Manure Management
Annotated Bibliography
May 19, 2006

The literature on manure management is very extensive and it is not feasible to compile a bibliography of all the literature that exists. This document attempts to focus on the literature and web sites that are the most relevant to the issues facing the Dane County Community Manure Feasibility Study Committee, based on the goals and issues that they have identified.

1. " Anaerobic Digester Developments on Wisconsin Dairy Farms. Turning the Liability of Animal Waste Into an Economic Asset", Larry Krom, Focus on Energy, 2006. Available electronically

This is a 58 slide Power Point-style presentation which describes the basics of anaerobic digestion (AD) of manure to produce methane, with an emphasis on the generation of electricity. Two digester types are explained (modified plug-flow and complete mix) and photos are shown of several Wisconsin farms, including Deere Ridge, Vir-Clar, Quantum Dairy, Double-S Dairy, Holsum Dairy, Wild Rose Dairy, Five-Star Dairy and Suring Dairy. The benefits of AD are shown, along with a map of AD systems in Germany and a map and list of Wisconsin projects. A simplified economic analysis is provided, along with a chart of rates paid by Wisconsin utilities for the purchase of power. Information is given on the number of dairy farms of various sizes in Wisconsin, and a task chart for the development of a digester project is shown.

2. "Manure Management Program", web page of Cornell University, http://www.manuremanagement.cornell.edu/

This web page posts documents for a wide range of manure management activities. In 2006, seventeen publications or links were posted through April 18th, including:

04-05-06	**New tool for nutrient management** A new website, called CNMP Watch, has been released for comprehensive nutrient management planning. It contains the latest news on Concentrated Animal Feeding Operations, animal manure management and new technology. www.cnmpwatch.com
04-05-06	"Biogas Processing"
04-03-06	"On-Farm Composting Handbook"
03-27-06	"An Assessment of Technologies for Management and Treatment of Dairy Manure in California's San Joaquin Valley"
02-16-06	"Heat Transfer Model for Plug Flow Anaerobic Digesters"
02-08-06	"Development of Standard Methods to Estimate Manure Production and Nutrient Characteristics from Dairy Cattle"
02-06-06	"Is the energy in manure worth harvesting?"
02-06-06	"Supplemental Manure Spreading Guidelines to Reduce Water Contamination Risk During Adverse Weather Conditions"
01-27-06	"Cost-effective and Environmentally Beneficial Dairy Manure Management Practices"
01-27-06	"Whole-Farm Nutrient Management on Dairy Farms to Improve Profitability and Reduce Environmental Impacts"
01-27-06	"Constraining Phosphorus in Surface Water Dairy Farm Resource Use and Profitability"
01-27-06	"Strategies for Increasing Implementation and Fostering Innovation in Dairy Manure Management"
01-19-06	"Anaerobic Digestion of Dairy Manure Implications for Nutrient Management Planning"
01-18-06	"Financial Planning for Manure Treatment Systems"

3. "Cost Feasibility Model and Manure Management Calculator for the Review of Dairy Manure Handling and Disposal Systems", Joseph M. Schultz, Master's Thesis, UW-Green Bay, 2004, 51 pages. Available electronically.

The abstract of the thesis reads as follows:

> In light of environmental regulation resulting from of increased animal concentration and pollution risks, manure management on dairy farms has become a major issue for the dairy industry. Traditionally, dairy manure has been landspread directly to farm fields or stored in lagoons and landspread seasonally. The development of several industrial technologies for the solids separation of dairy manures offers farmers the potential to reduce manure hauling costs and phosphorus concentrations of manures. Tinedale Farms of Kaukauna, Wisconsin, has implemented the AES *Nutrient Partitioning ™* system, configured in partnership between *meri Papertec Inc.* (*meri*) of Appleton, Wisconsin, and *Ag Environmental Solutions, LLC.* (*AES*) of Kaukauna, Wisconsin, after several failed attempts with other manure solids separation technologies. The system uses a *meri* rotating Elephant Filter™ for concentrating manures and a *meri* Mini-Press™, screw press to dewater the concentrated solids. AES trials at Tinedale farms found the total solids capture efficiency of the system to range from 75% to 91.7% when using polymers and chemical coagulants and 60% without. The phosphorus capture efficiency ranged from 68.6% to 91.7%, while the nitrogen capture efficiency range from 44.4% to 82.4% with the aid of polymers and chemical coagulants. The trials proved the technology's durability handling range of loading rates and performing acceptably under a range of manure concentrations and characteristics. A manure management optimization calculator was developed to analyze the basic solids separation technologies; high cost/high performance and low cost/low performance systems. Calculated output for a 1000 milking cow dairy with manure flushing (65 gal/cow/day flow) was $555 a day or $202,800 annually. Implementing a solids separation system cost $90 to $542 a day with an annual cost of $32,900 to $197,800. A dairy farm with manure scraping (35 gal/cow/day flow) had a calculated baseline cost of $256 per day or $93,400 annually. It was calculated that three systems provided the farm with a net daily revenue or income ranging from $131 to $478 per day. This equates to annual income of $47,800 to $174,500 respectively for these solid separators under scraping conditions. In all cases, implementing a manure solids separation system was found more feasible than simply storing manure in a lagoon and landspreading, legitimizing the potential financial benefits of incorporating a solids separation system onto the farm.

The thesis includes a short summary of both mechanical and chemical methods of solids separation for manure.

4. "Management on Dairy Farms. Articles/Reference Sheets", Cornell University, Web page http://www.ansci.cornell.edu/prodairy/enviro/enviropub.html accessed on May 1, 2006

This web page contains a variety of farm management fact sheets, with manure management issues including titles such as:

- What's ahead for manure management? — Don't expect to see genetically modified manure to solve environmental and economic challenges for manure management. But you can look for new technologies to help. By David Belcher
- Striking the right balance — Large imbalances of nitrogen and phosphorus can negatively impact your checkbook and the environment. By Karl Czymmek, Quirine Ketterings, Caroline Rasmussen and Larry Chase

- Early intervention heads off animosity — New York's odor reporting system encourages dairy owners and neighbors to talk to each other before complaints become war. By Lee Telega

- Are your cows getting too much phosphorus? — Research seems to say yes. But feed companies are cutting back to the benefit of the environment and your bottom line. By Larry E. Chase and Charlene M. Ryan

5. "Manure Management. The Power of Green Energy. Manure Management Through Elimanure® System", Skill Associates, no date. Available electronically.

This is a 23 slide Power Point-style presentation which describes the basics of this firm's manure drying and incineration system, which both produces electricity as well as resulting in an ash that is 2% of the original input. The slides both show a schematic of the system as well as the economics, and conclude that for a system with an initial investment of $3.6 million, there are annual savings of $1.35 million

6. "Manure into Gold. A Strategic Framework for Manure Management in Ontario. Draft", Ernest Lowe and Ivan Weber Centre for Research in Earth and Space Technology, March 2, 2004, 49 pages. Available electronically.

[annotation to be added]

7. "Centralized Manure Management List", Roger Kasper, Wisconsin Dept of Agriculture, Trade and Consumer Protection, March 21, 2005, 5 pages. Available electronically.

A list of projects (and searches for projects) is given, along with web page addresses, where available, for projects both in the US (17 projects) as well as internationally, including at least 20 in Denmark. Unfortunately, many of the links are to reports that either provide little information, are old (1998, for example), or have not been updated (such as sites that talk of projects under construction, but are several years old0.

8. "Anaerobic Digestion in the Dairy Industry: Pollution Control Opportunities", Peter Ciborowski, Minnesota Pollution Control Agency, Air Innovations Conference, August 10, 2004. Available electronically.

This is a 19 slide Power Point presentation which describes the stages of anaerobic digestion (hydrolysis, acidogenesis, acetogenesis and methanogenesis), five types of digesters (covered lagoon, plug flow, complete mixed, slurry loop, and anaerobic sequencing batch reactor), the typical parameters of digestion, and measures of control potential, environmental advantages and disadvantages, and a brief discussion of economic factors.

9. "Agricultural Biogas Casebook, 2002", Joseph M. Kramer, Resource Strategies, Inc., Madison, WI, 87 pages. Available electronically.

This casebook includes cases studies of 17 digesters in the Upper Midwest (8 from Wisconsin) – 3 under construction, 8 in startup and 6 in operation – along with summary statistics, references, a summary of state financial resources, a list of vendors and consultants and a description of complaints and problems experienced by digester owners.

10. Agricultural Biogas Casebook – 2004 Update", Joseph M. Kramer, Resource Strategies, Inc., Madison, WI, 69 pages. Available electronically.

This casebook follows the same format as the 2002 edition and again has case studies on 17 systems in the Upper Midwest (again, 8 from Wisconsin) – 5 under construction, 1 in startup and 11 in operation. Similar information is also provided on summary statistics, references, a summary of state financial resources, and a list of vendors and consultants. There are also short descriptions of 5 systems that are idle or have been removed from operation.

11. "Animal Agriculture and the Environment. Your Top 5 Environmental Questions Answered", Katharine Knowlton, Ph.D., Department of Dairy Science, Virginia Tech, Blacksburg, no date, 2 pages. Available electronically.

This fact sheet gives brief responses to the following questions:

1. How can energy be generated from dairy manure?
2. How do anaerobic digesters/methane generators work?
3. Are anaerobic digesters/methane generators economical?
4. These systems are so expensive and fairly complicated – do central digestion facilities serving many farms work? Is there government money available to support these?
5. Will an on-farm methane digester help me meet my nutrient management plan?
6. How else can I make money with manure?

12. **"**Anaerobic Manure Digestion Information and Resources", Minnesota Department of Agriculture**.** Accessed on the Internet at http://www.mda.state.mn.us/feedlots/digester.htm#resources on April 21, 2006.

This is an extensive web page of information on anaerobic digestion of manure, including an annotated bibliography of 16 reports (with links to the actual documents), case studies of Minnesota systems, information on financial assistance, and links to other web pages.

The annotations are as follows:

Burke, Dennis. 2001. ***Dairy Waste Anaerobic Digestion Handbook: Options for Recovering Beneficial Products from Dairy Manure*** **(PDF: 1.66 MB / 57 pages). Environmental Energy Company.**
This manual provides an introduction to the anaerobic digestion of dairy manure. The manual is divided into three parts: the first describes the operation and waste management practices of Idaho dairies; the second introduces anaerobic digestion and the anaerobic digestion process suitable for dairy waste; and, the third presents typical design applications for different type of dairies and establishes the cost and benefits of the facilities.

Ciborowski, Peter. 2001. ***Anaerobic Digestion of Livestock Manure for Pollution Control and Energy Production: A Feasibility Assessment.*** **MPCA.**
This report analyzed the factors that influence the economic viability of on-farm anaerobic digestion. The factors analyzed were: size of feedlot, manure characteristics, the level of on-farm electrical loads, and electrical buy back rates. The study looked at the viability of AD for dairy and swine and determined the limits for economic viability.

Escobar, Guillermo and Heikkila, Matti. 1999. ***Biogas Production in Farms, through Anaerobic Digestion of Cattle and Pig Manure: Case Studies and Research Activities in Europe*****. TEKES, OPET of Finland.**
AD systems are well known and widely used throughout the world. The factor most strongly influencing the economic merit of an AD facility is maximizing the sales of all usable co-products. Advanced technology end-use applications can increase the economic value of biogas, but only after sufficient production scale has been achieved to significantly reduce the unit cost of ownership. The use of more sophisticated AD process for industrial waste treatment will increase. AD can decompose some organic toxic and hazardous materials in co-digestion schemes and this potential will be realized. For the future, the driving forces for the use of AD will probably drift away from energy production. Organic stabilization, pathogen reduction, and the production of a high-quality soil improver will be important reasons to use AD in developing countries. Energy savings in operation and minimal sludge from AD versus aerobic treatment will become more important in energy and landfill deficient areas.

Fehrs, Jeffrey. 2000. ***Vermont Methane Pilot Project Resource Assessment*** **(PDF: 156 KB / 59 pages). Prepared for the Vermont Department of Public Service and Vermont Department of Agriculture, Food, and Markets.**
The purpose of this resource assessment is to quantify on a statewide (Vermont) basis the

amount of dairy manure and other organic residues and wastes that are generated and the amount could potentially be used in farm-based anaerobic manure digestion systems. Estimates of the electrical energy potential of farm-based anaerobic manure digestion are made based on quantities potentially available and assumed conversion factors and efficiencies. The residues and wastes included in the assessment are dairy manure, other manures, cheese whey, food processing residuals, brewery residuals, food waste, and biosolids. Of the 30 MW potential for AD in Vermont, 94% of that total would be from dairy manure.

Kramer, Joseph. 2002. ***Agricultural Biogas Casebook*** **(PDF: 904 KB / 87 pages). Resource Strategies, Inc. Prepared report for the Great Lakes Regional Biomass Energy Program Council of Great Lakes Governors.**
This casebook presents profiles of farms using ADs for animal manures in the Great Lakes States: Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin. The purpose of this casebook is to provide a picture of the current state of on-farm AD use in these states in the spring of 2002. The summary of information provided in these profiles can help those considering using AD technology to make informed choices and provide general improvement in implementation efficiency and operator success. Furthermore, through sharing their experiences, these early adopters may help service providers better understand the needs of their customers, and aid the next wave of adopters in making a smooth transition to using biogas systems.

Lazarus, William and Rudstrom, Margaretha. 2003. ***Financial Feasibility of Dairy Digester Systems Under Alternate Policy Scenarios, Valuations of Benefits, and Production Efficiencies: A Minnesota Case Study*****. Department of Applied Economics, University of Minnesota.**
The number of anaerobic digester (AD) systems on dairy and swine farms in the U.S. has approximately doubled in the last 5 years, nearly all at larger feedlot operations. Although the odor reductions due to AD can be fairly obvious to the nose, there is a critical need to better understand some of the more subtle environmental and economic impacts of AD systems. A multi- year collaborative effort was begun three years ago to answer some of these questions, and will wrap up next year. The NRCS-funded project is led by the non-profit organization The Minnesota Project and utilizes the research and outreach expertise of the University of Minnesota. This paper presents the results of the economic component of this project, focusing on a case study of a Minnesota digester at a dairy farm. The economic performance of AD systems is considered, compared with alternative options, such as a grazing system. An economic model has been developed to estimate financial viability under a variety of performance and policy scenarios. Results to date indicate that the current selling price of electricity is not sufficient to justify building an anaerobic digester in most cases unless there is some kind of incentive payment.

McNeil Technologies. 2000. ***Assessment of Biogas to Energy Generation Opportunities at Commercial Swine Operations in Colorado*****. Report submitted to the State of Colorado's Governors Office of Energy Management and Conservation.**
This project evaluates the potential for hog farms in Colorado to implement AD and electrical generation systems as one possible means to offset compliance costs associated with new air and water quality regulations in the state. These regulations, which resulted from an amendment to the Colorado Constitution, are aimed at controlling odors and groundwater contamination from commercial swine feeding operations. These new regulations include a requirement for large commercial hog feedlot operations to employ control technologies (such as covers) to minimize odor and water quality impact associated with their operations. The US DOE, Western Regional Biomass Energy Program, and the Colorado's Governor's Office of Energy Management and Conservation funded this project. The major findings of the study are: 1) large swine operations in Colorado that are subjected to the new regulations have the capacity to hold over 1.1 million swine each year and produce an estimate 1.4

million ponds of manure, 2) up to 4 MW of power could be produced using methane from hog facilities with anaerobic lagoons if the facilities employed AD and energy recovery systems, 3) one hog facility in the state, Colorado Pork, is using AD and energy recovery systems for on-farm energy generation…the facility is saving an estimated $3,292 each month in electricity costs, and 4) additional opportunities exist for AD and energy recovery in Colorado are possible.

Martin, John. 2003. ***A Comparison of Dairy Cattle Manure Management with and without Anaerobic Digestion and Biogas Utilization*** **(PDF: 1.11 MB / 58 pages). Eastern Research Group, Inc. prepared report for AgSTAR Program U.S. EPA.**
The objectives of this study were to compare: 1) the reductions in the potential air and water quality impacts of scraped dairy manure by preceding liquid-solids separation and storage with mesophilic anaerobic digestion in a plug flow reactor with a flexible geomembrane, and 2) the associated cost differential. The results of this study provide further confirmation of the environmental quality benefits realized by the AD of dairy cattle manure with biogas collection and utilization for the generation of electricity. The results also confirm that the environmental quality benefits can be realized while concurrently generating revenue adequate to recover capital invested and increase farm net income through on-site use and sale of electricity generated.

Mears, Daniel. 2001. ***Biogas Application for Large Dairy Operations: Alternatives to Conventional Engine-Generators*** **(PDF: 304 KB / 105 pages). Optimum Utility Systems prepared report for the Cornell Cooperative Extension Association of Wyoming County, NY.**
Dairy anaerobic digester systems process cow manure to generate a biogas that is typically used to generate electricity using an engine-generator system. Engine-generators in this service tend to require high-maintenance, and not all local electric utilities companies will purchase excess power at rates favorable to full biogas use. Large dairy operations can produce farm more biogas than they can use on site, so alternatives to electrical generation may be desirable. This report examines alternatives to conventional engine-generators that include: hot water boilers, absorption chillers, radiant heaters, and other technologies that may be adapted to biogas service.

Mehta, Aashish. 2002. ***The Economics and Feasibility of Electricity Generation using Manure Digesters on Small and Mid-sized Dairy Farms*** **(PDF: 257 KB / 21 pages). University of Wisconsin-Madison Dept. of Ag and Applied Economics Energy Analysis and Policy Program.**
This paper is to serve as a first pass at the economics of digesters and generators. Three generalizations came through in this paper: 1) there are significant external benefits to producing electricity using digesters instead of coal, 2) AD technology is still in its infancy, and 3) it is not useful to consider a farm's digestion/generations operations merely as an appended operation that could marginally improve it's bottom line….The economic linkages between digester and dairy operations are significant and complex.

Nelson, Carl and Lamb, John. 2002. ***Final Report: Haubenschild Farms Anaerobic Digester Updated*** **(PDF: 706 KB / 39 pages). The Minnesota Project.**
This report is an update of the December 2000 report and documents the installation and 34-month performance of a heated plug-flow anaerobic digester for managing dairy manure at Haubenschild Farms. This type of digester is appropriate for treating manure with a high solids content, such as cow manure that is collected by scraping.

Porter, K., Wiser, R., and Bolinger, M. 2002. ***Two Different Approaches to Funding Farm-Based Biogas Projects in Wisconsin and California*** **(PDF: 302 KB / 7 pages). Berkeley Lab, Clean Energy Group, and Exeter Associates.**
California and Wisconsin are the two leading dairy producing states in the nation. Both states

are interested in developing biogas projects from livestock manure, but have targeted their renewable energy application differently. California has allocated nearly $10 million in incentives and grants as a catalyst for dairy operations to further biogas systems in the state. Wisconsin has a more modest financial incentive and is relying more extensively on education and outreach and other regulatory mechanisms to encourage biogas facilities.

Rozdilsky, Jack. 1998. ***A Case Study of Michigan Farm-Based Anaerobic Digestion: Suggestions for Successful Farm-Based Bioenergy Systems*****. Michigan State University, Dept. of Resource Development Urban Studies.**
This paper briefly introduces the concept of AD and summarizes the status of farm-based ADs in Michigan. The paper explains the interrelated barriers of AD and the relatively low success rate of farm-based ADs in Michigan.

Safely, L.M., Vetter, R.L., and Smith, L.D. ***Management and Operation of a Full-Scale Poultry Waste Digester*** **(PDF: 44 KB / 6 pages). Poultry Science.**
A full scale (587 m3) poultry AD was monitored for 3 years. The digester processes the manure from 70,000 caged layers and is operated on a 22-day retention time at 35 C. Resulting biogas is used to fuel an 80 kW engine-generator set; the electricity is sold to the local utility. AD of poultry manure can be effectively accomplished on farm. Reasonable gas production and subsequent electrical cogeneration have been demonstrated. Maintaining a consistent TS level in the influent is important in getting consistent gas production. The removal of grit from the influent would have the single greatest impact on overall performance by reducing digester downtime. Competent management and personal attention is needed in certain areas of operation, namely, processing of digester influent, maintenance of equipment, and observation of system performance.

Wilkie, Ann. 2003. ***Anaerobic Digestion of Flushed Dairy Manure*** **(PDF: 182 KB / 3 pages). University of Florida Soil and Water Science Department, Proceedings from Anaerobic Digester Technology Applications in Animal Agriculture National Summit, p. 350-354, Water Environment Federation, Alexandria, Virginia.**
Fixed-film AD offers sustainable alternative to treat the liquid fraction of flushed dairy manure, providing major benefits in terms of energy production, waste stabilization and odor control, and pathogen reduction, while conserving the fertilizer value of the wastewater. The fixed-film digester developed at the University of Florida was designed specifically to treat the liquid fraction of flushed dairy manure, with a portion of the digester biogas being utilized to heat water for use in milking parlor.

White, John and Van Horn, Catherine. 1998. ***Anaerobic Digester at Craven Farms: A Case Study*** **(PDF: 2.47 MB / 18 pages). Oregon Office of Energy.**
Dairy farmers in Tillamook County (Oregon) are under financial and regulatory pressure to manage the manure their cows produce. Although the waste management systems farmers commonly use reduce the amount of manure in runoff, they do not remove harmful bacteria from the manure. Neither do they provide farmers with ways to offset farm costs. This case study explores an alternative for handling dairy waste that does both. AD is an effective method of making manure less environmentally harmful while providing farmers with economic benefits.

13. “Anaerobic Digesters and Methane Production... Questions that need to be asked and answered before investing your money”, Dennis Frame, et. al., Discovery Farms, UW-Madison, 2001, 6 pages. Available electronically.

This fact sheet describes the four basic steps of anaerobic digestion (hydrolysis, acidogenesis, acetogenesis and methanogenesis), the four main types of digesters (covered lagoon, complete mixed, modified plug-flow, and temperature-phased anaerobic digestion), looks at management methods of digestion of manure, why digestion systems fail, energy production estimates and requirements, and environmental benefits of systems.

14. “Dairy Manure Technology Feasibility Assessment Panel”, Accessed on the Internet on May 1, 2006 at http://www.arb.ca.gov/ag/caf/dairypnl/dairypanel.htm

The California Air Resources Board hosted a San Joaquin Valley Dairy Manure Technology Feasibility Assessment Panel to help determine which technologies and management techniques are most likely to improve the management and treatment of dairy manure in the San Joaquin Valley. Panel members were drawn from government, industry, academia, and environmental and conservation groups. The web page lists the members, the minutes from their four meetings, their request for technology and management practices information and a final report, titled “Final Report: An Assessment of Technologies for Management and Treatment of Dairy Manure in California's San Joaquin Valley”.

The report was published in December 2005 and is 212 pages long, with the bulk of the report (160+ pages) devoted to assessments of 44 systems and technologies for handling dairy manure. An appendix has a list of 113 vendors from both within the US, as well as other countries, and it is noted that the list is not all inclusive.

For each type of technology, the report describes the basic approach of the technology, and its advantages and disadvantages for the San Joaquin Valley.

15. “Biogas and Anaerobic Digestion”, web page of Penn State University, http://www.biogas.psu.edu/, accessed May 1, 2006

This web page both describes the basic technology of anaerobic digestion, but also has links to cases studies, including three community digester systems or feasibility studies – Port of Tillamook Bay, Oregon; a fact sheet by Cornell University of a study of a 10-farm system in Salem, NY; and the potential for wastewater utilities and dairies to work together, a Power Point presentation from Chino, CA.

16. “Johne’s Information Center”, University of Wisconsin School of Veterinary Medicine, http://www.johnes.org/, accessed May 19, 2006

This site gives a compilation of information on Johne’s disease, including education opportunities in Wisconsin. Categories of information include:

- Glossary
- History
- Biology of M. paratuberculosis
- Antimicrobial therapy
- Zoonotic potential
- Articles/brochures
- Presentations
- Links

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