5522	*
DIFFUSION			1.9484	*
/cut1	2.2619		4.5159	
/cut2	3.2144		5.5223	
/cut3	4.4552		6.9083	
/cut4	5.8321		8.1859	
Pseudo R^2	0.2614		0.2661	
n	147		139	
Log likelihood	-155.8775		-142.6463	

* Indicates significance at a 0.10 level. Values in parentheses indicate the standard error for the estimated parameter.

Table 5

Mean Values for Marginal Effect Calculations and

Full Model Marginal Effects Conditional on Change

	Mean Values for Marginal Effects Calculations		Marginal Effects $\partial \Pr[CONSIDER = 4]/\partial x_i$			
			No Change Expected		with EXPANSION_1 = 1	
Independent Variable	X_{small}	X_{large}	Full, X_{small}	Full, X_{large}	Full, X_{small}	Full, X_{large}
ACRE	342.04	684.14	0.00003	0.0001	0.0002	0.0002
ACRE2	171429	921765	-0.00000001	-0.00000002	-0.00000004 *	-0.0000001 *
HERD	423.13	1018.96	-0.0001	-0.0001 *	-0.0003 *	-0.0004 *
RENT%	26.48	31.23	-0.0002	-0.0004	-0.0010	-0.0012
MANURE%	66.55	69.11	0.0001	0.0003	0.0007	0.0008
URBAN%	57.6	64.69	0.000001	0.000002	0.000007	0.000008
EXPANSION_1	0	0	0.1508 *	0.2256 *	0.1508 *	0.2310 *
EXPANSION_2	0	0	0.0896 *	0.1471 *	0.2256 *	0.1976 *
MILK/COW	67.46	71.4	-0.0007	-0.0014	-0.0037 *	-0.0044 *
MANAGE	2	2.63	0.0120	0.0250	0.0663 *	0.0784 *
FLUSH	16.3	35.56	0.0005	0.0010 *	0.0026 *	0.0031 *
LEGAL	0.02	0.14	0.0228	0.0473	0.1256	0.1486
AGE	6.02	5.73	0.0136	0.0283	0.0751 *	0.0889 *
EDUCATION	3.77	3.58	0.0186	0.0386	0.1025	0.1213 *
RETIRE	0	0	-0.0107	-0.0239	-0.0749	-0.0977
INHERIT	0	0	0.0075	0.0157	0.0416	0.0493
YEARS	23.31	22.81	-0.0004	-0.0009	-0.0024	-0.0029
SOURCE	3.51	3.81	0.0038	0.0080	0.0212	0.0251
GROSS	10.2	23.02	0.0023	0.0048 *	0.0127 *	0.0150 *
AGEEDU	22.79	20.34	-0.0032	-0.0066	-0.0176 *	-0.0208 *
ENVIROp	4.87	4.95	0.0228	0.0474 *	0.1257 *	0.1487 *
DIFFUSION	0.09	0.07	0.0804	0.1672	0.4436	0.5248 *

* Indicates significance at a 0.10 level. Values in parentheses indicate the standard error for the estimated parameter.

CHAPTER 3

The Economics of Dairy Anaerobic Digestion with Co-Product Marketing

Introduction

The revival of interest in anaerobic digestion technology has followed a global recognition of climate change and the need for alternative energy sources. Digestion technology is environmentally beneficial as it captures and combusts the greenhouse gas methane. A metric ton of methane has a global warming capacity 23 times greater than carbon dioxide (Ramaswamy 2001 p. 388).[18] Digestion also reduces the chemical and biological oxygen demand of dairy manure runoff. Further benefits of digestion technology include electrical production, reduced on-farm odor, and pathogen-free fiber for animal bedding. These benefits make digestion technology potentially desirable for dairy farms and the surrounding communities.

While digestion technology has multiple benefits, it has not been widely adopted. The limited adoption of digestion could be due to financial infeasibility or lack of information regarding the financial feasibility of digestion. This paper explores the possibility that financial feasibility lies in co-product marketing. Co-products include revenues from marketable digester outputs (e.g. electricity), avoided costs on other aspects of the farm (e.g. bedding purchases), and revenue from services (e.g. accepting food waste). If co-products do substantially impact the financial feasibility of digestion, then the financial perspective of digestion for dairies needs to be reoriented.

The purpose of this paper is to examine the economics of anaerobic digesters for dairy manure under alternative co-product marketing scenarios. Using projections based

[18] This figure is for a 100-year time horizon.

on an operational digester, common indicators are calculated to gauge the economic performance of the operational digester. Several co-product marketing scenarios are formulated to gauge how the feasibility of the digester is affected.

Anaerobic Dairy Manure Digestion

Digesters have been installed on dairy farms for decades. Early installations of digestion technology resulted in mixed reviews. In a survey of six digesters installed in the 1980's, Morse, Guthrie and Mutters (1996) illustrated the numerous problems with digestion technology. Lack of cooperation on the part of utility companies was cited by several producers as an obstacle to successfully operating digesters (Ibid.). Other producers cited design and technical flaws as the reason for unsuccessful operation (Ibid.). The economic and technical uncertainties, coupled with a large capital expense, made anaerobic digesters a risky venture for early adopters of the technology. As a result, anaerobic digesters initially failed to gain widespread adoption on dairies in the United States.

Recent installations of anaerobic digesters on dairy farms have been more successful. The combination of available funding and innovative partnerships helped make digestion technology feasible for a larger number of dairy farms. In a national context, the U.S. Environmental Agency's AgSTAR program (2006) reported that between the years 2000 and 2005, at least 38 dairy digesters began operation nationally. In 2005 alone, 11 dairy digesters began operation (Ibid.). In the Pacific Northwest, there are currently five digesters in operation, all of which began operations after the year 2000 (Ibid.). [19] For historical comparison, Lazarus and Rudstrom (2007) indicated that between the years 1970 and 1990, 71 digesters began operation and had a 60% failure rate. While

[19] The Pacific Northwest encompasses Washington, Oregon and Idaho.

the U.S. is continuing to install digesters, the European Union remains the leader with 2,429 biogas operations across 16 countries (AD-Nett 2005).

In the U.S., the most popular system is the mesophilic plug-flow digester (US EPA 2006). Plug-flow systems are relatively simple. No mechanical apparatus is required once the manure enters the digester. The manure is moved by hydraulic pressure through an airless concrete structure for approximately 22 days to complete the digestion process. During this time the manure is broken down by mesophilic bacteria, resulting in the release of methane, carbon dioxide, hydrogen sulfide, and other trace gases. To maintain an optimal temperature of around 35ºC during this process of methanogenesis (Nyns 1989), a heat exchanger captures waste heat from the generator to heat the manure entering the digester.

The least expensive digestion system is created by covering an existing manure lagoon to capture combustible gasses. However, the digestion process is affected by the seasonal variability of temperatures in a covered lagoon system. Another system, similar to the plug-flow system, is the fixed-film digestion scheme that is designed to reduce retention time and odor for dairies using a manure flush system (Wilkie 2000). With a reduced retention time, the fixed-film digester could potentially have a lower capital cost than the mesophilic plug-flow digester. The physical structure of the digester is designed to maximize the bacterial contact with manure using a media suspended in the digester, thereby utilizing available bacteria efficiently (Ibid.). Efficient digestion reduces capital costs because a reduced holding time means a smaller and less expensive tank is needed. There is a suspended media packed into fixed-film digesters. However, the presence of the media increases problems with clogging, therefore limiting the application of fixed-film digesters.[20]

Construction of the first plug-flow dairy digester in Washington State was completed in November, 2004. Diverse parties lent support for the project. They included researchers studying digester co-product extraction and technical feasibility, local power utilities, and municipal entities. The use of a proven GHD mesophilic plug-flow design[21], in addition to the support of the previously mentioned groups, allowed the digester to avert many of the technical and economic issues hindering earlier digesters. Several more digesters are now in operation or under construction in the Pacific Northwest. Most of these projects are taking advantage of diverse partnerships such as environmental groups, tribal governments, local businesses, and local communities. Anecdotal evidence suggests that digestion technology has become a public relations tool for the dairy industry in addition to a manure management technology.

However, implementing digestion technology in the Pacific Northwest remains economically challenging because of low power rates in the region. Converting biogas to electricity is widely considered to be the primary source of revenue for digester operations. In regions where electricity prices are low because of inexpensive power sources, such as hydroelectric generation, other sources of revenue must be sought. Possible revenue sources include co-products such as fertilizer, fiber, and carbon credits. The digester owner may also charge a "tipping fee" for receiving food waste from local processing centers. Each of these co-products is discussed further in the next section.

Digestion Co-products

[20] They cannot be used on dairies with high solids manure or food waste. These systems are designed for flushed manure.
[21] GHD, Inc. is a digester engineering and construction firm based in Wisconsin.

Electricity. With a few exceptions, most digesters in operation today have the capacity to generate electricity. Determining the price for electricity produced from biogas remains an ongoing issue for potential adopters. Producers seeking economic benefits from electricity generation have several options including power purchase agreements, net metering, and green tag sales.

The power purchase agreement is a contractual arrangement between the producer and the local utility. Entering into the agreement requires negotiation, and the contract does not guarantee a renewal. Further, utilities may require costly feasibility studies before power purchase agreements are accepted

Net metering is an alternative to power purchase agreements. Washington net metering policy requires utilities to accept power produced from renewable fuels. Net metering is an offset system; if the amount of energy produced exceeds the producer's need, it creates a credit (Washington State Legislature 2006). Utilities have argued that retail power costs would increase because of the instability caused by higher levels of aggregate power demand being met by net metering systems (Ibid.; Cook and Cross 1999). This increase in price would occur because utilities often are not compensated for transmission and distribution under net metering systems (Cook and Cross 1999). Further, as noted by Wirl (1997, p. 81), "least cost planning is not economical for a utility that is regulated according to the common principle of setting price according to the fully distributed cost; in fact, such a utility is entirely indifferent and may or may not, start a conservation program, depending on management's preferences, because the profit does not change." Wirl's analysis implies that the decision to support local digestion projects may be dependent on the utility's management, which emphasizes the importance of fostering partnerships.

Sales of green tags are an increasingly popular option for digester operators looking to profit from their excess electricity. The green tag purchase replaces a certain block of traditionally produced energy with an equally sized block of renewable energy. This option allows citizens who view green power as a priority to pay extra to support it.

Digested Fiber. Many dairy farms use fiber separators to reduce the amount of solids stored in their lagoons. However, fiber separated from manure waste is not free of pathogens or weed seeds. While pathogens and seeds can both be eliminated from the fiber through composting, fiber separated following digestion is free from pathogens and seeds without the added capital, space, and time required for composting. This fiber is commonly used as bedding material for livestock and offsets the cost of traditional bedding materials such as sawdust. Digested fiber is also marketed as mulch for berry and hydroseeding operations. Technology is currently being developed with the goal of producing a potting soil amendment similar to peat moss from digested fiber (MacConnell and Coyne 2006).

Carbon Trading. Dairy farms with anaerobic digesters are eligible for carbon trading on the Chicago Climate Exchange (CCX). Because the U.S. has not ratified the Kyoto Protocol, it is not bound by international law to reduce carbon emissions. However, within the U.S., efforts have been made to establish municipal, regional, and national carbon emission reduction schemes (Bang et al. 2007; CCX 2007). One such effort, the CCX, was developed as a pilot project for exchanging carbon credits[22] on a standard legal platform (Sandor, Walsh and Marques 2002). The CCX is a voluntary

[22] One carbon credit is equivalent to one metric ton of emitted carbon.

trading program that provides economic incentive for carbon emitting companies to reduce carbon emissions on their own accord (Ibid.). Because CCX membership is not compulsory, the volume and price of U.S. carbon credits are substantially lower than in countries belonging to the Kyoto Protocol that have access to international trading platforms. The CCX traded 873,000 metric tons of carbon in April 2007 during which the European Climate Exchange (ECX) traded 57.8 million metric tons (CCX 2007). The April 2007 closing prices on the CCX and ECX for 2008 vintage carbon credits were $3.70 and $25.70, respectively (Ibid.). For digester owners, carbon trading is a potential source of revenue. However, given current CCX prices and the large brokerage commissions required for trading, the revenues for digester owners are quite low relative to their potential should the U.S. ratify the Kyoto Protocol or a similar carbon emission cap initiative.

Tipping Fees. Anaerobic digestion is not limited to manure. The dairy anaerobic digesters can also accept food wastes. Like manure, food waste is digested by the methanogenic bacteria in the digester which releases methane. Methane production from food waste is generally higher than from manure waste (El-Mashad and Zhang 2006; Scott and Ma 2004a). Tipping fees for receiving food waste may raise revenue substantially and increase electrical production for digester owners.

In dairy digesters, the large feedstock of animal manure helps stabilize the digestion process by providing a high buffering capacity (Murto, Björnsson and Mattiasson 2004). The high buffering capacity of dairy manure digesters means reasonable quantities of organic wastes can be added to the digester instead of disposing of them in a landfill (Ibid.; Scott and Ma 2004b). However, if the quantity of other wastes exceeds the buffering capacity of the manure, rapid changes in the digester's pH can occur and diminish the methanogenic processes (Ibid.). Even with the high buffering capacity of manure, some food wastes are not compatible with manure digesters and can have other adverse affects on digestion. Therefore, a digester operator faces additional risks when accepting food waste (Scott and Ma 2004a).

Other Potential Co-Products. While the primary potential sources of revenue for dairy manure digesters have been noted, several other sources may exist for some digesters. Notable among the possibilities are sales of scrubbed methane, services derived from waste heat, and sale of fertilizer-grade struvite.

The biogas produced from digestion is primarily composed of methane and carbon dioxide. As an alternative to burning the biogas, the gas can be scrubbed to remove everything but the methane. The methane can then be sold to natural gas providers. In 2006, at least one digester owner began selling gas in this manner (Parsons 2006). Prototype research at Western Washington University is also exploring the use of scrubbed methane for transportation applications (Leonhardt 2007).

A large amount of waste heat is produced in anaerobic digestion, only a portion of which is needed to keep the tank at optimum temperature. One potential application for this remaining heat is floor heating in livestock holding areas during the winter months. Other possibilities include ambient heating for adjacent greenhouse operations, heating for neighbors, and heating for the farm.

As environmental regulations increase, the amount of nutrients that can be applied to farm land may decrease. One technology that may enhance the benefits of anaerobic digestion is struvite extraction.[23] Fertilizer-grade struvite is composed of 6% nitrogen, 29% phosphorous, and 16% magnesium (Bridger, Salutsky and Starostka 1962). Struvite naturally forms in some waste water streams and is generally considered a nuisance in municipal waste water processing (Jaffer et al. 2002). One technology under development for livestock applications is the fluidized bed reactor (Bowers 2002). The struvite reactor infuses effluent manure from the digester with magnesium and anhydrous ammonia in order to force the precipitation of struvite crystals (Ibid.). Struvite extraction from digested manure waste has the added benefit of having high convertible phosphates which increases the potential amount of phosphorus that can be extracted (Bowers 2006). If struvite reactor technology comes to fruition for dairy manure digester applications, struvite may be sold as a specialty or bulk fertilizer product. Struvite is an alternative to current phosphate fertilizers (Lindsay 1979). For some applications, it is preferable to conventional fertilizers because it is less likely to burn sensitive plants (Bridger et al. 1962). Currently, few large scale struvite extractors exist. Thus, there are few established markets for struvite.

Procedures

The operational digester in Washington serves as the “base scenario” for economic analysis. Assumptions underlying the base scenario rely on data from the first two years of digester operations. The operational and financial data were provided by the digester owner, the company that constructed the digester, and the Washington State University research team working with the digester. Alternative scenarios are created that differ from the base scenario with regard to life of the digester, private investment cost, number of cows serviced by the digester, and individual co-products. Economic

[23] Magnesium ammonium phosphate hexahydrate.

indicators from the alternative scenarios are compared with the base scenario to gauge the effect of each alternative.

Two economic indicators are presented with each scenario – net present value (NPV) and internal rate of return (IRR).[24] These indicators are used because they consider the time value of money and the rate of return on investment to the digester owner. For investment in the digester to be considered feasible, the NPV must be positive and the IRR must be greater than the reference (discount) rate (Kay and Edwards 1999). If the NPV is negative, it indicates that the digester does not provide sufficient returns to the owner to cover the opportunity cost of capital. The IRR provides the actual rate of return on the digester investment (Ibid.). Other methods such as payback period and average return on investment do not adequately incorporate the time value of money. The NPV and IRR are both widely used methods for analyzing investment alternatives as well and could be comparable with similar studies. Thus, NPV and IRR are the preferred economic indicators.

Base Scenario

The economic analysis of the digester is conducted as though the digester is an independent enterprise from the dairy. As Martin observes, treating the digester investment as an independent enterprise enables the costs and benefits of this major investment to be examined in the context of alternative investments (2007). Benefits to the dairy such as avoided bedding expenses are considered revenues. Other factors such as dairy herd size also enter into the budget calculations because manure is the primary feedstock for digestion. The final economic indicators presented are for the digester

[24] To generalize the results of this study, it should be noted that the NPV and IRR estimates are based on pre-tax cash flows. The cash flow calculations exclude federal and state income taxes. Thus, the net present value and rate of return estimates can be compared with those for alternative investments on a pre-tax basis.

enterprise, not the dairy farm as a whole. From the base scenario, costs and revenues are projected for 20 years. All of the cash flows produced are in real dollar terms to avoid compensating for general inflation.

The base scenario digester is a hardtop plug-flow digester constructed for a maximum capacity of 1,500 head of cows.[25] The digester was oversized to allow for farm growth, off-farm manure, and food waste receipts. The digester was installed on a 500-cow dairy farm. In addition to the owner's herd, manure from 250 cows is trucked to the digester from two neighboring dairy farms. Food waste is added to the digester feedstock from a number of local food processors. Biogas produced in the digester is piped into a Caterpillar G398 reciprocating engine, retrofitted for natural gas combustion. The Caterpillar generator has a maximum generating capacity of 285 kilowatts per hour.

The capital cost of a digester is a major investment for a dairy farm. The construction cost for the base scenario digester totaled $1,136,364.[26] A breakdown of the component costs is provided in Table 1. Grants from the U.S. Department of Agriculture and Washington State University accounted for 38% of the capital cost. Experimental equipment for fiber processing and struvite extraction was also covered by grants from the USDA's Natural Resource Conservation Service; however, the actual value of this grant to the owner is unknown (Kruger 2007). The rest of the construction cost was financed privately by the digester's owner. The base scenario deducts the portion of the cost provided by the grants from the total capital cost. Deducting the grant receipts recognizes that present digester installations can receive substantial government support.

[25] The actual capacity is closer to 1,300 head in order to compensate for increased volume from rain (Frear 2007).
[26] The construction cost includes net expenses (or negative of net revenues) during a start-up phase that lasted approximately 100 days (Martin 2007). The start-up phase is a learning period for digester operators and is not representative of continuous digester operation.

Because of the presently high cost of digester installation in part due to the builder and operator unfamiliarity with the technology, government grants are important to offset these costs for early adopters.

Costs and revenues used for the base analysis began after the start-up phase ended. Thus, the first year of operational data began March 1, 2005. Using actual revenue and cost data from this digester for two years following start-up along with expectations regarding future operations of the digester, real value revenues and costs are projected for subsequent years. The first, second, and representative future-year real revenue and cost data are presented in Table 2.

Based on the recommendations of Martin (2007), the lifetime of the digester for the base scenario is expected to be 20 years. The discount rate used for the net present value (NPV) calculations is 2.25%, which is the mean of U.S. Treasury real long-term interest rates for the second half of 2004 (U.S. Treasury 2007).

Expected maintenance costs are extrapolated from a maintenance schedule provided by the digester construction company. Except in years when overhauls are needed, real maintenance costs are expected to increase 4% per year. The largest increase in maintenance costs comes from overhauling the natural gas generator every three years. In overhaul years, the cost of maintenance increases substantially.

Another significant expense is trucking manure to and from neighboring farms. Real delivery expenses are expected to remain constant as long as the quantity of manure transported to the farm remains the same.

A majority of the revenue markets examined in this study are in the early stages of development, so there is little empirical evidence on which to base market growth rates. Electricity production is the most reliable market because rates are contractual and production is dependent on herd size and food waste inputs. Starting the fourth year, a herd growth rate of 5% per year is expected in each of the following three years. It is not expected that more food waste will be brought onto the farm. Thus, changes in electricity production are projected to be due only to changes in herd size.

The supply of sawdust bedding is expected to decrease in the area surrounding the digester because a large mill in the area recently installed a cogeneration unit fueled by wood waste. To recognize the decrease in sawdust supply from burning the wood waste as fuel, the real cost of the avoided bedding is expected to increase 5% per year for four years while the market stabilizes.

The amount of fiber available for sale is dependent on the amount of manure and food waste entering the digester and on how much fiber is used on the farm. The quantity of fiber sold is expected to increase in the initial period due to herd expansion. During this period, the amount of fiber sold is assumed to increase at the same rate as the herd expands. Otherwise, the fiber sales are expected to remain constant.

The following sections describe several alternative scenarios that are contrasted to the base scenario. While each alternative is regarded as realistic, we do not explore the likelihood of any alternative scenario occurring in either the near- or long-term since the probabilities are highly uncertain. For instance, national carbon emission caps or electricity shortages would certainly increase the potential revenues for digester owners. Further, as world energy markets fluctuate, there may be increasing interest in scrubbing the gas for sale to gas companies or for use as a transportation fuel. However, to balance these possibilities for expanded revenues, history could also repeat itself. Renewable energy issues were hyped in the 1970's and 1980's, but then retreated from the public consciousness for more than a decade. While a decline in interest in alternative fuels would not behoove society, the economics of digester operations and adoption under harsh market conditions should be considered. Too much reliance on "best case" scenarios could prove economically disastrous for adopters of digestion technology.

Two additional implicit considerations are made for the base scenario. The first assumption is that the potential investor is risk neutral. This analysis focuses on investment returns without making an adjustment for risk[27]. The second assumption applies to cost increase or savings for manure handling. This analysis assumes that there is no net change in manure management costs. Under this assumption, a majority of the manure management practices are not expected to change, and thus the costs are not expected to change.

Base Scenario Variations – Alternative Digester Life, Investment, and Operational Scenarios

In the results, two alternative digester life scenarios are presented for context. One considers a 10-year operational life, and the other considers a 30-year life. The former is included to represent the possibility that rapid technological progress could make the existing digester design obsolete in a short period of time. The latter is included to represent a realistic potential life of the digester.

An alternative scenario is presented for a real discount rate of 3.25% in order to gauge the effect of inadvertently understating the actual discount rate.

The net capital cost in the base scenario was reduced by several grants. Future digesters may not have an opportunity to receive large levels of government support. One

[27] For instance, a risk premium could be added to the discount rate.

alternative scenario excludes the grants from the capital cost. Since 38% of the capital cost of the base digester was covered by grants, excluding them would seriously affect the feasibility of the digester.

The number of animals units adding waste to the digester affects how much electricity is produced, how much fiber is available, and the number of carbon credits possible. In the base scenario, manure from 250 cows is trucked in to the digester. Because the digester is located in an area with numerous dairies, there is potential for more neighbors to truck in manure. One alternative scenario is considered in which manure from an additional 250 neighboring cows is trucked in. This will increase the revenue streams but delivery expenses will also increase. Another scenario is developed for the possibility that no manure is trucked in.

The installed digester has a capacity of 1,500 cows. A scenario is developed that attempts to approximate the conditions of a 1,300 cow dairy. Specifically, there will be an increase in revenues from avoided bedding costs, fiber sales, carbon credits, and electricity. Electricity sales are capped at the generators capacity, because 1,300 cows should provide more gas than is needed by the generator. Tipping fees are excluded because of nutrient management and capacity concerns. By removing the tipping fees, this scenario illustrates how small farms can make up for low gas production using food waste.

Electrical Generation Scenarios

Three alternative scenarios are examined for electrical generation. The first scenario excludes electrical generation from the base scenario by removing all revenues from power sales. The engine maintenance expenses and the initial capital cost of the generation unit are also removed in this scenario. While a situation where a digester owner cannot receive some value from power generation is unlikely, low power rates or obstacles to selling electricity to the utility company could make the investment in generation equipment uneconomic.

The second electrical generation scenario considers how an additional $0.01 per kilowatt hour of power sold affects digester feasibility. While it is not expected that the utility company would renegotiate the purchase price of electricity, the increase illustrates how much revenue is generated by a marginal $0.01 increase in power rates. Another scenario is provided that uses the U.S. average all sector retail electricity price of $0.0877 (EIA 2007). This is higher than any rate charged by utilities in the Pacific Northwest, but it serves to illustrate how low electricity rates in the region affect digester feasibility.

A forth electrical generation scenario considers the installation of a higher efficiency generator. The combination of older technology and the quality of fuel results in low energy to electricity conversion efficiency. The generator used in the base scenario is 29% efficient in this respect. The company that installed the base scenario digester is exploring the use of a high efficiency generator for similar digester projects. The higher efficiency generator is 37% efficient and costs $68,000 more than the base scenario setup. A scenario is included to examine how digester feasibility would have changed if the higher efficiency generator was originally installed.

Tipping Fee Scenarios

The relative merit of accepting tipping fees for food waste requires careful analysis. In terms of volume, food waste in the base scenario accounts for only 17% of total digester influent (Frear 2007). However, because it has a higher nutrient and energy content than manure, 53.8% of total digester gas production is from food waste (Ibid.). While the added gas production results in more revenue from electrical production, the farm is left with more nutrients from the food waste residues. The excess nutrients could become prohibitive if the digester owner cannot meet nutrient management requirements. The first alternative tipping fee scenario considers how the economics of the digester would be affected if tipping fees were not an option. This scenario could result from increased nutrient management regulations or lack of food waste sources in the area. A second scenario is considered with food waste acceptance reduced 50% from the base scenario.

Carbon Credit Scenarios

Carbon credits provide an additional source of revenue without any direct costs to the digester owner. The first alternative carbon trading scenario excludes carbon trading, illustrating the economic implications of not having the opportunity to trade carbon credits. The second trading scenario considers the carbon trading brokerage fees. Several firms in the U.S. facilitate carbon trading on the CCX. The current brokerage fee for carbon trading is 50% of the traded value. For instance, the digester owner sold 7,300 carbon credits in the second year at a value of $4.50 per credit. After the brokerage fees were deducted, the digester owner received $16,425 of the total $32,850 trade value.

A scenario is included that reduces the brokerage fee to 25% of the trade value, thus providing more value to the digester owner while still providing income for the broker. The decrease in trading commission is based on sulfur dioxide trading commissions in the early 1990's (Joskow et al. 1998).

A third scenario examines how the digester owner would benefit by having access to the European carbon market. Since the U.S. has not joined the Kyoto Protocol, that market is not currently available to U.S. dairies. This analysis uses the conservative current U.S. market value for carbon credits. As concern for global warming increases, the market for carbon credits in the U.S. will increase. At present, U.S. policy does not recognize cap-and-trade programs as the best option for reducing national carbon emissions; carbon taxes are preferred (Dinan and Shackleton 2007). The CCX is similar to the European carbon trading marketing, but without the caps on carbon emissions. It is unclear how CCX carbon markets would be affected by a carbon tax scheme rather than the cap-based systems used by those countries that ratified the Kyoto Protocol. Given current federal policies towards carbon reduction, the general future of U.S. carbon trading is hard to gauge. However, it is reasonable to expect that the U.S. will ultimately take action with regards to carbon emission reduction that could result in carbon credit prices closer to those of the European carbon market.

Fiber Scenarios

Without established markets, fiber sales are fairly unpredictable. The fiber from the digester has been sold for $13.50 per ton, but sales have not been consistent. Currently, two-thirds of the available fiber is used for bedding. The first alternative fiber scenario considers the possibility that no fibers sales occur. The next scenario considers a digester owner who can sell all fiber at $13.50 per ton. The second scenario considers a contract to sell all fiber at $20 per ton and anticipates development of a potting medium market for the fiber. Even this higher price is considerably lower than the price of imported peat moss.[28] It will take proven substitutability and evidence of a reliable supply for the price of digested fiber to reach a level comparable to peat moss. A 4.7% growth rate in fiber price is used. This growth rate is roughly based off a prospective Seattle area market for digested fiber (Terre-Source 2003). Both of these scenarios remove the benefit of using the marketed fiber as bedding because all of the available fiber is sold.

Results and Discussion

The estimated NPV and IRR are presented for each scenario in Table 3. The results for the base scenario imply the digester system is an economic investment. With an NPV of $1.37 million, the projected cash flow from the digester is positive and implies that the discounted value of the net returns exceeds the original capital investment. The NPV is also large enough to suggest that even if costs modestly exceed expectations, the digester could remain economically feasible. The IRR for the base scenario is also large enough to imply that the digester is competitive with other investments.

The alternative digester lives reveal that the digester remains economically feasible for productive lives of 10-30 years. Increasing the digester life by 10 years has little impact on the IRR, but decreasing it by 10 years lowers the IRR by 21%. A 1% increase in the discount rate decreases the NPV by 14% and, of course, does not change the IRR. These three alternative scenarios provide a gauge of robustness for the economic viability of investment in the digester. Within reasonable limits, the results of these three scenarios suggest relatively little sensitivity of the economic feasibility of the investment to either the asset life or the discount rate.

[28] The 2006 weighted average of the price for imported peat was $213 per ton (USITC 2007).

Not including grants in the capital cost assumptions causes the NPV and IRR to drop substantially, by 31% and 45%, respectively. Nevertheless, the digester still provides an attractive rate of return that would be comparable to or higher than many alternative investments for most farmers. One of the purposes of public grant support for private investments is to compensate for the learning costs of installing new technologies. The digester in this analysis was the first such project completed by the construction company. If the same type of digester was built several times, it is likely that some costs would be saved. An example is the difference between digesters installed in the 1980's and digesters installed today. The basic technology is essentially the same but recently installed digesters provide cost savings and fewer technical deficiencies.[29] Continued improvements and experience should serve to counteract likely reductions in grant funding.

In comparison with the base scenario, a decrease in the quantity of manure trucked from off-farm sources is preferred. The results show that the base scenario herd size is preferred to bringing more manure to the digester from off-farm sources. This finding implies that the cost of hauling in off-farm manure currently exceeds its value from increased production of gas, fiber, and carbon credits. To remain economically viable, the cost of transporting manure to the farm needs to be reduced or tipping fees need to be charged. However, it should be cautioned that in a small herd digester that receives food waste, manure from other farms may be needed to buffer for variations in the quantity of food waste received. The value of additional buffering capacity is hard to

[29] For instance, the base scenario digester uses remote monitoring systems that save time and money. Another example is an improved system for cleaning the digester when it becomes clogged.

determine, but minimally adequate capacity is necessary to prevent failure of digester operations.

Using a larger herd and excluding food waste produces results that are similar to the base scenario. This result has interesting implication for the fixed capital constraint of digester installations. The result show that the extra upfront cost of an oversized digester can be made up with co-product sales and tipping receipts. For farms, an oversized digester could translate to securing future expansion efforts or potential community cooperation that may not be possible at the time of digester construction.

The importance of electrical generation is apparent when the base scenario and the scenario excluding electrical generation are compared. The decreases in NPV and IRR are substantial; however, the digester remains economically feasible even without the cash flows from power generation. The reduced capital and maintenance costs are responsible for the continuing feasibility. While there is broad emphasis on electrical generation as the primary revenue source for digester owners, the results of this study imply that power production and sales are not essential for the viability of the investment. Nevertheless, it is apparent that electrical generation provides significant benefits.

The contractual power purchase agreement used in the base scenario provides solid returns on the digester investment. If the power purchase arrangement had been set at $0.06 per kilowatt hour, the investment would be even more attractive. NPV would increase by 23% and IRR by 16%. However, installing a high efficiency generator at the lower power rate would have an even greater impact. It would increase NPV by 45% and IRR by 22%. Using the U.S. average retail price illustrates how the digester investment is affected by low electrical revenues in the Pacific Northwest. The NPV increase 88% and the IRR increases 57%. It is questionable whether a power purchase contract negotiated at this price; rather, the value would probably be received by the farm as offsets from net metering.

If no food waste is added to the digester with the associated tipping fees, the resulting digester investment is economically infeasible, and dramatically so. When accepting no food waste, the NPV is as large a negative value as the NPV for the base scenario is positive. This is a powerful illustration of the importance of tipping fees with regard to the base scenario's feasibility. When half of the base scenario's tipping fees are excluded, the NPV is also below the breakeven level. Of all the alternative scenarios considered, these are the only sources that generate a negative NPV. The IRR is less than the discount rate and indicates that the digester investment is not competitive with other financial investments even if the owner's portion of the cost is financed entirely with borrowed funds.

Comparing the base scenario with the scenarios that exclude power generation or tipping fee receipts reveals that the emphasis on electrical generation may be a secondary concern to establishing relationships with businesses producing large amounts of food waste. Food processors already handling and disposing of food waste are unlikely to have a preference where waste is dumped as long as cost is similar. Compared with utilities, working relationships with food processors could be easier to navigate. When planning a digester, the proximity to potential food waste sources should be considered if the additional nutrients can be absorbed.

The on-farm nutrient loading cost is not considered in the NPV for the base scenario. A plan must be in place to remove excess nutrients, if any, from the farm.

Digester effluent has value when it can be used as a fertilizer for agricultural operations with high nutrient demands. However, this could require transportation costs which would increase with the distance from the farm that the digested effluent must be transported. The base scenario's NPV is large enough that some added transportation costs may not greatly reduce the viability of the investment, especially if the digester owner can make revenue from selling the liquid effluent. Alternative technologies are also in development to precipitate struvite and ammonia sulfate on-site from digester effluent. These compounds can be shipped and stored in a dry state and marketed as alternative or specialty fertilizers.

Removing the option to sell carbon credits reduces the NPV of the digester investment by 19% and the IRR by 13%. If more digesters are installed in Washington, it will likely reduce the carbon trading brokerage fees due to lower transaction costs to the broker. The 25% commission scenario illustrates the benefits to the farmer of a reduced brokerage fees. If the brokerage fees were reduced by half, the NPV would increase by 11% and the IRR by 8%.

The ECX market price scenario reveals how dairy producers in the U.S. could stand to gain by accessing European carbon markets. The difference between the NPV value of the base scenario and the ECX trading scenario is substantial, with gains greater than $1 million. In fact, NPV and IRR for the digester investment increase more (by 83% and 55%, respectively) from this one change from the base scenario than from any other change considered. The future of voluntary U.S. carbon markets is uncertain given the current political preference for carbon taxes over cap-and-trade regulation. Several state and local governments are taking action in lieu of the federal government's failure to act

(Bang et al. 2007). State actions to cap carbon emissions should grow the carbon trading market within the U.S. However, without a homogenous federal cap policy, it is uncertain how stable the emerging market will be, and whether prices will reach ECX levels.

As the base scenario is configured, fiber sales contribute little to the digesters feasibility. Excluding cash flows reduces the NPV and IRR by 8% and 6% respectively. Two alternative scenarios are considered for marketing digested fiber. The digester investment is increasingly feasible using either of the fiber marketing schemes. Selling all of the available fiber at $13.50 a ton increases the NPV by 43% and the IRR by 19%. The scenario where all of the fiber produced is sold at a modestly higher price of $20 per ton increases the NPV by 79% and the IRR by 36%. These results emphasize the importance of technological and marketing efforts to develop viable co-products from digestion. However, the results are driven by a fairly aggressive yearly growth rate. For a digester operator to actually receive the gains reported for these alternative fiber marketing scenarios it would require strong market development.

Conclusions and Inferences for Decision Making

This paper has examined the economic feasibility of anaerobic digester systems in the Pacific Northwest. A base scenario digester system was developed for a dairy based on actual cost and revenue data from the first operational digester in Washington State. A number of actual co-products from the digestion process were considered in the analysis. They included electricity sales, tipping fees, carbon credits, and fiber sales. Base expectations were established regarding how co-product markets will develop, and resulting cash flow projections were computed for a 20-year operational life of the digester. From the cash flow projections, estimates of the net present value (NPV) and internal rate of return (IRR) were calculated.

Because of the high level of uncertainty about future markets and technology, cash flows, NPV, and IRR were calculated for a number of alternative scenarios. These scenarios included variations on the operational life of the digester, the discount rate, initial private capital cost, number of cows contributing manure, tipping fees for food waste, and markets for electricity generation, carbon credits, and fiber.

The main source of revenue for digesters in the U.S. has been the sale of electricity. Alternative electrical generation scenarios were considered that documented the importance of this source of revenue but also demonstrated that the traditional perception of digesters as primarily being electrical generators is outdated. The results suggest that when digestion is considered simply to be a waste management tool and a power generator, the financial feasibility of digestion is indeed marginal. However, if digestion is viewed in a wider context, it becomes an attractive investment. In order to take full advantage of potential co-products markets, the geographic placement of the digester is crucial.

Of the many alternatives considered to the base scenario, the only scenarios that made the investment infeasible were related to a substantial reduction in the amount of food waste received. Without the revenue from tipping fees and the additional electricity generated from the food waste, the digester configured for this study would not be economically feasible. Digester product revenues were actually of secondary importance to the revenues from tipping fees. Receiving food wastes have the added environmental benefit of diverting them from landfills. However, that benefit is limited by nutrient management regulations to what the farm can effectively utilize plus what can be efficiently extracted and moved to productive uses off the farm. Diverting excess nutrients from the dairy benefits the farm, society and the environment. In addition, capturing new sources of fertilizer that can displace conventional synthetic fertilizers promotes a more sustainable food system. Nutrient extraction technologies currently in development could prove to be a critical link in assuring economic feasibility of digesters and sustainable waste management practices.

With tipping fees from food waste, the digester would be economically feasible without generating any revenue from the sale of electricity, but it would be only marginally feasible. Without tipping fees from food waste, economic feasibility could be achieved by investment in a high efficiency generator combined with electricity prices nearly double the rates received in the base scenario. Electricity prices are important and warrant attention both by those considering investment in digester technology and by policy makers. Because of the way public utilities are regulated, additional legislation may be required to align the goals of utilities with small generators of green electricity.

While a change in relationships with utilities is important for the development of this source of revenue, more compensation for power production does not guarantee successful digester investments. This analysis reveals that co-product markets could greatly improve the economic feasibility of digesters for a large audience of potential owners even with current electricity prices. Revenues from carbon credits and fiber sales can provide important supplemental income to digester owners. Both can be enhanced by public policy to promote investment in digestion technology as a holistic approach to renewable energy and sustainable food production. Policy aimed at significantly reducing carbon emissions could result in carbon credit prices approaching those of the European carbon market. Investment in research and development could enhance the quality of the digested fiber product for organic uses and facilitate the movement of extracted nutrients off the farm. The broad benefits of digestion systems warrant careful policy attention when considering the direction of future renewable energy programs. In comparison to the current emphasis on biofuels that use conventional inputs to produce modest gains in energy from renewable sources, digestion is an integrated sustainable technology that contributes to climate, air, and water environmental goals.

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Table 1. Component Cost, Base Scenario Digester

Component	Cost
Pit	19,434.83
Digester	498,912.51
Gas Mixing	27,777.23
Co-Gen	282,087.41
Building	95,637.29
Total Capital Cost	$923,849.27
Other Costs	212,515.30
Total Cost	$1,136,364.57

Table 2. Yearly Cash Flows

Gross Revenue	Year 1	Year 2	Expected
Renewables (Tipping Fees)	82,169	121,564	111,767
Electric Sales	97,088	90,617	97,556
Carbon Credit	4,932	16,425	15,639
Avoided Bedding Cost	18,000	18,000	18,000
Tax Credit	38,835	36,247	39,022
Digested Fiber	10,265	2,372	6,319
Other Income	4,306	2,331	-
Total Revenue	255,595	287,555	288,303
Operating Costs			
Delivery	47,539	18,016	32,778
Building Repairs	7,088	16,058	3,500
Engine Repairs	11,569	25,808	12,032
Equipment Repairs	27,199	49,668	29,000
Oil	24,187	25,795	26,826
Utilities	30,139	16,949	6,000
Legal Fees	9645	751	751
Other Professional Service	11211.51	4,810	8,011
Miscellaneous	11,898	224	4,297
Total Operating Expenses	180,475	158,078	123,194
Income Above Operating Costs	75,119	129,477	165,110

Table 3. Budget System Results

Scenario	NPV $	NPV % Change from Base	IRR %	IRR % Change from Base
Base Scenario	1,372,777		18.68	
Alternative Digester Life, Investment, and Operational Scenarios				
10 Years	553,901	-59.65	14.80	-20.77
30 Years	1,660,989	20.99	18.93	1.35
Increase by 1%	1,186,654	-13.56	18.68	0.00
No Grants	946,099	-31.08	10.18	-45.48
Increase by 250 Cows	1,016,246	-25.97	15.35	-17.85
Decrease by 250 Cows	1,497,113	9.06	20.04	7.28
1,300 Cows, No Food Waste	1,721,941	25.43	23.42	25.40
Electricity Generation Scenarios				
No Power Generation	153,685	-88.80	4.50	-75.91
Increase by $0.01/kwh	1,692,841	23.32	21.63	15.82
U.S. average $0.0877/kwh	2,579,420	87.90	29.38	57.30
327 kwh Output	1,990,036	44.96	22.44	20.14
Tipping Fee Scenarios				
No Tipping Fees	-1,994,344	-245.28	-	-
Decrease Tipping Fees by 50%	-142,032	-110.35	-0.89	-104.77
Carbon Credit Scenarios				
No Carbon Trading	1,108,807	-19.23	16.30	-12.72
25% Commission	1,519,023	10.65	20.19	8.11
ECX Prices	2,513,094	83.07	28.86	54.52
Fiber Scenarios				
No Fiber Sales	1,262,199	-8.06	17.63	-5.63
All Fiber, $13.50/ton	1,966,705	43.26	22.17	18.67
All Fiber, $20.00/ton	2,462,566	79.39	25.34	35.68

APPENDIX A

SURVEY INSTRUMENT

APPENDIX A

SURVEY INSTRUMENT

The survey was conducted in May and June of 2006. Three mailings took place in three stages: the survey was mailed, two weeks later a reminder postcard was sent to non-responders, and two weeks following the postcard a second mailing of the non-responders was mailed. The response rate statistics and a summary of the collected survey data are available in Appendix B.

Included in this appendix are the two cover letters and the survey instrument. Note that the eighth page of the survey has six variations. These variations were randomly assigned.

Cover Letter: First Mailing

Dear Northwest Dairy Farmer,

We are asking for your participation in a survey on anaerobic digestion that is part of research on innovative manure management practices being conducted by the **School of Economic Sciences** at **Washington State University**. Until recently, anaerobic technology has not been an economically viable technology for waste management in the Northwest. However, with recent advances in the technology and potential incentives, it may soon have greater benefit for Northwest farms, especially given increased problems associated with urban expansion and environmental concerns.

We are asking you to complete this survey so we may better understand what technologies Northwest farmers use to manage their dairy waste and your interest in anaerobic digestion technology.

Your participation in this survey should take about 25 minutes. You are free to skip any questions you find unclear or objectionable.

Your responses will remain **strictly confidential**. Confidentiality means that your name will be kept separate from the survey at all times, making this a low risk survey. Each survey is coded to a master list for the purpose of determining who has not responded. Once we achieve a statistically adequate response rate, the master list will be destroyed. The results of the survey will never, under any circumstance, be reported in terms of individual farms or respondents.

By completing the survey you are acknowledging that you are at least 18 years of age and that you have consented to voluntary participation in this project. This survey is being conducted by WSU researchers, and the study has been reviewed and approved by the WSU Institutional Review Board. If you have questions about your rights as a participant please contact the WSU IRB at 509-335-9661 or irb@wsu.edu. If you have questions or concerns regarding the study please contact Dr. Richard Shumway at 509-335-1007 or shumway@wsu.edu.

Thank you for your time and consideration.

Sincerely,

C. Richard Shumway
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Cover Letter: Second Mailing

Dear Northwest Dairy Farmer,

This is the **second mailing** of the Anaerobic Digestion Adoption and Manure Management Survey. If you have already responded to this survey, we thank you for your participation, please discard the included copy.

We are asking for your participation in a survey on anaerobic digestion that is part of research on innovative manure management practices being conducted by the **School of Economic Sciences** at **Washington State University**. Until recently, anaerobic technology has not been an economically viable technology for waste management in the Northwest. However, with recent advances in the technology and potential incentives, it may soon have greater benefit for Northwest farms, especially given increased problems associated with urban expansion and environmental concerns.

We are asking you to complete this survey so we may better understand what technologies Northwest farmers use to manage their dairy waste and your interest in anaerobic digestion technology.

Your participation in this survey should take about 25 minutes. You are free to skip any questions you find unclear or objectionable.

In this second mailing, your responses will remain **anonymous**. Anonymity means that we can not associate your name with your survey response, making this a low risk survey. The results of the survey will never, under any circumstance, be reported in terms of individual farms or respondents.

By completing the survey you are acknowledging that you are at least 18 years of age and that you have consented to voluntary participation in this project. This survey is being conducted by WSU researchers, and the study has been reviewed and approved by the WSU Institutional Review Board. If you have questions about your rights as a participant please contact the WSU IRB at 509-335-9661 or irb@wsu.edu. If you have questions or concerns regarding the study please contact Dr. Richard Shumway at 509-335-1007 or shumway@wsu.edu.

Thank you for your time and consideration.

Sincerely,

C. Richard Shumway
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Anaerobic Digester Adoption and Manure Management Survey

Thank you for participating in the Anaerobic Digester Adoption and Manure Management Survey, administered by the **School of Economic Sciences** at **Washington State University**.

What is an anaerobic digester?

> An anaerobic digester is an enclosed tank through which manure is passed and broken down by naturally occurring bacteria. The process produces heat and releases biogas, which can be flared off or used to power a generator that produces electricity for use on the farm or for sale to a local utility. Heat produced can be recycled to maintain the required digester temperature or used for space or water heating elsewhere on the farm.

WASHINGTON STATE UNIVERSITY

World Class. Face to Face.

Please return the questionnaire in the postage-paid return-addressed envelope provided.

ODFA

Washington State Dairy Federation

IDAHO DAIRYMEN'S ASSOCIATION, INC

Your response to this survey is completely confidential.
You may skip any questions you find unclear or objectionable.

Questions about Your Dairy

A1. What was the **total number of acres** on which you grazed animals, raised crops, and operated your dairy in 2005?

Owned acres ___________ Rented acres ___________

Of your total acreage in 2005,

A2a. How many acres were used to **pasture cows**?	___________ acres
A2b. How many acres were planted in **alfalfa or grasses**?	___________ acres
A2c. How many acres were planted in **corn**?	___________ acres
A2d. How many acres were planted in **grains**?	___________ acres
A2e. How many acres were planted in other **crops**?	___________ acres

Which other crops were produced?____

Of your total acreage in 2005,

A3a. On how many acres did you **apply manure**?	___________ acres
A3b. On how many acres did you **apply other fertilizer**?	___________ acres
A3c. How many acres are within five miles of a **town** or **subdivision**?	___________ acres
A3d. For how many acres is **odor control** important?	___________ acres
A3e. How many acres are in close proximity to water sources where **water quality** is a concern?	___________ acres

Comments: ____

A4a. Do you have any business operations other than your dairy (e.g., pasteurization and cheese making, packaging, milling, greenhouse, swine, sheep, beef, etc.) that utilize large amounts of energy and/or produce manure?

☐ Yes (please see **A4b)** ☐ No (please skip to **A5)**

A4b. If you answered YES to A4a, please briefly describe the operations: ___________________________

____

A5a. Do you **plan to change the number of acres** you operate (own and rent) within the next five years? (please check one box)

Sell out	☐	→ Skip to **A6a**
Decrease number of acres	☐	→ Proceed to **A5b**
No change, my farm acreage is just right	☐	→ Skip to **A6a**
Expand number of acres, but there are issues	☐	→ Proceed to **A5b**
Expand number of acres, no serious issues expected	☐	→ Skip to **A6a**

A5b. Is the reason for your answer in **A5a** related to… (check any that apply)

☐ Urban expansion ☐ Air quality issues ☐ Water quality issues ☐ Retirement planning
☐ Legal issues ☐ Other: ______________________________

A6a. What was your **total number of milking cows** as of May 1, 2006? ______________

A6b. What was your **total number of non-milking cows** as of May 1, 2006? ______________

A7. How much milk was produced on your farm May 1, 2006? ____________ pounds

A8a. Do you plan to **change the size of your herd** within the next five years? (please check one box)

Sell out	☐	→ Skip to **A9**
Decrease herd size	☐	→ Proceed to **A8b**
No change, my herd size is just right	☐	→ Skip to **A9**
Expand herd size, but there are issues	☐	→ Proceed to **A8b**
Expand herd size, no serious issues expected	☐	→ Skip to **A9**

A8b. Is the reason for your answer in **A8a** related to (check any that apply):

☐ Urban expansion ☐ Air quality issues ☐ Water quality issues ☐ Retirement planning
☐ Legal issues ☐ Other: ______________________________

	Winter	Spring	Summer	Fall
A9. For each season in 2005, please indicate how many animals were **confined** in freestall barns or dry lots **where manure was routinely collected**.	______	______	______	______

A10. After your manure was collected and stored, how many **hours per week** were spent managing post collection dairy wastes in June 2005? (please check one box)

☐ less than 10 hours ☐ 10 to 19 hours ☐ 20 to 39 hours ☐ 40 hours or more

A11. For your **confined cows** in 2005, what percentage of the given beddings did you use?

Straw	________%
Sawdust / woodchips	________%
Sand	________%
Compost	________%
Dry lot	________%
Other: ___________________	________%

A12. What percent of manure is collected on your farm using the following practices?

Scrape:	________%
Flush:	________%
Other: _____________	________%

A13. What percentage of total manure is applied to your land? ________%

A14. Remember all questions in this survey are confidential, and any can be skipped.

Has your farm been involved in legal action concerning air quality? ☐ Yes ☐ No
Has your farm been involved in legal action concerning water quality? ☐ Yes ☐ No

Questions about New Technologies

B1. Have you considered adopting anaerobic digestion technology on your farm? (check one box)

☐ I am in the process of planning and constructing an anaerobic digester.
☐ I currently use anaerobic digester technology on my farm.
☐ I have used anaerobic digester technology on my farm in the past.
☐ Serious consideration.
☐ Some consideration.
☐ Minor consideration.
☐ Not at all.
☐ Other: ____

B2. How would you describe your level of knowledge regarding anaerobic digestion? (check any that apply)

☐ This is my first time hearing about anaerobic digestion.
☐ I have heard about anaerobic digestion from other farmers or industry people.
☐ I have read about anaerobic digestion in trade publications and journals.
☐ I have seen an anaerobic digester in operation.
☐ Anaerobic technology has been explained to me by an expert.
☐ I have researched anaerobic digestion extensively.
☐ Other: ____

B3. Regardless of your current plans, if you were considering adopting a technology such as an anaerobic digester, would the following **types of information** influence your decision?

Information on…	**Definitely No**	**Probably No**	**Probably Yes**	**Definitely Yes**
Available grant money	☐	☐	☐	☐
Related research	☐	☐	☐	☐
Water quality impacts	☐	☐	☐	☐
Air quality impacts	☐	☐	☐	☐
Expected profits/losses	☐	☐	☐	☐
Expected maintenance costs	☐	☐	☐	☐
Required labor/management time	☐	☐	☐	☐
Initial capital cost	☐	☐	☐	☐
By-product uses/markets	☐	☐	☐	☐
Testimony from experienced operators	☐	☐	☐	☐

Other/Comment: ____

B4. Regardless of your current plans, if you were considering adopting a technology such as an anaerobic digester, how influential would the following **investment considerations** be for your decision?

Investment Consideration	**No Influence**	**Minimal Influence**	**Influential**	**Make or Break the Decision**	**Don't Know**
Return on investment	☐	☐	☐	☐	☐
Payback period	☐	☐	☐	☐	☐
Government grant levels	☐	☐	☐	☐	☐
Investment cost per cow	☐	☐	☐	☐	☐
Interest rate on construction loan	☐	☐	☐	☐	☐
Labor/management time required	☐	☐	☐	☐	☐
Income from by-product sales	☐	☐	☐	☐	☐
Sale of digester services to other farmers or industries	☐	☐	☐	☐	☐
A contract in which an outside firm builds, owns, operates, and maintains the digester at no net cost or benefit to the farmer (BOOM contract)	☐	☐	☐	☐	☐

Other/Comment: ____

Regardless of whether you are now considering a change in your current manure management practices, please answer the following questions as though you were going to install a digester:

The by-products of anaerobic digestion have the potential to be sold as value-added products, such as bedding, compost, peat moss substitutes and slow-release fertilizers. These products would require additional time and money for preparation, marketing, and distribution. The sale of the by-products would provide additional income streams.

C1. How would you most likely handle the following value-added processes?

Value-added Process	Completely Outsource	Outsource More than Half	Outsource Less than Half	Not Outsource	Don't Know
Preparation	☐	☐	☐	☐	☐
Marketing	☐	☐	☐	☐	☐
Distribution	☐	☐	☐	☐	☐

C2. Please indicate your level of concern with the following by-product market commitments:

By-Product Marketing Issues	Large Concern	Moderate Concern	Not a Concern
Time (for maintenance, training, sales arrangements, etc.)	☐	☐	☐
Cost (for additional capital costs, maintenance, etc.)	☐	☐	☐
Skills (for marketing, technical training, etc.)	☐	☐	☐

C3. If you were considering an anaerobic digester for your farm, would you pursue a joint venture with other confined animal operations in your area?

☐ Yes
☐ No, this is not a desirable arrangement for my farm
☐ No, because there are no other confined animal operations in my operating area

C4. Please indicate how concerned you are with the following issues related to joint ventures:

Joint Venture Issue	Large Concern	Moderate Concern	Not a Concern	No Opinion
Biosecurity	☐	☐	☐	☐
Legal arrangements	☐	☐	☐	☐
Transportation/hauling	☐	☐	☐	☐
Long-term viability	☐	☐	☐	☐
Regulatory constraints	☐	☐	☐	☐

Other/Comment: ____

*Hypothetical Question***:** Suppose you have a 1,500 cow dairy. This dairy is currently experiencing environmental difficulties related to the storage of manure. A change must be made. Three investment alternatives are provided. Accompanying each alternative is the most likely return on investment (ROI) for each alternative and the range the actual ROI will fall within. For each investment scenario, please rank each investment alternative in the far right column using a scale of 1 (most desirable) to 3 (least desirable). Also, please check one box to indicate the most preferred alternative for each investment scenario.

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Investment 1.

Alternative	Investment	Odor Level	Expected ROI	Possible ROI Range	Risk Level	Your Ranking
Lagoon	160	High	-2%	-4 to 0%	Low	
Digester A	650	Low	4%	2 to 6%	Low	
Digester B	800	Low	6%	4 to 8%	Low	

Please pick the alternative you would prefer:

☐ Lagoon ☐ Digester A ☐ Digester B

Investment 2.

Alternative	Investment	Odor Level	Expected ROI	Possible ROI Range	Risk Level	Your Ranking
Lagoon	160	High	-2%	-4 to 0%	Low	
Digester A	800	Low	6%	2 to 10%	High	
Digester B	1000	Low	8%	6 to 10%	Low	

Please pick the alternative you would prefer:

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Investment 3.

Alternative	Investment	Odor Level	Expected ROI	Possible ROI Range	Risk Level	Your Ranking
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Digester B	800	Low	6%	4 to 6%	Low	
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Please pick the alternative you would prefer:

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C5. Please indicate which of the following benefits from digestion technology is most important to **you and your farm** (check only one):

☐ Odor Reduction ☐ Enhanced Nutrient Management
☐ By-product Sales ☐ Building Community Relationships

C6. Please indicate which of the following benefits from digestion technology is most important for the **dairy industry as a whole** (check only one):

☐ Reducing Greenhouse Gases ☐ Enhanced Nutrient Management
☐ Alternative Fuel Production ☐ Publicity

Questions on Background/Demographics:

D1. Gender? ☐ Male ☐ Female

D2. Age?

☐ < 30	☐ 31-35	☐ 36-40	☐ 41-45	☐ 46-50
☐ 51-55	☐ 56-60	☐ 61-65	☐ 66-70	☐ > 70

D3. Please enter the zip code located nearest to your home farm operations: ________________________

D4. Do you plan to retire or exit the dairy industry within the next 5 years?

☐ Yes ☐ No

D5. When you do retire, are there any members of the next generation who are likely to continue dairying after you retire?

☐ Yes ☐ No

D6. How long has your dairy farm been in operation? _________

D7. How many years have you been managing the dairy farm? _________

D8. What is the highest level of education you have completed?

☐ Some high school
☐ High school graduate
☐ Some technical school or college
☐ Technical school or community college graduate
☐ College graduate
☐ Master's degree
☐ Doctoral degree

D9. What areas of your farm are you involved with the most? (check all that apply)

☐ Herd management and production
☐ Crop management and production
☐ Finance and accounting

D10. Which of the following best describes your farming operation?

☐ Part of a non-family farm corporation or partnership
☐ Part of a family farm corporation or partnership
☐ Single proprietorship

D11. What is your level of ownership for this farm?

☐ Full owner (with spouse)
☐ Part owner
☐ Non-owner, manager

D12. Do you or your spouse/partner work off the farm?

☐ Self full time
☐ Self part time
☐ Spouse/partner full time
☐ Spouse/partner part time
☐ No

D13. What is the source of your household income?

☐ All farm income
☐ Mostly from operating the farm
☐ Mostly from off-farm sources
☐ Roughly the same from farm and off-farm sources

D14. What were your gross receipts from farming in 2005?

☐ Less than $250,000
☐ From $250,000 to $500,000
☐ From $500,000 to $1,000,000
☐ From $1,000,000 to $2,000,000
☐ From $2,000,000 to $4,000,000
☐ From $4,000,000 to $6,000,000
☐ From $6,000,000 to $8,000,000
☐ From $8,000,000 to $10,000,000
☐ If over $10,000,000, please indicate gross receipts to the nearest million: __________

We appreciate any thoughts you might have on digestion technology. Please feel free to use the space below and the following page to express any thoughts, ideas, reservations, and opinions you may have concerning digestion technology.

Thank you for taking the time to complete this survey.
Your response is invaluable to our research.

If you have any comments about this survey, anaerobic digesters, and/or manure management, please feel free to write them in the space below or on a separate page.

Please return the questionnaire in the postage-paid return-addressed envelope provided.

APPENDIX B

SURVEY RESULTS

APPENDIX B

SURVEY RESULTS

Response Summary

	Surveyed	Response	Response % of Mailing	Response % of State Mailing
Total Surveyed:	1,152	254	22%	
Usable Surveys:		230	20%	
Washington:	468	133		28%
Oregon:	337	62		18%
Idaho:	347	30		9%
State Unknown:		5		
Trial Mailing Responses:		10		
First Mailing Responses:		142		
Second Mailing Reponses:		77		

A1, A2, and A3. Acreage Ownership and Use

	Mean	StDev	Min	Q1	Median	Q3	Max	Missing
A1. Owned Acres	324	534	0	89	180	350	5500	5
A1. Rented Acres	138	308	0	0	50	155	3000	7
Total Acres	461	637	5	145	300	500	5500	7
A2a. Acres in Pasture	99	251	0	0	40	100	3000	5
A2b. Acres in Alfalfa	179	250	0	19	120	235.3	2500	12
A2c. Acres in Corn	123	262	0	0	30	140	2200	11
A2d. Acres in Grain	35	160	0	0	0	0	1400	6
A2e. Acres in Other Crops	28	123	0	0	0	0	1500	10
A3a. Acres with Manure Application	263	324	0	98	200	300	3200	1
A3b. Acres Fertilized	175	473	0	0	30	157.5	5000	2
A3c. Acres within 5 Miles of Town	235	416	0	0	115	325	3750	5
A3d. Acres where Odor Control is Important	208	391	0	0	50	285	3200	8
A3e. Acres where Water Quality is a Concern	187	244	0	0	100	300	1100	20

A4. Other Operations: 14 Yes, 1 Missing

A5. Expected Change in Acreage	
Selling Out	10
Decrease Number of Acres	23
No Change	117
Expand Number of Acres (w/ issues)	30
Expand Number of Acres (w/out issues)	43
Missing	7

A6 and A7. Milk Cows and Production

	Mean	StDev	Q1	Median	Q3	Maximum	Missing
A6a. Number of Milk Cows	574	1048	125	261	520	10000	3
A6b. Number of Non-Milking Cows	168	326	25	50	150	2500	3
Total Number of Cows	738	1235	164	330	680	10500	3
A7. Milk Production / Day	41316	78053	7500	16000	40000	700000	3
Milk per Cow per Day	65	15	57	66	75	94	3

A8. Expected Herd Change	
Selling Out	18
Decrease Herd Size	10
No Change	98
Expand Herd Size (w/ issues)	42
Expand Herd Size (w/out issues)	60
Missing	2

A10. Hours Spent Managing Manure (weekly)	
< 10	90
10 to 19	70
20 to 39	27
> 40	34
Missing	9

A11, A12 and A13. Farm Manure Handling

	Mean	StDev	Q1	Median	Q3	Max	Missing
A11. % Straw	24	37	0	0	29	100	2
A11. % Woodchips	54	46	0	80	100	100	2
A11. % Sand	7	23	0	0	0	100	3
A11. % Compost	7	22	0	0	0	100	3
A11. % Dry lot	4	14	0	0	0	100	3
A11. % Other Bedding	4	18	0	0	0	100	3
A12. % Scrape	81	34	80	100	100	100	0
A12. % Flush	16	32	0	0	0	100	0
A12. % Other Collection Means	3	12	0	0	0	100	1
A13. % Farm Manure Applied to Land	81	31	74	100	100	100	16

B1. Interesting in Adopting Anaerobic Digestion

Using Digester	2
Planning/Constructing Digester	4
Previously Used Digester	0
Seriously Considering Digester	27
Somewhat Considering Digester	45
Minor Consideration for Digester	57
Not Considering Digester at all	83
Other	9
Missing	3

B2. Sources Referenced for Anaerobic Digestion Information*

First Time	13
Other Farmers or Industry People	76
Trade Publications	157
Seen in Operation	63
Explained by an Expert	53
Researched Extensively	21
Other Sources	6
Missing	1

* includes multiple responses, $\Sigma \neq 230$

B3. Information Influential on Decision Making

	Definitely No	Probably No	Probably Yes	Definitely Yes	Missing
Available Grant Money	7	14	59	133	17
Related Research	7	22	93	74	34
Water Quality	9	29	84	77	31
Air Quality	7	32	84	77	30
Expected Profit/Loss	6	9	45	148	22
Expected Maintenance	6	10	48	141	25
Time Requirement	5	12	50	136	27
Initial Capital Cost	7	10	29	162	22
By-product/Use Markets	7	20	82	92	29
Testimony from Current Operators	5	24	75	92	34

B4. Investment Considerations Influential on Decision Making

	No Influence	Minimal Influence	Influential	Make or Break	Don't Know	Missing
ROI	4	12	88	101	4	20
Payback Period	4	12	104	81	7	22
Government Grants	5	17	106	76	5	21
Cost per Cow	4	16	112	61	8	26
Interest on Loan	5	25	122	44	10	23
Time Requirement	3	18	128	51	8	22
Income from By-products	7	36	121	31	9	24
Income from Services	31	62	74	13	20	30
Outside Build/Operate Contract	16	26	106	29	33	20

C1. Respondent's Handling of Value-added Processes

	Outsource 100%	Outsource > 50%	Outsource < 50%	Outsource 0%	Don't Know	Missing
Preparation	42	24	21	55	67	21
Marketing	61	38	17	23	69	22
Distribution	61	37	18	24	68	22

C2. Concerns Regarding By-product Marketing

	Large Concern	Moderate Concern	Not a Concern	Missing
Time	126	70	14	20
Cost	150	50	9	21
Skill	105	79	24	22

C3. Interest in Joint Ventures

Yes	105
No, not desirable	65
No, no confined animal operations in my area	45
Missing	15

C4. Concern Regarding Issues with Joint Ventures

	Large Concern	Moderate Concern	Not a Concern	No Opinion	Missing
Biosecurity	76	97	30	9	18
Legal Arrangements	114	79	10	8	18
Transportation	99	83	22	6	20
Long-term Viability	131	66	7	7	19
Regulatory Constraints	104	82	14	11	19

C5. Why Digestion is Important for Respondent's Farm

Odor Reduction	37
Enhanced Nutrient Management	78
By-product Sales	41
Building Community Relationships	17
Missing	57

C6. Why Digestion is Important for the Dairy Industry

Reducing Green House Gases	13
Enhanced Nutrient Management	60
Alternative Fuel Production	68
Publicity	38
Missing	51

D1. Gender

Male	189
Female	30
Missing	11

D2. Age

< 30	5
31-35	6
36-40	13
41-45	35
46-50	37
51-55	48
56-60	34
61-65	21
66-70	14
>70	8
Missing	10

D3. Most Popular Zip Codes

Lynden	21
Tillamook	10
Everson	10
Enumclaw	8
Stanwood	7

D4 and D5. Farm Future

D4. Planning to Retire within 5 Years	53
D4. Not Planning to Retire within 5 Years	162
Missing	15
D5. Next Generation Likely to Continue Farming	117
D5. Not Likely that Next Generation will Continue to Farm	84
Missing	29

	Next Generation Likely	Next Generation Unlikely
Retiring	17	31
Not Retiring	95	47

D6. Years Farm in Operation

Mean	42
Median	35
Minimum	1
Maximum	150
Missing	9

D7. Years Respondent Managing the Farm

Mean	23
Median	25
Minimum	0
Maximum	63
Missing	8

D8. Education

Some high school	9
High school graduate	41
Some technical school or college	62
Technical school or community college graduate	23
College graduate	73
Master's degree	7
Doctoral degree	9
Missing	6

D10. Business Type

Non-Family Corporation or Partnership	4
Family Corporation or Partnership	108
Single Proprietorship	113
Missing	5

D11. Ownership Status

Full Owner	142
Part Owner	108
Non-Owner	113
Missing	14

D12. Off-Farm Work

	Count	Missing
Respondent Full Time	10	7
Respondent Part Time	8	7
Spouse, Partner Full Time	32	7
Spouse, Partner Part Time	31	7
None	149	8
	230	

D13. Respondent Income Source

All Farm Income	141
Mostly Farm Income	37
Roughly 50 / 50	21
Mostly Off-Farm Income	15
Missing	16

D14. Distribution of Gross Receipts

< 250,000	23
250,000 to 500,000	40
500,000 to 1,000,000	41
1,000,000 to 2,000,000	43
2,000,000 to 4,000,000	25
4,000,000 to 6,000,000	9
6,000,000 to 8,000,000	5
8,000,000 to 10,000,000	4
> 10,000,000	10
Missing	27