

Date of Report: September 6, 2007

FINAL REPORT

LCMR Final Work Program Report

I. PROJECT TITLE: 10(c) Manure Methane Digester Compatible Wastes and Electrical Generation

Total Biennial Project Budget:

LCMR Appropriation:

\$100,000

Amount Spent:

\$ 94,604.89

Balance:

\$ 5,395.11

Other Funds: None

Funding Priority: Energy

Project Manager: Paul Burns

Affiliation: Minnesota Department of Agriculture, Agricultural Development and Financial Assistance Division (ADFA)

Mailing Address: 625 Robert Street North, St. Paul, MN 55155-2538

Telephone Number:

651- 201-6488

Email:

Paul.Burns@state.mn.us

Fax:

(651) 201-6120

Web Address: <http://www.mda.state.mn.us>

Legal Citation: ML 2005, First SS, Ch. 1, Art. 2, Sect 11, sub 10(c)

Appropriation Language: 10(C) \$50,000 the first year and \$50,000 the second year are from the trust fund to the commissioner of agriculture to research the potential for a centrally located, multifarm manure digester and the potential use of compatible waste streams with manure digesters.

Overall Project Outcome and Results

Experience and research indicates the potential for a centrally located, multifarm manure digester and the potential use of compatible waste streams with manure digesters.

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. Central anaerobic digesters are able to process compatible waste streams.

Central anaerobic digesters overall appear to have the most potential for economic feasibility where:

- nuisance odors require action;
- offsite organic waste is available which can be co-digested to increase gas output and/or generate tipping fees;
- the manure solids are separated and have a high value for dairy cow bedding or as a soil amendment;
- the biogas can replace large onsite retail purchases of electricity or heat; or
- the electricity is sold to the grid in a region of the U.S. with higher-than-average electricity prices.

Central anaerobic 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.

Challenges unique to centralized digesters include:

- organizing the group of farms, reaching consensus and commitment to the project, and providing a mechanism for farms to leave the group,
- sanitary issues involved in transporting manure between farms, and
- the capital investment and operating costs for the manure transportation equipment and loading/unloading facilities.

Project Results Use and Dissemination

Results were disseminated at two workshops for producers and researchers.

Results will be made available to producers, producer groups, agri-businesses and researchers interested in central anaerobic digesters.

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II. and III. FINAL PROJECT SUMMARY:

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- the capital investment and operating costs for the manure transportation equipment and loading/unloading facilities.

Results were disseminated at two workshops for producers and researchers.

Results will be made available to producers, producer groups, agri-businesses and researchers interested in central anaerobic digesters.

IV. OUTLINE OF PROJECT RESULTS:

Result 1: Evaluate the potential for either a centrally located digester or electrical generating facility.

The primary goals of the project were: 1) to determine the potential for a centrally located, multi-farm digester; and 2) to determine the potential use of compatible waste streams with manure digesters. The goals of Result 1 were accomplished through the following:

- Preparing a literature review, supplemented with an annotated bibliography and directory of designer and installers of central anaerobic digester
- Development of a user-friendly economic model for analyzing digester installations;
- Updating the manure digester economic feasibility spreadsheet;
- Preparing a white paper on the potential policy implications of implementing multiple farm manure digesters and co-digesting manure with other waste streams; and
- Conducting two workshops for producers, U of M and state agency staff on the results of the project.

The Literature Review

The main task of the project was to prepare a literature review (Attachment B) of the economic and technical feasibility of centralized or multiple farm manure digesters. The primary objective of literature review in the area of central anaerobic digesters was 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.

A comparison was 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.

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

- 1) A sufficient density of cow manure or other organic material is available;
- 2) Motivation for farmers to participate in central anaerobic digesters from both a financial and a societal point of view;
- 3) 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;
- 4) 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;
- 5) 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 by-products 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.

The Annotated Bibliography of References

Also prepared was an annotated bibliography (Attachment C) covering a wide range of references that were used to compile the literature review on centralized digesters. The references include research publications, reports from projects, personal communications from experts in the field and popular press reports. The significance of the reference to the report was indicated and the character of the report was also indicated so that the reader may make inferences as to the quality of the material contained in the reference. References were from a range of time periods and from both national and international sources.

An Updated Directory of Designers and Installers

An updated directory of central anaerobic digesters designers and installers was compiled (Attachment D). Contacts with engineering firms and industry officials were made to provide a list that could be used by individuals interested in learning more about anaerobic digestion for multiple farm digesters and/or multiple substrates for co-digestion.

Experienced design firms and independent developers both in the U.S. and Europe were contacted. Suggestions from these firms lead to an expanded group of firms to contact. The authors William Lazarus and Philip Goodrich made contacts at

professional meetings, at trade shows, through email, by telephone and by personal visits to research sites and digester sites in Minnesota, Wisconsin, New York, California, in Denmark, Sweden, and Germany.

The list as compiled by Philip Goodrich includes firms that the author would use as a starting place for developing a project that includes a multiple farm digester and co-digestion of energy products. The list may not include all qualified firms, but those that the author's experience and research criteria seemed best for Minnesota. Others are on self-contributed lists at AgSTAR (<http://www.epa.gov/agstar/tech/consultants.html>). The lists are not always up to date however.

The main criteria used in compiling this list included:

1. The firm has on farm digesters that have been completed and working;
2. The firm has the capabilities of working in cold climates;
3. The firm has the capabilities to provide after construction support for the project; and
4. The authors were able to determine that a US office exists for the firm.

Specific information that was learned during contacts with experienced designers is summarized below.

Before a project is committed to any engineering firm, it is the responsibility of the project manager to determine the current capabilities of the firm to successfully complete the project based on past performance, current economic conditions, and current personnel employed. Note, however, that there are not a large number of experienced engineers in the field.

If the digester contemplated is a large multi-input digester utilizing materials other than manure, there are a number of items that must be considered that are not usually a problem with a single farm manure digester.

1. The materials may contribute to health concerns for the farmers who are receiving the effluent from the digester. High temperature post processing of the effluent may be needed to satisfy security concerns.
2. The nature of the digester may lead to extensive environmental studies being required and hearings being held to satisfy neighbors concerned about added traffic, health concerns and materials being added to the local environment.
3. Permits from multiple regulatory bodies may be necessary if cross-jurisdictional issues arise.
4. The markets may change considerably over time and the financial projections may significantly change due to externalities that are difficult to foresee.
5. The financial inputs will be larger and a broader base of funding may be necessary for the project to succeed.
6. Strict control over the inputs from various sources will be needed to insure that toxic or dangerous materials do not enter the digester.
7. Detailed operational plans for emergencies, accidents, terrorism and extreme weather conditions need to be part of the plant manuals that are developed within the project scope.
8. Plans for adequate staffing of the plant with trained and qualified personnel are very important to the continued operation of the plant.

A White Paper on the Potential Policy Implications

A white paper on the potential policy implications of implementing multiple farm manure digesters and co-digesting manure with other waste streams was also prepared (Attachment E).

This is a short paper addressing policy implications and needs for implementing multiple farm digesters and co-digestion of manure with other sources that can be used as talking points for interested groups.

Farm-based digesters are a multi-faceted technology that offers a range of benefits. However, as a standalone electricity-supplying technology for individual farms or groups of farms, the farm-based digester has struggled in Minnesota and elsewhere in the U.S. due to generally marginal profitability.

A number of policies that may be beneficial are presented including some that are monetary incentives, some that change the relationship between regulated industries and independent producers of energy and biological products, and some that encourage the use of non-fossil fuels to reduce greenhouse gases while increasing sustainability.

No one policy will solve all the problems that are holding back the production of renewable energy from organic materials in Minnesota. A wide range of policy change opportunities exist that will allow Minnesota to achieve the goals of "20 by 2020" ahead of schedule.

Production of renewable energy by digestion uses no fossil fuel in the process. This highly efficient low input system utilizes waste materials which otherwise may be treated using fossil fuels. Developing this resource in rural Minnesota is a win-win situation for renewable energy, improving the environment, and maintaining sustainable communities.

The Manure digester Economic Feasibility Spreadsheet

The manure digester economic feasibility spreadsheet (on enclosed CD) developed by Dr. Lazarus has been updated to reflect inflation and new economic grant and loan programs that are available to assist farmers in putting in digestion systems.

This model was developed originally for use in preparing educational fact sheets on the Haubenschild digester, and then used for the Review of Agricultural Economics journal article cited in the literature review. The main updating done for this LCMR project was to add an expense line item for manure transportation, and to update the digester capital investment and the other prices to projected 2007 levels. The manure digester economic feasibility spreadsheet was used for the economic modeling of the centralized digester concept. A simpler, user-friendly economic model (discussed on page 6) was also developed and implemented as a spreadsheet, but it was not available when the economic modeling (manure digester economic feasibility spreadsheet) was done.

The modifications to the manure digester economic feasibility spreadsheet included updating the digester installation costs and adding a cost line item for the cost of the manure transportation required for the centralized digester. While adding the annual manure transportation cost was a relatively minor change to the spreadsheet structure, arriving at the manure transportation cost itself was an involved calculation carried out in a modified version of MACHDATA.XLS, downloadable at <http://www.apec.umn.edu/faculty/wlazarus/machinery.html>, which was originally developed for updating the extension machinery cost publication. The process was to visit Stearns County and decide on the farm sizes and the dairy herd-to-digester distances that would be analyzed – 1, 2, and 3 miles one-way. Road travel speeds and loading/unloading times were decided on in collaboration with the University of Minnesota. Collaboration considered load sizes, the number of loads, and a travel schedule to make sure one tractor and tank manure applicator would be able to complete the hauling during the time available in addition to the usual task of spreading the manure on the cropland of the farms. The MACHDATA.XLS spreadsheet uses formulas for economic depreciation and repairs that are published in the American Biological and Agricultural Engineers' Standards publication. Those formulas are based on an assumed useful life for a given machine, which can be varied to arrive at an approximate optimal combination of repairs and depreciation. A simulation over a range of machinery life spans was carried out to determine how much more frequently the tractor and tank would need to be replaced and the additional costs involved when the manure transportation activity is added. The final machinery cost assumptions we arrived at are described in the economic modeling report.

The manure digester economic feasibility spreadsheet is an annual discounted cash flow capital budgeting model. Given the high failure rates that have been experienced by older on-farm digesters, the planning horizon for the analysis was limited to ten years with a zero value even though some digesters have operated over longer life spans. The spreadsheet formulas are set up with space to expand the planning horizon to twenty years if desired. The model is set up with the capability to enter either actual historical data or projections, because the farm we worked with had data on actual operating costs, sales of electricity and digested manure or digestate, and avoided heating costs for 1999-2004. The second five years of the analysis were then projected based on averages with inflation adjustments.

As an annual discounted cash flow model, the spreadsheet is relatively complex but factors in several important considerations that simpler models ignore: inflation, leverage effects, and income taxes. The results are expressed in a number of different

measures that may be appealing to different users, such as payback period, breakeven electricity price, net present value (along with the annualized equivalent), rates of return on assets and equity, and impact on milk production cost. One unique aspect of the model is that it calculates the present value of the various operating subsidies along with the construction grants to clearly show how much of the profitability situation is due to market returns and how much is from subsidies.

A User-friendly Economic Model for Analyzing Digester Installations

A user-friendly economic model for analyzing digester installations on dairy farms was developed in an Excel spreadsheet (on enclosed CD). The model is intended to help users make rough initial calculations of the annual costs and returns to be expected from owning and operating a methane digester on a dairy farm. The model is readily usable to analyze the feasibility of multiple farm digesters.

The main issues the model addresses include: herd size, digester installation cost, amount and value of any electricity generated, co-product value, and public support. It is not intended to address the engineering or design issues, and particularly the amount of biogas output to be expected.

Workshops

Two workshops were conducted with farmers, U of M, and state agency staff to disseminate the results of the project and to present the User-Friendly Economic Model Analyzing Digester Installations. One workshop was presented using Internet "Breeze" to conduct the workshop over the Internet. It was planned that the Internet workshop would allow more people to participate and involve much less cost to participants. This was not very successful because of technical difficulties with the equipment and lack of support from the lab providing the base for the workshop. A second workshop where the participants were in the same room with the presenter gained more participation from farmers, extension staff, government and state agency staff.

Publications

The main publication from this project is the literature review that will be published in an economic or an engineering journal within the next year.

MDA Student Worker

The MDA hired one student worker for the summer of 2006 to assist in meeting the goals and objectives of this LCMR project by developing educational materials and assist U of M staff with this LCMR project. Originally, the student was going to assist the MN Project with the LCMR project *Dairy Digester*; however, the *Dairy Digester* project was delayed and then extended by one year, and no longer needed the help of the student worker.

During the summer of 2006, the student worker worked on a PowerPoint presentation and short video presentations on manure digestion and centralized manure digesters. The student worker also interviewed a number of officials and leaders in government, academia, and private industry to get their feedback on the use of centralized digester systems and the use of multiple waste streams co-digested with manure.

Work objectives that were completed include:

- **Interviews with Government and Academic Officials:** The student worker conducted a series of phone and face-to-face interviews with government officials involved with energy and agricultural policy and also with academic researchers working with anaerobic manure digestion. All of the information from the interviews was inputted into a MS Access database for further dissemination. The student worker report and summary of the information is in Attachment F.
- **PowerPoint Presentation:** The student worker developed a PowerPoint presentation for MDA and University staff to use on anaerobic manure digestion. The presentation has been posted on the MDA website at <http://www.mda.state.mn.us/renewable/waste/default.htm> See Attachment G for a copy of the presentation.
- **Video Presentations:** The student worker developed two short video presentations for the LCMR project. These presentations were developed to help explain how anaerobic manure digestion works to a general audience. The student worker also developed a video presentation to disseminate the results of a past MDA LCMR project

involving a fuel cell running off of biogas from an anaerobic manure digester. The presentation has been posted on the MDA website at <http://www.mda.state.mn.us/renewable/waste/default.htm>

- **Farmfest 2006:** The student worker helped staff the MDA booth at Farmfest 2006 in Redwood County. Farmfest is a regional farm show event and typically 40,000 farmers attend this event every year. The MDA had a display on the LCMR project and the student worker helped answer questions and provide information about the objectives of this LCMR project.
- **Information Gathering:** The student worker helped MDA staff in gathering new information on centralized systems for anaerobic manure digestion. This information was used by the student worker, U of M, and MDA staff in developing work products for the LCMR project.

Remaining Balances and Budget Adjustment

The overall project had a budget balance of \$5395.11. Originally, \$10,000.00 was budgeted for the student worker, however, because the MN Project LCMR project *Dairy Digesters* was delayed and then extended by one year, the student worker was not needed, which resulted in a balance of \$5379.17. There was also a balance of \$15.94 remaining from the \$90,000.00 budgeted for the University of Minnesota.

Budget Adjustment Explained:

The \$90,000 budget to the University of Minnesota was adjusted to reflect payment for editing services and the higher salary and fringe benefits of University personnel. The details are as described as follows:

- On July 13, 2007, the contractor requested to use "Printing" and "Supplies" budget funds to pay for editing services. An editor was hired to proofread the literature review. In a telephone conversation with LCMR staff, Susan Thornton on the same date, Ms. Thornton recommended the overall budget summary include a budget adjustment column reflecting the revisions rather than submitting a budget amendment at the late date. Funds from "Printing" and "Supplies" were moved to "Other" to pay for the editing services.

"PERSONNEL: Staff Expenses, wages, salaries" exceeded the original budget by \$179.07 as a result of a change in a University of Minnesota employee classification which was paid a higher salary than the previous employee working on the project.

- "PERSONNEL: Staff benefits" exceeded the original budget by \$2,688.21 as a result of a change in a University of Minnesota employee classification in a higher salary and fringe benefit classification.

The exceedances in Personnel budget items were discovered by MDA upon review of the final invoice from the University of Minnesota. Some funds from "Supplies" and "Travel expenses in Minnesota" were moved to the Personnel budget items to cover the additional costs.

V. TOTAL LCMR PROJECT BUDGET

All Results: Personnel:	\$85,000	Revised: \$87,867.28
All Results: Other:	<u>\$15,000</u>	<u>\$12,132.72</u>
TOTAL BUDGET:	\$100,000	\$100,000.00

Personnel: Total of \$87,867.28: 1) \$10,000 for a student intern hired by the MDA to assist in information gathering, report development, and outreach efforts related to the project. The intern was actively enrolled in an accredited University or College and accrued academic credit for her work. 2) \$77,867.28 for U of M Biosystems and Agricultural Department Staff to conduct the work needed to fulfill the objectives of the project. **Other:** (*Specify*) \$12,132.72 for supplies, printing, and travel expenses for the U of M Biosystems and Agricultural Engineering Department to assist with completing the objectives of the project.

I. PAST, PRESENT AND FUTURE SPENDING:

VII. PROJECT PARTNERS:

- Livestock producer(s) in Minnesota with operational on-farm manure digesters and Various Livestock Organizations: Minnesota Milk Producer's Associations, Minnesota Cattleman's Association, Minnesota Pork Producer's Association, and the Minnesota Turkey Growers Association.
- University of Minnesota (to receive \$90,000 for this project)
- The Minnesota Project
- Minnesota Department of Commerce
- U.S. EPA AgSTAR Program
- Agricultural Utilization Research Institute (AURI)

A. Other Funds being Spent during the Project Period: None

B. Past Spending:

1. Through the MDA Biogas Loan Program, Dennis Haubenschild secured a loan for \$150,000 as part of his financing package to construct his manure digester.
2. MDA spent \$6,250 in FY01 to research odor emissions from manure storage areas from a dairy feedlot using a manure digester and a traditional dairy feedlot.
3. Currently, the MDA, the University of Minnesota Biosystems and Agricultural Engineering Department, the Minnesota Project, and dairy farmer Dennis Haubenschild are cooperating in an LCMR project entitled *Advancing Utilization of Manure Methane Digester Electrical Generation*. LCMR awarded MDA with \$221,000 to accomplish this project. This project spurred a parallel project involving the evaluation of a sterling engine in tandem with the fuel cell. This project is being funded by non-LCMR sources. Additional cooperators for this project are DTE Energy, Great River Energy, Electric Power Research Institute (EPRI), East Central Energy, and John Deere. John Deere Inc. provided a \$40,000 grant to the University of Minnesota to construct a building for both of the research projects.

VIII. DISSEMINATION:

Results were disseminated at two workshops for producers and researchers.

Results will be made available to producers, producer groups, agri-businesses and researchers interested in central anaerobic digesters.

IX. LOCATION: State-wide livestock producers, agri-businesses and researchers interested in central anaerobic digester.

X. REPORTING REQUIREMENTS:

This is the final work program report.

XI. RESEARCH PROJECTS: None

To better explain the project the following attachments and CD have been enclosed.

Attachments:

- Attachment A: Overall LCMR budget Summary
- Attachment B: Literature Review
- Attachment C: The Annotated Bibliography of References
- Attachment D: Directory of Designers and Installers

Attachment E: White Paper on Potential Policy Implications
Attachment F: LCMR Interview Project Summary
Attachment G: PowerPoint Presentation on Anaerobic Manure Digestion
Attachment H: Final Report to the Minnesota Department of Agriculture

CD:

Economic Model for Analyzing Digester Installations, Instructions and Summary
The Manure Digester Economic Feasibility Spreadsheet and Summary

None. Attachment A: Overall
LCMR Budget Summary

Proposal Title: *Manure Methane Digester Compatible Wastes and
Electrical Generation*

Project Manager Name: Paul
Burns, MDA

Total LCMR Funds: \$100,000

2005 LCMR Budget	Result 1 Budget:						
BUDGET ITEM	Total Budget	Revised Budget *	Balance (based on revised budget)	Funds Spent (as of 6/30/06)	Funds Spent (between 6/30-12/31/06)	Funds Spent (between 1/1-3/31/07)	Funds Spent (between 4/1-6/30/07)
**PERSONNEL: Staff Expenses, wages, salaries (Due to a change in U of M employee classification the salary benefits were higher, exceeding the original budget by \$179.07)	70,000.00	70,179.07	5,395.11	10,352.97	33,863.81	5,926.64	14,640.54
PERSONNEL: Staff benefits (Due to a change in U of M employee classification the fringe benefits were higher, exceeding the original budget by \$2,688.21)	15,000.00	17,688.21	0.00	1,819.56	11,046.04	2,111.58	2,711.03
Contracts							
Professional/technical: U of M for research and information gathering (see additional budget pages for detail) (\$90K)							
MDA Work							
<u>Project Management: Intern(s) working for the MDA (see additional budget pages for detail) (\$10K)</u>							
Equipment / Tools							
Office equipment & computers - NOT ALLOWED unless unique to the project							
Other Capital equipment							
Land acquisition							
Land rights acquisition							
Printing	2,000.00	0.00		0.00	0.00		
Supplies	7,000.00	3,983.56	0.00	2,665.92	754.07	151.35	412.22
Travel expenses in Minnesota	4,000.00	3,741.66	0.00	800.04	2,614.56	292.11	34.95

Travel outside Minnesota	2,000.00	2,000.00	0.00	0.00	2,000.00		
Construction							
Other land improvement							
Other (payment for editor)		2,407.50	0.00				2,407.50
COLUMN TOTAL	100,000.00	100,000.00	5,395.11	15,638.49	50,278.48	8,481.68	20,206.24

*Funds for "Printing" and "Supplies" were moved to "Other" to pay for an editor to proofread the literature review. This budget adjustment was discussed with Susan Thornton on 7-13-07. On 7-13-07 the U of M contractor requested to pay for editing services from the "Printing" and "Supplies" budget items. All work was completed by June 30, 2007. Budget Adjustment column was added per telephone conversation with Susan Thornton on 7-30-07.

**Includes Staff expenses for U of M (\$60,179.07) and MDA student worker (\$10,000). MDA student worker budget attached.

Attachment A: Minnesota Department of Agriculture Budget

Proposal Title: *Manure Methane Digester Compatible Wastes and Electrical Generation*

Project Manager Name: Paul Burns, MDA

LCMR Funds: \$10,000

2005 LCMR Budget	<u>Result 1</u> <u>Budget:</u>	-	-	
BUDGET ITEM – For MDA Student Worker	Total Budget	Funds Spent (as of June 30, 2006)	Funds Spent (between July1, 06- January 31, 07)	Budget Balance (as of January 31, 2007)
PERSONNEL: Student workers (non-classified) will be hired to assist in information gathering, report development, and outreach efforts related to the project.	10000.00	993.85	3626.98	5379.17
PERSONNEL: Staff benefits				
Contracts				
Other direct operating costs				
Equipment / Tools				
Office equipment & computers - NOT ALLOWED unless unique to the project				
Other Capital equipment				
Land acquisition				
Land rights acquisition				
Printing				
Other Supplies				
Travel expenses in Minnesota				
Travel outside Minnesota				
Construction				
Other land improvement				
Other				
COLUMN TOTAL	10000.00	993.85	3626.98	5379.17

Attachment B

LITERATURE REVIEW ON CENTRAL ANAEROBIC DIGESTERS

**Report Submitted as Part of Legislative Commission on Minnesota
Resources Project**

**Manure Methane Digestion Compatible Wastes and Electrical
Generation**

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**By The University of Minnesota
Departments of Bioproducts and Biosystems Engineering and Applied
Economics**

Principal Investigators

Philip R. Goodrich

and

William Lazarus

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EXECUTIVE SUMMARY

This review is prepared for a wide audience¹. The motivation for its preparation is a belief that Minnesota can improve the utilization of the manure and organic wastes that are by-products 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

¹ Funding for this project was provided by (The Environment and Natural Resources Trust Fund) as recommended by the Legislative Commission on Minnesota Resources (LCMR).

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 by-products 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.

LITERATURE REVIEW ON CENTRAL ANAEROBIC DIGESTERS

By

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

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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]. “Psychrophilic” 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 by-products 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 2,000 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 eight 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 4,400 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 by-product of the ethanol producing process which is mainly used for animal feed. This by-product 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 switchgrass 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.

Andigen’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 time. 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.

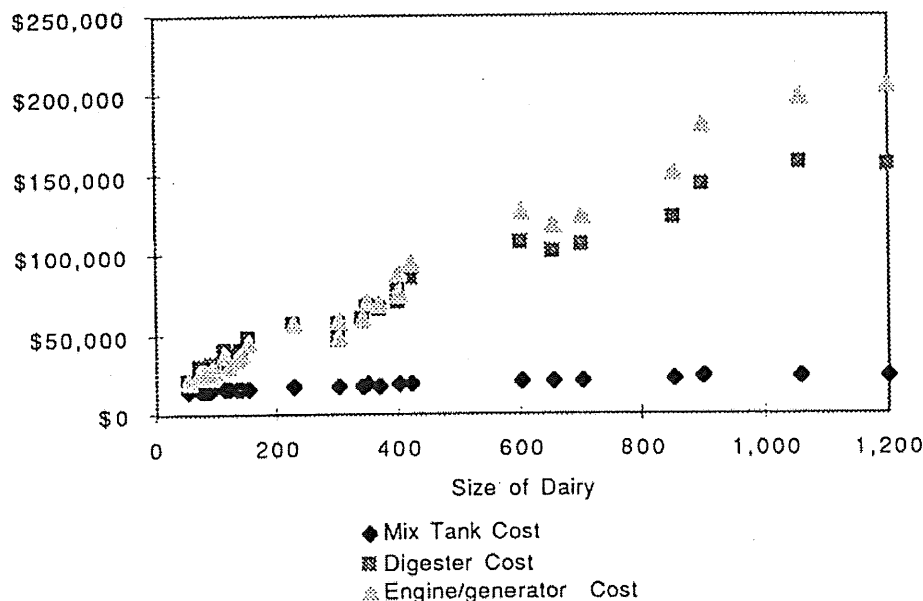


Figure 1. Comparison of the per cow costs of the three main components for on-site anaerobic digestion system.

Source: [Jewell et al., 1998]

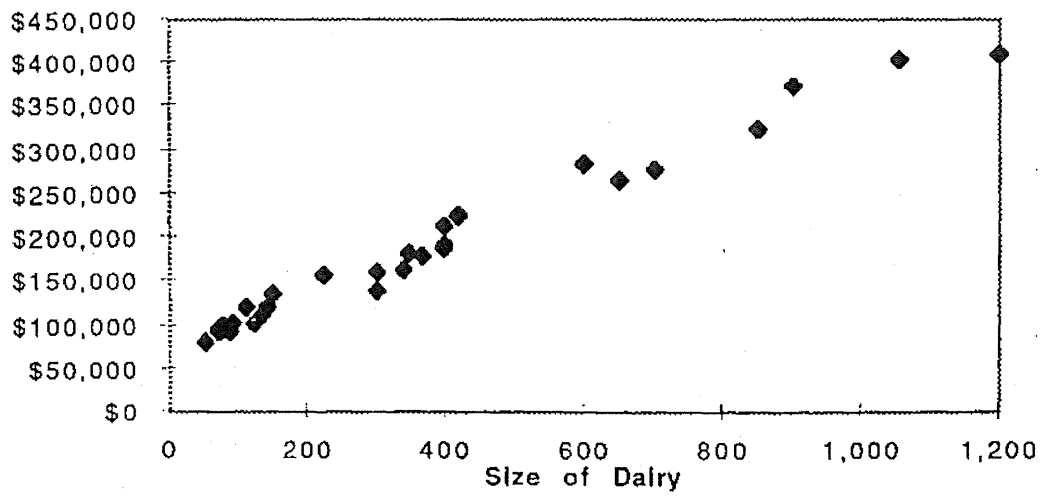


Figure 2 - The total capital cost of a methane recovery facility.

Source: [Jewell et al., 1998]

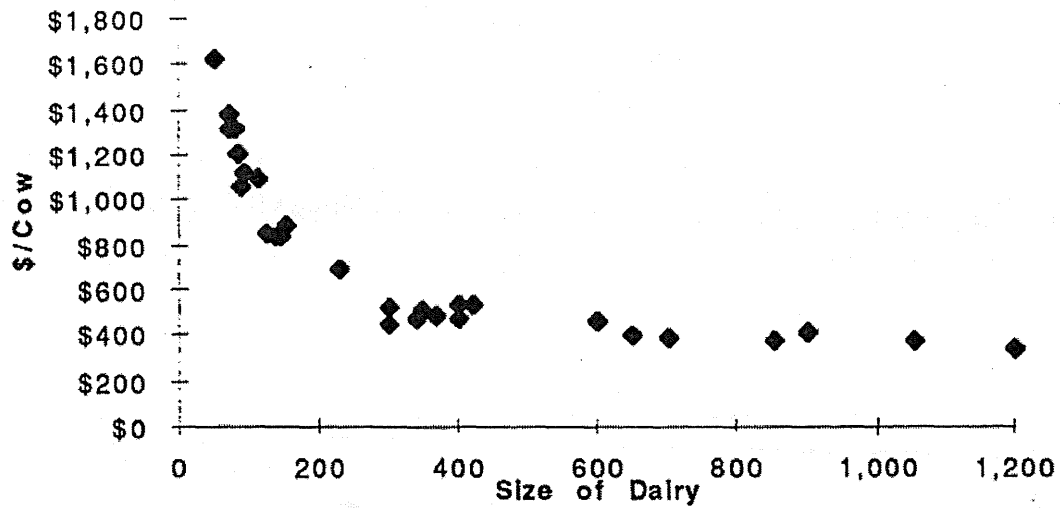


Figure 3 - Total capital cost of on-farm methane generation and cogeneration facilities for varying size of dairies.

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, yielding 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	Incremental Costs with Transport:		
	without manure transportation	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.

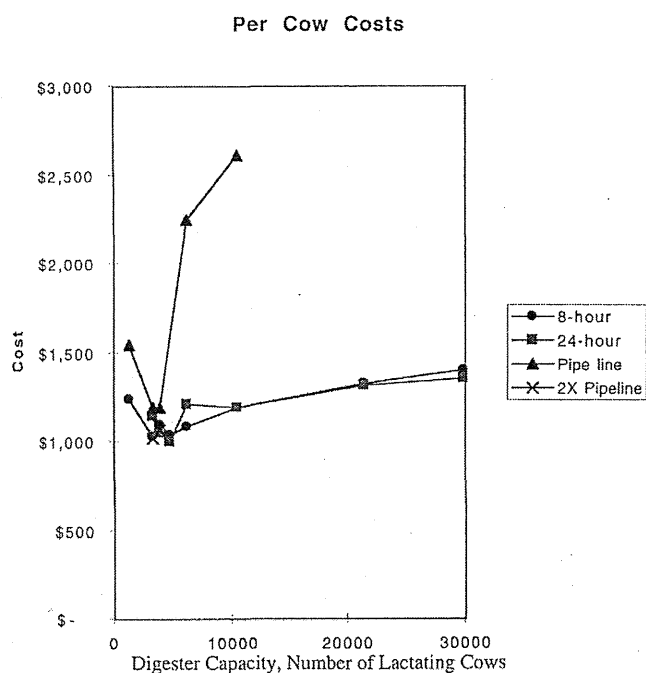


Figure 4. Present value transporting manure to and from central processing plant using trucks on an 8-hour schedule, trucks on a 24-hour schedule, a single pipeline and a double pipeline for digesters with capacity to serve specific numbers of lactating cows.

Source: [Jewell et al., 1998]

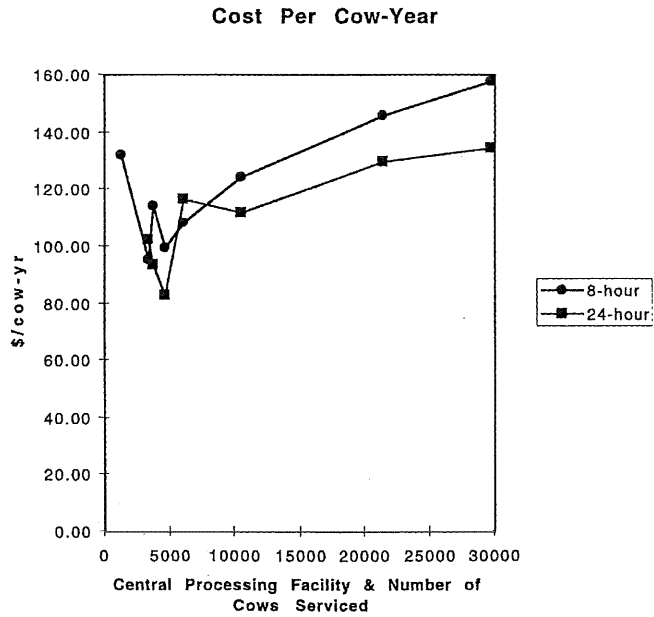


Figure 5. Yearly cost per cow for manure transportation for 8 hour and 24 hour operation of central processing facility.

Source: [Jewell et al., 1998]

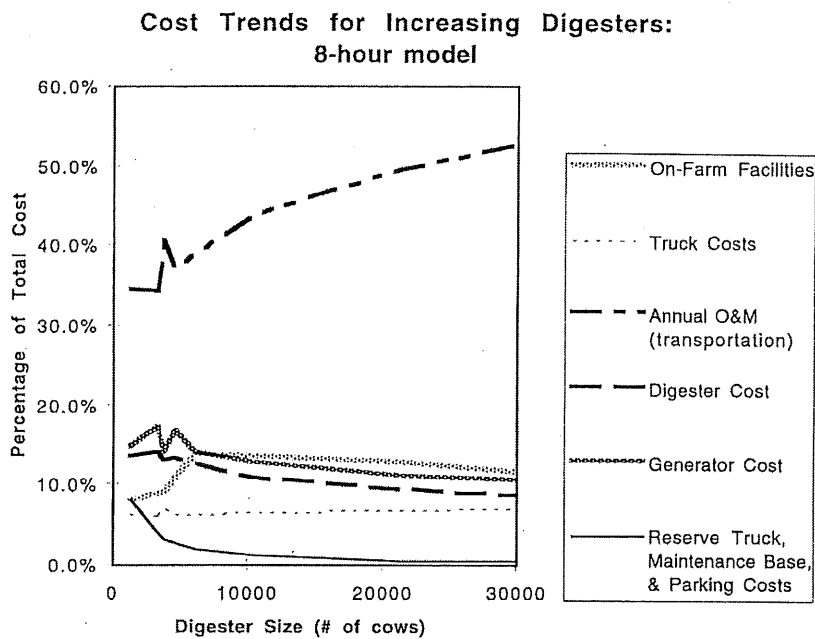


Figure 6. Contrasts of component cost of centralized manure management system.

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 – into 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 is 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 volatilize 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 was completed 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 greenhouse 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 CO₂ 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 tenfold 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 Greenhouse Gases (CO₂, CH₄, and N₂O) 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 CO₂ equivalent (which is 33.6 Euros per ton CO₂ equivalent)². This rendered the values provided in Table 4. They analyze a plant that has a capacity of processing 550 tons 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.

² 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 ₂ O-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 farmland in reference case	12.19 DKK per ton organic waste
Organic waste not spread on farmland 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 capital³. 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.

³ The total may not add up to 100 percent due to rounding.

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, undated]. There 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 by-product 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 (PUC). 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 to 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 landfills; 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 to 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 by-products 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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**ANNOTATED BIBLIOGRAPHY OF REFERENCES FOR
LITERATURE REVIEW ON CENTRAL ANAEROBIC
DIGESTERS**

**Report Submitted as Part of Legislative Commission on Minnesota
Resources Project**

**Manure Methane Digestion Compatible Wastes and Electrical
Generation**

July 25, 2007

**By The University of Minnesota
Departments of Bioproducts and Biosystems Engineering and Applied
Economics**

Principal Investigators

Philip R. Goodrich

and

William Lazarus

Deliverables 1(a) and 1(b)

EXECUTIVE SUMMARY

The annotated bibliography covers a wide range of references that were used to compile the literature review on centralized digesters. The references included research publications, reports from projects, personal communications from experts in the field and popular press reports. The significance of the reference to the report was indicated and the character of the report was also indicated so that the reader may make inferences as to the quality of the material contained in the reference. References were from a range of time periods and from both national and international sources.

ANNOTATED BIBLIOGRAPHY OF REFERENCES FOR LITERATURE REVIEW ON CENTRAL ANAEROBIC DIGESTERS

William Lazarus

Al Seadi, Teodorita. Danish Centralized Biogas Plant Descriptions. 2000. Bioenergy Department, University of Southern Denmark. <http://websrv5.sdu.dk/bio/pdf/rap2.pdf>.

Descriptive overview of centralized Danish digesters and development efforts, and detailed information on 18 operating digesters. One limitation *is that there is no comparable information on individual farm digesters.*

American Public Power Association. Farm Methane: Installation, Implementation and Monitoring, DEED Project Summary Abstract - G-202. 11/25/2005.
<http://www.appanet.org/applications/deed/viewDeed.cfm?targetDeedID=162>.

The feasibility of a centralized digester to serve dairy farms in the Enosburg Falls area of Vermont. 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.

Bachewe, F., Lazarus, W., and Goodrich, P. Economic Analysis of a Central Anaerobic Digester Serving Multiple Dairy farms. Project Report to the Minnesota Department of Agriculture. Forthcoming. 2006.

Exploratory feasibility analysis that looks at how manure transportation costs would affect digester economics if four small dairy farms with a total of 675 cows were to jointly utilize a digester if located 1, 2, or 3 miles apart.

The key assumptions and parameters are included in this report. A limitation is that the digester considered is smaller than most centralized digesters actually operating and being considered elsewhere. The report includes quite a bit of detail on the machinery cost calculations, but doesn't consider a lot of other important issues such as business models and financing considerations. The audience is technical. The method is economic-engineering. Conclusions: profitability is marginal given the current economic situation in Minnesota, especially with regard to electricity prices.

Belmont Bio-Ag, *Welcome To Belmont Bio-Ag* (web page),
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Promotional website describing a combination cattle feedlot-digester-ethanol plant. We mentioned it as one venture that is attempting to get more value from the biogas as a natural gas substitute rather than attempting to generate electricity

as most digesters do. Not a lot of information on the details of the technical design and economic projections. Apparently aimed at investors and the general public.

Burke, Dennis. *Dairy Waste Anaerobic Manure Digestion Handbook: Options for Recovering Beneficial Products from Dairy Manure*. 2001. Olympia, WA, Environmental Energy Company.

Discusses dairy housing systems, manure transport and processing, factors affecting conversion of waste to gas, different digester types, analysis of anaerobic processes, and other topics. No mention of peer review. Cited with regard to the chemical makeup of biogas. Cited with regard to the chemical makeup of biogas.

Canadian Sphagnum Peat Moss Association, *Welcome To The Canadian Sphagnum Peat Moss Association* (web page), www.peatmoss.com, undated, accessed 1/12/2007.

General information about the peat moss industry. We cited it for the information about the volume of U.S. peat moss sales, some of which could potentially be replaced by digested manure solids.

Chapman, Shaun. *Freeing the Grid: How Effective State Net Metering Laws Can Revolutionize U.S. Energy Policy*. 11/2006. Network for New Energy Choices. <http://www.newenergychoices.org/uploads/netMetering.pdf>.

State-by-state comparison of net metering regulations and related policy issues.

Davis, Martha, *New Energy Initiatives: Opportunities for Collaboration Between Dairies and Wastewater Utilities* (web page), <http://www.uwcc.wisc.edu/farmercoops04/davis/davis.pdf>, accessed 12/4/2006.

Slide set describing a central digester operating in the Chino Basin of California. This digester apparently serves seven farms with a total of 6,250 dairy cows along with municipal sewage, although the slide set cited does not provide much detail.

DeVore, George. Tillamook, Oregon Methane Energy Development Program. 4/24/2006. <http://www.epa.gov/agstar/pdf/conf06/devore.pdf>.

Slide set describing the original plans for a centralized dairy farm digester, early performance and problems, lessons learned and plans for improving performance in the future. Like most slide sets, there is not a lot of detail. Audience: digester conference attendees (most likely developers, academics, government). The author is a digester operator. Conclusions: There have been problems that resulted in early economic performance not meeting projections, but still optimistic about the future.

E3 Biofuels, *The E3 BioSolution: Merging Technologies for Earth, Energy, Environment* (web page), <http://www.e3biofuels.com/index2.html>, accessed 8/2/2006.

Promotional website describing a combination cattle feedlot-digester-ethanol plant. We mentioned it as one venture that is attempting to get more value from the biogas as a natural gas substitute rather than attempting to generate electricity as most digesters do. Not a lot of information on the details of the technical design and economic projections. Apparently aimed at investors and the general public. The authors are a project development company.

Effenberger, Mathias. Biogas Opportunities - Pathways and Wrong Tracks to Success. Organic Inputs and Renewable Energy: Learning from the European Biogas Model. 4/6/2006. http://www.omafra.gov.on.ca/english/engineer/facts/bg_pres4.pdf.

A slide set with a range of general information. We have cited slide 10, which shows relative volumes of biogas output per unit for a number of digester feed stocks. The source is not mentioned, but in a follow up email the author said that the numbers are mostly from a review of the literature. As with any slide set, details are lacking.

EnerNex Corporation, *Wind Integration Study - Final Report* (web page), http://www.state.mn.us/mn/externalDocs/Commerce/Wind_Integration_Study_092804022437_WindIntegrationStudyFinal.pdf, 2004

Report that discusses the issues and impacts of increased wind electricity on the overall electricity supply and its reliability.

Environmental Resource Recovery Group, LLC. Anaerobic Digesters for King County Dairies, Final Report for King County, Washington. 6/2003. <http://dnr.metrokc.gov/wlr/lands/2003-anaerobic-digesters-report.htm>.

Feasibility study for a centralized dairy farm digester. The assumptions about manure solids utilization were critiqued in the Terre-Source study. We cited it mainly as background for readers of the Terre-Source study. The authors are with a consulting firm.

Frazier, Barnes & Associates, LLC. Feasibility Study: West Michigan Regional Liquid Livestock Manure Processing Center (LLMPC). 4/25/2006. http://www.michigan.gov/documents/CIS_EO_West_Michigan_Centralized_AD_Feasibility_Study2006_165007_7.pdf.

Compares four different complete mix digester designs and financial estimates by vendors who submitted information. Considered the impact of providing off-farm organic wastes and energy crops. We included a few of their key findings on capital cost and technical performance. We mentioned that they found that the Biopower Technologies design had the best but still negative economic net returns, and suggested that that one be studied further. Methods: producer survey, technical evaluation, discounted-cash-flow financial analysis with sensitivity analysis, discussion of business models. The author(s) are with a consulting firm.

Conclusions: Recommended further evaluation, but the return on investment numbers for the base situation evaluated was negative.

Goodrich, Philip. Moving Small Digester Biogas to Market as a Replacement for Natural Gas. A Report Presented for Agricultural Utilization Research Institute/Agricultural Innovation Center. 6/26/2006.

Exploratory economic-engineering analysis that looked at several equipment arrangements that might be used to haul upgraded and compressed biogas from a 300-cow dairy farm, 30 miles to a location where the gas might replace natural gas. Projected costs exceeded gas value at current prices of around \$1 per therm.

Hjort-Gregersen, Kurt. Centralized Biogas Plants Integrated Energy Production, Waste Treatment and Nutrient Redistribution Facilities. 1999. Danish Institute of Agricultural and Fisheries Economics. <http://websrv4.sdu.dk/bio/pdf/centra.pdf>.

Descriptive publication that discusses the rationale for the centralized Danish digesters, government policies, technologies, costs and benefits. It was used here as a general reference on why the Danes have emphasized centralized digesters and how they are working out. There is no mention of peer-review. Author's background: academic. Conclusions: profitability is acceptable. They depend on off-farm organic waste to enhance gas output and for tipping fees.

Holm-Nielsen, Jens Bo and Saedi, Teodorita A. I. Biogas in Europe: A General Overview. Esbjerg, Denmark, Bioenergy Department, South Jutland University. <http://www.ecop.ucl.ac.be/aebiom/articles/biogas/biogas.htm>.

Discusses the situation and outlook for digesters in 15 EU countries, and the role of government policy. We mentioned it as a source of information on European policies and suggestions for U.S. policy. Conclusions: Environmental concerns have been a driving force as important as energy needs in fostering the growth of European digesters. The public perception of biogas is generally positive. A number of policy initiatives could be taken to promote additional digesters and overcome barriers.

Hurley, S., Ahern, J., and Williams, D., *Clustering of Independent dairy Operators for Generation of Bio-Renewable Energy: A Feasibility Analysis, A Report Prepared for the California Institute for the Study of Specialty of Crops* (web page), <http://cissc.calpoly.edu/research/dairy-grant-final-report-7-31-06-exec-summary-2.pdf>, 2006, accessed 12/4/2006.

Feasibility analysis of possible digester sites for a centralized digester serving the large California dairies. We used it to point out the importance of the limitations presented by current policies regarding selling electricity back to the grid. It is a long report with lots of detail to wade through. Methods: economic-engineering, GIS. Conclusions: "... economic performance of the anaerobic digestion plants analyzed in the study heavily depends on how the regulatory environment

interacts with the centralized digesters and states that it does not take much in terms of added regulatory costs to make the feasible plants infeasible.”

Initiative for Renewable Energy and the Environment, University of Minnesota. Cluster: Bioenergy and Bioproducts. 09/05/2003. <http://www1.umn.edu/iree/bio.html>.

Discusses renewable energy research needs.

Inland Empire Utilities Agency, *Inland Empire Dairy Manure to Energy “Cow Power” Renewable Energy Program* (web page), <http://www.epa.gov/agstar/pdf/conf06/clifton.pdf>, 2006, accessed 12/4/2006.

Slide set describing the Inland Empire Utilities Agency, a regional wastewater treatment and water supply system in the Chino Basin that accepts manure from dairy farms in the area, and improvements that they have made in the digester system.

Jewell, W. J., Wright, P. E., Fleszar, N. P., Green, G., Safinski, A., and Zucker, A. Evaluation of Anaerobic Digestion Options for Groups of Dairy Farms in Upstate New York. 8/1998. NRAES. <http://www.nraes.org/publications/aben97.html>.

An early analysis of a proposed centralized dairy farm digester in upstate New York, looking at a range of digester sizes. We included their graphs of the cost-size relationship. A limitation is that the cost data is over ten years old. Methods: descriptive, economic-engineering. Conclusions: they recommended construction of a 4,000- to 6,000-cow facility as a first step. The stabilized waste would be returned to farms initially, while instituting efforts to cost-effectively reclaim other byproducts such as fiber.

Jung, H. Adjunct Professor, Department of Agronomy, University and USDA Agricultural Research Service, personal communication. 06/16/2006.

Cited with regard to the feasibility of digesting distiller’s grains.

Kildegaard, A, 2006, “Renewable electricity policy in Minnesota: Can we change the subject?” In the *CURA Reporter*, December 2006 issue. Published by the University of Minnesota Center for Urban and Regional Affairs, Minneapolis MN. accessed at: <http://www.cura.umn.edu/reporter/06-Wint/Kildegaard.pdf>.

Discusses the pros and cons of the quantitative renewable electrical portfolio standards popular in the U.S. versus the mandated minimum prices (“feed-in tariffs”) used in Denmark, Germany and Spain. Also provides a brief history of competition in the electricity sector. Discusses a recent distributed power generation rulemaking procedure by the Minnesota Public Utilities Commission as a case study of the political process and issues raised, in particular the calculation of the capacity component of avoided costs and the planning horizons used for calculating projected demand.

Kubsch, Kristin. Cooperative Anaerobic Digestion as a Manure Management Alternative in Northeastern Wisconsin. 2003. University of Wisconsin, Green Bay.

Feasibility analysis of a centralized digester. We cited data on potential capital constraints on digester installation.

Lazarus, W. and M. Rudstrom. "The Economics of Methane Digester Operation on Minnesota Dairy Farms." *Review of Agricultural Economics* (2007)

Description and discounted-cash-flow analysis of one operating digester with projections of economic feasibility of future digesters with different levels of public support and electricity prices. We cited the investment numbers and the comparison of electricity prices and other factors. A limitation is that it is based largely on only one farm. The audience is technical, economists. It has been accepted in a peer-reviewed journal. Conclusion: Under current economic conditions in Minnesota, digester profitability would be marginal without current state subsidies plus grants.

Lewis, Joseph. Bio-Gas Plants and Hog Farming in North Carolina. 2001. Duke University, North Carolina.

Examines the potential for swine-farm-based digesters in North Carolina, drawing analogies to the situation in Denmark. We cited what it says about potential benefits and policy issues.

MaxYield Cooperative, *Anaerobic Digestion Project* (web page), <http://www.maxyieldcooperative.com/content/page.asp?pid=1253>, 2006, accessed 12/4/2006.

Promotional website describing a proposed centralized swine digester for Iowa, being studied via USDA funding. Odor abatement is mentioned prominently as one objective. We mentioned it as an example of digesters under consideration. Not a lot of information on the details of the technical design and economic projections. Apparently aimed at investors and the general public. The author is a farm supply/grain marketing cooperative.

Myers, M. E. and Deisinger, C. Developing a Community Model for Wisconsin. Cooperative Development Services, USDA.

Centralized digester feasibility analysis that includes a discussion of business models for digester ownership. Conclusions: a digester jointly owned by five farmers would experience a net loss for the first ten years of operation, but after that would generate annual profits.

Minnesota Department of Agriculture. Opportunities, Constraints, and Research Needs for Co-digestion of Alternative waste Streams with Livestock Manure in Minnesota. 2005. Agriculture Resource Management and Development Division.

<http://www.mnproject.org/pdf/CombinedWasteStreamsReport.pdf>.

Publication discussing the number of digesters in Minnesota and future potential for expansion.

National Rural Electric Cooperative Association. White Paper On Distributed Generation. 12/2/2005.

<http://www.nreca.org/Documents/PublicPolicy/DGWhitepaper.pdf>.

Discusses pitfalls likely when rural electric cooperatives are required to offer net metering or otherwise purchase electricity from distributed generation sources. We included it in order to provide the rural electric cooperative perspective.

New Rules Project, *Net Metering of Electricity* (web page),

<http://www.newrules.org/electricity/nmeter.html>, undated, accessed 1/5/2007.

Compares net metering regulations across states. We cited it with regard to some of the unique aspects of California's net metering law.

Nielsen, L. H. and Hjort-Gregersen, K. Socio-Economic Analysis of Centralized Biogas Plants. undated. Danish Research Institute of Food Economics, C/o University of South Denmark, Niels Bohrsvej 9, DK-6700 Esbjerg, Denmark.

Summary of digester profitability from an individual farm perspective, and value of societal benefits external to (not captured by) the farm. Identifies the societal benefits that they considered important. Doesn't really provide much detail on how they estimated some of the benefits, such as reduced N-eutrophication of ground water. Audience appears to be academics and policymakers, but farmers and developers may also find it useful.

Method: budgeting. No mention of peer-review. Conclusions: profitability is not attractive from the perspective of the individual farm, but looks favorable when the societal benefits are considered.

Norfelt, Tomas Fibiger, *Organic Farming in Denmark 2003* (web page),

http://www.organic-europe.net/country_reports/denmark/default.asp, 2003, accessed 8/12/2006.

Website with information on Danish agriculture, which we cited to show how similar Denmark, is to Minnesota.

Pacific Gas and Electric Company, *Net Energy Metering for Biogas Digester Generators* (web page), http://www.pge.com/suppliers_purchasing/new_generator/ebio/, 2006, accessed 3/7/2007.

Contains information on the process of application and the requirements that should be satisfied by customers that need to produce electricity from biogas plants.

Port of Tillamook Bay, *Bio-Gas Methane Facility - Hooley Digester* (web page), <http://www.potb.org/methane-energy.htm>, undated, accessed 12/4/2006.

Promotional website describing the centralized dairy digester also described in the slide set by Devore. We cited it to provide some additional background information to go with the Devore slide set. The author is a local government entity.

Sebesta Blomberg & Associates, Inc. Methane Digester Economic & Technical Feasibility Study, West River Dairy & City of Morris. 10/2005. AURI Center for Producer Owned Energy.

Feasibility analysis of a large digester and gasification plant serving mainly a large, individual dairy farm in western Minnesota, but also considering bringing in manure from neighboring farms. Discusses the technical feasibility and cost of a number of aspects including a 12-mile manure pipeline. Evaluates several digester designs. We mentioned it as a source of information, but we did not include much detail from it. Like several other feasibility analyses cited, it is difficult to determine how likely it would be that the projected performance would be achieved if the digester is actually built. The audience is technical, probably aimed mainly at local government and investors, but not explicitly stated. Methods: descriptive, financial analysis. The authors are with an engineering firm.

Swanson, Laura. Tillamook Digester Produces Power, Fiber and Interest. Biocycle April 2005 eNews Bulletin. 3/2005.
http://www.harvestcleanenergy.org/enews/enews_0405/enews_0405_Tillamook_Digester.htm.

A magazine article that provides a few details not included in the Devore slide set.

Terre-Source LLC. Study to Evaluate the Price and Markets for Residual Solids from a Dairy Cow Manure Anaerobic Digester.
<ftp://dnr.metrokc.gov/dnr/library/2003/kcr1540.pdf>.

The solids study found that a number of the original study's (by the Environmental Resource Recovery Group) assumptions were not realistic, such as: the cost of handling the solids, which had originally been estimated at \$5/ton, compared with \$10-15/ton on a similar operation. Equipment and storage space may have been underestimated. A 3-5 year ramp-up period was thought to be needed to develop the solids market before the projected price would be achieved. Marketing staff would be needed. The solids volume would be reduced due to solids degradation and moisture loss, there might be odor problems, and sulfides in the solids might need to be dealt with. We mentioned it as a source of information about the value of manure solids. The authors are with a consulting firm.

Thomson Gale, *Minnesota - Animal husbandry* (web page), <http://www.city-data.com/states/Minnesota-Animal-husbandry.html>, 2005, accessed 8/12/2006.

Website with general information about the Minnesota livestock industry.

U.S. AgSTAR, *Market Opportunities for Biogas Recovery Systems: A Guide to Identifying Candidates for On-Farm and Centralized Systems* (web page), http://www.epa.gov/agstar/pdf/biogas%20recovery%20systems_screenres.pdf, 2004

Discusses the benefits of digesters, the importance of size economies and type of manure handling system, and has profiles of the ten states thought to have the most potential for dairy or swine farm digesters. We summarize what the report said about the potential for digesters in Minnesota, and how similar North Carolina's swine industry is to Denmark, where swine farm digesters are popular. Audience: "intended for anyone interested or involved in the development of renewable sources of energy; distributed generation; or the development, design, and financing of biogas systems at animal feeding operations." Conclusions: "...biogas recovery systems are estimated to be technically feasible at about 7,000 dairy and swine operations in the U.S. ... these facilities have the potential to collectively generate up to 6 million megawatt-hours (MWh) per year, and displace about 700 MW of fossil fuel-fired generation on the electrical grid..."

U.S. AgSTAR, *Winter 2006 AgSTAR Digest* (web page), <http://www.epa.gov/agstar/>, 2006

General information promoting digesters, including a chart of trends in methane reductions and kilowatt-hours of electricity generated by digesters by year, an estimate of the number of farm-based digesters that might be economically viable, digester numbers by state, an explanation of how their greenhouse gas reductions are estimated, and formulas for projecting digester costs at different farm sizes. We included the digester cost-size formulas.

U.S. Energy Information Administration, *Net Generation by Energy Source by Type of Producer* (web page), <http://www.eia.doe.gov/cneaf/electricity/epa/epat1p1.html>, 2006

Source with data on total U.S. electrical generation capacity, used to calculate the percentage that digesters could potentially supply.

Wells, P., Cooperband, L., and Lawless, G., *Feasibility of Cooperative Acquisition and Processing of Diverse Organic Waste Streams in Wisconsin's Fox River Valley, Phase I Final Report* (web page), <http://www.wastenot-organics.wisc.edu/05frvor/FRVORAbridgedReport1.pdf>, 2001, accessed 12/4/2006.

Feasibility study of a centralized digester in an area where off-farm organic wastes are available and may enhance the economic potential.

WestStart-CALSTART. Swedish Biogas Industry Education Tour 2004: Observations and Findings. 11/12/2004.

http://www.calstart.org/info/publications/Swedish_Biogas_%20Tour_2004/Swedish_Biogas_Tour_2004.pdf.

Report containing a lot of detailed information about biogas utilization in Sweden, and especially the unique ways that they are using the biogas as a transportation fuel. We cited data from it on the size of one of their biogas upgrading facilities.

**LIST OF INDUSTRY CONTACTS ON ANAEROBIC
DIGESTERS**

**Report Submitted as Part of Legislative Commission on Minnesota
Resources Project**

**Manure Methane Digestion Compatible Wastes and Electrical
Generation**

July 25, 2007

**By The University of Minnesota
Departments of Bioproducts and Biosystems Engineering and Applied
Economics**

Principal Investigators

Philip R. Goodrich

and

William Lazarus

Deliverable 1(c)

This report partially fulfills the objectives of the project "Manure Methane Digester Compatible Wastes and Electrical Generation". Funding for this project was provided by the Environment and Natural Resources Trust Fund as recommended by the Legislative Commission on Minnesota Resources (LCMR).

EXECUTIVE SUMMARY

Contacts with engineering firms and industry officials were made to provide a list that could be used by Minnesota persons wanting to make decisions about using anaerobic digestion for multiple farm digesters and/or multiple substrates for co-digestion.

Experienced design firms and independent developers both in the U.S. and Europe were contacted. Suggestions from these firms lead to an expanded group of firms to contact. The authors William Lazarus and Philip Goodrich made contacts at professional meetings, at trade shows, through email, by telephone and by personal visits to research sites and digester sites in Minnesota, Wisconsin, New York, California, in Denmark, Sweden, and Germany.

The list as compiled by Philip Goodrich includes firms that the author would use as a starting place for developing a project that includes a multiple farm digester and co-digestion of energy products. The list may not include all qualified firms, but those that the author's experience and research criteria seemed best for Minnesota. Others are on self-contributed lists at AgSTAR (<http://www.epa.gov/agstar/tech/consultants.html>). The lists are not always up to date however.

The main criteria used in compiling this list included:

1. The firm has on farm digesters that have been completed and working
2. The firm has the capabilities of working in cold climates
3. The firm has the capabilities to provide after construction support for the project
4. The authors were able to determine that a U.S. office exists for the firm

Specific information that was learned during contacts with experienced designers is summarized below.

Before a project is committed to any engineering firm, it is the responsibility of the project manager to determine the current capabilities of the firm to successfully complete the project based on past performance, current economic conditions, and current personnel employed. Note however that there are not a large number of experienced engineers in the field.

If the digester contemplated is a large multi-input digester utilizing materials other than manure, there are a number of items that must be considered that are not usually a problem with a single farm manure digester.

1. The materials may contribute to health concerns for the farmers who are receiving the effluent from the digester. High temperature post processing of the effluent may be needed to satisfy security concerns.
2. The nature of the digester may lead to extensive environmental studies being required and hearings being held to satisfy neighbors concerned about added traffic, health concerns and materials being added to the local environment.
3. Permits from multiple regulatory bodies may be necessary if cross-jurisdictional issues arise.

4. The markets may change considerably over time and the financial projections may significantly change due to externalities that are difficult to foresee.
5. The financial inputs will be larger and a broader base of funding may be necessary for the project to succeed.
6. Strict control over the inputs from various sources will be needed to insure that toxic or dangerous materials do not enter the digester.
7. Detailed operational plans for emergencies, accidents, terrorism and extreme weather conditions need to be part of the plant manuals that are developed within the project scope.
8. Plans for adequate staffing of the plant with trained and qualified personnel are very important to the continued operation of the plant.

The following list of companies that design and install digesters is presented with no rankings.

Ag Environmental Solutions

Carl Theunis

2768 Poplar Street Kaukauna WI 54130

Tel: 920-532-4804

Number of Years in Business: 6

Email: aes@athenet.net

Web: NA

Number of Commercial Farm Projects: 1

Fax: 920-532-5039

Number of Employees: 6

US

Ag Environmental Solutions employs a process patented by Iowa State Research that is licensed to the company. Ag Environmental Solutions' Tinedale Project is one of the largest dairy farm biogas systems in the U.S. with a 2,500-head capacity. The process is a complete mix using thermophilic and mesophilic temperatures enabling the system to produce a Class A bio-solid.

Agri Bio Systems

Richard Vetter, PhD, PAS, ACAN

2333 Tara Drive Elgin IL 60123

Tel: 847-888-7854

Years in Business: 21

Email: rvagribio@aol.com

Web: NA

Number of Commercial Farm Projects: 7

Fax: 847-888-1484

Number of Employees: NA

US

Agri Bio Systems performs feasibility assessments and designs and installs biogas systems in the U.S. and abroad. Examples of biogas systems include: 1) Lindstrom Farm, a 50-cow dairy farm in Welch, MN; 2) Leefer Farm, a 1,000-cow beef confinement farm in Carbin Carlinville, IL; 3) Smith Farm, a 70,000-broiler poultry farm in Princeton, NC; 4) Naser Farm, a 1,000-sow finishing swine farm in Sibley, IA; 5) Hamilton Farm, a 450-sow finishing farm and a 120,000-layer poultry farm in Iowa Falls, IA; 6) Huntington Dairy, a 300-cow dairy farm in Cooperstown, NY; 7) Cushman Farm, a 600-cow dairy in Franklin, CT; and 8) International Project, Taiwan, Environmental Training Center for Waste Management. Agri Bio Systems also acts as a coordinator on numerous animal waste and food waste projects.

BioEnergy Solutions

Doug Williams, P.E.

200 New Stine Road, Suite 220

Bakersfield, CA 93309

Tel: 661-617-6240

Number of Years in Business: 20

Email: d.williams@bioensol.com

Web: http://bioensol.com/index.php?option=com_frontpage&Itemid=1

Number of Commercial Farm Projects: 4

Fax: 661-617-6238

Number of Employees: 3

US

This company was founded by a group of dairy farmers who understand the daily challenges faced by farmers and food processors. Our mission is to provide innovative solutions that help farmers and others in the food industry meet increasingly strict air quality requirements in ways that still enable them to succeed in a competitive market. We build digesters and export the cleaned gas to pipelines.

Biogas Energy Systems

Seattle Washington

Tel: 815-301-3432

Number of Years in Business:

Email: info@biogas-energy.com

Web: http://www.biogas-energy.com/docs_en/home.html

Number of Commercial Farm Projects: 4 in US

Fax: 815-301-3432

Number of Employees: NA

US/Germany

Biogas Energy conducts thorough preparation for development of all biogas facilities to avoid unnecessary costs, ensure rapid construction, and guarantee smooth and cost-

effective operations. Our tried and tested techniques are used in Europe to complete one project per week without issues, and our experience enables us to avoid the pitfalls that arise.

Environomics

Richard Mattocks

5700 Arlington Avenue, Suite 17A

Riverdale NY 10471

Tel: 718-884-6740

Number of Years in Business: 23

Email: utter@compuserve.com

Web: www.waste2profits.com

Number of Commercial Farm Projects: 24

Fax: 718-884-6726

Number of Employees: 2

Environomics has worked on over 20 farm-scale biogas digester projects. These projects include plug-flow digesters for multiple dairy facilities throughout the U.S., ranging in size from 30 to 1,000 cows. Depending on the farm, the biogas is used to generate electricity and to fuel boiler systems. The remaining farm-scale projects include mixed digesters for several swine farms throughout the U.S. for farrow-to-finish farms, ranging in size from 1,000 to 3,000 sows. The swine farms use the biogas to generate electricity. In addition, Environomics is experienced in permitting, utility negotiations, public relations, feasibility studies, and publications.

GHD Inc.

Steve Dvorak

P.O. Box 69

Chilton WI 53014

Tel: 920-849-9797

Number of Years in Business: 18

Email: ddghd@tds.net

Web: www.ghdinc.net

Number of Commercial Farm Projects: 15

Fax: 920-849-9160

Number of Employees: 14

US

GHD provides engineering and system installation experience in the anaerobic digester industry. GHD has five operating anaerobic digesters utilizing its proprietary mixed plug flow digester design in the Midwest and one additional digester under construction.

RCM Digesters, Inc.

Mark Moser

P.O. Box 4716

Berkeley CA 94704

Tel: 510-658-4466

Number of Years in Business: 21

Email: rcmdigesters@att.net

Web: www.rcmdigesters.com

Number of Commercial Farm Projects: 30

Fax: 510-658-2729

Number of Employees: 2

US

RCM Digesters, Inc. has designed 30 farm-scale biogas projects. Examples include: 1) Apex Pork (for AgSTAR), a swine farm in Rio, IL with a covered, heated, mixed lagoon; 2) Freund Dairy (for AgSTAR), a dairy farm in East Canaan, CT with a plug flow digester; 3) AA Dairy (for AgSTAR), a dairy farm in Candor, NY; 4) Martin Hog Farm (for AgSTAR), a swine farm in South Boston, VA with a covered lagoon; 5) Barham Hog Farm (for AgSTAR), a swine farm in Zebulon, NC with a covered lagoon; 6) Craven Dairy, a dairy farm in Cloverdale, OR with a plug flow digester; 7) Cal Poly Dairy (for AgSTAR), a dairy farm in San Luis Obispo, CA with a covered lagoon; 8) Palmer Hog Farm, a swine farm in Yell County, AR with a covered lagoon; 9) Tohoku Farm, a swine farm in Aamori Prefecture, Japan with a mixed digester; and 10) Langerwerf Dairy, a dairy farm in Durham, CA with a plug flow digester.

Environmental Products & Technology Company (EPTC)

Marvin Mears

Tel: 805-492-6865

2219 E. Thousand Oaks Blvd

Suite 373

Thousand Oaks, CA 91362

Number of Years in Business: 12

Email: marvin@eptcorp.com

Web: eptcorp.com

Number of Commercial Farm Projects: 0

Fax: NA

Number of Employees: 9

US

Environmental Products & Technology Company (EPTC) developed two anaerobic digester projects at Utah State University. Both systems are multi-tank systems with the objective of developing short hydraulic retention time cycles. Short hydraulic retention time can reduce both the size of the system and system-related costs. Environmental Products & Technology Company has developed a closed loop waste management

system designed to treat and convert an organic waste product into a series of desirable and marketable reuse products.

R. K. Frobel & Associates

Ronald K. Frobel, P.E.

1153 Bergen Parkway

Suite M-240

Evergreen CO 80439

Tel: 303-679-0285

Number of Years in Business: 18

Email: geosynthetics@msn.com

Web: NA

Number of Commercial Farm Projects:

Fax: NA

Number of Employees: 3

US

Established in 1988, R.K. Frobel & Associates Consulting Engineers provides design and construction assistance in the growing field of geosynthetics, including design assistance in both animal waste lining systems and waste/anaerobic digester cover systems. Design assistance is provided to full-service engineering firms or facility/farm owners. As principal of R.K.Frobel & Associates, Mr. Frobel has over 25 years of experience in synthetic lining and cover systems including agricultural applications.

Microgy, Inc.

Environmental Power Corporation

Tel: 303-384-9402

1600 Jackson St., Suite 350

Golden, CO 80401

Number of Years in Business:

Email: NA

Web: <http://www.environmentalpower.com/companies/microgy/inquiries.php4>

Number of Commercial Farm Projects: 2

Fax: 303-384-9403

Number of Employees: NA

US

Our systems use a thermophilic anaerobic digestion method, which processes manure and other agricultural, and food industry waste at an elevated temperature for an extended period of time, helping address air quality, water quality, and other waste management issues. Methane, sulfur compounds and other gases, which would otherwise have been released into the atmosphere, are captured. Digesting manure helps minimize run-off and other water quality issues. Weed seeds and pathogens are killed during the digestion

process. Manure odor is reduced by as much as 95%. Digesting manure assists with CAFO nutrient management plan and other regulatory compliance.

Sharp Energy, Inc.

Roy Sharp

24684 Road 148

Tulare CA 93274

Tel: 559-688-2051

Number of Years in Business: 23

Email: rsharp6363@aol.com

Web: NA

Number of Commercial Farm Projects: 6

Fax: 559-688-1111

Number of Employees: 2

US

Sharp Energy, Inc. consults, designs, and sets up effective and efficient waste management and energy production systems. Sharp Energy developed systems for the following farms: 1) Royal Farms, a 16,000-head swine farm in Tulare, CA; 2) Sharp Ranch, a 5,000-head swine farm in Tulare, CA; 3) Sharp Enterprises, an 8,000-head swine farm in Caruthers, CA; 4) 6,000 head dairy heifer ranch in Lindsay CA; and 5) Petrorio Farm, a 3,000-head swine farm in Skopje, Macedonia. Sharp Energy designed covers for the following farms: Cal Poly San Luis Obispo (an AgSTAR Demonstration Farm), a 300-cow dairy in San Luis Obispo, CA; and Laurencio Dairy, a 1,200-cow dairy in Tulare, CA.

Tiry Engineering

Michael Tiry, P.E.

PO Box 44

Chippewa Falls WI 54729

Tel: 715-723-6777

Number of Years in Business: 20

Email: mtiry@millstream.net

Web: <http://www.tiryengineering.com/portfolio.html>

Number of Commercial Farm Projects: 4

Fax: 715-725-0323

Number of Employees: 3

US

We provide consulting services assisting landowners with feasibility studies and vendor selection as well as designs around the area in which the digester will be built. We have designed an anaerobic digester that produces 1 kilowatt per 5 cows.

**Policy Implications for Multiple Farm Digesters and
Co-digesting Manure with Other Waste Streams**

**Report Submitted as Part of Legislative Commission on Minnesota
Resources Project**

**Manure Methane Digestion Compatible Wastes and Electrical
Generation**

July 25, 2007

**By The University of Minnesota
Departments of Bioproducts and Biosystems Engineering and Applied
Economics**

Principal Investigators

Philip R. Goodrich

and

William Lazarus

Deliverable 2(b)

This report partially fulfills the objectives of the project "Manure Methane Digester Compatible Wastes and Electrical Generation". Funding for this project was provided by the Environment and Natural Resources Trust Fund as recommended by the Legislative Commission on Minnesota Resources (LCMR).

EXECUTIVE SUMMARY

A short paper addressing policy implications and needs for implementing multiple farm digesters and co-digestion of manure with other sources has been formulated.

Farm-based digesters are a multi-faceted technology that offers a range of benefits. However, as a standalone electricity-supplying technology for individual farms or groups of farms, the farm-based digester has struggled in Minnesota and elsewhere in the U.S. due to generally marginal profitability.

A number of policies that may be beneficial are presented including some that are monetary incentives, some that change the relationship between regulated industries and independent producers of energy and biological products, and some that encourage the use of non-fossil fuels to reduce greenhouse gases while increasing sustainability.

No one policy will solve all the problems that are holding back the production of renewable energy from organic materials in Minnesota. A wide range of policy change opportunities exist that will allow Minnesota to achieve the goals of “20 by 2020” ahead of schedule.

Production of renewable energy by digestion uses no fossil fuel in the process. This highly efficient low input system utilizes waste materials which otherwise may be treated using fossil fuels. Developing this resource in rural Minnesota is a win-win situation for renewable energy, improving the environment, and maintaining sustainable communities.

Policy Implications for Multiple Farm Digesters and Co-digesting Manure with Other Waste Streams

Suggested Key Talking Points on Centralized Digesters

Bill Lazarus and Phil Goodrich

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Farm-based digesters are a multi-faceted technology that offers a range of benefits. However, as a standalone electricity-supplying technology for individual farms or groups of farms, the farm-based digester has struggled in Minnesota and elsewhere in the U.S. due to generally marginal profitability.

Most existing digesters are on individual farms. There are at least two centralized digesters in the U.S. – the Hooley facility at Tillamook, Oregon, and the Inland Empire digester in the Chino Basin of California.

Digesters overall appear to have the most potential for economic feasibility where:

- nuisance odors require action,
- offsite organic waste is available which can be co-digested to increase gas output and/or generate tipping fees,
- the manure solids are separated and have a high value for dairy cow bedding or as a soil amendment (the above comment about marginal profitability assumes no solids value or separator investment),
- the biogas can replace large onsite retail purchases of electricity or heat (such as integrated with a milk processing plant, an ethanol plant or a village district heating facility), or
- the electricity is sold to the grid in a region of the U.S. with higher-than-average electricity prices.

Situations vary widely, so it is difficult to say exactly how much public support would be required to assure economic viability of a centralized digester in Minnesota. By comparison, the breakeven electricity price for a well-managed 800-cow **individual** dairy farm digester in 2004 was around \$0.08/kwh **without subsidies**, or around twice the wholesale electricity price. Digesters have been incentivized via a variety of construction grants, lower-than-market-rate loans, and operating subsidies. In our projections, utilization of the current incentives would bring down the breakeven electricity price for a well-managed individual farm digester far enough to achieve profitability under good management. Few additional individual farm digesters are currently being installed in Minnesota, however, so this lack of construction activity suggests that those incentives may not really be sufficient even for individual farm digesters let alone centralized ones. Digester installation costs have increased since 2004, probably due mainly to improved but more costly digester designs and materials and also by the biofuel-driven construction boom, so the breakeven for an individual farm digester may be near \$0.09-0.10/kwh in 2007. Relating those costs to a hypothetical **centralized** digester, if that same digester

were supplied by four smaller farms totaling 675 cows within a one- to three-mile radius rather than one 800-cow farm, manure transportation costs would probably increase that breakeven electricity price to around \$0.14-0.15/kwh.

There are 20 centralized digesters operating in Denmark, where electricity prices are higher and where the country as a whole has made a commitment to energy self-sufficiency. The centralized digesters operating in Denmark, Oregon, and California are much larger than the 800-cow size discussed above. For example, one California study looked at sizes from 9,000 to 63,500 dairy cows. If the centralized farm digester is explored further in Minnesota, the feasibility of a larger size should be studied. The feasibility analysis that was conducted for a proposed centralized digester for the Morris area has so far not resulted in the project moving forward. If state policymakers are interested in determining the incentives required for a larger centralized digester to be viable, perhaps the economic model used in that study could be tweaked to project how profitability in that situation would improve as the incentives are increased.

Challenges unique to centralized digesters (as opposed to individual ones) include:

- organizing the group of farms, reaching consensus and commitment to the project, and providing a mechanism for farms to leave the group,
- sanitary issues involved in transporting manure between farms, and
- the capital investment and operating costs for the manure transportation equipment and loading/unloading facilities.

Carbon credits can be sold based on the methane destroyed in burning the biogas. The revenue potential of carbon credit sales does not appear to be significant at present, but could become more valuable if future U.S. policy were to mandate carbon reductions.

Minnesota made a significant step forward by passing the 20 by 2020 legislation in the 2007 legislative session. This will help sustainability in Minnesota and especially in outstate Minnesota. More support for medium size digestion systems to compete is needed to develop the construction and servicing infrastructure that already exists for the wind energy.

Items that may be considered beneficial to developing centralized anaerobic digestion are presented next.

It may be beneficial to have true net metering of electricity that totals the number of kilowatt-hours used for all facets of the farm within a circle of about 2 miles of the location where the digester is producing electricity. Then the number of kilowatts generated on the farm would first offset all of those used kilowatt-hours. Excess electricity would then be purchased at the retail rate that would have been charged by the distribution company.

Also beneficial would be a reduction in burdens placed on independent generators including electrical demand charges, wheeling charges, and special switching equipment requirements.

Incentives other than tax credits may be used. Tax credits are often more valuable to large corporations that are diversified, but have much less value to farm based central digester operations.

An incentive that may be considered is requiring that power companies purchase up to the equivalent of one megawatt of locally biologically produced energy at 1.5 times the retail price of energy produced by coal or fossil natural gas.

Eliminating or reducing taxes on locally produced energy and bioproducts may promote more local energy.

Requiring that green credits accrue to the producer of the renewable energy may be a good incentive that benefits local communities.

There may be a good to promote development of other useful products from biogas such as hydrogen, compressed natural gas, anhydrous ammonia, process cooling, process heating, and transportation fuels.

Production of renewable energy by digestion uses no fossil fuel in the process. This highly efficient low input system utilizes waste materials which otherwise may be treated using fossil fuels. Developing this resource in rural Minnesota is a win-win situation for renewable energy, improving the environment, and maintaining sustainable communities.

LCMR Interview Project Summary:

This project, funded by LCMR, is intended to serve as general knowledge for the Minnesota Department of Agriculture, legislature, livestock producers and other stakeholders. Many researchers, agencies and university leaders were interviewed regarding their view of manure digestion, its future, community digesters, small digesters, alternate waste streams, and other related topics. The major opportunities and constraints of manure digestion are discussed in Part I. Unique ideas and views are listed in Part II and attributed to the source.

Part I: Conclusion:

Throughout the interviews there were many unique opinions about manure digestion and its future. Despite all the differing views, there were major points of consensus. Among these points of consensus were the main constraints and opportunities of manure digestion along with a few other topics.

Most were in agreement that the main constraints of manure digestion are the poor renewable energy buyback rate of utilities, the reluctance of farmers to manage electricity and lack of an infrastructure. There were also a few common solutions to these problems. The general answer for all three of these problems was time. The majority thought that problems would be resolved by themselves when manure digestion was more economically viable. The thought is that as the prices of electricity and liquid heating fuels rise and the push for energy policies to increase their renewable energy purchases increases, manure digestion will rise with it.

Another main solution for these common problems is to look to government. Government could make a mandate favoring renewable energy and keep giving incentives to make manure digesters as low risk as a new technology can be until the infrastructure is established. The hesitation many farmers have with managing electricity could be reduced if a third party handled the digester. The problem with this is that an infrastructure needs to be formed before manure digestion management would be profitable for any business. To encourage businesses, government could even consider giving incentives to the third party. Most agreed this is a viable option, but that it would be better to keep as much money public as possible.

Not only was there agreement on the main constraints of manure digestion, but the main opportunities as well. The consensus is that the major opportunities manure digestion offers are energy production, odor reduction and the environmental benefits. Many of the interviewees stated that odor mitigation was currently the biggest plus of manure digestion. With expanding suburbs, residential areas are getting closer to farms. In order to keep neighbors happy and pass zoning regulations, manure digesters' odor reduction plays a key role.

In contrast, the energy production from manure digestion has more promise than current status. As oil prices rise, alternate sources of fuel will become essential and more price-competitive. Manure digestion's constant base load of electricity makes it a very valuable source of energy. Not only the electricity, but also the heat can be utilized. For

example, if a greenhouse or ethanol plant was placed next to large digesters, it could offset some of the heating costs.

As oil prices rise, so do carbon emissions. There is a push for more environmentally friendly regulations and energy that manure digestion fits into. Some people and businesses believe that the trading of carbon credits will soon become as widespread as it is in Europe. Those people are voluntarily trying to manage their carbon emissions today so that when the time does come that it is mandatory, they will already have their foot in the door. Since a portion of methane is twenty-one times worse for the environment than the same size portion of carbon dioxide, the reduction of methane is crucial.

Besides the main opportunities and hindrances to manure digestion, there were a few side issues that were agreed upon. There was a general belief that alternate waste streams had potential and it would be worth the time and money to research the best waste streams. The other issue to resolve regarding alternate waste streams is whether or not the effluent is as valuable when other waste is added. Most interviewees were also like-minded in that China and India's use of very small digesters for heat would not be wise to use as a model for the United States. The standards of living are too different in China to use as a model for the United States. Since the viability of small digesters and community digester systems could not be agreed upon, individual views can be found in Part II.

Part II: Summary of Individual Responses

1. **Brach, John, State Engineer for NRCS:** There is a solid future for anaerobic digestion. The government should make a standard net metering law. The government should also put together standard forms into a package to make the application process simpler. Research should be done on the feasibility of using a digester's heat to help fuel an ethanol plant. Small digesters could be feasible if the gas were used for something other than electrical generation, such as heating. In community digester systems, biogas is better to transport.
2. **Ciborowski, Peter, Pollution Control Agency:** There is not much future with manure digestion. Small digesters, community digesters, alternate waste streams and digesters on swine farms are all not feasible. The government should take no action to help manure digestion. After a renewable energy infrastructure is built, manure digestion will become more widespread. The exact environmental benefits of manure digestion are unknown and need to be researched.
3. **Elde, Robert, University of Minnesota:** We should look into converting sludge to dimethyl ethyl, an almost perfect substitute for ether. Small digesters will become economically viable. Building a sustainable community is technically feasible, but difficult to engineer.
4. **Goodrich, Phil, University of Minnesota:** Manure digestion is economically dead because wind energy is cheaper. The government should give more incentives for reducing greenhouse gases since this is the biggest pro of manure digestion. The government could also organize a deal with a contractor. The contractor will then build many digesters at once to get a cheap price. Corn makes a very good alternate waste stream. Just because it can be used for feed doesn't mean it can't be used for fuel.

5. **Hansen, Wayne, AURI Center Project Specialist:** Yes, small digesters work. However, they work much better for heat than electricity. Community digester systems will only become economically feasible if DOT changes its regulations on the cleanliness of transported gas. Otherwise, transportation costs are simply too high.
6. **Haubenschild, Dennis, Dairy Farmer:** Manure digestion has a strong future. In order to sustain today's lifestyle we need to find new ways, such as manure digestion, to produce energy. Both community digester systems and small digesters are viable. The government should consider creating a mandate that forces utility companies to purchase renewable energy. If a fair market value can be created, manure digestion shouldn't need to be subsidized. More research should be done on energy crops.
7. **Janni, Kevin, Head of Air Quality, Ventilation, and Air Systems, University of Minnesota:** Manure digestion will soon build an infrastructure. Third parties will play a large part in training and maintenance. The government needs to force utilities to buy energy from manure digestion. Small digesters are not economically feasible and neither is transporting biogas.
8. **Kean, Al, State Engineer for BWSR:** Farmers haven't fully utilized the government programs already out there. Before adding more incentives and loan programs, a study should be done on the pros and cons.
9. **Kuzel, Fred, Director of Great Lakes Biomass State and Regional Partnership:** Manure digestion has a very strong future proven by the recent increase in digester installations. The government is treating manure digestion with the appropriate amount of time and money. Small digesters will never be a viable option, but community digester systems might be. Manure, not biogas, should be transported in a community digester system.
10. **Lazarus, Bill, Economist at the University of Minnesota:** Manure digesters technically work, but their energy requires a higher buyback rate before they become feasible in the United States. Corn silage with ground grain is a good alternate waste stream. Transportation in community digester system isn't as large of an issue as people make it out to be. You are just transporting the manure to a different location than you would without a digester. There isn't much added transportation. It is more advantageous to transport biogas in a community digester system than manure.
11. **Limback, Linda, Commerce:** Manure digestion may become viable, but not until we have used all the more efficient sources of energy first. The government could throw in incentives if prices fall below a certain point. Government could also put together a package to make the application process easier.
12. **Meinke, Rolly, Sales Manager for Genex Farm Systems:** Manure digestion will eventually be economically feasible. It needs an infrastructure first. The government should make a few mandates so that everybody is working together and the utilities are paying more for energy. Neither community digester systems nor small digesters are economical.
13. **Meyer, Dan, Iowa State University Field Specialist - Agricultural Engineering:** Helpful government programs exist, but are not being utilized.

Both community digester systems and small digesters are viable. Transporting biogas, not manure, is best in a community digester system.

14. **Noty, Lisa, USDA Rural Development:** Finding a standard digester design is very important. Small digesters aren't feasible, but there could be commercial sources that change that.
15. **Pawlisch, Melissa, University of Minnesota Clean Energy Resource Teams Coordinator:** The future of manure digestion depends on energy costs. The government should provide standard digester models to reduce costs. Small digesters are viable although they are a risk to start. In community digester systems, either manure or biogas could be transported.
16. **Rasmussen, Lowell, University of Minnesota - Morris:** Small digesters will become successful after big digesters do. Corn stover works very well as an alternate waste stream.
17. **Reese, Mike, University of Minnesota - Morris:** The government should stimulate the manure digestion industry. Capitol grants would be good addition to the current programs. The government could also give incentives to a third party. The bigger the digester, the better.
18. **Schmidt, David, University of Minnesota Assistant Extension Engineer:** The economy will decide if manure digestion has a future. Right now digesters aren't economical. Government should put more money into researching how to make digesters more economical. Community digester systems and small digesters just aren't economical.
19. **Sparby, Michael, AURI Project Development Director:** Neither small digesters nor community digester systems are feasible. The transportation costs involved in community digester systems are just too high to make them feasible.
20. **Sullivan, Jim, Pollution Control Agency:** There isn't a strong future for manure digesters in Minnesota, just potential. Small digesters are feasible, but risky because return for small farmers will be critical. If community digester systems are viable, it would be better to transport the manure than the biogas.
21. **Taylor, Mike, Commerce:** The key to making manure digestion feasible is to simplify it. Farmers could even modify current systems to capture low-grade methane. We should get what we can from what we have. Make it as low risk as possible. The government shouldn't tie manure digestion to so many regulations. The government could give tax benefits to companies, such as ethanol plants, that get heat from anaerobic digesters to offset their costs. The government could also select an ideal digester that fit all permit requirements at low costs. This would make the process simpler for the farmer. Right now, digesters either need to be very huge or very small to be feasible.
22. **Timmerman, Denny, AURI Project Development Director:** Small digesters are feasible for heat, not electricity. Community digesters systems raise too many transportation issues. There needs to be a policy addressing the selling and transportation of methane before community digester systems could be viable.
23. **Unknown National Leader #1:** Manure digestion has a very strong future in Minnesota. Once manure digestion becomes more popular, then we should address the question of what other waste streams are plausible. If the manure from many farms is transported to a central digester, this would solve a few

issues. First of all, this would remove the manure and digester management away from the farmer. It would allow central processing of the manure for air and water quality, odor control and nutrient recovery. On the other hand, energy production would be more reliable if there are individual digesters on each farm and the biogas is transported to a central site. This technique may call for the installation of a biogas grid. If uniform digesters were used in this situation, a troubleshooting team could take care of all of them. Small digesters have limited benefits.

24. **Unknown National Leader #2:** Manure digestion will become much more widespread. If a community digester were feasible, it should be predominantly owned by a business entity familiar with waste treatment processes. Community digesters aren't feasible because of their transportation costs. Small digesters are feasible if they are used for their heat, not their electricity.
 25. **Zhu, Jun:** Manure digestion will be cost-competitive with other forms of energy very soon. There is no minimum size of a small digester. As long as it reduces the cost of heating and electricity, it is meeting its goal. The manure digester should be completely self-adjustable to make it as low-maintenance as possible. This also keeps cost down because then a third party isn't involved with maintenance. A new idea is to use hydrogen-forming bacteria instead of methane-forming bacteria. This way, the hydrogen can go directly into a fuel cell. The currently used methane-forming bacterium has to be cleaned extensively before it is suitable for use by a fuel cell.
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Questionnaire

1. What is your knowledge/experience with manure digesters?

A. Future of Manure Digestion:

1. What do you think the future of manure digestion is in
 - a. Minnesota:
 - b. U.S.:
 - c. Europe:
 - d. In general:
2. What do you believe the biggest pro of manure digestion is?
3. What do you believe the biggest con of manure digestion is? Do you believe this can be remedied? How?
4. Do you believe policies and regulations regarding manure digestion and renewable energy in Minnesota need to change? If so, how?
5. Do you think it is appropriate for the state to allocate grants and loans towards farms implementing manure digestion? If so, how much? If not, why?
6. How valuable is manure digestion compared with other forms of renewable energy?

B. Opportunities for Small Digesters:

1. Do you believe that small digesters on small farms are economically viable? Why or why not?
2. Do you believe that India's use of small digesters for heat and small generators would be wise to use as a model for the United States? Why or why not?
3. What is your knowledge of community digester systems?
4. What are your thoughts on community digester systems? Are they plausible?
5. In a community digester system, which of the following two options do you believe to be more advantageous and why?
 - a. Transportation of manure for individual farms to a central digesterOR
 - b. Individual digesters at many sites, then transportation of the biogas to a central energy generation site.

C. Co-digestion of Manure with Other Wastes:

1. What are your thoughts and knowledge of co-digestion of manure with other wastes?
2. What do you believe the best choice of waste streams is and why?
3. Very little information on the technical and economic feasibility of different waste streams is available. Do you believe this is worth the time and money to research?
4. Do you believe that co-digestion of alternative waste streams would be beneficial

- in a community digester system?
5. Do you believe that the community digester system should be predominantly owned by the farmers? Why or why not? If not, who should own the community digester system?

A. General Company Information:

1. Describe what type of farm typically buys your equipment (location, size, type of farm, etc.)
2. What are the costs of your company's digesters?
3. What, if anything, does your company produce other than digesters?
4. How much maintenance is required for your digesters?
5. What kind of expertise is required for repair/maintenance of your digesters?
6. Does your company offer a repair/maintenance service? If so, what is the cost?
7. What, if any, are the regulatory and technical barriers of your company's digesters?
8. Would you consider doing business in Minnesota in the future?
9. What do you believe the future of anaerobic digestion is?

B. Types of Digesters:

1. What types of digesters does your company sell?
2. What types of digesters is your company working on?
3. How many of the digesters you produce are geared towards large farms? Mid-size? Small?
4. What do farmers primarily buy your digesters for (odor management, electricity production, environmental benefits, etc.)?
5. Do your digesters have any mechanism for agitation of the manure? If so, what and how often does it agitate the manure?

C. Co-digestion of Alternative Waste Streams with Livestock Manure:

1. Does your company use different waste streams than manure for digestion? If yes, continue to questions 2-11. If no, is your company considering using different waste streams than manure in the future? Why or why not?
2. What type of waste streams does your company use?
3. What is the availability of this waste stream in Minnesota?
4. How is the waste stream transported and what are the costs?
5. What makes the alternative waste stream suitable for digestion with manure?
6. What is the strength of the alternative waste stream? Is it consistent?
7. At what frequency and consistency is the waste stream added to the manure?
8. Is biogas production enhanced by the addition of the waste stream? If so, by how much?
9. Does the use of this waste stream waive fees for waste treatment?
10. Does the farmer typically receive a tipping fee for taking the waste stream? If so, approximately how much?

D. Community Digester Systems:

1. What is your knowledge of community digester systems?
2. What are your thoughts on community digester systems? Are they plausible?
3. Would your company embark on a community digester project? Why or why not?
4. In a community digester system, which of the following two options do you believe to be more advantageous and why?
 - a. Transportation of manure from individual farms to a central digester
 - OR
 - b. Individual digesters at many sites, then transportation of the biogas to a central energy generation site.
5. Do you believe that co-digestion of alternative waste streams would be beneficial in a community digester system?
6. Do you believe that the community digester system should be predominantly owned by the farmers? Why or why not? If not, who should own what parts of the community digester system?

Mailing list of Consultants

Company	Consultant	E-mail	Phone
Baumgartner Environics, Inc.	John Baumgartner	jbaumgartner@bei-ec.com	320/523-1644x1102
Bioenergy & Environmental, LLC	Jun Yoshitani	westoak@ix.netcom.com	630/588-8776
Biogas Direct LLC	Michael Zander	info@biogas-direct.com	608/546-2246
Bridgestone Associates, Ltd.	Martin C.T. Anderson	mcta@brdgstn.com	610/388-6191
Conestoga-Rovers & Associates	Brandon Moffatt	bmoffatt@craworld.com	519/884-0510
Dennis Gerber	Dennis Gerber	dhgerber@attbi.com	408/395-9020
E3 Ventures	Mike Walker	mwalker@e3ventures.com	919/469-3737
EnviroEnergetics	Sam Ghosh	ghoshsambhunath@hotmail.com	801/596-2166
Environmental Resource Recovery Group, LLC (EnRRG)	Burt Tribble	btribble@enrrg.com	913/886-8051
ENVIRONOMICS LLC	Richard Matfocks	rpm@waste2profits.com	917/359-5616
Fraunhofer Center for Energy and Environment	Junchul Kim	jckim@enrg.pitt.edu	412/624-8609
Gas Technology Institute	J. Robert Paterek	robert.paterek@gastechnology.org	847/768-0720
General Bioenergy, Inc.	Phillip Badger	pbadger@bioenergyupdate.com	256/740-5634
GHD, Inc.	Melissa Dvorak	mdvorak@ghdinc.net	952/920-2495
GHD, Inc.	Steve Dvorak	ghdinc1@verizon.net	920/849-9160
MacMillan & Associates	Roy MacMillan	rm@macmillan-group.com	503/628-0277
MCON BIO, Inc.	Hans Meyer	mconbio@mconbio.com	909/600-1385
Meridian Capital Investments, Inc.	Gino Heilizer	gheilizer@meridianinvestments.com	301/983-5000
National Methane	William J. Lingo	ilingo@dma.org	937/256-7500
Nelson and Associates	D.O. "Swede" Nelson	swedenelson@msn.com	650/364-7273
Omega-Alpha Recycling Systems	Robert Hamburg	anomalous@citlink.net	304/655-8662
R. K. Frobel & Associates	Ronald K. Frobel	geosynthetics@msn.com	303/679-0285
RCM Digesters, Inc.	Mark Moser	m.moser@rcmbiothane.com	510/834-4568
Richmond Energy Associates	Jeff Forward	forward@sover.net	802/434-3770
Robert A. Beckstrom, Electrical Consultant	Robert (Bob) Beckstrom		209/576-1740
Selective Site Energy	Terry Super	terry.super@selectivesite.com	913/438-7700
The Dubara Company	Stephen Hoyt	steveh@albany.net	518/732-7618
Tim Goodman & Associates	Tim Goodman	tgoodman1@mn.rr.com	952/544-2307
Universal Entech, LLC	Daniel Musgrove	dmusgrove@earthlink.net	602/268-8849
Williams Creek Consulting, Inc.	Joel Johnston	jjohnston@williams creek.net	317/722-9567
	Stan Weeks	SWeeks1997@aol.com	518/583-1914
Native Energy		info@nativeenergy.com	1-800/924-6826
Integrity Nutrient Control Systems, Inc.		integrity@nutrientcontrol.com	717/261-5711
Waste Energy Solutions (WES)		info@fromwastetoenergy.com	412-364-1281
Microgy Cogeneration Systems	Dan Eastman		262/242-9430
Rein and Associates	David Rein	rein@cableone.net	(218) 233-8463

Mailing List for Leaders

Agency	Name	Phone	E-mail
U of M	Bob Elde	612/624-2244	elde@umn.edu
U of M	Kevin Janni	612/625-3108	kjanni@umn.edu
U of M	Phil Goodrich	612/625-4215	goodrich@tc.umn.edu
U of M	David Schmidt	612/625-4262	schmi071@tc.umn.edu
U of M	Bev Durgan	612/624-2703	durga001@umn.edu
U of M	BILL LAZARUS	612-625-8150	WLazarus@tc.umn.edu
U of M	MIKE RESSE		reesem@morris.umn.edu
U of M	MELISSA PAWLISCH	612-624-2293	pawl0048@umn.edu
MPCA	Wayne Anderson	651-296-7323	wayne.p.anderson@pca.state.mn.us
MPCA	Bob Finley	320/214-3794	Robert.Finley@pca.state.mn.us
MPCA	Peter Ciborowski	651/297-5822	Peter.Ciborowski@state.mn.us
MPCA	Jim Sullivan	651/297-1788	Jim.Sullivan@state.mn.us
Commerce	Mike Taylor	651/296-6830	Mike.Taylor@state.mn.us
Commerce	Linda Limback	651/296-1883	Linda.Limback@state.mn.us
USDA RD	Lisa Noty	507/373-7960x120	lisa.noty@mn.usda.gov
USDA NRCS	John Brach	651-602-7880	john.brach@mn.usda.gov
BWSR	Al Kean	651/297-2907	al.kean@bwsr.state.mn.us
MN Milk Producers	Bob Lefebvre	1-877-577-0741	blefebvre@mnmilk.org
MN Farm Bureau	Jeremey Geske	651-905-2107	jgeske@fbmn.org
MN Farmers Union	Thom Peterson	651-639-1223	thom@mfu.org
Federal	Mike Bednarz	312/886-8585	michael.bednarz@ee.doe.gov
Federal	Kurt Roos	202/343-9041	Roos.Kurt@epamail.epa.gov
Federal	Stephen Jann	312-886-2446	jann.stephen@epa.gov
Federal	Fred Kuzel	312-407-0177	fkuzel@cglg.org
Federal	Sheryl Kunickis		sheryl.kunickis@nps.ars.usda.gov

U of M Mailing List

Agency	Name	Phone	E-mail
U of M	Bob Elde	612/624-2244	elde@umn.edu
U of M	Kevin Janni	612/625-3108	kjanni@umn.edu
U of M	Phil Goodrich	612/625-4215	goodrich@tc.umn.edu
U of M	David Schmidt	612/625-4262	schmi071@tc.umn.edu
U of M	Bev Durgan	612/624-2703	durga001@umn.edu

Recent Progress in Manure Digestion



What's New With Manure Digestion?

- Haubenschild Farm Fuel Cell Project
- LCMR's European Digester Tour
- Loan Program: How to Apply

Produced by the Minnesota Department of Agriculture

Haubenschild Farm Fuel Cell Project



Produced by the Minnesota Department of Agriculture

Background on Haubenschild Dairy:

- The 900-head dairy has a well-established manure digester
- Biogas is being converted to electricity by a 130 kW engine generator
- Digester produces excess biogas

Produced by the Minnesota Department of Agriculture

Objectives:

- Evaluate the feasibility of a fuel cell to convert biogas (methane) to electricity.
- Next step may be to produce hydrogen for farm use from biogas.

Produced by the Minnesota Department of Agriculture

Procedures to Achieve Objective:

- Develop biogas cleanup system
- Install fuel cell on digester
- Test the fuel cell
- Monitor systems for energy, consumption and emissions

Produced by the Minnesota Department of Agriculture

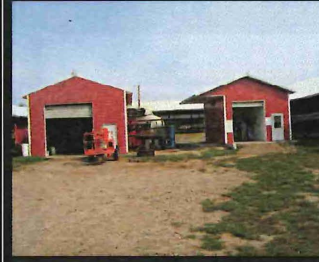
website at
<http://www.mda.state.mn.us/news/publications/renewable/waste/manuredigestion.ppt>

Challenges:

- Hydrogen sulfide removal
 - Initial concentration ~ 3000 ppm
 - Need concentration < 25 ppb
- Carbon dioxide removal
 - Need concentration < 50,000 ppm (5%)
- Moisture removal
 - Need dry gas

Produced by the Minnesota Department of Agriculture

Haubenschild Equipment Rooms



- Building on right houses the fuel cell
- Building on left houses the generator

Produced by the Minnesota Department of Agriculture

Emissions from Haubenschild Generator Vs. Plug Power™ Proton Exchange Membrane (PEM) Fuel Cell

	Engine Generator	Fuel Cell
CO	→ (800 ppmv) 4.18 g/kWh	→ (<1 ppmv) 0.014 g/kWh
NO _x	→ (2960 ppmv) 25.5 g/kWh	→ (<1 ppmv) ~0.023 g/kWh
SO _x	→ (277 ppmv) 3.34 g/kWh	→ (<1 ppmv) ~0.030 g/kWh
C _x H _y	→ (20460 ppmv) 53 g/kWh	→ (1700 ppmv) 14.5 g/kWh

Produced by the Minnesota Department of Agriculture

Problems:

- Need to receive more money for the electricity produced
- Need a more stable gas cleanup system

Produced by the Minnesota Department of Agriculture

What Do We Do Now?

- Compress, transport and sell methane
- Make and sell hydrogen
- Get more value and less regulation

Produced by the Minnesota Department of Agriculture

Benefits

- Reduces odors and emissions
- Promotes rural economy
- Reduces reliance on foreign fuel
- Reduces soil and water pollution

Produced by the Minnesota Department of Agriculture

LCMR's European Digester Tour



Produced by the Minnesota Department of Agriculture

European Digesters:

- Most are mesophilic
- All are aboveground
- Have stirring devices
- Most are larger than Haubenschild's digester

Produced by the Minnesota Department of Agriculture

Alternate Waste Stream in Europe

- Many digesters use alternate waste streams of slaughterhouse wastes, other waste fats, or crops such as corn silage.
- Corn silage is said to generate plenty of heat to operate the digester.

Produced by the Minnesota Department of Agriculture

Community Digesters in Europe:

- Community digesters receive manure from 18-60 farms.
- Regulations encouraged community digesters by requiring 6 to 0 months of manure storage.
- Storages were located in the fields where manure would be applied.

Produced by the Minnesota Department of Agriculture

Loan Programs: How to Apply

- First determine the appropriateness of a certain system for your farm
- Fill out loan or grant application

Produced by the Minnesota Department of Agriculture

Checklist to Evaluate the Likelihood of Heated Manure Digestion System Success

Key Issues		YES	NO
Site Permanency	Projected facility life is less than 10 years		
Bedding	Sand (dairy)		
Confinement	Dairy: animals on pasture or on drylots more than 10% of the time		
	Hogs: "all in-all out"		
Storage	Storage and collection pit the same		
Manure removal	Push		
Site Development	Problem finding 150X150 area for system		
Limitations			
Water managed	No water meter or meter is unread		
	Rainwater comes in		
	Dairy: parlor holding area holed down, not scraped		
	Parlor/tailrace water flows to manure pit		
Management	Is there question who will be in charge		
	Problem finding a good Farm Mechanic or service company		

NOTE: Any "YES" in the above list is an area which may require costly changes that reduce likelihood of system success.
Is the producer willing to make necessary changes?

Produced by the Minnesota Department of Agriculture

Checklist to Evaluate the Likelihood of Heated Manure Digestion System Success (Continued)

Weighted Items					Weight	Selection
(Select the best description, place corresponding Weight value in the Selection column. Add Selection values, compare with guideline Interpretation below)						
Why animal is Digester?	A good idea					3
	Environmental Concerns					3
	Financial benefit					6
Animal numbers	1-50	51-100	101-200	201-500	501-1000	1
	101-100	501-1000	1001-2000	2001-5000	5001-10000	3
	1001-1000	1000-1500	2500-5000	5000-10000		6
Electric rate, Annual kWh charge	0-50	51-100	101-200	201-500	501-1000	1
	101-200	201-500	501-1000	1001-2000	2001-5000	3
	501-1000	1000-1500	2500-5000	5000-10000		6
Floor heating	In use in the production area (and/or holding area)					10
Fuel rate, average	In use and Propane					1
	In use and Propane					2
	In use and Propane					4
	In use and Propane					6
Use depreciation On taxes	No					0
	Partial					3
	Fully					6
Score						
Interpretation: 0-20 = success questionable; 21-35 = success probable; 36-45 = greatest chance of success. Copyright R. D. V. B. 07/03/05/06/07/08/09/10/11/12/13/14/15/16/17/18/19/20/21/22/23/24/25/26/27/28/29/30/31/32/33/34/35/36/37/38/39/40/41/42/43/44/45/46/47/48/49/50/51/52/53/54/55/56/57/58/59/60/61/62/63/64/65/66/67/68/69/70/71/72/73/74/75/76/77/78/79/80/81/82/83/84/85/86/87/88/89/90/91/92/93/94/95/96/97/98/99/100/101/102/103/104/105/106/107/108/109/110/111/112/113/114/115/116/117/118/119/120/121/122/123/124/125/126/127/128/129/130/131/132/133/134/135/136/137/138/139/140/141/142/143/144/145/146/147/148/149/150/151/152/153/154/155/156/157/158/159/160/161/162/163/164/165/166/167/168/169/170/171/172/173/174/175/176/177/178/179/180/181/182/183/184/185/186/187/188/189/190/191/192/193/194/195/196/197/198/199/200/201/202/203/204/205/206/207/208/209/210/211/212/213/214/215/216/217/218/219/220/221/222/223/224/225/226/227/228/229/230/231/232/233/234/235/236/237/238/239/240/241/242/243/244/245/246/247/248/249/250/251/252/253/254/255/256/257/258/259/260/261/262/263/264/265/266/267/268/269/270/271/272/273/274/275/276/277/278/279/280/281/282/283/284/285/286/287/288/289/290/291/292/293/294/295/296/297/298/299/300/301/302/303/304/305/306/307/308/309/310/311/312/313/314/315/316/317/318/319/320/321/322/323/324/325/326/327/328/329/330/331/332/333/334/335/336/337/338/339/340/341/342/343/344/345/346/347/348/349/350/351/352/353/354/355/356/357/358/359/360/361/362/363/364/365/366/367/368/369/370/371/372/373/374/375/376/377/378/379/380/381/382/383/384/385/386/387/388/389/390/391/392/393/394/395/396/397/398/399/400/401/402/403/404/405/406/407/408/409/410/411/412/413/414/415/416/417/418/419/420/421/422/423/424/425/426/427/428/429/430/431/432/433/434/435/436/437/438/439/440/441/442/443/444/445/446/447/448/449/450/451/452/453/454/455/456/457/458/459/460/461/462/463/464/465/466/467/468/469/470/471/472/473/474/475/476/477/478/479/480/481/482/483/484/485/486/487/488/489/490/491/492/493/494/495/496/497/498/499/500/501/502/503/504/505/506/507/508/509/510/511/512/513/514/515/516/517/518/519/520/521/522/523/524/525/526/527/528/529/530/531/532/533/534/535/536/537/538/539/540/541/542/543/544/545/546/547/548/549/550/551/552/553/554/555/556/557/558/559/560/561/562/563/564/565/566/567/568/569/570/571/572/573/574/575/576/577/578/579/580/581/582/583/584/585/586/587/588/589/590/591/592/593/594/595/596/597/598/599/600/601/602/603/604/605/606/607/608/609/610/611/612/613/614/615/616/617/618/619/620/621/622/623/624/625/626/627/628/629/630/631/632/633/634/635/636/637/638/639/640/641/642/643/644/645/646/647/648/649/650/651/652/653/654/655/656/657/658/659/660/661/662/663/664/665/666/667/668/669/670/671/672/673/674/675/676/677/678/679/680/681/682/683/684/685/686/687/688/689/690/691/692/693/694/695/696/697/698/699/700/701/702/703/704/705/706/707/708/709/710/711/712/713/714/715/716/717/718/719/720/721/722/723/724/725/726/727/728/729/730/731/732/733/734/735/736/737/738/739/740/741/742/743/744/745/746/747/748/749/750/751/752/753/754/755/756/757/758/759/760/761/762/763/764/765/766/767/768/769/770/771/772/773/774/775/776/777/778/779/780/781/782/783/784/785/786/787/788/789/790/791/792/793/794/795/796/797/798/799/800/801/802/803/804/805/806/807/808/809/810/811/812/813/814/815/816/817/818/819/820/821/822/823/824/825/826/827/828/829/830/831/832/833/834/835/836/837/838/839/840/841/842/843/844/845/846/847/848/849/850/851/852/853/854/855/856/857/858/859/860/861/862/863/864/865/866/867/868/869/870/871/872/873/874/875/876/877/878/879/880/881/882/883/884/885/886/887/888/889/890/891/892/893/894/895/896/897/898/899/900/901/902/903/904/905/906/907/908/909/910/911/912/913/914/915/916/917/918/919/920/921/922/923/924/925/926/927/928/929/930/931/932/933/934/935/936/937/938/939/940/941/942/943/944/945/946/947/948/949/950/951/952/953/954/955/956/957/958/959/960/961/962/963/964/965/966/967/968/969/970/971/972/973/974/975/976/977/978/979/980/981/982/983/984/985/986/987/988/989/990/991/992/993/994/995/996/997/998/999/1000/1001/1002/1003/1004/1005/1006/1007/1008/1009/1010/1011/1012/1013/1014/1015/1016/1017/1018/1019/1020/1021/1022/1023/1024/1025/1026/1027/1028/1029/1030/1031/1032/1033/1034/1035/1036/1037/1038/1039/1040/1041/1042/1043/1044/1045/1046/1047/1048/1049/1050/1051/1052/1053/1054/1055/1056/1057/1058/1059/1060/1061/1062/1063/1064/1065/1066/1067/1068/1069/1070/1071/1072/1073/1074/1075/1076/1077/1078/1079/1080/1081/1082/1083/1084/1085/1086/1087/1088/1089/1090/1091/1092/1093/1094/1095/1096/1097/1098/1099/1100/1101/1102/1103/1104/1105/1106/1107/1108/1109/1110/1111/1112/1113/1114/1115/1116/1117/1118/1119/1120/1121/1122/1123/1124/1125/1126/1127/1128/1129/1130/1131/1132/1133/1134/1135/1136/1137/1138/1139/1140/1141/1142/1143/1144/1145/1146/1147/1148/1149/1150/1151/1152/1153/1154/1155/1156/1157/1158/1159/1160/1161/1162/1163/1164/1165/1166/1167/1168/1169/1170/1171/1172/1173/1174/1175/1176/1177/1178/1179/1180/1181/1182/1183/1184/1185/1186/1187/1188/1189/1190/1191/1192/1193/1194/1195/1196/1197/1198/1199/1200/1201/1202/1203/1204/1205/1206/1207/1208/1209/1210/1211/1212/1213/1214/1215/1216/1217/1218/1219/1220/1221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Attachment H

**University of Minnesota
Department of Bioproducts and Biosystems Engineering
Manure Methane Digester Compatible Wastes and Electrical Generation**

Final Report July 25, 2007

**For
Minnesota Department of Agriculture**

Legislative Commission on Minnesota Resources

**Philip R. Goodrich
Principal Investigator
1390 Eckles Avenue
St. Paul, MN 55108**

**goodrich@umn.edu
612-625-4215**

This report partially fulfills the objectives of the project "Manure Methane Digester Compatible Wastes and Electrical Generation". Funding for this project was provided by the Environment and Natural Resources Trust Fund as recommended by the Legislative Commission on Minnesota Resources (LCMR).

1.0 Introduction and Background

Paul Burns, Minnesota Department of Agriculture (MDA), formulated the concept for the project *Manure Methane Digester Compatible Wastes and Electrical Generation* that was realized through funding by the Legislative Commission on Minnesota Resources. Input from Philip Goodrich, David Schmidt, William Lazarus, Amanda Bilek, Richard Huelskamp, Dennis Haubenschild, and Matt Drewitz assisted in the development of the work plan and revisions of the proposal.

The University of Minnesota was subcontracted by the Minnesota Department of Agriculture for \$90,000 to provide professional/technical services to accomplish the goals and objectives of the project. The primary goals of the subcontract to the University of Minnesota Department of Bioproducts and Biosystems Engineering (name change July 1, 2006) are 1) to determine the potential for a centrally located, multi-farm digester and 2) to determine the potential use of compatible waste streams with manure digesters.

2.0 Progress Made to Reach Project Goals

The original timeline included a start date of January 1, 2006. The effective date of the contract was March 16, 2006 due to delays in getting the contract documents approved and signed.

The Literature Review

The literature review of the economic and technical feasibility of centralized or multiple farm manure digesters has been completed and delivered to the Minnesota Department of Agriculture (Deliverables 1(a), 1(b)). The update of the existing report on waste streams was incorporated into the single document.

This review was prepared for a wide audience. The motivation for its preparation was 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 was 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:

- 1) A sufficient density of cow manure or other organic material is available;
- 2) Motivation for farmers to participate in central anaerobic digesters from both a financial and a societal point of view;
- 3) 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;
- 4) 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.
- 5) 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.

The Annotated Bibliography of References

The annotated bibliography of references has been completed and delivered to the Minnesota Department of Agriculture (Deliverables 1(a), 1(b)). The annotated bibliography covers a wide range of references that were used to compile the literature review on centralized digesters. The references included research publications, reports from projects, personal communications from experts in the field and popular press reports. The significance of the reference to the report was indicated and the character of the report was also indicated so that the reader may make inferences as to the quality of the material contained in the reference. References were from a range of time periods and from both national and international sources.

An Updated Directory of Designers and Installers

An updated directory of designers and installers was completed and delivered to the Minnesota Department of Agriculture (Deliverable 1(c)). Contacts with engineering firms and industry officials were made to provide a list that could be used by Minnesota

persons wanting to make decisions about using anaerobic digestion for multiple farm digesters and/or multiple substrates for co-digestion.

Experienced design firms and independent developers both in the U.S. and Europe were contacted. Suggestions from these firms lead to an expanded group of firms to contact. The authors William Lazarus and Philip Goodrich made contacts at professional meetings, at trade shows, through email, by telephone and by personal visits to research sites and digester sites in Minnesota, Wisconsin, New York, California, in Denmark, Sweden, and Germany.

The list as compiled by Philip Goodrich includes firms that the author would use as a starting place for developing a project that includes a multiple farm digester and co-digestion of energy products. The list may not include all qualified firms, but those that the author's experience and research criteria seemed best for Minnesota. Others are on self-contributed lists at AgSTAR (<http://www.epa.gov/agstar/tech/consultants.html>). The lists are not always up to date however.

The main criteria used in compiling this list included:

1. The firm has on farm digesters that have been completed and working
2. The firm has the capabilities of working in cold climates
3. The firm has the capabilities to provide after construction support for the project
4. The authors were able to determine that a US office exists for the firm

Specific information that was learned during contacts with experienced designers is summarized below.

Before a project is committed to any engineering firm, it is the responsibility of the project manager to determine the current capabilities of the firm to successfully complete the project based on past performance, current economic conditions, and current personnel employed. Note, however, that there are not a large number of experienced engineers in the field.

If the digester contemplated is a large multi-input digester utilizing materials other than manure, there are a number of items that must be considered that are not usually a problem with a single farm manure digester.

1. The materials may contribute to health concerns for the farmers who are receiving the effluent from the digester. High temperature post processing of the effluent may be needed to satisfy security concerns.
2. The nature of the digester may lead to extensive environmental studies being required and hearings being held to satisfy neighbors concerned about added traffic, health concerns, and materials being added to the local environment.
3. Permits from multiple regulatory bodies may be necessary if cross-jurisdictional issues arise.
4. The markets may change considerably over time and the financial projections may significantly change due to externalities that are difficult to foresee.

5. The financial inputs will be larger and a broader base of funding may be necessary for the project to succeed.
6. Strict control over the inputs from various sources will be needed to insure that toxic or dangerous materials do not enter the digester.
7. Detailed operational plans for emergencies, accidents, terrorism, and extreme weather conditions need to be part of the plant manuals that are developed within the project scope.
8. Plans for adequate staffing of the plant with trained and qualified personnel are very important to the continued operation of the plant.

A User-friendly Economic Model for Analyzing Digester Installations

A user-friendly economic model for analyzing digester installations on dairy farms was developed in an Excel spreadsheet. This spreadsheet along with written instructions on how to use it was delivered to the Minnesota Department of Agriculture (Deliverables 1(a), 2(a)).

This spreadsheet is intended to help users make rough initial calculations of the annual costs and returns to be expected from owning and operating a methane digester on a dairy farm. The model is readily usable to analyze the feasibility of multiple farm digesters, by entering the manure transportation costs in row 125 of the “Start_w_One_Scenario” sheet or in row 56 of the “Details_for_Selected_Scenario” sheet. The manure transportation cost data entry cells are less prominently displayed than the other inputs to make the data entry as simple as possible for users who are mainly interested in individual farm digesters. A spreadsheet such as this one can be made easier or more difficult to use, by reducing or increasing the number of inputs required. We started out trying to set this spreadsheet to only require around four input numbers. Quite a few other inputs are required, but we “hid” the rest of them down in the detailed enterprise budget where a casual user would not see them. We then tested the spreadsheet on three types of scenarios: 1) a large (for MN) 950-cow dairy farm that is typical of those farms installing digesters across the U.S., 2) several smaller 150-300 cow dairy farms whose operators are interested in installing digesters, but which are small enough that conventional digester designs are difficult to pencil out profitably unless highly subsidized (we were exploring lower-cost designs under a state-funded research project), and 3) a proposed, large urban digester that would accept food wastes as well as manure and where the biogas would be burned directly rather than used to generate electricity. The spreadsheet seems to be able to successfully analyze these three quite diverse scenarios, but only when we had to expand the number of input variables to quite a few more than the four we hoped to use. The inputs we settled on are the ones you see in this version.

The main issues that it is intended to address include: herd size, digester installation cost, amount and value of any electricity generated, co-product value, and public support. It is NOT intended to address the engineering or design issues, and particularly the amount of biogas output to be expected. The EPA AgSTAR website and a number of other sources contain information on digester design and operation.

The worksheet contains six sheets: Instructions-General, Instructions_Line-by-Line, Data-Collection-Form, Start_w_One_Scenario, Compare_Multiple_Scenarios, and Details_for_Selected_Scenario. The Start_w_One_Scenario sheet has the inputs listed at the top. Below the inputs area is an area that shows four key results: Initial investment 1) before grants and 2) net of grants; 3) net return/year over operating and ownership costs; and 4) simple payback period, in years.

The spreadsheet contains a macro to help with data entry. For the macro to operate properly, the Excel macro protection feature must be set to Medium or Low, NOT High. Select Tools, Options, and then Security. Click on the Macro Security button at the bottom to make that change.

The spreadsheet assumes that the user has done at least a little preliminary research and analysis on biogas output, and has arrived at projected biogas output in terms of cubic feet/cow/day.

Along with manure transportation cost, a few other input variables such as the value of any odor reduction benefit are also still more or less “hidden” in the detailed enterprise budget at the moment rather than being included in the inputs area because they are less likely to vary from one analysis to the other. These other inputs are formatted in green in the enterprise budget, and can be changed directly in those green-shaded cells if desired.

The Compare_Multiple_Scenarios sheet allows the user to enter data for the input variables for up to 20 different scenarios and to compare the four key results across the scenarios.

The Details_for_Selected_Scenario sheet allows you to select any one of the 20 scenarios from a dropbox at the top. The detailed budget calculations for that scenario will then appear in that sheet for “drill down” analysis of the detailed calculations.

A White Paper on the Potential Policy Implications

A white paper on the potential policy implications of implementing multiple farm manure digesters and co-digesting manure with other waste streams has been completed and delivered to the Minnesota Department of Agriculture (Deliverable 2(b)).

This is a short paper addressing policy implications and needs for implementing multiple farm digesters and co-digestion of manure with other sources that can be used as talking points for interested groups.

Farm-based digesters are a multi-faceted technology that offers a range of benefits. However, as a standalone electricity-supplying technology for individual farms or groups of farms, the farm-based digester has struggled in Minnesota and elsewhere in the U.S. due to generally marginal profitability.

A number of policies that may be beneficial are presented including some that are monetary incentives, some that change the relationship between regulated industries and independent producers of energy and biological products, and some that encourage the use of non-fossil fuels to reduce greenhouse gases while increasing sustainability.

No one policy will solve all the problems that are holding back the production of renewable energy from organic materials in Minnesota. A wide range of policy change opportunities exist that will allow Minnesota to achieve the goals of “20 by 2020” ahead of schedule.

Production of renewable energy by digestion uses no fossil fuel in the process. This highly efficient low input system utilizes waste materials which otherwise may be treated using fossil fuels. Developing this resource in rural Minnesota is a win-win situation for renewable energy, improving the environment, and maintaining sustainable communities.

The Manure digester Economic Feasibility Spreadsheet

The manure digester economic feasibility spreadsheet developed by Dr. Lazarus has been updated to reflect inflation and new economic grant and loan programs that are available to assist farmers in putting in digestion systems. The data entry section has been modified so that the user can more easily use the program. The completed spreadsheet has been completed and delivered to the Minnesota Department of Agriculture (Deliverable 3(c)).

The manure digester economic feasibility spreadsheet is an annual discounted cash flow capital budgeting model. Given the high failure rates that have been experienced by older on-farm digesters, the planning horizon for the analysis was limited to ten years with a zero value even though some digesters have operated over longer life spans. The spreadsheet formulas are set up with space to expand the planning horizon to twenty years if desired. The model is set up with the capability to enter either actual historical data or projections, because the farm we worked with had data on actual operating costs, sales of electricity and digested manure or digestate, and avoided heating costs for 1999-2004. The second five years of the analysis were then projected based on averages with inflation adjustments.

As an annual discounted cash flow model, the spreadsheet is relatively complex but factors in several important considerations that simpler models ignore: inflation, leverage effects, and income taxes. The results are expressed in a number of different measures that may be appealing to different users, such as payback period, breakeven electricity price, net present value (along with the annualized equivalent), rates of return on assets and equity, and impact on milk production cost. One unique aspect of the model is that it calculates the present value of the various operating subsidies along with the construction grants to clearly show how much of the profitability situation is due to market returns and how much is from subsidies.

The model was developed originally for use in preparing educational fact sheets on the Haubenschild digester, and then used for the Review of Agricultural Economics journal

article cited in the literature review. The main updating done for the present project was to add an expense line item for manure transportation, and to update the digester capital investment and the other prices to projected 2007 levels.

Workshops

One workshop was presented using Internet "Breeze" to conduct the workshop over the Internet. It was planned that the Internet workshop would allow more people to participate and involve much less cost to participants. This was not very successful because of technical difficulties with the equipment and lack of support from the lab providing the base for the workshop. A second workshop where the participants were in the same room with the presenter gained more participation from farmers, extension staff, government staff, and state agency staff (Deliverable 3(a)).

Publications

The main publication from this project is the literature review that will be published in an economic or an engineering journal within the next year (Deliverable 3(a)).

Meetings and Reports

Goodrich and Lazarus met periodically with Matt Drewitz, Paul Burns, and Becky Balk to discuss the project. Reports were submitted as prescribed in the plan of work and the financial office of the U of M submitted invoices for payment according to the schedule (Deliverables 4(a) 4(b)).

Final Report Development

This report is the final report being submitted to Minnesota Department of Agriculture in addition to the deliverables as assistance to the MDA staff in preparing the final report to LCMR.