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Staff Paper Series

REVIEW OF THE LITERATURE ON THE ECONOMICS OF CENTRAL ANAEROBIC DIGESTERS

by
Fantu Bachewe, William Lazarus, Philip Goodrich, Matt Drewitz, and Becky Balk

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ABSTRACT

Minnesota can improve the utilization of manure and organic wastes via the production of biogas that can be used to produce heat and electricity. Denmark serves as a role model for Minnesota in the number of central anaerobic digesters that it supports. During anaerobic digestion methane is produced when naturally occurring anaerobic bacteria decompose organic matter in the absence of oxygen. This process produces what is called biogas, which usually is a mixture of 55 – 65 percent methane plus carbon dioxide with trace gases such as hydrogen sulfide. Co-generation using manure and other feedstocks can produce more energy than manure alone. Central digesters are more likely to process wastes from food processing plants and other sources resulting in the need for more specialized unloading facilities and larger storage spaces. Digesters can be owned by farmers or consumers cooperatives, third party/non-farming investor(s), state or municipal government, or established as a cooperative or limited liability corporation. Problems associated with centralized digester operation include capital constraints, low profitability, lower-than-expected waste availability, electricity connection and pricing, and waste disposal constraints.

EXECUTIVE SUMMARY

This review is prepared for a wide audience. The motivation for its preparation is a belief that Minnesota can improve the utilization of the manure and organic wastes that are byproducts of livestock farming and other activities, via the production of biogas that can be used to produce heat and electricity. A comparison is made between Minnesota and Denmark due to the many similarities between the two entities. Denmark serves as a role model for Minnesota in the number of central anaerobic digesters that it supports while Minnesota has none even though in terms of livestock and other organic waste production Minnesota has a similar potential to benefit from the development of central anaerobic digesters.

Anaerobic digestion is an alternative to traditional manure management. During anaerobic digestion methane is produced when naturally occurring anaerobic bacteria decompose organic matter in the absence of oxygen. This process produces what is called biogas, which usually is a mixture of 55 – 65 percent methane and 35 – 45 percent carbon dioxide with some other trace gases such as hydrogen sulfide in small amounts.

Central anaerobic digesters are different from anaerobic digesters that process single farm manure due to the variations in wastes they process. Typically central anaerobic digesters are larger in size than single farm anaerobic digesters. They are more likely to process wastes from food processing plants and other sources resulting in the need for more specialized unloading facilities and larger storage spaces. They also are managed and organized to accommodate large scale digestion.

The works discussed in the report suggest that the following items will increase the likelihood of the success of central anaerobic digesters in Minnesota:

i) A sufficient density of cow manure or other organic material is available;
ii) Motivation for farmers to participate in central anaerobic digesters from both a financial and a societal point of view;
iii) Accurate estimates of the costs of transporting the manure or other organic wastes are present, as transportation will constitute a sizable cost in the life of a central anaerobic digester;
iv) Public sector support of central anaerobic digester facilities by federal, state, and local governments is present due to the recognition of external benefits such as environmental, health, “infant industry” arguments, differences between individual and social discount rates, and energy security.
v) Power purchase agreement terms and conditions negotiated with utility companies for electricity or gas generated for sale by central anaerobic digesters is supportive of financial success.

Co-generation using manure and other feedstocks can produce more energy than manure alone. Additionally, there are important food processing sub-sectors that can significantly contribute to co-generation of wastes in Minnesota, however, further study is needed to determine the economic feasibility. The potato and sugar beet processing industries can supply spoiled and rejected raw material, substandard output, and wastewater to central anaerobic digesters depending on the feasibility of transportation. Organic wastes from dairy processing plants, meat processing and rendering facilities, catering, institutional and domestic kitchens, and restaurants are also potentially useful. Fats and oils have been identified as having high potential for addition to digesters and several digesters of Danish design in the United States are adding up to 10 percent oil to the animal manure to increase the gas output. Other sources include byproducts

from the developing ethanol industry, crop residues, paper mill processing wastes and even crops grown directly for energy such as corn silage or grain sorghum.

Review of costs and benefits associated with central digestion suggest that it may be difficult to infer future costs and benefits from literature values because of the wide variation and changing market conditions. Costs of manure transport to the central digester and the spent material back to the land were especially difficult to calculate.

Since central anaerobic digesters are more likely to process non-farm organic wastes they benefit other sectors of the economy. But the cost involved in transporting influent and effluent is an inherent disadvantage in the establishment of central anaerobic digesters.

Central anaerobic digesters can be set up under several ownership arrangements. They can be owned by farmers or consumers cooperatives, third party/non-farming investor(s), state or municipal government, or established as a cooperative or limited liability corporation. Currently the cost of establishing and operating central anaerobic digesters on a cash basis is high compared to their monetary returns. However, assigning monetary value for all external benefits of central digestion plants would likely result in total long term benefits equal or greater than the costs incurred in construction and operation.

Problems associated with centralized digester operation include capital constraints, low profitability, lower-than-expected waste availability, electricity connection and pricing, and waste disposal constraints. Local, federal, and state government policy instruments that can influence the establishment, operation, and profitability of central anaerobic digesters include investment policies and grants towards initial investment allowing farmers and other investors to pass the initial hurdle of acquiring the critical level of investment; tax and subsidy policies that encourage the establishment of central anaerobic digesters and their economic feasibility; electricity connection and pricing policies that will attract new investors; support for farmer and consumer cooperatives to establish new digester generator systems; and waste disposal and environmental policies that will induce farmers and processing plants to seek anaerobic digestion as a remedy.

Waste disposal and environmental policies that encourage the establishment of central anaerobic digesters are the most frequently suggested policies in the literature. There is a wide variety in purpose and in form of these policies. Some initiatives started out to reduce greenhouse gas emissions; others started from a decision to recycle a specific amount of organic wastes by a given time; and, yet others, to protect water resources, the environment, and the public from undesirable aspects of dairy farming.

Key words: anaerobic digester, methane, biogas, economics

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CHAPTER I – INTRODUCTION 1
1.1 Intended Audience, Types of Sources Reviewed and Comments about Reliability. 1
1.2 Background Information 2
1.3 Motivations and Objectives of the Literature Review 3
CHAPTER II – TYPES OF CENTRAL ANAEROBIC DIGESTERS 6
2.1 Size of Central Anaerobic Digesters 6
2.2 Types of Wastes Processed 7
2.3 Forms of Central Anaerobic Digester Ownership 11
2.4. Technological Considerations 12
2.5 Costs of Central Anaerobic Digesters 14
2.6 Costs of Manure Transportation 20
CHAPTER III – ADVANTAGES ASSOCIATED WITH CENTRAL ANAEROBIC DIGESTERS 26
3.1 Economies of scale 26
3.2 Environmental Benefits 28
CHAPTER IV – PROBLEMS ASSOCIATED WITH OPERATING CENTRAL ANAEROBIC DIGESTERS AND POLICY OPTIONS FOR ADDRESSING THOSE PROBLEMS 32
4.1 Investment, Investment Grant, Tax, and Subsidy Policies 32
4.2 Electricity Connection and Pricing Policies 34
4.3 Waste Disposal and Environmental Requirement Policy 38
CHAPTER V - CONCLUSIONS 41
REFERENCES 42

CHAPTER I – INTRODUCTION

There is an increased awareness of the potential benefits of producing electricity from the biogas created by manure digesters within Minnesota. However, due to the need for economies of scale to be cost effective manure digesters may be cost prohibitive for most Minnesota farms. One potential solution to the capital cost limitation for smaller farms is to spread the cost among several farms by using a centrally located facility. Yet, this solution has its own challenges to being economically competitive including the expense and complexity of transporting manure or biogas.

In November 2005 the Legislative Commission on Minnesota's Resources funded the "Manure Methane Digester Compatible Wastes and Electrical Generation" project. The project had two objectives. The first was to review previous feasibility studies done in other regions of the United States and in other countries. The second was to analyze the logistics, economics and technical feasibility for multi-farm manure digestion. This literature review is part of the feasibility study.

1.1 Intended Audience, Types of Sources Reviewed and Comments about Reliability

This report is intended for an audience of farmers, consultants, and local or state policymakers interested in doing a preliminary economic evaluation of an agriculturally related central digester. The sources reviewed in this report include refereed journal articles as well as extension monographs, slide sets, web sites of public entities and private firms, consultant feasibility analyses, government information bulletins, and university research project reports.

The information in such a wide variety of sources differs in reliability, so readers are cautioned to consider the source when making use of the information. Refereed journal articles are usually considered to be the most reliable because the review process corrects most errors. However, the journal articles reviewed tended to be quite narrowly focused on anaerobic digester topics of more interest to researchers than to the broader public audience described above. The result is that all but one of the sources cited in this report fall into the other categories.

Readers need to keep in mind that some of the literature cited includes performance and cost information for digesters that have been up and running for several years while other sources describe feasibility analyses of digesters that have not yet been installed. Only feasibility analyses that, in the authors' judgment, appear to be accurate and reliable are included in this report. Nevertheless, some sources such as the Devore slides show that actual digester operating performance does not always match pro forma projections.

1.2 Background Information

Anaerobic digestion is an alternative to traditional manure management. During anaerobic digestion methane is produced when naturally occurring anaerobic bacteria decompose organic matter in the absence of oxygen. This process produces what is called biogas, which usually is a mixture of 55 – 65 percent methane and 35 – 45 percent carbon dioxide with some other trace gases such as hydrogen sulfide in small amounts [Burke, 2001]. The methane produced in this process can be used to generate electricity or for heating purposes. Also, in favorable circumstances there is the potential to purify the methane into a marketable, natural gas grade biogas that can be used for household and industrial consumption. Generating renewable energy with this process leads to reduced odor pollution, fewer pathogens and reduced biochemical oxygen demand. In addition, little change occurs in the fertilizing value of the manure and organic matter that passes through the process.

Anaerobic digesters create a favorable, controlled environment for bacteria to decompose organic matter under three different temperature regimes. Anaerobic digesters that work between temperatures of 95 and 105 degrees Fahrenheit (F) are called “mesophilic” while those that work between 120 and 140 degrees F are known as “thermophilic” [Lazarus and Rudstrom, 2007]. “Psycrophilic” digestion occurs naturally at temperatures lower than 95 degrees F in ponds, swamps and lagoons but is not very efficient. However, in some warmer locations covered lagoon digesters are successfully used to degrade organic manures and produce energy. The organic matter that can be processed in anaerobic digesters include manure from dairy, swine, beef, and poultry, wastewater sludge, municipal solid waste, food industry wastes, grain industry and crop residues, paper and pulp industry wastes, or any other biodegradable matter.

Central anaerobic digesters are different from anaerobic digesters that process single farm manure due to the variations in wastes they process. Typically central anaerobic digesters are larger in size than single farm anaerobic digesters. They are more likely to process wastes from food processing plants and other sources resulting in the need for more specialized unloading facilities and larger storage spaces. They also are managed and organized to accommodate large scale digestion.

As discussed in chapter three, the larger size gives central anaerobic digesters economies of scale advantages. The larger scale of these facilities also forces central anaerobic digester to increase their storage capacity for organic materials before and after digestion. Central anaerobic digesters presented in many of the works we reviewed do the additional job of separating the waste after digestion and most importantly, as the literature in this area shows, most of the central anaerobic digesters pasteurize the digestate to kill pathogens. The primary factor that can make or break the economic feasibility of central anaerobic digesters is the distance involved in transporting the manure and wastes from the sites where it was created to the central anaerobic digester plant.

This literature review is organized as follows. In chapter two the main types of central anaerobic digesters are outlined including various sizes, forms of ownership, and technological and spatial considerations. Chapter three covers the advantages that are attributed to centralized digesters. Discussion in this chapter includes the advantages that are attributed to all digesters with special attention given to the advantages associated with central anaerobic digesters. The fourth chapter deals with problems associated with establishing central anaerobic digesters. While financial constraint is an obvious problem this chapter will also review such problems as lack of reliable and consistent sources of wastes, stringent local and federal policies, and other issues that are associated with the planning and execution of a central anaerobic digester project. The last chapter, chapter five, deals with actions local, state, and federal governments can take to foster the establishment of central anaerobic digesters. This includes legislation, tax and subsidy provisions, grants, and special laws on electricity prices that encourage the establishment of more central anaerobic digesters.

1.3 Motivations and Objectives of the Literature Review

The motivation for this literature review is the possibility of establishing central anaerobic digesters in Minnesota that would take advantage of the manure produced by dairy and other animal farming activities, and wastes from other sources in the state. The possibility is apparent when comparing Minnesota with countries of comparable economic and social aspects and with other states in the United States that are preparing to operate centralized digesters.

Internationally, Minnesota is comparable to Denmark in many aspects. Denmark has a population of 5.4 million, a land area of 42,930 square kilometers, and a gross national per capita income of $35,000 in 2000, while Minnesota's population is 4.9 million, its size is 218,601 square kilometers, more than five fold than that of Denmark, and its gross national per capita income was $31,935 in 2000 [Norfelt, 2003]. In 2000 Denmark had 1.85 million cattle of which 614,000 were dairy cows and 11.5 million pigs and hogs. In 2003 Minnesota had 2.5 million cattle and calves of which 463,000 were dairy cows, 5.9 million pigs and hogs, and the state produced more turkeys in 2001 (about 45 million) than any other state except North Carolina [Thomson, 2005]. On average the economy and agriculture of the state of Minnesota can be considered comparable to the one in Denmark even though a large difference exists in the size of the two land areas.

As of November 2005 Minnesota had only two farm scale anaerobic digesters that were fully operational while by the year 1999 Denmark had 20 central anaerobic digesters that had a capacity of processing 750 to 7,500 cubic meters (26,486 to 264,860 cubic feet) of manure and wastes daily [Minnesota Department of Agriculture, 2005]. Most of Denmark's central anaerobic digester plants are breaking even or making profits. Those that are not breaking even are in that situation due mainly to problems associated with faulty constructions and poor management [Hjort-Gregersen, 1999]. The history of anaerobic digesters in Denmark goes back to the oil crisis of the 1970's, following which farm size anaerobic digesters were established. The first centralized Danish anaerobic

digester was established in 1984 with the sole purpose of producing green energy. It was running even before the environmental, waste recycling, and positive green house effects of central anaerobic digesters were recognized. Upon recognizing these benefits the Danish government has supported the development of central anaerobic digesters by preparing the appropriate legislative framework, research and development programs, investment grants and other subsidies [Hjort-Gregersen, 1999]. The experience in Denmark, which will be examined in detail in the subsequent chapters, suggests that central anaerobic digesters may be economically feasible in Minnesota because the state's agriculture is similar to Denmark's in many respects.

Total electricity generated in the United States (US) in 2005 was 4 trillion MWh, according to the US Energy Information Administration [2006]. So, Minnesota's swine and dairy manure could provide 0.007 percent of US electricity by this measure.

In 2006, a Minnesota-based study of a hypothetical farm with 675 cows implementing an on-farm anaerobic digester resulted in increased farm profits [Bachewe et al., 2006]. Based on this study it is assumed that farms with more than 500 cows can establish anaerobic digesters that are profitable. The role of central anaerobic digesters in Minnesota would be to process manure produced on the 5,762 farms that have less than 500 cows, especially in areas that have intensive dairy farming.

A number of studies have been undertaken in other states to examine the potential for central or farm level digesters. One study [Lewis, 2001] picks a specific central anaerobic digester site in Denmark, the Ribe plant and compares it to the current situation in North Carolina. The study compares and contrasts the reasons for establishing a plant and its workings and by doing so the author tries to make the point that what is possible in Ribe, Denmark can be replicated in North Carolina. The author states "North Carolina could incorporate a system similar to one found in Ribe, Denmark. North Carolina would use a system of centralized plants distributed strategically over the Southeast Region of the state." [p. 11]

Kubsch considers the potential for establishing centralized anaerobic digesters in northeastern Wisconsin [Kubsch, 2003]. The study evaluates whether there is enough manure to digest in a central anaerobic digester, whether the construction of a central anaerobic digester facility is cost effective/profitable for farmers, and whether farmers would be motivated to participate in a central anaerobic digester or what factors can lead them to be interested in such an activity. Kubsch concludes that many social, economic, and technical aspects need to be considered when planning to establish a central anaerobic digester in the region. Her research indicates that central anaerobic digester facilities have the potential to use manure as a source of energy, to help reduce the environmental drawbacks of traditional manure management, and limit the risks to farmers if central anaerobic digesters are established through a cooperative pooling of their resources. She concludes, "A centralized anaerobic digester facility has the potential to provide economic benefits to farmers if digested byproducts are produced and sold and/or a government financial incentive is utilized. Enough recoverable manure is present

within the nine county study area and moderate to very high levels of motivation are present in certain counties." [p.10]

Myers and Deisinger develop a business model for jointly owned manure digesters applicable to Pepin County, Wisconsin, an area served by the Wisconsin Focus on Energy Program [Myers and Deisinger, 2005]. The model was developed with the hope that it will be applicable statewide. The work includes a feasibility study to identify appropriate sites for a central anaerobic digester including analysis of the inputs and outputs, the transportation needs and interconnection requirements, and financial considerations of a jointly owned central anaerobic digester. The study derives four key points for success in its investigation: 1) a minimum of 2000 cows is required to establish the type of central anaerobic digesters considered; 2) the farms contributing manure should be within a five mile radius of the digester site; 3) the manure hauler needs to be part of the team planning and developing the jointly owned central anaerobic digester; and, 4) grant funds are needed to contribute one-third to one-half of the start up capital costs if the project is located near an electricity service territory that pays the standard buy-back rate. The financial analysis in this study, which considers a planning horizon of 30 years, determines that the central anaerobic digester considered would experience a net loss in the first ten years while in year 11 and beyond it would generate annual profits. A net present value analysis to determine the net worth of the project would increase the study's usefulness. Furthermore, the authors state "…the project requires *grant subsidies to make it financially feasible*. Maximum funds from Focus on Energy and the USDA Section 9006 federal grant program, and an additional $150,000 from United States Development Agency rural development value added (VAPG) federal grant program are used to provide a total of $730,000 (or 34 %) of the capital needed for start-up." The authors conclude that if higher experimental buy-back electricity rates that are currently paid by the two electric utilities in Wisconsin are available, the financial feasibility improves substantially.

The works discussed above suggest that the presence of the following items will increase the likelihood of the success of central anaerobic digesters in Minnesota:

i) A sufficient density of cow manure or other organic material;
ii) Farmers have the motivation to participate in central anaerobic digesters from both a financial and a societal point of view;
iii) Accurate estimates of the costs of transporting the manure or other organic wastes are available, as transportation will constitute a sizable cost in the life of a central anaerobic digester;
iv) Public sector support of central anaerobic digester facilities by federal, state, and local governments due to the recognition of external benefits such as environmental, health, "infant industry" arguments, differences between individual and social discount rates, and energy security.
v) Power purchase agreement terms and conditions negotiated with utility companies for electricity generated for sale by central anaerobic digesters are supportive of financial success.

The literature is lacking in studies that evaluate the central biorefinery concept where organic materials are used to generate a series of high value materials in the process. Existing studies tend to focus on electrical energy as the primary output, possibly with some value assigned to separated solids marketed as a soil amendment. If the biogas could be used directly for heating rather than to generate electricity, conversion losses would be avoided and the BTU basis value would be at least three times higher. This higher potential value must be weighed against both cleanup costs and/or the higher per-mile cost of transporting the biogas to a potential use. Co-location with a system that needs heat such as district heating or an ethanol plant might be more advantageous. The E3 venture at Mead, Nebraska and the Belmont Bio-Ag site in Wisconsin are two recent co-located digesters with ethanol plants [Belmont Bio-Ag; E3 Biofuels]. Those digesters are single-farm ones rather than central digesters. Production of other high value outputs such as anhydrous ammonia, hydrogen, "plant tea" compost, high quality irrigation water or perfume might be possible approaches to improving digester economic viability, but systems producing these outputs have not appeared in the literature.

The primary objective of this review of literature in the area of central anaerobic digesters is to facilitate their establishment in the state of Minnesota. More specific objectives include: 1) describing the types of digesters that might be suitable at central locations in Minnesota; 2) suggesting different forms of ownership that could alleviate the burden and risk to individual farmers; 3) indicating the type of problems that could be faced when executing a central anaerobic digester project; and, 4) demonstrating to local, state, and federal decision-makers the multiple benefits of central anaerobic digesters as a basis for informed policy discussions. The following chapters are designed to provide a step-by-step discussion of the methods for reaching these objectives.

As a continuation of this study we suggest as future topic studying the administrative and reliability costs and benefits of adding a digester or other small power source to the electric grid in the same manner that is currently done for wind energy sources as documented in the *Wind Integration Study-Final Report*, a study that was done by Xcel Energy and the Minnesota Department of Commerce [EnerNex Corporation, 2004].

CHAPTER II – TYPES OF CENTRAL ANAEROBIC DIGESTERS

This chapter describes the different sizes of central anaerobic digesters that are operating. It reviews the type of wastes that these digesters process, the forms of ownership that are available for farmers and investors, and finally deals with the type of technology that is available and its costs.

2.1 Size of Central Anaerobic Digesters

Al Seadi, [2000] summarizes the characteristics of twenty Danish centralized anaerobic digester plants. The Revninge plant processes the smallest volume, 9,790 cubic meters of manure and organic waste annually supplied by two farms and industrial sources, while

producing 355,000 cubic meters of biogas. The plant with the smallest digester volume, Davinde, is supplied manure from three dairy farms, three swine farms, and a small amount of sludge and waste from two fish processing plants. The Davinde plant also produces the smallest volume of biogas, 282,000 cubic meters. Forty-nine farms supply the plant that produces the largest amount of biogas, the Studsgard plant. In 1998 this plant processed 111,470 cubic meters of manure and wastes annually producing 5.8 million cubic meters of gas. Twenty-two percent of the slurry processed is from dairy farms while 78 percent is from swine farms. Five of the swine farms are connected to this plant by a slurry transport pipeline system. In addition to manure this plant uses organic waste from food processing plants and source separated organic household waste. This plant has two digesters each with a capacity of 3,000 cubic meters.

The plant that has the largest number of suppliers is the Lemvig plant. Eighty farms, ten summer supplier farms, and a variable number of occasional suppliers feed this plant. On average this plant processes 40 percent cattle (dairy), 59 percent swine, and one percent mink and poultry slurry. In addition to the 362 metric tons of animal manure, this plant processes 75 tons of other wastes daily. In 1998 this plant processed 156,390 cubic meters of biomass, producing 5.3 million cubic meters of biogas. This plant has three digesters each with a capacity of 2,533 cubic meters of manure (a total capacity of 7,600 cubic meters).

Each of the 20 central digesters operating in Denmark in 1999 was supplied manure by an average of 32 farms while the standard deviation of the number of suppliers was 27. These farms provided an average of 187 cubic meters of biomass daily, with a standard deviation of 142 cubic meters of biomass provided. The average biogas produced by the biomass from these farms was 2.5 million cubic meters. The range of gas production is from 5.6 million cubic meters for the Studsgard plant and 0.282 million cubic meters for the Davinde plant. Goodrich and Lazarus [2006] visited the Fangl, Ribe and Lintrup (Linkogas) plants during a study trip to Denmark, Sweden and Germany during May 2006.

In the United States, the Port of Tillamook Bay's Hooley central digester in Tillamook Oregon has two operational bays and is taking manure from 8 different dairy farms. The total capacity of the two bays is 3000 cubic meters and the production of biogas is enough to produce 150 kWh [Swanson, 2005]. In Laholm, Sweden the biogas plant receives about 150 cubic meters of manure and industrial waste per day with about 10 percent solids content. The two main digester tanks have a total volume of 4400 cubic meters and produce raw gas with 70 percent methane content at an output flow rate of 400 cubic meters per hour [WestStart-CALSTART, 2004].

2.2 Types of Wastes Processed

In this section we indicate the kind of wastes that central anaerobic digesters can process in addition to dairy, swine, or poultry manure. The use of other organic wastes both enhances the economies of scale inherent in central anaerobic digesters and increases the

efficiency, as most organic wastes produce larger amounts of biogas per cubic meter than manure. Identifying the types of wastes that are currently being used in Denmark and the types of wastes that could potentially be used in Minnesota helps the operators and owners of central anaerobic digesters diversify their waste sources and improve their economic feasibility.

The central anaerobic digesters in Denmark have a varied processing capacity with a difference in annual manure/wastes processing capacity of 6,960 cubic meters between the smallest and the largest plants. On average the 20 plants processed 67,972 cubic meters of biomass annually or 186 cubic meters of biomass daily. The smallest capacity plant processes about 16 percent of the average processing capacity of 3,390 cubic meters while the largest plant has a processing capacity of 221 percent of the average plant size. This variation in size is demonstrated by the significant difference in capacity. The smallest plant has only seven percent of the capacity of the largest. This variation is good news for farmers/investors who will have alternatives to choose from based on their needs.

As Table 1 indicates, the largest proportion of the material processed comes from agriculture, which contributed an average of 72 percent to the total organic material processed in these plants. In 1998, the average proportion of total agricultural biomass contributed by dairy manure was 58 percent while the average proportion of swine manure was 44 percent. These two sources constituted the two most important sources of agricultural biomass contributing an average of 38 and 33 percents of the total organic material processed. The two sources jointly contributed 82 percent to the total agricultural biomass in the Thorso plant. The plant that used the smallest proportion from these two sources, while six of the plants had their entire agricultural biomass coming from dairy and swine manure. On average the 20 plants had 97 percent of their agricultural biomass coming from dairy and swine manure. Three percent of the agricultural biomass came from sources such as mink manure, poultry manure, and crop residue.

A study by Nielsen and Hjort-Gregersen [undated] assumes that the biogas production capacity of non-farm organic waste is 75 cubic meters per cubic meter of material. This is more than three times the biogas production capacity of farm-produced slurry, which is 22 cubic meters per cubic meter of material. This difference in biogas produced is important as it shows the potential for increasing the biogas output of a farm digester by adding organic wastes from food processing and other plants. The 20 plants in Denmark have used such diverse sources as intestinal contents from food processing plants, fat or flotation sludge, fodder, fish processing, fruit and vegetables, breweries, sugar industry, bleaching earth, tanneries, medical industries, sewage, sludge, and household wastes.

On average 28 percent of the material processed in the plants in 1998 came from one or more of the sources listed above. The plants vary in the proportion of organic waste they process. The smallest amount of organic waste was processed in the Davinde plant with only 6 percent of its input coming from non-farm organic sources while for the Vegger plant 75 percent of the digester input came from non-farm organic materials. Although

the total biomass processed in the Vegger plant, 20,554 cubic meters, was greater than the biomass processed in Davinde, 12,190 cubic meters, by a factor of 1.69, the amount of biogas produced in Vegger at 2.013 million cubic meters was about 7.14 fold of that produced in Davinde at 0.282 million cubic meters. This shows that the efficiency of biogas production is dependent on the type of wastes put into the digesters and the economic performance of these plants can be improved by incorporating as much suitable and distance-wise economically feasible organic material as possible.

The four important organic waste sources are fat or flotation sludge, intestinal contents, fish processing wastes, and wastes from medical industries. These waste sources contributed an average of 23, 22, 18, and 9 percent of total organic wastes, respectively; or about 5, 6, 5, and 2 percent of the total material processed in the plants. In aggregate the average total contribution of these four waste sources to total organic wastes was 73 percent, the remaining 27 percent of the organic wastes came from the other sources listed above.

Effenberger indicates up to twenty times as much biogas can be produced using such organic material as baking wastes, waste grease, and canola cake as can be produced from cattle manure [Effenberger, 2006]. Waste bread, molasses, and skimmed grease provide between 16 and 19 times the amount of biogas produced from cattle manure, while other organic digestible material such as corn silage would provide between six and twelve times the amount.

The Minnesota Department of Agriculture report classifies five types of organic waste that are suitable to digest with animal manure and are potentially available for co-digestion in Minnesota [Minnesota Department of Agriculture, 2005]. These are waste from food industry, grain industry, paper and pulp industry, domestic sources (human waste sludge and yard wastes), and crop residues.

There are important food processing sub-sectors that can significantly contribute to co-generation of wastes in Minnesota, however, further study is needed to determine the economic feasibility. The potato and sugar beet processing industries can supply spoiled and rejected raw material, substandard output, and wastewater to central anaerobic digesters depending on the feasibility of transportation. Organic wastes from dairy processing plants, meat processing and rendering facilities, catering, institutional and domestic kitchens, and restaurants are also potentially useful. Fats and oils have been identified as having high potential for addition to digesters and several digesters of Danish design in the United States are adding up to 10 percent oil to the animal manure to increase the gas output. Although the study indicates that there are potential sources of such wastes, further study is needed when considering a specific location for the establishment of a central anaerobic digester.

Table 1. Capacity and type of wastes processed by Danish central anaerobic digestion plants

Plant	Digester capacity	Cattle manure	Pig manure	Total ag biomass	Intestinal contents	Fat or floatation sludge	Waste total	Biomass total	Cattle manure out of ag biomass	Pig manure out of ag biomass	Ag biomass out of total biomass	Intestinal cont. out of wastes	Fat or flot. Sludge out of wastes	Wastes out of total biomass
	cubic meters	- - - - cubic meters processed/year - - - -							- - - - percent - - - -					
Hashhoj	2900	7822	17718	27497	7639	8213	18657	46154	28.45	64.44	59.58	40.94	44.02	40.42
Thorso	4600	29432	45232	91741	10026	4200	23272	115013	32.08	49.30	79.77	43.08	18.05	20.23
Arhus	7500	18413	103401	121902	3045	1030	17443	139345	15.10	84.82	87.48	17.46	5.90	12.52
Filskov	880	17655	841	18514	5454	6052	11506	30020	95.36	4.54	61.67	47.40	52.60	38.33
Stdsgard	6000	13908	72567	87235	4880	563	24135	111470	15.94	83.19	78.33	20.22	2.33	21.67
Babjerg	5000	58650	23703	89560	0	5689	25373	114933	65.49	26.47	77.92	0.00	22.42	22.08
Snertinge	2800	9949	19055	29004	116	6210	14805	43809	34.30	65.70	66.21	0.78	41.95	33.79
Blahoj	2800	20821	2120	23283	159	4685	6992	30275	89.43	9.11	76.91	2.27	67.01	23.09
Vaarst	2000	8458	6350	14808	5436	5355	16489	31297	57.12	42.88	47.31	32.97	32.48	52.69
Nysted	5000	8841	45550	54556	125	408	3793	58349	16.21	83.49	93.50	3.30	10.76	6.50
V. Hjermitslev	1500	7015	3595	10610	0	0	5636	16246	66.12	33.88	65.31	0.00	0.00	34.69
Vegger	800	13656	0	13656	1150	2613	6898	20554	100.00	0.00	25.13	5.60	12.71	74.87
Davinde	750	6728	4707	11435	0	254	755	12190	58.84	41.16	93.81	0.00	33.64	6.19
Sinding_Orre	2100	11980	23654	35720	5797	0	13723	49443	33.54	66.22	72.24	42.24	0.00	27.76
Fangel	3200	11541	32462	48504	2276	3855	9243	57747	23.79	66.93	83.99	24.62	41.71	16.01
Revninge	540	5311	2206	7517		807	2272	9789	70.65	29.35	76.79	0.00	35.52	23.21
Ribe	4650	91164	24492	118920	19695	11887	43058	161978	76.66	20.60	73.42	45.74	27.61	26.58
Lintrup	6900	45671	32494	91295	5567	591	37870	129165	50.03	35.59	70.68	14.70	1.56	29.32
Lemvig	700	51031	67372	119478	11673	6441	36909	156387	42.71	56.39	76.40	31.63	17.45	23.60
Hoddsager	880	10449	1619	12248	3898	0	6234	18482	85.31	13.22	66.27	62.53	0.00	33.73
Average	3075	22425	26457	51036	4347	3443	16936	67972	58	44	72	22	23	28
Minimum	540	5311	0	6898	0	0	755	9789	15	0	25	0	0	6
Maximum	7500	91164	103401	121902	19695	11887	43058	161978	198	85	94	63	67	75
Sum	61500	448495	529138	1020725	86936	68853	338719	1359444	1155	877	1433	435	468	567

Source: Raw numbers taken from Table 5.1 “Biomass treatment and biogas production in 1998” of [Hjort-Gregersen, 1999]; percentages calculated by authors.

The Minnesota Department of Agriculture study identifies the growing number of ethanol plants with wet and dry distillers grains in the grain industry category. Distillers grain is a byproduct of the ethanol producing process which is mainly used for animal feed. This byproduct can also be used as a waste in an anaerobic digester if its benefit in producing biogas is more efficient than its use as a feed. The cost benefit analysis on this product has not yet been determined. As more ethanol plants are built, the supply of distillers grain may affect the market and the excess may be available for digestion. However, future ethanol conversion processes are expected to convert very high percentages of the cell wall polysaccharides (80 to 90 percent) to ethanol, leaving mainly lignin which cannot be converted to methane by microbes. So, the residue may need to be combusted rather than digested [Jung, 2006]. In Minnesota, damaged grains that are determined unfit for sale are frequently disposed of by land application to agricultural fields or by placing in a land fill, however, such grains could be processed in anaerobic digesters. Bio-products from biodiesel plants as well as wastes from soybean processing and grain milling plants can also be important potential waste streams in this category.

In the category of paper and pulp, materials that can be used for co-digestion may come from newspaper and recycled paper that can be processed in anaerobic digesters. Also, wastes from paper mill processing and logging plants can make an important contribution.

Crop residues form another potential waste category. The report indicates that some amount of corn stover can be removed and used in digestion without affecting the soil erosion protection function of corn stubble. In addition to corn stubble the report suggests the use of the stubble from small grains such as oats and wheat. Grain sorghum is also a possible crop. However, indications are that using alfalfa and switch grass will have a greater potential to increase the amount of biogas produced. Energy crops grown specifically for input into digesters may also be used. In Germany a large number of the digesters are utilizing corn silage and/or grain crops to increase the output from the digesters.

2.3 Forms of Central Anaerobic Digester Ownership

This section discusses the options for ownership of a central anaerobic digester. Forms of ownership that are already implemented and those that are suggested by researchers are included.

Danish farmers started establishing central anaerobic digesters in the form of cooperatives, as a result, nine of the twenty central anaerobic digesters are owned by farmer cooperatives. Some of the Danish central anaerobic digesters are directly connected to the heating and electric system of the community that they are serving. This has created a form of cooperation between farmers and consumers. As a result, five of the central anaerobic digesters are cooperatives that are owned by consumers and farmers. In

a similar mode, some of the central anaerobic digesters were established due to a local government's determination to satisfy their goals. Local governments have provided grants and support to digester projects, and three of the 20 central anaerobic digesters are municipality owned and operated.

Myers and Deisinger [2005] recommend that farmers involved in a central anaerobic digester project form a limited liability corporation (LLC) rather than a cooperative. This recommendation is made because a LLC form of ownership allows owner-investors to structure the business in ways that preserve traditional cooperative values while safeguarding additional flexibility that a cooperative may not provide. In addition, LLCs provide flexibility as they permit additional investment from non-farmers and do not have a limit on the returns on investment.

Another model is currently found in Wisconsin. In this model the farmer sells the manure to an entity owning the digester. The output of the digester is sold to another entity that takes the biogas and either converts it to energy or cleans it. This entity owns the conversion equipment, likely an engine generator or a fuel cell. The energy is then marketed by this last entity. The risks and returns are thus separated and held by various sectors. Variations on this model are being tried at different locations in Wisconsin [Goodrich, 2006].

2.4. Technological Considerations

Myers and Deisinger [2005] consider three types of digesters to install for a central anaerobic digester: 1) plug flow, 2) complete mix, and, 3) upright cylinder design. They state that the low technology and low-cost covered lagoon digesters are less appropriate for centralized digestion that uses manure from several sources. The authors compare the three types of digesters in terms of their advantages and disadvantages.

The authors define a plug flow digester as "a long trough with an air-tight cover. A new "plug" of manure is added daily at one end, which pushes the material already in the digester slowly through the system. As the manure progresses through the trough, it decomposes and produces methane that is trapped in the expandable cover." [p. 4] They note that plug flow digesters have a longer track record and a relatively simple proven technology that is less capital intensive than complete mix digesters and therefore more accessible to a greater number of farmers. Although plug flow digesters have been known to be best for mechanically scraped manure, modified plug flow digesters are developed to accommodate flush systems. The disadvantages of plug flow digesters is that they are limited to the mesophilic temperature, are incompatible with sand bedding, and a surface layer of fiber begins to form immediately and continues to grow over time, eventually requiring complete cleaning.

A complete mix digester "is a large, vertical, poured concrete or steel circular container. The container is covered to maintain anaerobic conditions and the appropriate temperature. The manure is collected in a mixing pit and fed into the digester by either a gravity-flow or pump system. Manure is mixed periodically within the digester,

improving efficiency by creating a more homogeneous mix and minimizing separation of solids." [p. 5] Complete mix digesters can work at thermophilic temperatures, which makes them more efficient, resulting in increased gas production. This efficiency is a result of the manure mixing inherent in these digesters. Mix digesters are compatible with water flush collection systems due to the lower solids content they require. The disadvantages of complete mix digesters is that they are much more capital intensive than plug flow digesters, have higher energy requirements, and are more visible than plug flow digesters.

Myers and Deisinger state that upright cylinder design digesters are a cross between complete mix and plug flow digesters and are intended to mitigate the disadvantages of both. The upright cylinder design is believed to hold the most promise for future applicability for different sized farms and for economic feasibility. The advantages are that it can be built in modules making future expansion easy, has a low initial cost for the containment cylinder (<$300 per cow), needs shorter construction time, has a minimal footprint, is adaptable to all bedding systems, and enhances the opportunity for significant co-digestion of outside organic material. The disadvantages of the upright cylinder design are that it needs more mechanical equipment, piping, sensors and controls than the other designs and has a short track record.

The authors selected a complete mix digester rather than a plug-flow for a jointly owned central anaerobic digester, as it will be able to provide the plant with positive cash flow and has a proven track record.

Frazier, Barnes and Associates, LLC [2006] studied the feasibility of establishing regional anaerobic digesters using cattle manure in Western Michigan. Their report summarizes the capital cost and other characteristics associated with each of the four considered technologies: Waste Energy Solutions; RCM Biothane; Andigen; and Biopower Technologies, Incorporated. Waste Energy Solutions has partnered with a Danish company to develop anaerobic digestion systems for development in the United States markets using Danish technology. It offers turnkey projects. RCM Biothane is one of the leading anaerobic digester design companies in the United States. RCM Biothane specializes in livestock digesters, from lagoons to complete mix and plug flow for both dairy and swine operations and it has been involved in industrial wastewater treatment since 1979.

Andingen's complete mix digester is an Induced Blanket Reactor (IBR). The principal feature of this digester is the super rich concentration of digesting bacteria. The IBR system uses reactor tanks that may be placed above or below ground. Swine manure and other influents are heated before entering the digester tank. The IBR operates in the mesophilic temperature range, and is designed to handle up to 10 percent solids content in the influent stream. Biopower Technologies is marketing a modification to a process being commercialized in Europe, a variant of a Fixed-Film Digester. Table 2 summarizes the important characteristics associated with these technologies.

Table 2. Summary of Technology Characteristics by Supplier

	Waste Energy Solutions	RCM-Biothane	Andigen	Biopower Technologies
Total solids allowed	10 %	10%	10%	7.5%
Capital cost	$12,478,363	$6,353,750	$4,581,232	$3,744,259
Digester type	Complete mix	Upflow anaerobic sludge blanket	Induced blanket reactor	Fixed-Film
Licensed system	Yes	No	Yes	Yes
Operating Temperature	Thermophilic	Mesophilic	Mesophilic	Mesophilic
Hydraulic Retention time	14 days	3 days	5 days	3 to 5 days
Methane in Biogas	75%	65%	70%	65%

Source: [Frazier, Barnes & Associates, LLC, 2006], Table 1

2.5 Costs of Central Anaerobic Digesters

Part of the appeal of supporting anaerobic digester construction is the green energy production, pollution reduction and other external benefits of anaerobic digestion. Identifying and assigning monetary value to all external benefits is a daunting task, but one can start by comparing the benefits that already have monetary value with the costs owners have already paid or are expected to pay.

The cost part of the equation is discussed in this section of the literature review. Although the data is somewhat dated, the cost discussion starts by using the construction expenses incurred by Haubenschild Farms for their digester near Princeton, Minnesota as reported in Bachewe et al., [2006]. The authors adjusted actual 1999 costs for inflation through 2006 to analyze the economic feasibility of four other comparable scenarios that will be discussed in this section. Additionally this section will cover the construction cost aspects of the Ribe digester in Denmark which was covered in the North Carolina study [Lewis, 2001]. The costs of the remaining Danish plants are all in current Danish Krone (DKK) and are not comparable with each other [Hjort-Gregersen, 1999; Lewis, 2001]. Cost estimates for the centralized anaerobic digester suggested by Myers and Deisinger to be constructed in Wisconsin are included. In addition digester cost formulas suggested by AgSTAR and the costs of central anaerobic digesters in upstate New York [Jewell et al., 1998] will be discussed. The review of cost data revealed that different researchers categorize the costs in different ways making a parallel comparison impossible except at total cost level. The reader needs to be aware of this situation, as they will note different levels of aggregation in each project.

In 1999 Haubenschild Farms installed a heated plug flow digester with a 130-kilowatt engine/generator to utilize biogas. The total cost of this system was $355,000. At the time the farm installed this system it had 400 cows. In 2000 the number grew to 550 cows and in 2001 the farm reached its goal of 800. On average the farm has 730 cows over a planning horizon of ten years. The digester cost $125,100 and the energy conversion equipment, engine and generator cost $157,500. Mix tank/manure collection equipment cost $32,400 while engineering design and other services cost $40,000. Using the 800-

cow number this investment is $444 per cow while using the average number of 730 cows the investment is $482 per cow.

The difference between the Haubenschild Farm and the first of the other four scenarios included in the Minnesota study, labeled the “2007 single farm”, is the assumption that the 2007 single farm has 675 cows in its entire planning horizon of ten years [Bachewe et al., 2006]. The 2007 single farm also invests in a manure separator worth $50,000. Since this farm is assumed to be operational in January 2007, to compare costs the prices of the other components of the Haubenschild Farm were increased by an annual inflation rate of three percent. Using this formula, the cost of the digester for the 2007 single farm is estimated to be $158,952 while engineering design, mix tank/manure collection, and energy conversion (energy and generator) cost $50,820, $41,170, and $198,010, respectively. The total cost of the digester generator system is $498,975. At 675 cows this entails an investment of $739 per cow. The per cow investment is $257 higher than the one at Haubenschild Farms due to the following expenditures, fewer cows (increased investment per cow by $55), inflation in building materials and equipment costs (increased investment per cow by $128) and the inclusion of a separator (increased investment per cow by $74).

The remaining three scenarios in the study are different from the 2007 single farm in only one aspect. These scenarios assume that manure is collected from four different farms and that the investment costs incurred in each case is identical to the 2007 single farm scenario. Additionally, the assumption is that the central anaerobic digester is established on the largest of the four farms, the operation with 300 cows, while manure is transported from three other farms each with 125 cows. The difference within the remaining three scenarios studied is in the distance manure is transported. The three smaller farms are assumed to be located at one, two, and three miles from the farm where the central anaerobic digester is located. The manure transportation aspect will be discussed in the following section.

Lewis [2001] gives a close look at the workings of the Ribe central anaerobic digester plant in Denmark. As we recall from Table 1 this plant is the sixth largest plant in terms of its processing capacity. Established in 1991, it has always had positive net earnings between 1991 and 2000. Unlike the transportation scenarios that were included in the Minnesota study where the assumption is that the farm uses transportation equipment already available for other farming activities, this plant had acquired its own transportation equipment for the sole purpose of transporting manure and wastes. In the Danish plant descriptions by Al Seadi, the Ribe plant is described as having three digesters each with a holding capacity of 1,745 cubic meters. The plant also owns slurry storage tanks at farms or in rural areas. The plant uses three vacuum tankers to transport the slurry from its 69 suppliers located an average distance of 11 kilometers (7 miles) from the digester. After processing, the manure is transported to storage tanks at various field locations that are often not the same locations where the manure was produced. This field side storage is one of the benefits that the farmers value because they can spread manure quicker because they do not have to haul from storage at the animal production site [Goodrich, 2006].

The feasibility study for a digester to be established in Wisconsin uses price information submitted by manufacturers [Myers and Deisinger, 2005]. The researchers specify the components they want to be included in the pricing of a digester generator system that uses manure from 2,000 cows. Four companies submitted such pricing information. There were seven components that were suggested to be included: mix/holding tank for manure, holding tank for receiving organic waste used as substrate, complete mix digester, effluent tank to receive treated liquid, solids separation equipment, post digestion storage, and electric generator set. Similar to researchers, manufacturers have their own pricing mechanisms and do not always include all components. Manufacturer American Biogas submitted a price of $1.8 million for a turnkey operation that includes all the components listed above except the mix/holding tank. Applied Technologies Incorporated submitted a price of $1 million for all the components excluding the post-digestion storage facilities. The firm GHD Incorporated submitted a price of $1.5 million for these components, but this price does not include the electric generator set. All the three manufacturers above did not include the cost of engineering, construction, and installation in their prices. The firm MCON Bio Incorporated estimated a price of $2.5 million for a Danish turnkey operation that includes all the components including the cost of engineering, installation, and construction.

The winter 2006 edition of AgSTAR Digest lists anaerobic digestion plants that are currently operating or are at construction or start up stage. The costs incurred in these plants were used to construct a model that calculates construction costs of different types of digesters. The results of these analyses were used to develop the cost algorithms used in Farmware, Version 3.0. These models describe, "…the relationships between capital cost and size for different types of operating digesters for dairy and swine manures with internal combustion engine generator sets." [U.S. AgSTAR, 2006. p. 4]
The formula to calculate the total costs to install a covered lagoon digester that uses dairy manure is given by:

$$y=233.43x + 38056$$

Where x is the number of cows and y is the total cost of installing a covered lagoon digester for x number of cows.

This equation has an R^2 ratio of 0.967, that is to say the formula fits the data 97 percent of the times. Accordingly, the construction cost (rounded to the nearest $100) of a digester-generator system that uses dairy manure from 1,000 cows is $271,500 and it is $388,200 if the number of cows grows to 1,500.

Similarly, the same type of digester generator system (covered lagoon with internal combustion engine-generator system) that uses swine manure has a cost-swine head relationship given by the equation:

$$y=63.863x + 35990$$

This equation has an R^2 of 0.9792. According to this equation a farm with 1,000 swine can establish such a system for about $99,900.

The cost – number of cows relationship for plug flow and flexible cover digester systems using the same type of engine-generator system is given by:

$$y=22.69x + 288,936$$

This equation has an R^2 of 0.76, indicating that the equation fits the data less precisely than the above two. According to the equation a farm with 2,000 cows incurs a cost of about $742,300. But the real data indicates that farms may be incurring a cost below this amount or much higher than this amount.

Jewell's New York study uses data collected from Cornell University's Extension Surveys, and a computer model that among other things calculates the sizes of digester-generator systems depending on the amount and type of manure to be utilized [Jewell et al., 1998]. The authors add a flat engineering fee of $25,000 to the total cost of facilities, which are not included in the AgSTAR model. This study states that "Capital costs for centralized facilities were based on the daily amount of manure each facility would handle… Combined digester and cogeneration costs varied from less than a million for 2,500 cows to nearly $8 million for a 30,000-cow facility; and this approached a constant of $250 per cow for facilities larger than 5,000 animals [p. 5-5]. The outputs of the computer model used by the authors provided the following series of diagrams that have been scanned from the report. They show the costs of construction, digestion, and cogeneration at different herd sizes.

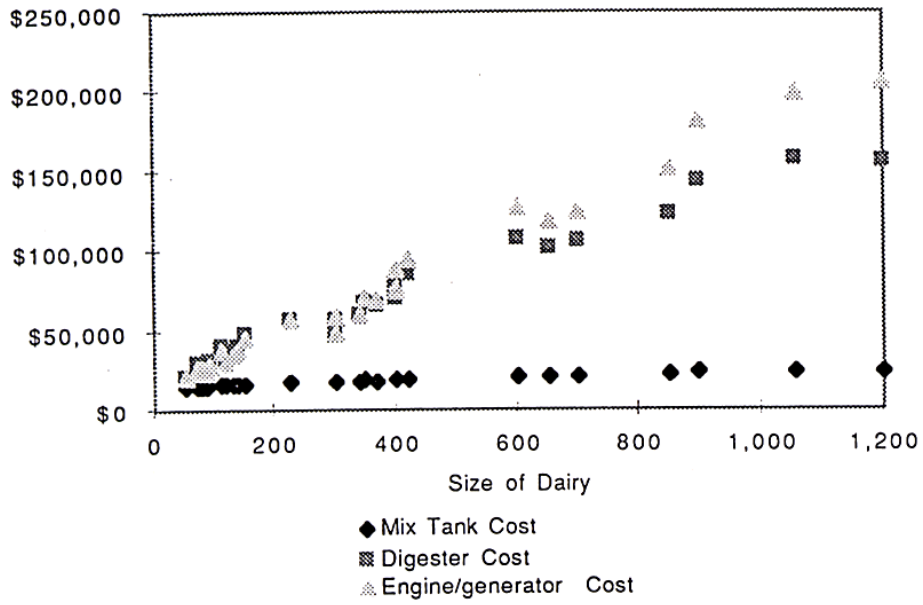

Figure 1. Comparison of the per cow costs of the three main components for on-site anaerobic digestion system

Source: [Jewell et al., 1998]

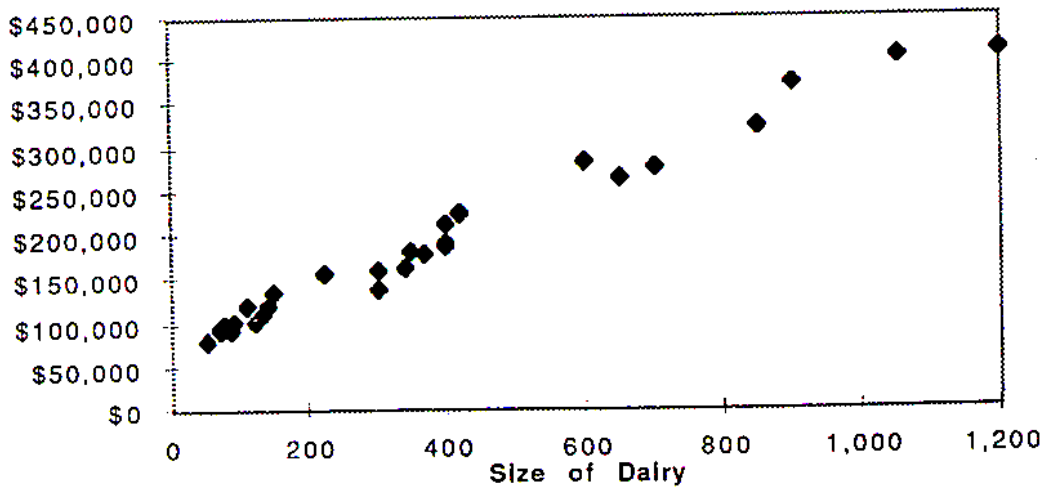

Figure 2 - The total capital cost of a methane recovery facility.

Source: [Jewell et al., 1998]

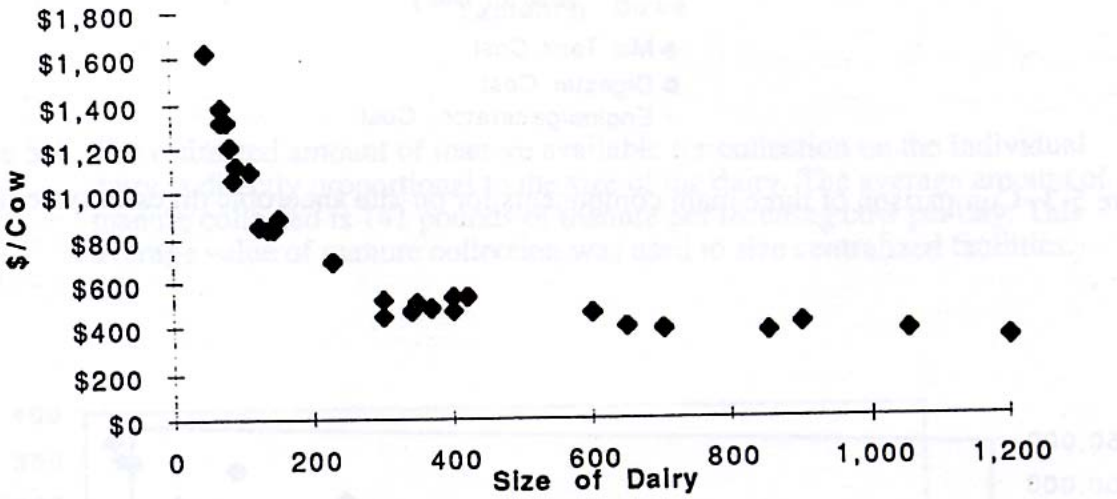

Figure 3 – Total capital cost of on-farm methane generation and cogeneration facilities for varying size of diaries.

Source: [Jewell et al., 1998]

Three published feasibility studies contain information about central digesters. One study looked at the feasibility of building a digester to handle 100,000 gallons/day of swine manure from within a 20-mile radius in Ottawa and Allegan Counties in western

Michigan [Frazier, Barnes & Associates, LLC, 2006]. The study did not relate this volume to a number of swine, but if it were dairy cows providing the volume/day of Haubenschild Dairy, it would be the equivalent of around 3,500-4,000 dairy cows. The analysis looked at a number of feedstocks in addition to swine manure, including slaughterhouse waste and corn stover. The proposed location was adjacent to a landfill that is already compressing and marketing landfill gas, and the study considered both generating electricity with the biogas and cleaning and compressing it for marketing as a natural gas substitute. However, the financial returns looked marginal to negative in the scenarios they considered to be most realistic.

Another feasibility study was conducted for the city of Morris, Minnesota [Sebesta Blomberg & Associates, Inc., 2005]. The proposed digester was intended mainly to serve a single 5,800-cow dairy farm, but the study also contains information on nearby farms that could also provide manure to the digester. This study considered installing a 12-mile pipeline that would transport the biogas to a local industrial park rather than generating electricity.

The feasibility of a centralized digester to serve dairy farms in the Enosburg Falls area of Vermont has also been studied [American Public Power Association, 2005]. They examined two digester designs, one for 1,200 cows and the other for 2,000 cows. The smaller design included addition of a substrate to increase gas production. The maximum manure hauling distance was assumed to be five miles. The projected economic feasibility appeared to be positive. A central digester was also recently proposed for Kossuth County, Iowa [MaxYield Cooperative, 2006].

At least two centralized digesters are operating in the United States. The Port of Tillamook Bay in Oregon operates one well-publicized central digester. One source of information on Tillamook is a slide set presented at the 2006 AgSTAR National Conference and the port's webpage [DeVore, 2006; Port of Tillamook Bay, undated]. Part of the motivation for the digester was to protect the bay from nutrients from local dairy farms, which had a total of 32,000 cows. Concerns about cost led to the size being scaled back to 4,000 cows. The digester went into operation in 2003 after an initial investment of $1.7 million. The digester has been losing money due to the following factors, lower-than-expected output, high manure trucking costs, and low sales of manure solids that were wetter than ideal for marketing as a soil amendment. A number of changes were being made to improve profitability, including expansion of the digester size, adding a third engine, and replacing the solids separator to achieve drier solids that would be more marketable.

Another central digester is operating in the Chino Basin of California. The Inland Empire Utilities Agency is responsible for treating wastewater and providing drinking water for a region in the Chino Valley [Synagro Technologies Inc., 2006]. The animal manure digester processes the manure from 3,750 dairy cows to generate biogas that is converted into electricity. The unique part of this system is that the electricity is used internally at the plant to power a system that removes salt from groundwater that is then provided to residential and business customers. This allows the utility to forgo the purchase of

electricity to power the desalter at a price of more than ten cents per kilowatt-hour. This is a value for electrical energy that is far more than other methane digester operators have reported when the electricity is sold to the grid or offsets purchased power. Heat is also used in the digester. The cost of the digester system, generators, and associated systems to run the desalting plant as presented in a report [California Energy Commission, 2005] was approximately 11 million dollars. Comparisons to other central digesters in the world show that this cost is much higher than others.

2.6 Costs of Manure Transportation

One of the most important factors that distinguish central anaerobic digesters from single farm owned anaerobic digesters is the transportation of manure and wastes that these plants have to accomplish. A first option has been previously illustrated; some of the central anaerobic digesters in Denmark are connected to their sources through manure pipelines. This method of transport is applicable if the distance between the source and the central anaerobic digester plant are short enough to permit such a connection. However, the longer the distance between the source(s) and the processing facility the more likely complete pipeline connections will be too costly. The second option is to use transportation equipment that is already being used for other purposes. This is possible if the total hours of service required from the equipment are short enough to allow for other services. This approach was followed to calculate the manure transportation costs in the Minnesota study [Bachewe et al., 2006]. The third option is to prepare an entire set of equipment to transport slurry. Central anaerobic digesters in Denmark have been using a combination of specialized transportation equipment in combination with pipelines. The study of options for farms in the York area of New York further explores this option [Jewell et al., 1998].

The Minnesota and New York studies will be discussed in detail while also briefly touching on other literature. An important point the reader needs to consider when reviewing this section is that transportation costs are influenced by not only ground distances between the source and central anaerobic digester plant, but by the location of the sources and how the effluent and influent are transported between central anaerobic digesters and farms/sources. This can be a complicated task when there are a large number of suppliers. Additionally, efficient routes can result in cost savings. Another variable that can influence the cost of transportation is the need to provide differing levels of biosecurity. Transportation planning is influenced by the need to sanitize the vehicle between trips to farms. Usually this is handled by hauling several loads sequentially from one farm to the digester and backhauling digestate to the same farm. The equipment is then sanitized before going to another farm.

The Minnesota study assumed that manure would be transported via a 6,000-gallon tank applicator pulled by a 160-horsepower tractor. The general parameters used to calculate transportation costs for 2006 include an interest rate of six percent and an insurance rate of 0.85 percent of the average investment. A fuel price of $2.20 per gallon and lubrication cost of 15 percent of fuel prices, a property and sales tax rate of zero percent of purchase price, a storage cost of $0.33 per square foot space, and a wage rate of $15 per hour for

operating the machines. The tractor and tank are assumed to be used 750 and 260 hours, respectively, for other tasks not involving manure transportation. These parameters were used to calculate the manure transportation costs per year on a real basis ignoring inflation. This estimated transportation cost is used for year one of the digester discounted cash flow analysis and is inflated at three percent per year for the later years.

The manure transportation tanker is assumed to have a capacity of 6,000 gallons. It is assumed to apply manure for 354 hours per year. The tanker is assumed to be replaced after 3120 hours of accumulated service. Without manure transportation related to the central anaerobic digester, this calculates to a useful life of twelve years. Adding the extra hours of usage for manure transportation, the useful life drops to ten, nine, and eight years in the transport scenarios at one-, two-, and three-mile distances.

The expected tanker purchase price is $35,000, while the trade in value is $13,855, implying an annual depreciation of $2,399. Annual ownership, repair and maintenance are assumed to cost $4,633, yeilding an accumulated repair cost of 92 percent of the list price at trade in. The annual ownership cost of the tanker is $3,633. This includes a depreciation cost of $1,982 and a total overhead cost of $1,651; the overhead cost includes an interest payment of $1,446, and an insurance cost of $205. The only annual operating cost for the tanker is assumed to be $1,000 in repairs, which added with the annual ownership cost of $3,633 adds up to $4,633. Manure transport at one-, two-, and three-mile distances adds $455, $884, and $1,280 in tanker ownership, repair and maintenance, respectively.

Table 3. Details of the Manure Transport Calculations in the Minnesota Study

	Costs without manure Transportation	Incremental Costs with Transport: One mile	Two miles	Three miles
Tractor hours % of tank hours	100%	157%	149%	144%
Tank annual repairs	1000	1181	1362	1538
Tank years owned	12	10	9	8
Tractor lifetime hours to trade	6000	8000	8000	8000
Tank annual hours	260	47	94	140
Tractor annual hours	450	222	269	316
Tractor years owned	13	8.23	7.85	7.50
Tank total ownership and operating cost/year	$ 4,633	$ 455	$ 884	$ 1,280
Tractor total ownership and operating cost /year	$ 18,290	$ 5,286	$ 6,536	$ 7,780
Tank and tractor cost	$ 22,922	$ 5,741	$ 7,419	$ 9,064
labor cost for hauling (not loading/unloading)	$ 4,680	$ 3,996	$ 4,842	$ 5,670
Total cost w/labor	$ 27,602	$ 9,737	$ 12,261	$ 14,734

Source: [Bachewe et al., 2006], Table 2.

The tractor used to pull the tanker is assumed to be a new, 160 PTO horsepower (HP) mechanical front-wheel-drive model. It uses 0.04 gallons of fuel per tractor HP-hour. The tractor is expected to be used for 450 hours per year for non-transporting purposes while

it will be used for 222, 269, and 316 more hours to transport manure between the one, two, and three mile multi-farms, respectively. The tractor is assumed to be traded in after 6,000 hours when not used for manure transport, which would be after 13 years. The assumption is that the years of useful life of the tractor will be shortened due to the extra transport hours. However, with transport the tractor will accumulate more hours of use (8,000). Incorporating an increased number of lifetime hours still results in a drop in years of useful life to eight years.

The assumed purchase price of the tractor is $94,000. On the eighth year, it is expected to be traded in for $33,879, with an accumulated depreciation of $60,121 or $7,515 per year. The total ownership and operating cost of the tractor is $18,290. This includes the annual operation cost of $8,696 and ownership cost of $9,593. The three manure hauling distances of one, two, and three miles cost an additional $5,286, $6,536, and $7,780 per year, respectively, in ownership and operation costs. The total tanker and tractor ownership and operation cost is $22,922 when labor costs for hauling are included it is $27,602. Hauling the manure between the four farms adds a total ownership, operating and labor cost of $9,737 for the one-mile multi-farm, $12,261 for the two-mile multi-farm, and $14,734 for the three-mile multi-farm scenario.

The other scenario that was to be analyzed in the feasibility study was for individual digesters to be located at multiple farm sites and the biogas transported to a central energy generation site. However, a study conducted for the Agricultural Utilization Research Institute found that biogas upgrading, compressing, and transport costs would exceed the value of the gas at current prices of around $1.00 per therm [Goodrich, 2006]. The biogas would have been transported in a transportation-approved trailer (such as a stock trailer) using a number of high-pressure tanks, pulled by a pickup truck. The one-way distance considered was 30 miles. The unfavorable economic results from that study led this study to refocus its attention to the manure transport scenario.

The New York study uses the U.S. Environmental Protection Agency (EPA) truck-hauling model to estimate the cost of transporting manure from specific dairies located within a 20-mile radius of the town of York where a specific location was picked to establish the central anaerobic digester and cogeneration system. The study locates each dairy, calculates the amount of manure they produce, and defines a road route for transporting the manure. Moreover the study considers various transportation options and chooses the truck hauling option.

The New York study listed ten cost categories for the truck hauling option:

1) Truck acquisition (capital) costs, including a spare truck
2) Driver labor
3) Operational labor
4) Loading area costs
5) Fuel
6) Vehicle maintenance
7) Loading facility maintenance

8) On-farm manure storage
9) Loading/unloading time
10) Maintenance base and parking

At the time the study was conducted, the present value of the truck acquisition costs assuming an interest rate of 10 percent and a life of five years with no residual value for used trucks resulted in a year zero cost estimate of $80,258 for a 4,000 gallon truck or $100,323 for a 6,000 gallon truck. For driver labor, the average of two cost estimates was used; the authors indicate that EPA assumed $22.97/hour for a driver's wage including fringe benefits and an eight hour working day, while Van Schaick (1996, as referred by the authors) estimated this value at $17.50/hour, the authors used the average of the two, $20.25/hour. The authors consider two types of working shifts, 8 hour and 24 hour. In each case the actual work hours that the driver is suppose to be driving, loading, and unloading is 7.2 and 21.6 hours, respectively. EPA defines operational labor as the total number of hours of labor required, including drivers and operators of central biosolids loading, expressed as a percentage of total driver hours. The authors assume one employee per ten drivers for this purpose. This is 110 percent of the total driver hours. The cost of constructing a loading/unloading area is calculated assuming that 70 percent of the farms in the 150-500-cow size range would need a collection point at the freestall barn, and 50 percent of the total number of these would also need a second collection point at their heifer barn. This assumes that 30 percent of these farms already have a collection point at the main barn and half of these also have a collection point at their heifer barn. Farms that have over 500 cows are assumed to need two collection points in 70 percent of the cases and 50 percent of the total are assumed to need a third collection point. The authors include other fine details concerning the collection points that would contribute to increased costs.

The authors assume a fuel cost of $1.35 per gallon diesel with five miles per gallon fuel consumption for a 6,000-gallon truck driven at a speed of 35 miles per hour. The authors compare three cost estimates to derive the sixth cost category of vehicle maintenance, which includes insurance, registration, tires, repair, and routine maintenance of each truck. The authors adopt a maintenance cost per mile of 43 cents for 4,000-gallon trucks and 49 cents for 6,000-gallon trucks. The annual maintenance cost for the loading facility is assumed to be five percent of the original capital cost. Moreover the authors add to capital costs the present value of operation and maintenance costs, assuming a 15 year life at 10 percent interest rate, to yield a present cost of each truck with its associated routes and loading areas. For on-farm manure storage for digested manure, volume of the storage area is calculated assuming 20 gallons of manure per cow per day plus additional 50 percent to allow for precipitation and the assumption that the manure will be stored for nine months for safe land application. Among other things, the authors conclude that one pit is required per each 200 lactating cows.

Time allocated to unload the manure, clean the vehicle, and load effluent at the digester is assumed to be one-half hour per load. Time at the farm to unload the effluent into storage pit, reposition the truck at the barn, and load the manure at this collection point is assumed to require another one-half hour per load for farms with less than 500 cows and

0.6 hour for farms with more cows. The authors add the capital cost of one additional spare truck to the system cost. They also consider the cost of building a parking/truck terminal area. Trucks are parked outside with a covered 54'x75' space for maintenance services costing $30,300. Using the cost assumptions given above and a few other adjustments to EPA's truck hauling model the authors come up with the following transportation cost schedules that were scanned from the publication. The last figure compares transportation cost trends with cost trends of other components of the central anaerobic digester.

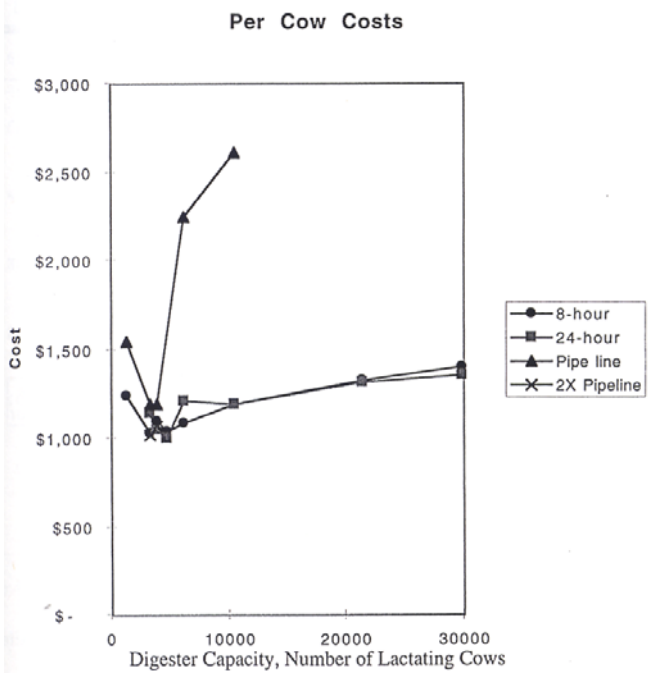

Figure 4. Present value transporting manure to and from central processing plant using trucks on an 8-hour schedule, trucks on a 24-hour schedule, a single pipeline and a double pipeline for digesters with capacity to serve specific numbers of lactating cows.

Source: [Jewell et al., 1998]

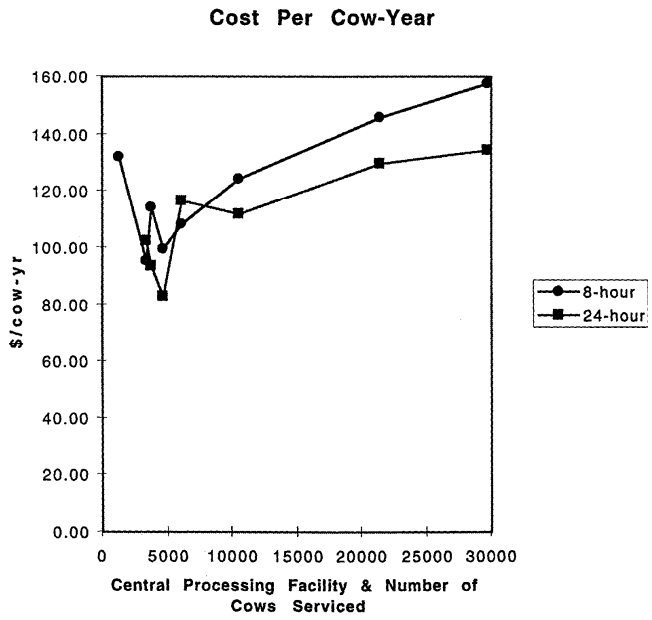

Figure 5. Yearly cost per cow for manure transportation for 8 hour and 24 hour operation of central processing facility.

Source: [Jewell et al., 1998]

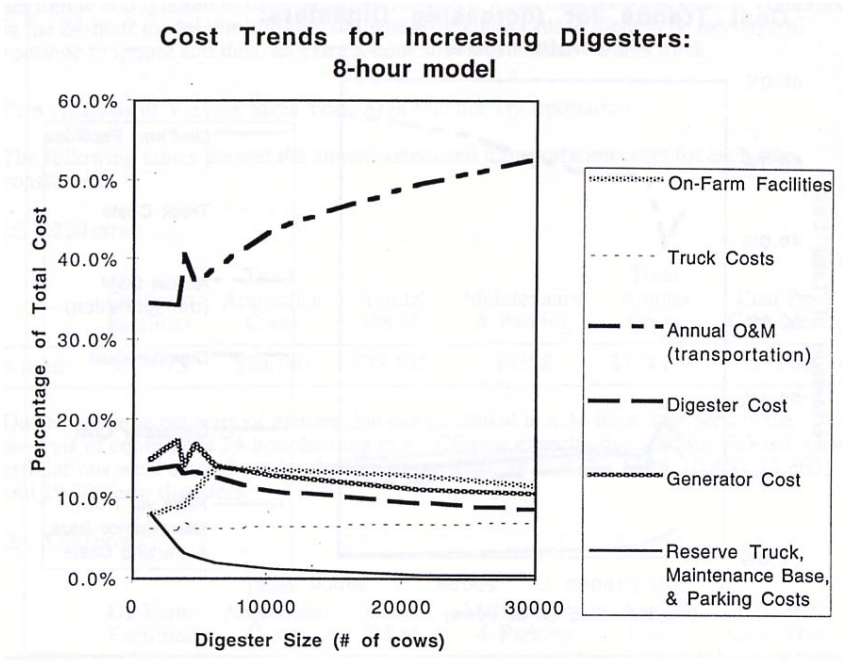

Figure 6. Contrasts of component cost of centralized manure management system.

Source: [Jewell et al., 1998]

CHAPTER III – ADVANTAGES ASSOCIATED WITH CENTRAL ANAEROBIC DIGESTERS

Sound public policy requires accurate estimation of benefits and costs. The challenge in completing a cost-benefit analysis of a digester is that it can be made from several, at times conflicting, perspectives. Benefits and costs can be estimated from the private perspective of the farmer, or from the perspective of society at large. Some benefits such as reduced groundwater pollution may benefit society but be "external" to the farm so the farmer receives no economic benefit from them. Other benefits of digesters such as odor reduction may be important to the farmer but may be difficult to value in economic terms. On the other hand, the farmer may discount future benefits more heavily than society does, so the farmer may reject an investment with a longer-term payoff that might have been desirable from a social perspective.

In 1987 Denmark implemented the first Fresh Water Action Plan, which restricted dairy farmers' manure management practices and imposed additional costs on them. Central anaerobic digesters were seen to have social benefits because they would help farmers to meet those legislative demands.

In addition to income generation, Lewis [2001] cites other benefits that reinforce the establishment of central anaerobic digesters, such as increased water quality which can be a serious problem due to the overflow and/or seeping of nitrates from lagoons, the potential to reduce ammonia and phosphorus pollution, improvement in air quality for residents in farming areas that suffer from the odor pollution, reduction of emissions of methane – a greenhouse gas – in to the atmosphere, and reduction of health risks that could be associated with extended living near hog farms with an open lagoon. These issues are discussed in more detail in section 3.2. Although North Carolina is larger than Minnesota in terms of swine population Minnesota is larger in dairy and faces the same risks and potential from farming activities, so the qualitative implications in the Lewis study apply as much to Minnesota as they do to North Carolina.

Economies of scale and environmental benefits associated with central anaerobic digesters will be discussed in the following sections. Central anaerobic digesters have additional benefits that include improving neighbor relations, bolstering weak or dim spots on the electrical grid, accepting alternative waste stream inputs from other industries that help to reduce waste treatment costs, and reduced costs to industry and government due to the centralized infrastructure [Drewitz, 2006].

3.1 Economies of scale

This category of benefits is meant to represent the economic benefits that central anaerobic digesters generate as the result of their large size something that is unavailable to most average size farms that are considering building anaerobic digesters. It is also where the economic benefits that central anaerobic digesters generate by producing green

energy that can be used to generate electricity, biogas used for heating and other purposes are discussed. This discussion could relate to some very large farms that have enough manure and other resources so that they can generate the same influence and benefits as central digesters.

Many of the studies reviewed had estimated or/and actual figures of economic benefits associated with operating central anaerobic digesters. In the Minnesota study a hypothetical setting was considered [Bachewe et al., 2006]. Four farms with a total number of 675 cows are assumed to establish a central anaerobic digester. The central anaerobic digester is to be located at the farm with 300 cows while manure is assumed to be transported from the remaining three farms with 125 cows each, located at one mile away from the central anaerobic digester. Also considered were alternative distances of two and three miles. The per cow contribution towards an inflow to the farm in the form of electricity was $32.61 for these scenarios. These farms were assumed to benefit from carbon credits; production subsidy; Federal tax credit, and grants and interest that result in a subsidy per cow of $1.30, $18.77, and $7.64, respectively. A total non-energy inflow of $36.64 is assumed to accrue for these farms from the bedding value of the digested material. In general, the total per cow inflows of these farms was about $101. These farms take a period of nine to more than ten years (depending on the distance) to pay the investment back. In general the financial performance of these scenarios is at the margin. However, there are two qualifications. First, the central anaerobic digester considered in the study is modeled after the 800-cow individual farm anaerobic digester at Haubenschild Farms. This is smaller than the central digesters discussed in other reports reviewed, so there may be economies of scale that are not reflected. Second, the financial analysis of the study leaves out the external benefits that the digester provides to society. A more detailed analysis could consider such external benefits.

Hjort-Gregersen [1999] argues that in the Danish situation farmers gain considerable economic advantages from improved nutrient utilization and cost savings by participating in centralized biogas production plants. The study reveals that farmers connected to central digesters gain considerable derived economic benefits from the operation of the plant. One of the reasons farmers participate in this cooperative solution is the legislative push from the government that required farmers to construct large slurry storages, increasing their costs of managing waste. While the cost saving from slurry storage was the main incentive for them to join in central anaerobic digesters there were other benefits realized afterwards. One such benefit is the reduction in cost of transporting the slurry from the barns to the field where it is end-used. Without participating in the central anaerobic digesters farmers travel a considerable distance to reach the fields where the manure is spread but by participating in the central anaerobic digesters farmers were able to arrange for the digested material to be stored close to their fields. They also benefit from renting storage spaces appropriate for their capacity as the central anaerobic digesters have large storage facilities, reducing the cost incurred on storage. The study of ten farmers that are collaborating with Lintrup plant in Denmark revealed that farmers derived an economic benefit of about five DKK per cubic meter of slurry mainly from saved slurry storage costs and reduced fertilizer purchase.

As well as the transportation and storage cost savings, central anaerobic digesters provide farmers with slurry that has increased nutrients. Since all of the central anaerobic digesters use organic waste in addition to mixed animal manure, the nutrient content of the digested material is substantially increased. The resulting increase in biogas production was discussed in section 2.2. In this section the discussion will be on the benefit received from mixed animal manure. For instance pig slurry contains surplus phosphorus but is short in potassium making it less desirable for use as a soil amendment on pig farms while the reverse is true for cattle manure. The mixing of these manures in the central anaerobic digester results in a balanced digested material that is suitable for both pig and cattle farms; and, a reduction in the environmental cost as the nutrients are well absorbed by the crops. In addition to these benefits farmers that have less manure than they need have more options to obtain access to surplus manure while those in surplus have more options to freely dispose of the surplus. Lewis, referring to farmers in Denmark, indicates that with the establishment of central anaerobic digesters farmers benefited from reduced transportation costs. Moreover, local storage tanks enabled farmers to swap or sell waste making manure management and coordination easier. The study indicates that there was a 65 percent reduction in time of transport and 95 percent reduction in the distance of transport. In particular farmers producing more manure than they can use benefited from the central anaerobic digesters as it gave them an ample storage space and a possibility to sell or give away their excess manure.

In a study that analyzes three central anaerobic digester plants in Denmark with a capacity of processing 300, 550, and 800 cubic meters of biomass, Nielsen and Hjort-Gregersen [undated] find considerable economies of investment costs with increased size. The authors conclude that “Centralised biogas plants are economically feasible under Danish preconditions without investment grants if gas yields of 25 - 34 cubic meters of biogas per cubic meter of biomass treated are obtained.” The authors also note that such levels of biogas yields can be achieved by organic waste mixing rates of 10 to 21 percent of the amount of biomass treated.

This section concludes by indicating gains from other economies of scale that benefit central anaerobic digesters. The investment in a single central anaerobic digester avoids the multiple operations of single farm digesters and achieves considerable reduction in investment. Since central anaerobic digesters do not have to be operated by farmers they are more likely to be constructed than farm level anaerobic digesters that are owned by the farmer and face several constraints including the size of the farming operation. Since central anaerobic digesters are more likely to process non-farm organic wastes they benefit other sectors of the economy. The inherent disadvantage in the establishment of central anaerobic digesters in the cost involved in transporting influent and effluent.

3.2 Environmental Benefits

Although environmental benefits are one of the clear gains of anaerobic digestion they are frequently forgotten in terms of being assigned monetary value. To the authors’ knowledge few studies try to internalize such gains in their cost-benefit analysis. This

leads to underestimated values of anaerobic digestion and biogas production projects. This section will briefly review different authors' perspectives on the environmental gains of central anaerobic digesters. It will also review a study that explicitly tries to assign monetary values for such gains and examine the feasibility of a central anaerobic digester project from a wider perspective.

Lewis [2001] argues that excess phosphorus that seeps into water bodies can become a contaminant as it contributes to excessive growth of algae and other plants that accelerate the eutrophication of surface waters. Eutrophication of water bodies, which is richness in minerals but a lack of oxygen, limits the use of surface water for recreation, industry, and drinking. The author argues that if untreated or under-treated manure is applied onto a field, compounds may volatize rapidly causing a disturbing smell and it may cause excess nitrate to seep into the ground causing ground water contamination. High nitrates in lakes, rivers, and streams increase algae growth that in turn can cause fish and other aquatic life to die off. Nitrates also pose numerous adverse health effects to human beings, and contribute to the economic loss suffered due to reduced aquatic life.

Lewis also refers to other works that provide differing perspectives on the effect of odor and toxic substances on people residing in close proximity to hog farms. One study done with a sample size of 18 people living in close proximity and a control group of 188 people who did not live in close proximity revealed that 14 out of the 18 people living in close proximity had symptoms known to represent toxic or inflammatory effects on the respiratory tract. This was a higher percentage than for the control population. The study concludes that people that live in close proximity more frequently show symptoms that are similar with those suffered by workers on hog farms. Others criticized this work for its few sample subjects but agreed that such odors may represent degradation to the quality of life rather than real adverse health effects. Moreover, people that live close to such odorous farms may lose value on their property and be psychologically stressed due to the odor and the sight pollution. The EPA study [Inland Empire Utilities Agency, 2006] discusses a number of external benefits of anaerobic digesters in a work that is done on Ireland. The European Union regulation requires anaerobic digesters to be fitted with pasteurization/ hygienisation units that treat effluent at a minimum of 70 degrees Celsius for an hour. Such treatment kills all pathogens and seeds, thereby eliminating cross-farm contamination of pathogens or weeds.

Jewell et al. [1998] argue that methane is one of the most effective heat-trapping green house gases. These gases cause increased temperature of the biosphere, also known as global warming, and threaten to change the global weather patterns. Harnessing methane emissions makes an important contribution to the environment. The study points out that a cow can burp 200 liters of methane and over 5,000 liters of CO_2 per day, this equals about 15 percent of all man made emissions and is exceeded only by emissions generated by landfills. Compare this with the ten fold emission that is caused through untreated degradation of manure and the suggestion is that anaerobic digesters play a more important role than just producing biogas. This is apparent from the Neilsen and Hjort-Gregersen study that is reviewed next.

Neilsen and Hjort-Gregersen indicate that traditional economic analyses and feasibility studies do not consider what are called "external benefits". The authors underscore that "…externalities are important economic effects seen from a welfare-economic point of view, and in socio-economic analysis, since these derived costs or benefits accrue to some members of the society." [Nielsen and Hjort-Gregersen, 1999. p.4] These authors undertake their "socio-economic feasibility analysis" in four stages. The first stage, which they call R0, is a pure economic analysis in that it considers only the biogas and electricity generation benefits of central anaerobic digesters and the costs involved. The second stage, R1, includes external benefits that central anaerobic digesters provide for agriculture and industry. The third stage, R2, includes environmental externalities that central anaerobic digesters provide. This includes reduction of Green House Gases (CO_2, CH_4, and N_2O) emissions and N-eutrophication of ground water. The fourth scenario, R3, includes monetary value towards reduced obnoxious smells. The authors tried to include as many external benefits as they could. Yet, they point out that there are more benefits to which monetary values could not be attached including benefits from increased flexibility in agriculture, options for extending production at dairy and hog farms in relation to biogas plants, employment and trade effects of central anaerobic digesters, and the energy security effect of central anaerobic digesters. An additional benefit that may be added is the benefit of reduced Greenhouse Gas (GHG) emissions due to the substitution of biogas for fossil fuels.

To assign monetary value to externalities the authors use the rate used by the Danish Energy administration. GHG reduction has an external value of 250 DKK (Danish Krone) per ton CO_2 equivalent (which is 33.6 Euros per ton CO_2 equivalent)[3]. This rendered the values provided in Table 4. They analyze a plant that has a capacity of processing 550 ton per day and used year 2000 prices to calculate the cost benefit analysis for the plant for the period of 2001 through 2020. Excluding externalities, the plant incurs a loss of 6.635 million DKK as annuity. When external benefits for agriculture and industry are included, they find a profit of 0.003 million DKK as annuity. If reduction of GHGs emissions and N-eutrophication of ground water are considered the profit jumps to 5.082 million DKK. If the external effect of obnoxious smells are considered the annuity goes up to 5.805 million DKK. This study is interesting in that it quantifies the external benefits, which are often omitted in other studies due to the difficulty of quantifying them.

[3] This conversion rate uses the average 2000 conversion rate of 1 Euro for 7.43 DKK. The average year 2000 US dollar to DKK exchange rate is 8.0887. Source: http://www.oanda.com/convert/fxhistory.

Table 4. Monetary Values of Externalities Realized Through Anaerobic Digestion

Monetized externalities:	Biogas Plant size:
Socio-economic value per ton of biomass	550 ton/day (20 %waste)
Agriculture	**Monetized value**
Storage, handling and distribution on liquid manure	
Storage savings for liquid manure	1.00 DKK per ton liquid manure
Transport savings in agriculture	0.50 DKK per ton liquid manure
Value of improved fertilizer	5.41 DKK per ton treated
Value of reduced obnoxious smells	5.00 DKK per ton liquid manure
Industry	
Savings related to organic waste treatment	125 DKK per ton of organic waste
Environment	
Value of GHG reduction (CO_2, CH_4, and N_2O-reduction)	22.38 DKK per ton treated
Value of reduced N-eutrophication of ground water	2.92 DKK per ton treated
Liquid manure	2.77 DKK per ton liquid manure
Organic waste spread on farm land in reference case	12.19 DKK per ton organic waste
Organic waste not spread on farm land in reference case	-22.50 DKK per ton organic waste

Source: [Nielsen and Hjort-Gregersen, undated], Table 3.2.

CHAPTER IV – PROBLEMS ASSOCIATED WITH OPERATING CENTRAL ANAEROBIC DIGESTERS AND POLICY OPTIONS FOR ADDRESSING THOSE PROBLEMS

Problems associated with the operation of centralized digesters include capital constraints, low profitability, lower-than-expected waste availability, electricity connection and pricing, and waste disposal constraints. Local, federal, and state government policy instruments that can influence the establishment, operation, and profitability of central anaerobic digesters include investment policies and grants towards initial investment allowing farmers and other investors to pass the initial hurdle of acquiring the critical level of investment; tax and subsidy policies that encourage the establishment of central anaerobic digesters and their economic feasibility; electricity connection and pricing policies that will attract new investors; support for farmer and consumer cooperatives to establish new digester generator systems; and waste disposal and environmental policies that will induce farmers and processing plants to seek anaerobic digestion as a remedy.

4.1 Investment, Investment Grant, Tax, and Subsidy Policies

Livestock farming is a capital-intensive activity. Kubsch refers to data from the Wisconsin Dairy Task Force which states that 11.3 percent of Wisconsin dairy farmers are heavily indebted, with a debt level of 40 percent or more [Kubsch, 2003]. If farmers are to cooperatively establish a central anaerobic digester, another capital-intensive activity, they will increase their debt and could have difficulty finding loans. This situation is exacerbated by the long payback period and the large operating and maintenance expenditures required. In Minnesota, Haubenschild Farms obtained grants, technical assistance, and low-interest loans from the state and federal government.

Grants are available for those interested in making an investment in central anaerobic digesters in the State of Minnesota [Minnesota Department of Agriculture, 2005]. However, public support for digesters appears to be less strong in Minnesota than in North Carolina, where it is argued that: “Because residents of North Carolina are affected by externalities stemming from hog farms, the state should invest a percentage comparable to the Danish Government. Any other outside groups or corporations who desire to invest in the centralized biogas system would be allowed to do so.” [Lewis, 2001. p. 11].

The main federal financial support available for investments in digesters in Minnesota are the 2002 Farm Bill section 9006 grants and guaranteed loans, and the Renewable Electricity Production Credit (REPC). The grants are available for up to 25 percent of project costs, while the guaranteed loans can be up to 50 percent [p. 36]. The grants and loans will be available through the 2007 fiscal year under the 2002 Farm Bill, with future availability dependent on what happens with the 2007 Farm Bill. Digesters are considered “open-loop biomass” for the purpose of the REPC, which is available at 0.9 cents per kWh for the first five years of digester operation. This is a lower level of support than for wind and most other forms of renewable electricity, for which the REPC

is 1.9 cents per kWh for ten years. The REPC is also reduced by the amount of government grants, subsidized financing, and other credits, so it becomes an “either-or” choice between that and the section 9006 program. A livestock producer receiving a section 9006 grant for 25 percent of the project cost will likely be better off taking the grant rather than the REPC. This is in contrast with the situation faced by a wind farm, which will likely be better off with the REPC (i.e. the present value of the ten years of REPC payments may exceed 25 percent of the project cost). The 9006 grants and loans come from a limited pool of funds and require a lengthy application, so not all interested producers may receive them whereas the REPC is available to any producer with taxable income. The REPC is currently set to expire on December 31, 2007. The German government has set up a sliding scale of support for digester development so that the economic community can plan for payback of loans issued to farmers who want to build digesters. The most beneficial support is a guaranteed price for each kilowatt of electricity that is higher than the retail price of electricity.

By the year 2000, four of the twenty central anaerobic digestion plants operating in Denmark were considered to be producing unsatisfactory economic returns. All of these plants suffered from faulty construction and/or inappropriate technology during their construction stage. The Fangel Plant suffered from inappropriate construction and equipment that lead to operational instability and increased operating costs. As a result considerable renovation and installation of new equipment had to be performed on the plant. Similar renovation, installation, and investment were done on the Sinding plant due to the problems it suffered during the construction stage. The Arhus plant suffered from inappropriate construction while the Snertinge plant suffered from a number of problems including those that required further investments after the plant went into operation.

The geographic locations chosen for central anaerobic digesters is also another issue that significantly affected the economic performance of some plants in Denmark. These plants were established to process a large amount of influent but could not get the required supply. The result was a negative impact on earnings.

In Denmark the government, in its push to reduce pollution and dependence on fossil fuels, allocated 12 million DKK for development, follow-up, and information activities of the manure digestion idea for the period of 1998-2001. In addition to this the government provides an investment grant of 20 to 40 percent of the cost of establishing central manure digesters. It also provides a state production grant of 0.27 DKK per kWh of electricity produced and extends a low interest, long-term loan for up to 20 years.

The Robe plant in Denmark contributed only 16 percent of the needed capital from its own sources for initial construction, and none of the other plants invested their own capital in the initial investment of their plants [Table 7.1, Hjort-Gregersen, 1999]. By comparison government grants towards initial investment constituted from 11 to 45 percent of initial investments, the average government grant being 27 percent of initial investments. The remaining 73 percent of the funds came from three other sources: indexed loans, mortgage loans, and bank loans. On average 56 percent of the funding came from indexed loans, mortgage loans contributed nine percent of the funds while

bank loans contributed an average of eight percent of the funds. The amount of own capital used by the Ribe plant represented an average of only 0.3 percent of the total capital[4]. Bachewe's Minnesota study reports that grants and subsidized low-interest public financing of the Haubenschild Farms digester amounted to 78 percent of the total investment, while the farm's equity capital amounted to 22 percent.

4.2 Electricity Connection and Pricing Policies

The November 2006 report of Network for New Energy Sources compares State net metering regulations that affect how electricity from central digestion plants is valued when selling to the electricity grid [Chapman, 2006]. This report indicates that by 2006, 36 states had adopted statewide programs that set rules by which customers who generate their own electricity can interconnect to the central transmission grid known as "net metering". These programs have been described as the most significant policy tool at any level of government that boosts the decentralizing of energy sources and increase of 'green' American energy sources. By compensating customers for reducing demand and sharing excess electricity, net-metering programs are powerful, market-based incentives that states can use to encourage energy independence.

The report indicates that Minnesota became the first state in the U.S. to mandate net metering by legislative statute in 1983. States that support such legislation believe that the program is an easy way to promote investment in renewable energy without spending a substantial amount of public funds. By providing a market mechanism for compensating customers for excess generation, the program was intended to offset some of the up-front capital costs associated with installing renewable energy systems. Some of the objectives of the states that adopted such statutes included encouraging greater renewable energy generation, promoting distributed generation of electricity, reducing demand on central transmission grids, rewarding early investment in renewable technologies, and facilitating energy self-reliance. The report indicates that although states have adopted similar net metering statutes, no two states share the exact same regulations or procedures governing how the programs are implemented and monitored.

To measure and compare net metering regulations between 34 of the 36 states the report developed an index that rewards program elements that promote participation, expand renewable energy generation, or otherwise advance the goals sought by net metering. According to this index New Jersey is the state with the best performance while Minnesota, the state that adopted net-metering regulations first, over two decades ago, is sixth. However, this high ranking may not be entirely relevant to the digester situation because Minnesota's 40 kWh maximum appears to be below current minimum economically feasible digester generator sizes. The Haubenschild Farms generator, for example, is 135 kWh.

California's net metering law was established in 1995 and has seen many modifications over the years including three separate bills enacted in 2005 [New Rules Project,

[4] The total may not add up to 100 percent due to rounding.

undated]. The are many exceptions but, in general, the current rules allow on-site energy projects of up to 1 MW access to net metering. The combined capacity of net-metered systems may not exceed 0.5% of any utility's peak demand. While net metering in California generally applies to wind and solar energy projects, there is a pilot program that allows fuel cells and biogas digester systems to qualify. California's rules allow qualifying net metered projects to interconnect with their utility without having to pay additional charges including any new or additional demand charges, standby charges, customer charges, minimum monthly charges, interconnection charges, or other charges that would increase an eligible customer-generator's costs beyond those of other customers in their rate class.

The Pacific Gas and Electric Company web page contains additional information on the process of application and the requirements that should be satisfied by customers that need to produce electricity from biogas plants [Pacific Gas and Electric Company, 2006]. Pacific Gas and Electric Company's Net Energy Metering Service for Biogas Customer-Generators (NEMBIO) rate schedule is an optional rate schedule for customers with an eligible biogas digester operated in parallel with the electric company to supply some or all of the customer's energy needs. A biogas digester is defined as a generating facility used to produce electricity by a manure methane production project or as a byproduct of the anaerobic digestion of bio-solids and animal waste. Pacific Gas and Electric Company requires that the generating facility meet all applicable safety and performance standards established by the National Electrical Code, the Institute of Electrical and Electronics Engineers, accredited testing laboratories such as Underwriters Laboratories and, where applicable, rules of the Public Utilities Commission regarding safety and reliability. Moreover, the utility requires that biogas digester generators must commence operation by December 31, 2009 to be eligible for the program according to Public Utilities Code section 2827.9 (the statute governing the NEMBIO program). The statute caps availability of NEMBIO to 50 MW. Once this limit is reached, the NEMBIO rate will be closed to new customers unless extended by law.

Michael Dworkin, former Chair of the Vermont Public Service Board and former chair of the National Utility Commissioners' Committee on Energy Resources & the Environment argues that we are facing an "Energy Trilemma," – an energy world strained by three forces: financial stress, environmental constraints, and security risks. He continues by stating that we need solutions now that help us on some or all of these fronts, without making others worse [Chapman, 2006]. Dworkin suggests that net-metering needs to be considered as a vital part of the larger effort to supplement the current centralized, fossil-fired, costly electric grid with clean, secure, and cost-effective energy and renewable resources. The distribution of these resources throughout the system can both help and be helped by investments in clean net-metered generation. The most important need is encouragement, not discouragement, of small, clean, and distributed investments that can help us on all three fronts of our energy Trilemma -finance, environment, and security.

The Lazarus and Rudstrom analysis shows how the electricity price affects digester profitability [Lazarus and Rudstrom, 2007]. The Haubenschild Farms were able to secure a favorable price of 7.25 cents per kWh for the first five years of their operation and the

contract was changed to four cents per kWh thereafter, with an average price of 5.8 cents per kWh. Given current and future considerations, the remaining four farming scenarios included in that study are assumed to receive 3.56 cents per kWh. This pricing had a significant negative effect on the economic performance of the hypothetical scenarios relative to Haubenschild Farms. In such cases government production subsidies and other forms of production support will reduce the risks associated with investing in central anaerobic digesters. While Minnesota offered its own per kWh production incentives and low-interest loans for digesters, such incentives may or may not be available in the future. This is why the Minnesota study looked at scenarios both with and without such provisions for on-farm digesters to be established in the future. It should also be noted that such provisions were available only for on-farm digestion plants. It is not clear if central digesters will be provided this type of support, as they may not involve farmers or farm owners.

It should also be noted that to qualify for net metering in Minnesota, anaerobic digesters must operate generators that do not exceed a 40 kWh maximum cap. Under current net metering rules, participants are paid the going retail rate for the net excess electricity they generate for each billing cycle. This would amount to approximately twice the 3.56-cent rate mentioned above. Central digesters would almost certainly be larger than this 40-kWh net metering cap. One method for encouraging central digesters is to raise the net metering cap. Another modification to the net metering regulation that may encourage central digesters would be to apply the regulation on the basis of each of the participating farms or other processing plants that contribute organic wastes.

The pricing of electricity generated from distributed, renewable sources and sold to the grid is complex. The history of competition in the electricity sector and the issues involved in setting rates and standards was reviewed by Kildegaard in a recent article in the University of Minnesota Center for Urban and Regional Affairs' CURA Reporter publication. [Kildegaard, A., 2006] The 1978 federal Public Utility Regulatory Policy Act required utilities to buy electricity from certain qualifying facilities, mainly small-scale suppliers such as digesters, at avoided costs. While the Public Utility Regulatory Policy Act only applied to facilities installed before 2000, the avoided cost concept continues and has been incorporated into standards adopted by the Minnesota Public Utility Commission. It appears from Kildegaard's discussion that the most controversial issue is how to value the standby generating capacity that the utility must provide in case the small-scale supplier fails. This is a significant challenge considering that the availability of the small-scale supplier may reduce the "need" for the utility to invest in additional capacity to meet projected demand. The Minnesota PUC has decided on a five-year planning horizon for determining "need", which Kildegaard argues is too short.

One other source that lays out the rural electric cooperatives' perspective on pricing electricity from distributed generators is a white paper by the National Rural Electric Cooperative Association [National Rural Electric Cooperative Association, 2005]. That paper argues that distributed generation is in danger of being oversold. It poses genuine safety and reliability risks, and can pose economic risks to some incumbent utilities and their consumers.

In contrast to current Minnesota policy, digester plants in Denmark receive significant government support in terms of favorable rules for connection to the electric grid. Most of the plants are connected with community heating sources and do not have to go through the steps necessary to generate electricity or invest in electricity generation equipment. Danish plants are provided with a subsidy of 0.27 DKK per kWh of electricity generated in addition to the favorable prices they receive. Law mandates the electricity prices at which the utility companies are obliged to buy the excess electricity production. Moreover, biogas and heat produced from the plants are exempted from any energy tax.

Hurley and Williams also conclude that the economic performance of central anaerobic digesters proposed for California dairy farms would be heavily dependent on the regulatory environment. They found that the digesters would be marginally profitable under current policies, but if additional regulatory costs were imposed the digesters would lose money [Hurley et al., 2006].

A central digester has been proposed to serve an estimated fifteen dairy farms (6,075 cows) in King County, Oregon [Environmental Resource Recovery Group, LLC, 2003]. A follow-up study from the proposed digester examined the question of the feasibility of marketing the digested manure solids [Terre-Source LLC]. The solids study found that a number of the original study's assumptions were not realistic, such as: a) the cost of handling the solids, originally estimated at $5/ton compared with $10-15/ton on a similar operation; b) equipment and storage space may have been underestimated; c) a 3-5 year ramp-up period was thought to be needed to develop the solids market before the projected price would be achieved, rather than sales beginning immediately; d) marketing staff would be needed and had not been budgeted; e) the solids volume would be reduced due to solids degradation and moisture loss; f) there might be odor problems; and, g) sulfides in the solids might be an issue [p. 22].

This discussion of solids marketing raises another ancillary issue. The size of the potential market for digested manure solids, assuming that the number of digesters is greatly expanded and it proves profitable to market the solids across the United States. The Canadian Sphagnum Peat Moss Association claims to supply over 98 percent of the peat moss used in the United States. In 1999 they sold 10.3 million cubic meters for almost $170 million [Canadian Sphagnum Peat Moss Association, undated]. That works out to $16.50/ cubic meter. The Hurley et al. study assumes a solids production rate of around 17 cubic yards/cow/year or 13 cubic meter/cow/year. If the market for manure solids could be expanded to replace, say, 25% of that peat moss, that would be around 2.5 million cubic meters, stated another way it would approximate the supply from digesters for around 200,000 dairy cows. That would equal manure solids from 2% of the 9 million dairy cows in the United States.

4.3 Waste Disposal and Environmental Requirement Policy

Waste disposal and environmental policies that encourage the establishment of central anaerobic digesters are the most frequently suggested policies in the literature. There is a wide variety in purpose and in form of these policies. Some initiatives started out to reduce greenhouse gas emissions; others started from a decision to recycle a specific amount of organic wastes by a given time; and, yet others, to protect water resources, the environment, and the public from the undesirable results of dairy farming. Whatever the reason for increased regulation, the end result has been the accelerated establishment of anaerobic digesters. Following are highlights from the rules and regulations that have contributed to increased establishment of anaerobic plants.

The first example is from the numerous State legislative efforts listed in the North Carolina study [Lewis, 2001]. The study cites the 1995 Senate Bill 1080 that imposed mandatory setback requirements on all new or expanded factory hog farms. The 1997 House Bill 515 imposed a partial moratorium on new and expanded factory hog farms and directed the state to develop a plan to phase out anaerobic waste lagoons and spray fields. Phasing out lagoons is considered a necessary catalyst for implementation of any new system designed to effectively utilize or dispose of waste. This law required setbacks from hog houses and lagoons to be at least 2,500 feet from any outdoor recreational, facility, national park, state park, historic property, or child care center; at least 500 feet from any well supplying water to a public water system; and at least 500 feet from any other well supplying water for human consumption. The study indicates that such regulation forces farmers seek other forms of waste treatment such as anaerobic digesters.

The next example of regulatory framework that served to increase establishment of anaerobic digesters comes from California where in 1990 they set a 50 percent waste diversion goal by the year 2000 and the creation of the California Integrated Waste Management Board. All jurisdictions in California were required to collect data on local waste streams and develop solid waste management plans. The California Integrated Waste Management Board fosters market development for recyclable materials and provides education/outreach on waste reduction programs. The third example comes from Washington State where the legislature created the Clean Washington Center in 1991. The Clean Washington Center has worked in partnership with business, industry and local governments to develop markets for recycled materials. They provide technical assistance in business development, recycling technology, product marketing and policy research and analysis.

The common denominator of these state initiatives include commitment to divert significant waste streams from land fills; creation of waste management boards to tackle issues at the community level; and, economic incentives for development of by-product processing facilities such as digesters and markets for end products.

In contrast to the previous examples, Wells et al. [2001] argue that the solid waste management regulations in Wisconsin are landfill oriented and have not yet addressed the beneficial blending and processing of agricultural, municipal, and industrial organic by-

products. In particular the Fox River Valley is faced with increasing obstacles to land spreading or land filling of organic wastes. The region is home to food processors, municipal wastewater treatment and solid waste facilities, paper mills, wood manufacturers and livestock producers. Dairy herd expansion in this region is progressing at one of the highest rates in the state and the region represents one of the fastest growing urban populations in Wisconsin. Since the processing plants are located in close proximity, they are competing with each other for open lands on which to spread their organic wastes. Several towns in the Fox River Valley have adopted ordinances that restrict the movement and land spreading of manure and biosolids. In general the situation in the region has led to increased competition for land, rising landfill costs, and increasingly restrictive regulations on spreading of organic wastes. These in turn have led farmers and industries in the Fox River Valley to seek alternatives to direct land spreading and/or land filling of raw wastes. The study suggests that the farms and industries involved can create a centralized organic waste acquisition and processing establishment that would reduce waste handling costs for most of the industries, farms, and municipal agencies participating in the project.

Internationally, examples of a supportive regulatory environment come from Australia, New Zealand, and Denmark. Wells et al. [2001] state that in the early 1990's, the Australia-New Zealand Environmental and Conservation Council conducted an inquiry into existing waste management practices which resulted in a mandate for a 50 percent reduction in wastes to landfills by the year 2000. Policies and legislation were introduced to minimize waste; including financial support for innovative waste minimization programs and the development of standards and quality control criteria for recycled organic materials.

A study in Denmark indicates that the government's commitment to reduce air pollution and greenhouse gas emissions contributed to its decision shift some of its consumption from fossil fuels to renewable energy sources [Hjort-Gregersen, 1999]. This led to the development of centralized biogas plants that have been discussed in detail. However, the establishment of these plants was only possible due to several preconditions. Such preconditions included a targeted 20 percent reduction of the 1988 carbon dioxide emission level by 2005 and a determination to recycle 50 percent of organic waste by 2005. These fundamental decisions served as the base for further legislation such as the requirement that farms provide six to nine months' of slurry storage capacity, restrict raw manure application on land, and prohibit organic waste in landfills. Additionally, taxes were levied when wastes were incinerated but not if recycled. These and the support of veterinary and environmental authorities for co-digestion of manure and organic wastes led to one of the exemplary cases of the development of central anaerobic digesters in the world.

Holm-Nielsen and Al Seadi [undated] examined livestock farming in association with anaerobic digestion in the 15 European Union countries, and came up with a set of regulations that are intended to reduce the environmental and social burden of large scale farming and lead to increased capacity for renewable energy production. Suggested regulations include programs to stimulate recycling of organic waste and organic

resources, especially wet organic waste, and synchronization of animal manure storage and handling requirements throughout the region. They focus on large-scale animal production with little, if any, land area to recycle organic waste through crop production. In addition to this, the study suggested policy development that will lead to an overall strategy of mandatory synchronization between animal stocking rate and farmland area, Research & Development on small systems, and improved post treatment/separation technologies. Among other things, the study suggested programs for active promotion and dissemination of biogas technologies and knowledge transfer due to the need to overcome transport and processing constraints. It also indicated that an overall policy to stimulate electricity production from renewable sources, support cleaner energy, and encourage use of renewables in combined heat and power systems are important tools to increase anaerobic digestion.

As noted by Michael Dworkin, the costs of sulfur containment and of nitrogen control are now showing up in the bills charged by some utilities [Chapman, 2006]. The costs of mercury controls will soon come and the financial costs associated with carbon capture lie ahead. The costs of land for power plants and transmission lines are rising fast. These costs in bills and rates are but a small part of the true environmental costs that are being faced, and an even smaller part of the true environmental costs that are being passed on to the next generation.

After reviewing these articles, it appears that an integrated overall waste management strategy that is synchronized with a renewable energy production is one of the keys to a successful future for anaerobic digester projects. The strategy may include a plan for increased processing of organic waste and increased electricity production from organic waste. However, as noted above, many diverse factors serve as the motivation for an overall waste management and renewable energy production strategy.

Once the strategy has been determined, many details will need to be addressed. These details include legislation that puts strict waste management requirements on livestock farms, processing plants, and other organic waste sources in a way that leads to voluntary establishment of central anaerobic digestion plants and financial support for those who follow the socially desirable route along with fees and/or penalties for those who need extra incentive to adopt change.

CHAPTER V - CONCLUSIONS

This review is prepared for a wide audience. The motivation for its preparation is a belief that Minnesota can take advantage of the manure and organic wastes that are produced as byproducts of other activities, for the production of biogas that can be used to produce heat and electricity. A comparison is made between Minnesota and Denmark due to the many similarities between the two entities. Denmark serves as a role model for Minnesota in the number of central anaerobic digesters that it supports while Minnesota has none. Yet, based on livestock and other organic waste production Minnesota has a similar potential to benefit from the development of central anaerobic digesters.

A preliminary investigation of the literature made it clear that establishing central anaerobic digesters requires the following preconditions: 1) a sufficient density of cows or availability of other organic material; 2) motivated farmers; 3) accurate estimation of transportation costs; and, 4) favorable power purchase agreement terms and conditions that are negotiated with utility companies for electricity generated for sale by central anaerobic digesters. Each of these factors has a substantial impact on the financial viability of a central anaerobic digester.

The advantage of central anaerobic digesters in terms of their larger size relative to farm scale digesters comes from their ability to process other organic wastes in addition to dairy, swine, or poultry manure. Experience shows that central anaerobic digesters are able to process such diverse organic wastes as fat or flotation sludge, intestinal contents, fish processing wastes, wastes from medical industries, paper and recycled paper, wet and dry distillers grains, and other wastes.

Central anaerobic digesters have many forms of ownership. They can be owned by farmers or consumers cooperatives, third party/non-farming investor(s), state or municipal government, or established as a cooperative or limited liability corporation. Currently the cost of establishing and operating central anaerobic digesters on a cash basis is high compared to their monetary returns. However, assigning monetary value for all external benefits of central digestion plants would likely result in total long term benefits equal or greater than the costs incurred in construction and operation.

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