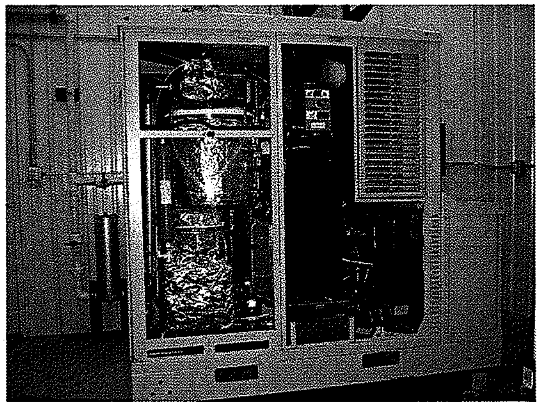
2003 LCMR Project: *Advancing Utilization of Manure Methane Digester Electrical Generation*

Final Report to the Legislative Commission of Minnesota Resources (LCMR)

06 - 0057



Proton Electron Membrane Fuel Cell

Submitted by:
Minnesota Department of Agriculture
Agricultural Resources Management and Development Division

MINNESOTA DEPARTMENT OF AGRICULTURE
FROM THE FARM TO YOUR FAMILY

2003 LCMR Project: *Advancing Utilization of Manure Methane Digester Electrical Generation*

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December 20, 2005

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2003 LCMR Project Abstract: ***Advancing Utilization of Manure Methane Digester Electrical Generation***

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A water-scrubbing tower removed soluble carbon dioxide and hydrogen sulfide while retaining insoluble methane in biogas stream. A final iron sponge scrub removed residual hydrogen sulfide. This simple pressure and flow control system was satisfactory to clean up the biogas. Optimization will reduce the energy used for gas cleanup.

Caterpillar engine generator emissions were compared to Plug Power™ (PEM) fuel cell using biogas in both technologies. The greenhouse emissions from the fuel cell are minimal compared with the internal combustion engine. Emissions of nitrogen oxides (NOx), carbon monoxide (CO), sulfur dioxide (SO_2) were less than detection limits. Total hydrocarbons (THC) were 1,790 ppmv or 14.5 g/kWh_e. Average genset emissions at 103 kW were NOx = 2,963 ppmv or 25.5 g/kWh_e, CO = 799 ppmv or 4.18 g/kWh_e, THC = 20460 ppmv or 53 g/kWh_e, SO_2 = 277 ppmv or 3.34g/kWh_e.

With assistance from the Minnesota Project and Minnesota Department of Agriculture, outreach efforts for the project consisted of 2 field days, 35 small tours, 10 formal presentations, and 2 papers presented at international conferences.

The primary recommendation to farm operators considering a fuel cell is to wait until the cost of fuel cells (currently greater than $10,000/ kW) is economically viable. The current pricing structure for electrical energy purchase by energy companies and co-ops does not provide enough income to farmers to make most operations economically viable. The value of renewable energy and incentives for making renewable must increase.

November 23, 2005

2003 LCMR Final Work Program Report

Date of First Status Report: December 31, 2003 (Revised January 28, 2004)
Date of Second Status Report: June 30, 2004 (Revised July 22, 2004)
Date of Third Status Report: December 31, 2004 (Revised April 15, 2005)
Date of Final Report: September 30, 2005
Date of Work program Approval: June 25, 2003
Project Completion Date: June 30, 2005

I. PROJECT TITLE: Advancing Utilization of Manure Methane Digester Electrical Generation

Project Manager: Paul Burns, Assistant Director, Agricultural Resources Management and Development Division
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Total Biennial LCMR Project Budget:
LCMR Appropriation: **$ 221,000.00**
Minus Amount Spent: **$220,965.34**
Equal Balance: **$34.66**

***See Attachment A for Additional Budget Details**

Legal Citation: ML 2003, Chap. 128, Art. 1, Sec. 9, Subd. 10(b).

Appropriation Language: 10(b) Advancing Utilization of Manure Methane Digester Electrical Generation

$111,000 the first year and $110,000 the second year are from the trust fund to the commissioner of agriculture to maximize the uses of manure methane digesters by identifying compatible waste streams and the feasibility of micro turbine and fuel cell technologies.

II. and III. FINAL PROJECT SUMMARY

A commercial 5kW proton exchange membrane (PEM) fuel cell was successfully operated in February 2005 on anaerobic digester biogas produced on a Minnesota dairy.

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IV. OUTLINE OF PROJECT RESULTS:

<u>Result 1: Evaluating the Feasibility of Fuel Cell/Micro turbine Technology</u>

A. Final Report Summary for Result 1, June 30, 2005:

The University of Minnesota Engineering team, led by Dr. Phil Goodrich, and farmer/cooperator Dennis Haubenschild successfully commissioned a proton electron membrane fuel cell (PEM) using biogas from anaerobically digested cow manure. To the best knowledge of the project participants, this is the first demonstration of a fuel cell running on biogas from livestock in the world. This project was made possible through the funds from this LCMR grant, the project cooperators (Minnesota Dept. of Ag, U of M, Dennis Haubenschild, and the MN Project), and private organizations that contributed cash, equipment, and time to make this project a success.

There is a significant amount of background and supporting material that was developed for this project. In order to best organize this information effectively, a large proportion of the information for the final report is broken down into a series of appendices. These appendices are listed below and are attached to this final reporting document:

- Appendix A: Final Budget
- Appendix B: Report to MDA from the U of M Biosystems and Ag Engineering (BAE) Department.
- Appendix C: Powerpoints on the LCMR project developed by the U of M BAE
- Appendix D: MN Project final report to MDA
- Appendix E: MN Project fact sheets developed and submitted to MDA
- Appendix F: MN Project Web site information on the LCMR Project
- Appendix G: MDA Manure Digester Web site materials
- Appendix H: Digital photos for the project
- Appendix I: Poster displays developed for this project
- Appendix J: Schematic of energy flow at the Haubenschild Dairy
- Appendix K: Articles about the fuel cell project in the press
- Appendix L: Dataset example from fuel cell data acquisition system

B. Site Preparation

The site for the fuel cell project was the Dennis Haubenschild Dairy farm located 1 hour north of the Twin Cities Metropolitan area near Princeton, MN. Haubenschild farm was an ideal location for the project of a number of reasons: 1) Working manure digester on site with a proven track record of successful operation, 2) Related research already being undertaken on the farm related to manure digesters, 3) Surplus gas production at the site so the economic impact to the electrical production of the existing engine generator set would be minimal, 4) and the relative close proximity of the farm to the U of M campus.

The U of M received a gift of $40,000 from John Deere Inc. to construct a research building on the Haubenschild farm to assist with this LCMR project and future research projects. The research building was very important for the success of this project and for the ability of the all parties involved to secure future research funding. Once the building was constructed, gas piping and other infrastructure needed to prepare the research facility for the fuel cell was installed. Dennis Haubenschild and U of M staff worked cooperatively in designing and constructing the research facility. Haubenschild also provided in-kind infrastructure and tools to assist the U of M and the contractors in preparing the site.

C. Fuel Cell Selection

One of the most crucial steps in the project was finding a fuel cell that was suitable for the project. A number of criteria needed to be considered when developing the strategy for purchasing a fuel cell for the project: 1) cost, 2) fuel cell type, 3) technical support, 4) easy of use, and 5) commercial availability. The U of M collected background information on fuel cell types and developed a request for proposal (RFF) based on that information. Plug Power Inc. responded to the RFP and was awarded the bid for the project. Plug Power Inc. produces proton electron membrane (PEM) fuel cells that are commercially available and had been used in various commercial and residential situations. This type of fuel cell is a lower temperature, lower cost fuel than other types of fuel cells being developed, but required a great deal of treatment of the biogas for impurities before the gas enters the fuel cell. Other types of fuel cells that run at a much higher temperature (molten carbonate and solid oxide) that have the potential to use biogas with less involved gas clean up, but there were no commercially available units ready for use in this type of application that met the budgetary limits of the project.

D. Data Acquisition System Installation

Numerous computer and monitoring systems needed to be installed in the research building before the fuel cell could be installed. Biogas monitoring and other data systems were installed and tested before the fuel cell was installed. Also, computer systems were installed so U of M staff and Dennis Haubenschild could receive and send electronic information from the research site. For more details on the data acquisition system, see Appendix B. The software programs that ran the Plug Power PEM fuel cell and the data acquisition system were able to collect a wide range of data. Because of the large amounts of data collected by the fuel cell software, an example data set is provided in Appendix L.

E. Fuel Cell Installation

The fuel cell arrived at the Haubenschild farm in September of 2005. Before the fuel cell could be installed, one U of M staff person went through a week of intensive training on how the use the fuel cell. Later in 2005, a second U of M staff was trained by Plug Power Inc. at their training center. U of M staff worked on completing the installation of the data acquisition system, electrical hook ups, and gas piping in the research building before the fuel cell was fully installed. U of M staff also installed a computer in the research building that would run the fuel cell software programs, collect data for the project, and allow data to be transferred from the Haubenschild farm back to the U of M.

F. Biogas Clean Up

Biogas, which is the gas produced from anaerobic digester of manure, is approximately 50-60% methane (CH_4), 30-40% carbon dioxide (CO_2), and a small percentage of impurities such as hydrogen sulfide (H_2S) and water vapor. Natural gas, by comparison, is approximately 99% methane. The PEM fuel requires pure hydrogen as fuel, so hydrogen must be derived from the methane, and CO_2 (carbon) and other impurities must be separated out. The first step was to monitor the biogas composition coming from the manure digester and after the biogas clean up process before the gas enters the fuel cell reformer. The methane content of the biogas from the Haubenschild manure digester was approximately 55%. The methane content of biogas is variable because of a number of factors including: the season of the year, health of the cows, and the management of the feed. Carbon dioxide clean up was very important as it acted in diluting the hydrogen content of the biogas. Hydrogen sulfide, although a very small constituent of biogas, is very caustic to the internal systems of the fuel cell. Hydrogen sulfide levels of 3,000 to 5,000 ppm were observed in the raw biogas and reductions of 2 orders of magnitude were needed in order to safely use the biogas.

Three different systems were used to clean up the biogas: 1) water tower system, 2) pressure swing absorber, and 3) lime solution system. Ultimately, the water tower system, which was very effective at scrubbing CO2, was the most effective biogas clean up system tested. For more details on these systems, see Appendix B.

G. Running the fuel cell on natural gas

The fuel cell was first tested and commissioned on pure natural gas in January xx, 2005. This allowed the U of M researchers to become familiar with the operations of the fuel cell and to make sure it was functioning properly before it was run on biogas from the Haubenschild anaerobic manure digester. The Plug Power Inc. PEM fuel cell has a reformer that converts the methane (CH4) in the natural gas into pure hydrogen (H2) that ultimately fuels the electrochemical reactions in the fuel cell. Natural gas is almost composted almost entirely of methane and has very few impurities. Because of the experimental nature of this project, it was important that a natural gas source was available to start the fuel cell up initially and gradually add biogas to the fuel cell and reformer. This was very important in extending the life of the fuel cell stack for multiple experiments.

H. Running the fuel cell on biogas

The fuel cell was run on natural gas and was thoroughly tested before being run on biogas. Aforementioned, clean up of the biogas was essential and needed to occur before the biogas entered the fuel cell and its reformer. Once the first biogas cleaning system was in place, the fuel cell was first run on biogas on February xx, 2005. From February to June 2005, the fuel cell was run on biogas intermittently for a few hours to a day at a time. In order to preserve the integrity of the fuel cell and extend the life of the fuel cell stack, the fuel cell was only run on biogas for relatively short periods of time. In addition, the various biogas clean up systems needed to be monitored closely and a researcher from the U of M was needed on site to do ensure that those systems were operational. U of M researchers were able to study the following parameters when running the fuel cell on biogas: 1) biogas quality before and after clean up, 2) biogas clean up technology feasibility, 3) fuel cell start up and shut down procedures, 4) fuel cell stack emissions, 5) electrical output, and 6) reliability of the entire system.

I. Success running a fuel cell from digested dairy manure

This project was successful in being the first fuel cell to ever run from biogas from digested animal manure. This fact was groundbreaking and very exciting for all parties involved. A lot of hard work and effort was involved in getting the stage where the fuel cell was operational and using biogas to produce electricity. There was a great deal of positive press and reports that came out of this effort, which helped showcase LCMR's involvement in this project and renewable energy. Read further in Appendix K for specific articles written by the media about the project. Also, staffs from the U of M and the MN Project were able to speak about this project to national and international audiences at conferences and meetings.

J. Pros and Cons of Fuel Cells vs. Conventional Engine Generators

Below is a brief summary of the differences, both positive and negative, between using a fuel cell vs. a conventional internal combustion generator to produce electricity from biogas derived from a manure digester.

Attribute	**Fuel Cell**	**Conventional Internal Combustion Engine Generator Set**
Capital Cost per Kilowatt	High ($10,000-12,000)	Low ($50-100)
Biogas Cleanup	Biogas needs to be cleaned to strict specifications	Little or none needed
Maturity of Technology	Rapidly emerging	Mature
Greenhouse Emissions	Minimal	Carbon dioxide, carbon monoxide, sulfur oxides, particulates
Noise Level of Equipment	Minimal	Very high and sound mitigation necessary
Moving Parts to Fail	Very few and most at ambient temperature	Many moving parts in a hot, challenging environment needing oil and cooling
Changes Occurring	Changing rapidly with extensive development	Mature and changing slowly
Maintenance Cost	Very high because of limited life of the fuel cell stack material	Variable given the maintenance and reliability of the unit

At the present time, fuel cell technology is not an economically viable option for livestock producers looking at producing electricity from biogas. The environmental benefits of the fuel cell are promising, but until the price comes down, this technology will have limited applicability on current farms with manure digestion.

K. Emission Reductions and Environmental Benefits

Emissions from Haubenschild Caterpillar™ engine generator were compared to Plug Power™ Proton Exchange Membrane (PEM) Fuel Cell (see table below) on March 11, 2005 using biogas in both technologies.

	Engine Generator	Fuel Cell
CO	(800ppmv) 4.18 g/kWh	(<1 ppmv) 0.014 g/kWh
NOx	(2960ppmv) 25.5 g/kWh	(<1 ppmv) <.0023 g/kWh
SO_X	(277ppmv) 3.34 g/kWh	(<1 ppmv) <0.030 g/kWh
$C_X H_Y$	(20460ppmv) 53 g/kWh	(1790 ppmv) 14.5 g/kWh

The data was shown in grams of pollutant emitted per kWh of electricity produced by a specific generator to better compare the emission from the 5kW fuel cell that produces less electricity than the 130kW internal combustion engine. These results show that emissions of carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SOx), and hydrocarbons (CxHy) are minimal in the fuel cell compared to the internal combustion engine. In the fuel cell, many of the pollutants are filtered out in the gas clean up process.

L. Education and Outreach

The MN Project, the U of M, Dennis Haubenschild, and the MDA worked cooperatively together on the education and outreach component of the project. The MN Project worked on developing educational materials, constructing a website with information on this project, and coordinating a field day to showcase the fuel cell technology. The MN Project also worked with the U of M on giving presentations on the LCMR at various meetings and conferences (see Attachment D for more detail). The U of M presented papers at national conferences, assisted with numerous field days, and worked with the media to provide information on the LCMR project (see Attachment B for more detail). Farmer Dennis Haubenschild gave many tours of his farm where he explained the LCMR project to captive audiences on his farm. Haubenschild also worked with the media in providing information on the success of the project and his future vision for renewable energy as it relates to anaerobic manure digesters. The MDA assisted in coordinating outreach efforts, developed a press release on the success of the project, and worked with media on disseminating information about the LCMR project.

M. Public/Private Partnership Development

This project was very successful in developing partnerships between the public and private sector. The funds awarded by LCMR for this project were very important in leveraging additional private and public funds (cash and technical assistance) that helped enhance this project. Here is a listing of outside contributors to the project:

- John Deere Inc.
- First District Dairy
- East Central Energy
- Great River Energy
- Energy and Power Research Institute (EPRI)

This project was enhanced by cooperation with other agencies, private sector funds, donated equipment, and additional U of M funds. This project has a great potential to bring in additional Federal, State, and private funds for future research on anaerobic manure digestion and renewable energy technologies.

N. Budget

The $221,000 in funds for this project (except for $34) was expended through work completed by the U of M Biosystems and Agricultural Engineering Department, the MN Project, and Dennis Haubenschild. The MDA worked with LCMR staff to amend the budget on a few separate occasions in order to reflect the amount of work U of M staff were undertaking and the additional staff time needed. Because of the unique nature of the project, it was difficult to find contractors with the proper knowledge to install some of the equipment and set up the fuel cell so it was more practical for U of M staff to do the work themselves.

O. Research Needs

This project covered new ground in understanding animal agricultures role with renewable energy and the hydrogen economy in Minnesota. This project proves that there is a great potential for the use of fuel cells and hydrogen on working farms in Minnesota once current technology and economic barriers have been hurdled. The following are potential research areas that could help accelerate the knowledge base and adoption of fuel cell and renewable energy technology on farms with anaerobic manure digesters:

- The feasibility of other fuel cell types needs to be researched (solid oxide and molten carbonate fuel cells). It is important to identify fuel cells that may be able to run on biogas that requires less pretreatment and will be able to provide heat for keeping the manure digester warm and operational during the winter months.
- The feasibility of producing hydrogen gas from biogas on-site, storing the hydrogen fuel, and ultimately transporting the hydrogen is a very realistic possibility and needs to be researched.
- In the future, as economics change for fuel cells, it is important that the U of M work to update economic feasibility data for manure digesters with this information.

P. Current Economics, Future Considerations, and Potential Outcomes for Fuel Cells

P(1). Is the PEM fuel cell an economically viable alternative to the conventional internal combustion engine?

At the current moment, the fuel cell technology including PEM fuel cells are not a viable alternative to the conventional internal combustion engine in Minnesota. If the emissions from the internal combustion engine are restricted as they are being restricted in

California, then they become a better candidate. The cost per kW installed is still too high to match the old and established technology.

Table 1: Cost per kWh to Purchase Electrical Generation Systems that can burn Biogas

Electrical Generation System	Cost per kWh	Size of Individual Electrical Genset
Internal Combustion Engine	$500-$1000	20 kW-500kW
PEM Fuel Cell	$2,000-$15,000	3kW-10kW
Solid Oxide Fuel Cell	$3,000-$25,000	1kW- 20kW
Molten Carbonate Fuel Cell	$1500-$2000	100kW- 1,500 kW
Micro turbine	$700-$1,100	30kW-80kW
Sterling Engine	$1000-$2000	30kW-55kW

Micro turbine Cost Capital Cost $700-$1,100/kW O&M Cost $0.005-0.016/kW Maintenance Interval 5,000-8,000 hrs (Courtesy of California Distributed Energy Resources Guide on Micro turbines)

Table 2: Energy Production Costs per kW to by Different Energy Generation Processes

Energy Source	Production Costs per kW in U.S. Dollars ($)
Coal	.02
Natural Gas	.04-.06
Nuclear	.01-.10
Solar	.20-.25
Geothermal	.10-.20
Wind	.03-.16
Biomass Incineration	.03-.10
Biogas from Manure Digestion (Internal Combustion Engine)	.04-.10
Biogas from Manure Digestion (PEM Fuel Cell)	.20-.30

*Average Retail Price for electricity in MN is 6-8 cents/kW

Table 3: Cost of Fuel Cell and Internal Combustion Engine at Haubenschild Dairy

Genset Type	Genset Capital Cost	Operation and Maintenance Costs	Life Span
Caterpillar Internal Combustion Engine (130 kW)	$110,000 or $846/kW	$15,000-$25,000/year	5 years (second engine in place)
Plug Power Fuel Cell (5 kW)	$80,000 or $16,000/kW	Unknown (will be high until technology is mature)	Unknown (will be shorter than internal combustion engine)

P(2). What is the value of demonstrating the use of a fuel cell for alternative electrical generation from biogas?

The best value of the demonstration is that fuel cells can be mated to the renewable resource that is expanding at a rapid rate in most dairy states. Dairy production uses large quantities of electricity in the production of low cost food for Americans. Independence is valuable. Also the emissions from the fuel cell conversion to electricity are very low compared to the engine generator.

P(3). What are the next critical steps and issues to be resolved for fuel cells to be adopted on livestock operations using manure digesters?

The suppliers of fuel cells are lowering the cost of the fuel cell per unit of energy generated. This is the most important step. The second most important step is to develop lower cost reliable and environmentally friendly methods to prepare the biogas for use in the fuel cell.

P(4). What will be the role of the U of M on future fuel cell research?

Research is underway at the U of M to lower the cost of cleaning up the impurities in biogas so that the biogas can be used as a renewable fuel for making hydrogen that can be marketed for use in fuel cells or for other uses. There are researchers approaching the problem of getting fuel cells much smaller and more compliant with small devices such as phones.

P(5). What will be the potential future role of the MDA in fuel cell and hydrogen research involving manure and other biomass sources?

MDA needs to continue to support research that assists farmers to develop alternative income streams from products produced. Fuel cells and hydrogen are promising technologies that may be harnessed to add value to crops and livestock farms. Additional employment opportunities and new business will be generated that will assist the state. MDA needs to continue to foster support for development of renewable energy and new products through incentives, loans and support for legislation, which fosters development and adoption of the new technologies.

P(6). What is the fate of the fuel cell purchased through the LCMR project?

The fuel cell will be used to test digester biogas mixtures that have been treated in various ways to remove impurities. This research will be carried out at the Haubenschild farm for the next 1-2 years. The ability to withstand different levels of impurities will enhance the knowledge of bringing renewable energy to rural communities and enhancing income to the rural communities supported by agriculture.

Q. Project Description: This project will undertake a small-scale pilot project using fuel cell technology and will also evaluate micro-turbines as possible alternatives. The majority of manure digesters designated for electrical generation in the U.S. use internal combustion engine technology to power generators that produce electricity. Alternatives for farmers are needed to increase the use of this technology in Minnesota. Fuel cells are an emerging technology and this project would evaluate future technical feasibility of their use through the operation of a fuel cell in conjunction with a manure digester.

Micro-turbines are coming into the mainstream for alternatives for electrical generation and have potential advantages for reduced maintenance compared to internal combustion engines when fueled with biogas. The advantages are: 1) fewer moving parts and less maintenance 2) reduced NO_x and CO emissions 3) less sensitivity to H_2S corrosion than internal combustion engines. This technology will be researched through the literature, published data, and site visits to operational micro turbines. Total funds to the University of Minnesota for researching both technologies are $202,500.

The Minnesota Project will assist the Minnesota Department of Agriculture and the University of Minnesota in disseminating data and information collected in Result 1. The Minnesota Project will assist with work shops, facilitation, education, stakeholder involvement, and web site development for this project. Total funds to the Minnesota Project are $7,500.

Dennis Haubenschild, a farmer with an operational manure digester, or another farmer with an operational manure digester, will work with this project by hosting the fuel cell on-farm. Mr. Haubenschild will assist in the maintenance and operation of the fuel cell during the duration of the project. Mr. Haubenschild will assist with field days and dissemination of information on the project. Total funds to the Dennis Haubenschild farm are $9,125.

Amendment to Budget Description (September 1, 2004):
Upon the completion of the site preparation for the fuel cell, configuration of the biogas collection system, and portions of the data management systems, the University of Minnesota budget needs to be modified to reflect changes in the anticipated costs. No additional funds are being requested, but changes in the line item budgets are needed to effectively complete the objectives of the project. The cost of the fuel cell and the communications link were slightly less than anticipated. The line item for "Monitoring Equipment and Service Contracts" can also be reduced because of warranties for the fuel cell and other equipment covers these costs. For the cost of site preparation, the University undertook a larger portion of this, because qualified individuals for accomplishing some of the task involved (ex. biogas plumbing) were not available. This resulted in additional costs being applied to the "Personnel" line item, but less costs being applied to the "Site Preparation for Fuel Cell" line item.

Amendment to Budget Description (January 28, 2005)

Upon installation of the fuel cell, initial configuration of the biogas cleaning system, and most of the data management systems, the University of Minnesota budget needs to be modified to reflect changes in costs. No additional funds are being requested, but changes in the line item budgets are needed to effectively complete the objectives of the project.

Capital equipment (instruments/gas cleanup) will be leased instead of being purchased because of the specialized nature of the devices and the short-term use of the devices. This is more cost effective. Thus a short term leasing item is new and some money from capital equipment is reallocated to that item.

Another department at the University of Minnesota is conducting the tests for emissions and this cost needs to be classified differently than anticipated. The cost was planned but is being accounted for with a different category. Money from capital equipment is reallocated to the new laboratory services item.

Maintenance contracts will not be needed since instruments are not purchased. This money is reallocated to travel, which has increased due to inflation and additional trips needed to complete work at the farm.

Personnel developed and installed the gas systems and did more preparation that was originally budgeted in site preparation category. So site preparation funds are being reallocated to personnel. Some funds from capital equipment/monitoring equipment are also being reallocated to personnel and fringe benefits so that the necessary monitoring can be completed to finish the project.

Amendment to Budget Description (May 27, 2005)

The University of Minnesota budget needs to be adjusted to reflect additional supplies and staff time needed to develop an additional biogas clean up system for this project. Also, additional travel was necessary for staff to be up at the Haubenschild farm to collect data and research the fuel cell. Funds for result 2 need to be adjusted to reflect staff time needed to assist with the waste streams report. Printing costs will be minimal for this report and that portion of the budget was reduced.

The MN Project budget needs to adjust their budget in order to accommodate expenses that will be incurred for the June 20, 2005 field day for the project. Funds from salaries will be shifted to printing and travel categories.

Summary Budget Information for Result 1:

LCMR Budget	**$219,125.00**
Amount Spent	**$219.123.78**
Balance	**$ 1.22**

Completion Date:
U of M: Result 1 will be completed entirely by June 30, 2005. The fuel cell will be purchased by July 1, 2004. The fuel cell will be fully installed and data collection will begin by August 30, 2004. Additional data collection will occur in FY 2005 until June 30, 2005.

The Minnesota Project: Result 1 will be completed entirely by June 30, 2005. The Minnesota project will update their website to include the on-going LCMR project by June 30, 2004. By June 30, 2005, the Minnesota Project will conduct a workshop or related educational event to engage stakeholders on the results of this project.

Result 2: Identify Compatible Waste Streams

Final Report Summary for Result 2, June 30, 2005:

The Minnesota Department of Agriculture and the U of M worked cooperatively in developing the report entitled *Opportunities, Constraints, and Research Needs for Co-Digestion of Alternative Waste Streams with Livestock Manure in Minnesota.* This report is attached as Appendix M the to full LCMR report. This report will be used as the baseline for work accomplished in the 2005 LCMR project "Manure Methane Digester Compatible Wastes and Electrical Generation." This area of study is expanding quickly as more manure digesters are being constructed throughout the nation and especially the Midwest. With current energy prices increasing and the need to treat high strength organic wastes to improve water quality, there is a great potential for co-digestion of manure with other waste streams to produce renewable energy.

Project Description: A total of $1,875 has been budgeted for Result 2. This funding will be used for the printing costs of the report. The Minnesota Department of Agriculture and the University of Minnesota will offer in-kind services to develop the report. To increase the flexibility and potential uses for manure digesters, other types of waste streams could be used to supplement the production of biogas from a manure digester. There is a need to determine specifically what types of waste streams are most compatible with a manure digester. The Minnesota Department of Agriculture and the University of Minnesota will conduct a literature review and develop a report on the following: 1) which waste stream combinations are technically feasible to blend with manure including manure not currently practical for digestion, 2) which manure and waste stream combinations produce the highest rate of biogas yield, and 3) which waste stream combinations are economically achievable.

Summary Budget Information for Result 2:

LCMR Budget	**$1,875.00**
Amount Spent	**$1,841.56**
Balance	**$ 33.44**

V. TOTAL LCMR PROJECT BUDGET (AMENDED 05-27-2005)

All Results: Personnel: $96,366
All Results: Equipment: $92,990
All Results: Development: $0
All Results: Acquisition: $0
All Results: Other: $31,644 (site preparation for fuel cell, printing, communications, travel, supplies)

Final LCMR Project Budget	
Total LCMR Budget:	$221,000.00
Total Amount Spent:	$220,965.34
Final Project Balance:	$34.66

All funds will be through professional/technical contracts from the Minnesota Department of Agriculture to the University of Minnesota, The Minnesota Project, and Dennis Haubenschild. After completion of the first report to LCMR on December 31, 2003, MDA will work on clarifying the reporting requirements by LCMR on in-kind services for this project at a future date.

TOTAL LCMR PROJECT BUDGET: $ 221,000

Explanation of Capital Expenditures Greater Than $3,500: Purchasing a fuel cell for the research project will be largest capital expense. The cost will be approximately $80,000 for the fuel cell, maintenance agreements with the manufacture, and equipment associated with connecting the fuel cell to the manure digester and the electrical grid. The maintenance agreement between the manufacture will cover maintenance of the fuel cell and components, replacement of defective parts, calibration of the fuel cell, and technical trouble shooting of problems associated with the general operation of the fuel cell. This maintenance agreement differs with the funding being granted Dennis Haubenschild (or other farmer with an operational manure digester) who will be performing daily general maintenance and upkeep needed to ensure the continuous operation of the fuel cell in the on-farm setting. The fuel cell and associated components will be under the control of the University of Minnesota. The fuel cell will be located temporarily on a Minnesota farmer's property, which is the site of an existing manure digester for data collection. After adequate data has been collected at the on-farm site, the fuel cell will be permanently stationed at the University of Minnesota. The University of Minnesota is planning on constructing a digester on the St. Paul campus on the near future and the tentative plans are to incorporate the fuel cell into that future project. The fuel cell and it's associated components will be used in the same manner as in the LCMR project throughout the equipments useful life at the University of Minnesota and if the use changes a commitment to pay back the to the Environment and Natural Resources Trust Fund an amount equal to either the cash value received or the residual value approved by the director of the LCMR if it is not sold.

Additionally, monitoring equipment ($11,677) will be leased (amended 05-27-2005) to conduct analysis of the biogas and collect data related to the project.

VI. PAST, PRESENT AND FUTURE SPENDING:

A. Past Spending: 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. The University of Minnesota was involved with early digestion work in the 1970's and received funding for their research. The Agricultural Research Utilization Institute (AURI) has developed a feasibility study for manure digesters for livestock operations.

B. Current Spending:
Additional spending on this project may occur if pending funding sources for renewable energy sources are appropriated to the University of Minnesota. Also, all entities involved with pursue other sources of funding to enhance and complement this project.

C. Required Match (if applicable): Does not apply.

D. Future Spending: Fuel cell and manure digester research will continue to be pursued for decades to come. Fuel cells, which are in their infancy, will necessitate further research in applying this technology in a cost effective and reliable manner. It is anticipated that the University of Minnesota will continue to research both of these technologies, which will necessitate further funding.

VII. Project Partners:
A. Partners Receiving LCMR Funds (for more detailed information, see Attachment A):
Funds from this project will be directed from the Minnesota Department of Agriculture to the University of Minnesota, The Minnesota Project, and a farmer working with an operational digester.

University of Minnesota Biosystems and Agricultural Engineering Department: $204,375

The Minnesota Project: $7,500

Dennis Haubenschild (MN farmer with an operational manure digester) or other farmer(s) with operation manure digesters: $9,125

B. Project Cooperators:

- Dennis Haubenschild (MN farmer with an operational manure digester) or other farmer(s) with operation manure digesters
- University of Minnesota Biosystems and Agricultural Engineering Department
- Minnesota Project
- Minnesota Department of Commerce
- U.S. EPA AgSTAR Program
- Agricultural Utilization Research Institute
- Various Livestock Organizations: Minnesota Milk Producer's Associations, Minnesota Cattleman's Association, Minnesota Pork Producer's Association, and the Minnesota Turkey Growers Association.

VIII. DISSEMINATION: Information will be disseminated through publications, literature reviews, tours, press releases, and web site development. The Minnesota Project and the University of Minnesota will help coordinate this effort and will conduct meetings and/or workshops to get the results of this project to the appropriate audiences. The Minnesota Department of Agriculture will develop a manure digester web page (www.mda.state.mn.us) to make information from this project readily available, while also providing links to other research and development efforts that are being undertaken nationally and internationally.

IX. LOCATION: Work will take place at the U of M St. Paul Campus in St. Paul, MN (Ramsey County). Research may be conducted also at the Southern Research and Outreach Center in Waseca, MN (Waseca County). Also, work may take place on a dairy farm that has an operational manure digester near Princeton, MN or another Dairy farm in Minnesota that has an operational manure digester.

X. REPORTING REQUIREMENTS:
Periodic work program progress reports will be submitted not later than December 31, 2003, June 30, 2004, and December 31, 2004. A final work program report and associated products will be submitted by June 30, 2005.

XI. RESEARCH PROJECTS: Does not apply.

Appendix A: Final Budget

Attachment A: Budget Detail for 2003 Projects - All Subcontractors (Professional/Technical Contract and Service Contracts)

Proposal Title: *10(b) Advancing Utilization of Manure Methane Digester Electrical Generation*

Project Manager Name: *Paul Burns*

2003 LCMR Proposal Budget	Result 1: Budget	Result 1: Funds Spent	Result 1 Balance: June 30, 2005	Result 2: Budget	Result 2: Funds Spent	Result 2 Balance: June 30, 2005	Final Budget Balance for Project: June30, 2005	Total Budget for Project
BUDGET ITEM								
PERSONNEL:	$ 85,256.00	$ 85,254.65	$ 1.35	$ 1,594.00	$ 1,594.00	$ -	$ 1.35	$ 86,850.00
PERSONNEL: Staff benefits – @31.8%	$ 9,318.00	$ 9,317.96	$ 0.04	$ 198.00	$ 197.64	$ 0.36	$ 0.40	$ 9,516.00
Contracts								
Professional/technical: University of Minnesota Biosystems and Agricultural Engineering Department (see additional								
Professional/technical: Livestock Producer(see additional								
Professional/technical: The Minnesota Project(see additional budget pages								
Space rental: NOT ALLOWED								
Other direct operating costs								
Equipment / Tools: Fuel Cell and Related Components (5KW Fuel Cell, Associated Equipment, and Service and Maintenance Contract)	$ 79,787.00	$ 79,786.95	$ 0.05				$ 0.05	$ 79,787.00
Office equipment & computers for data acquisition system	$ 1,536.00	$ 1,535.89	$ 0.11				$ 0.11	$ 1,536.00
Capital equipment: Monitoring Equipment (Data Acquisition and On Line Gas Analysis)	$ 11,667.00	$ 11,666.38	$ 0.62				$ 0.62	$ 11,667.00
Montitoring Equipment Maintenance and Service Contracts			$ -				$ -	$ -
Land acquisition								
Land rights acquisition								
Printing and Publications	$ 1,179.00	$ 1,179.46	$ (0.46)	$ 83.00	$ 49.92	$ 33.08	$ 32.62	$ 1,262.00
Advertising								
Communications, telephone, mail, Web Link for data acquisition	$ 2,277.00	$ 2,277.28	$ (0.28)				$ (0.28)	$ 2,277.00
Office Supplies	$ 200.00	$ 200.00	$ -				$ -	$ 200.00
Site Preparation for Fuel Cell			$ -				$ -	$ -
Supplies	$ 11,511.00	$ 11,511.21	$ (0.21)				$ (0.21)	$ 11,511.00
Travel expenses in Minnesota	$ 8,322.00	$ 8,322.00	$ -				$ -	$ 8,322.00
Travel outside Minnesota Training for fuel cell operation at factory	$ 1,500.00	$ 1,500.00	$ -				$ -	$ 1,500.00
Construction								
Other land improvement								
Short Term Leasing of Equipment (Amended 01-28-05)	$ 1,696.00	$ 1,696.00	$ -				$ -	$ 1,696.00
Laboratory Services (Amended 01-28-05) Other	$ 4,876.00	$ 4,876.00	$ -				$ -	$ 4,876.00
COLUMN TOTAL	$ 219,125.00	$ 219,123.78	$ 1.22	$ 1,875.00	$ 1,841.56	$ 33.44	$ 34.66	$ 221,000.00

Attachment A: Budget Detail for 2003 Projects - University of Minnesota (Professional/Technical Contract)

Proposal Title: *10(b) Advancing Utilization of Manure Methane Digester Electrical Generation*

Project Manager Name: *Paul Burns*

Total LCMR Requested Dollars: $ *221,000*
U of M Request:
$204,375

2003 LCMR Proposal Budget	Result 1: Budget	Result 1: Funds Spent	Result 1 Balance: June 30, 2005	Result 2: Budget	Result 2: Funds Spent	Result 2 Balance: June 30, 2005	Budget Balance: June 30, 2005
BUDGET ITEM							
PERSONNEL:Two (2) temporary engineering staff hired by the U of M to work on the project who are supervised by Project Investigator, Dr. Philip Goodrich, U of M Dept. of Biosytems and Agricultural Engineering	$ 70,881.00	$ 70,880.87	$ 0.13	$ 1,594.00	$ 1,594.00	$ -	$ 0.13
PERSONNEL: Staff benefits – @31.8%	$ 9,318.00	$ 9,317.96	$ 0.04	$ 198.00	$ 197.64	$ 0.36	$ 0.40
Contracts							
Space rental: NOT ALLOWED							
Other direct operating costs							
Equipment / Tools: Fuel Cell and Related Components (5KW Fuel Cell, Associated Equipment, and Service and Maintenance Contract)	$ 79,787.00	$ 79,786.95	$ 0.05				$ 0.05
Office equipment & computers for data acquisition system	$ 1,536.00	$ 1,535.89	$ 0.11				$ 0.11
Capital equipment: Monitoring Equipment (Data Acquisition and On Line Gas Analysis)	$ 11,667.00	$ 11,666.38	$ 0.62				$ 0.62
Montitoring Equipment Maintenance and Service Contracts	$ -	$ -	$ -		$ -	$ -	$ -
Land acquisition							
Land rights acquisition							
Printing and Publications	$ 179.00	$ 179.46	$ (0.46)	$ 83.00	$ 49.92	$ 33.08	$ 32.62
Advertising							
Communications, telephone, mail, Web Link for data acquisition	$ 1,527.00	$ 1,527.28	$ (0.28)				$ (0.28)
Office Supplies							
Site Preparation for Fuel Cell		$ -	$ -				$ -
Supplies	$ 11,511.00	$ 11,511.21	$ (0.21)				$ (0.21)
Travel expenses in Minnesota	$ 8,022.00	$ 8,022.00	$ -				$ -
Travel outside Minnesota Training for fuel cell operation at factory	$ 1,500.00	$ 1,500.00	$ -				$ -
Construction							
Other land improvement							
Short Term Leasing of Equipment (Amended 01-28-05)	$ 1,696.00	$ 1,696.00	$ -				$ -
Laboratory Services (Amended 01-28-05)	$ 4,876.00	$ 4,876.00	$ -				$ -
Other							
COLUMN TOTAL	$ 202,500.00	$ 202,500.00	$ (0.00)	$ 1,875.00	$ 1,841.56	$ 33.44	$ 33.44

Attachment A: Budget Detail for 2003 Projects - The Minnesota Project (Professional/Technical

Proposal Title: *10(b) Advancing Utilization of Manure Methane Digester Electrical Generation*

Project Manager Name: *Paul Burns*

Total LCMR Requested Dollars: $ *221,000*
Minnesota Project Request: $7,500

2003 LCMR Proposal Budget	Result 1 Budget: Evaluating the Feasibility of Fuel Cell/Microturbine Technology	Result 1: Budget	Result 1: Funds Spent	Total Project Balance (Result 1): June 30, 2005
BUDGET ITEM				
PERSONNEL: Project Investigator Ms. Amanda Bilek, The Minnesota Project	~~$ 6,100.00~~	$ 5,250.00	$ 5,248.78	$ 1.22
PERSONNEL: Staff benefits –				
Contracts				
Professional/technical: University of Minnesota Biosystems and Agricultural Engineering Department				
Professional/technical: Livestock Producer				
Professional/technical: The Minnesota Project				
Space rental: NOT ALLOWED	X			
Other direct operating costs				
Equipment / Tools:				
Office equipment & computers				
Other Capital equipment				
Land acquisition				
Land rights acquisition				
Printing	~~$ 250.00~~	$ 1,000.00	$ 1,000.00	$ -
Advertising				
Communications, telephone, mail, etc. (Web Development)	~~$ 375.00~~	$ 375.00	$ 375.00	$ -
Communications, telephone, mail, etc. (Telephone)	~~$ 375.00~~	$ 375.00	$ 375.00	$ -
Office Supplies	~~$ 200.00~~	$ 200.00	$ 200.00	$ -
Other Supplies				
Travel expenses in Minnesota	~~$ 200.00~~	$ 300.00	$ 300.00	$ -
Travel outside Minnesota				
Construction				
Other land improvement				
Other				
COLUMN TOTAL	~~$ 7,500.00~~	$ 7,500.00	$ 7,498.78	$ 1.22

Attachment A: Budget Detail for 2003 Projects - Dennis Haubenschild/Farmer (S

Proposal Title: *10(b) Advancing Utilization of Manure Methane Digester Electrical Generation*

Project Manager Name: *Paul Burns*

LCMR Requested Dollars: $ ***221,000***
Dennis Haubenschild/Farmer
Request: $9,125

2003 LCMR Proposal Budget	Result 1 Budget: Evaluating the Feasibility of Fuel Cell/Microturbine Technology	Result 1: Funds Spent	Result 1 Balance: June 30, 2005
BUDGET ITEM			
PERSONNEL: Staff Expenses, wages, salaries – Dennis Haubenschild or other farmer for operation and maintence of on-farm fuel cell co-located with a manure digester. Time will .5 hr/day maintence for 1 year (365 days) at $50/hr	$ 9,125.00	$ 9,125.00	$ -
PERSONNEL: Staff benefits –			
Contracts			
Space rental: NOT ALLOWED	X		
Other direct operating costs			
Equipment / Tools			
Office equipment & computers			
Other Capital equipment			
Land acquisition			
Land rights acquisition			
Printing			
Advertising			
Communications, telephone, mail, etc.			
Office Supplies			
Other Supplies			
Travel expenses in Minnesota			
Travel outside Minnesota			
Construction			
Other land improvement			
Other			
COLUMN TOTAL	$ 9,125.00	$ 9,125.00	$ -

Appendix B: U of M Final Report to MDA

University of Minnesota
Department of Biosystems and Agricultural Engineering
Advancing Utilization of Manure Methane Digester Electrical Generation
Final Report
August 1, 2005
For
Minnesota Department of Agriculture
Legislative Commission on Minnesota Resources

1.0 Introduction and Background

Paul Burns, Minnesota Department of Agriculture (MDA), formulated the concept for the project *Advancing Utilization of Manure Methane Digester Electrical Generation*, which was realized through funding by the Legislative Commission on Minnesota Resources. Input from Philip Goodrich, R. Vance Morey, David Schmidt, Dennis Haubenschild, John Lamb and Matt Drewitz assisted in the development of the work plan and revisions of the proposal.

The University of Minnesota was subcontracted by the MDA for $202,500 to provide professional/technical services to accomplish the goals and objectives of the project. The primary goal of the subcontract to the University of Minnesota Department of Biosystems and Agricultural Engineering was to evaluate alternative technologies for producing electricity from biogas that are more environmentally friendly and easier to maintain than conventional internal combustion engines. Because of funding limitations, only one technology, the fuel cell, could be studied. This project resulted in the first ever fuel cell run on biogas from anaerobic digestion of livestock manure.
Microturbine technology is also emerging, but was not researched specifically for the LCMR project. An update of the state of this technology being used with anaerobic digestion is summarized in this report. The Sterling engine also is a prospective alternative generation technology and there was a proposal by the Electric Power Research Institute (EPRI) to research and demonstrate this technology on the Haubenschild farm research site. However that project was not undertaken for various reasons. Steam turbines and steam engines are another option, but they are not efficient enough for the size needed for on-farm anaerobic manure digesters.

2.0 Process Development to Reach Project Goals

Introducing a fuel cell into an existing dairy farm with an anaerobic manure digester involved a great deal of planning and preparation. This report details the steps taken to meet the objectives of the project. Because of the unique and innovative nature of this project, changes in the process or protocols were changed as needed and documented by U of M research staff.

2.1 Fuel Cell Technology Research and Fuel Cell Purchase

Information about fuel cells and application of the technology to digesters was gathered from the literature and from industry sources. The pros and cons of different types of fuel cells were determined and a matrix was established to assist in choosing a fuel cell that would be best for application to biogas produced by anaerobic digestion of manure. Contacts with companies in the fuel cell industry were made to determine the possibilities for obtaining a fuel cell(s) for the project. Specifications for purchase of a fuel cell were created and all equipment purchasing protocols requirements of the University of MN were followed. A request for proposal (RFP) was developed and bids were requested from companies that were developing and selling fuel cells. The availability of production type fuel cells was very limited.

Upon the deadline for bid submittal, only one company had bid on the request. An evaluation was made to determine if a second RFP would yield more proposals. Ultimately, it was decided to accept the bid that was submitted and that opening up a second RFP would not be effective. The U of M purchased a fuel cell from Plug Power Inc of Latham, NY because the product met the specifications needed for the project and the company had a proven track record of producing and installing a reasonable number of fuel cells on natural gas. A history of legitimate installations was lacking in most other companies found in our background research. The company also had a significant user training program and a local representative with trained personnel and expertise.

2.2 Research Site Development and Infrastructure

Research space was another item that was addressed. John Deere Inc. donated funds to construct a small building on the site to provide shelter and space for the fuel cell, data equipment and for the experimental apparatus. This was designed and constructed by a contractor early in the project timeline. This donation contributed immensely to the project because no funds from LCMR were designated for the purchase of land or buildings. This project resulted in several private-public partnerships like this one, which were instrumental in the success of the project.

Extensive plumbing to get the gas from the digester to the research facility was necessary and U of M staff developed the piping design and layout. The piping system was connected to the existing biogas feed line that was routed from the digester to the existing main engine room. Data acquisition lines were installed at critical locations in the digester and in the engine room to assist in data collection.

The data acquisition system was purchased, installed, and sensors were wired at critical junctures. A computer was installed at the research site and was loaded with numerous software programs needed to collect and analyze monitoring data. Software developed to control the National Instruments FieldPoint™ system was one of the primary programs installed on the computer. A wireless broadband connection service was purchased and installed to provide remote access to the computer from the U of M St. Paul Campus offices. The computer can be accessed from anywhere over the Internet using a program called PC-anywhere™.

The purchased fuel cell was delivered September 18, 2004, installed in the fall of 2004, commissioned on natural gas on January 27, 2005, and finally commissioned on biogas on February 25, 2005.

2.3 Biogas Clean Up System Development

The biogas contains contaminants that must be removed prior to using the gas in the fuel cell. This necessitated developing equipment to remove the contaminants to a level consistent with proper operational characteristics of the fuel cell. Research identified several methods for removing hydrogen sulfide from the gas stream. Removing the carbon dioxide from the biogas stream was a significant problem. Use of environmentally challenging chemicals on the farm was not a choice. The means to use simple chemicals was difficult too. We tried several systems with wet and dry chemicals with limited success because vessels leaked gas and the chemicals did not absorb sufficient carbon dioxide from the gas stream.

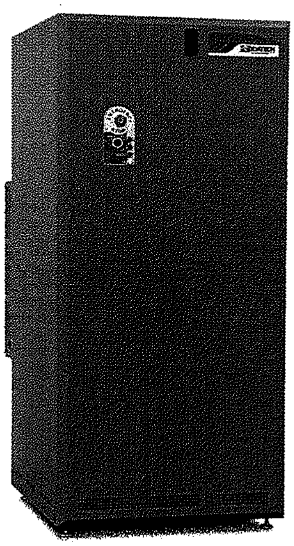
We then leased a pressure swing absorber and tested the capabilities of this unit to separate out the carbon dioxide. Under our conditions, the pressure swing absorber did not function well. The level of wasted gas was high and venting the wasted methane gas to the atmosphere was not correct in the context of protecting the environment. The venting methane gas was also a safety hazard.

A water scrubbing tower was constructed to remove contaminates from the biogas. Methane is very insoluble in water, but carbon dioxide is quite soluble in water at elevated pressures. Hydrogen sulfide is also mildly soluble in water. Therefore both contaminates could be removed at the same time. With a control system, this system was satisfactory to clean up the biogas for the fuel cell.

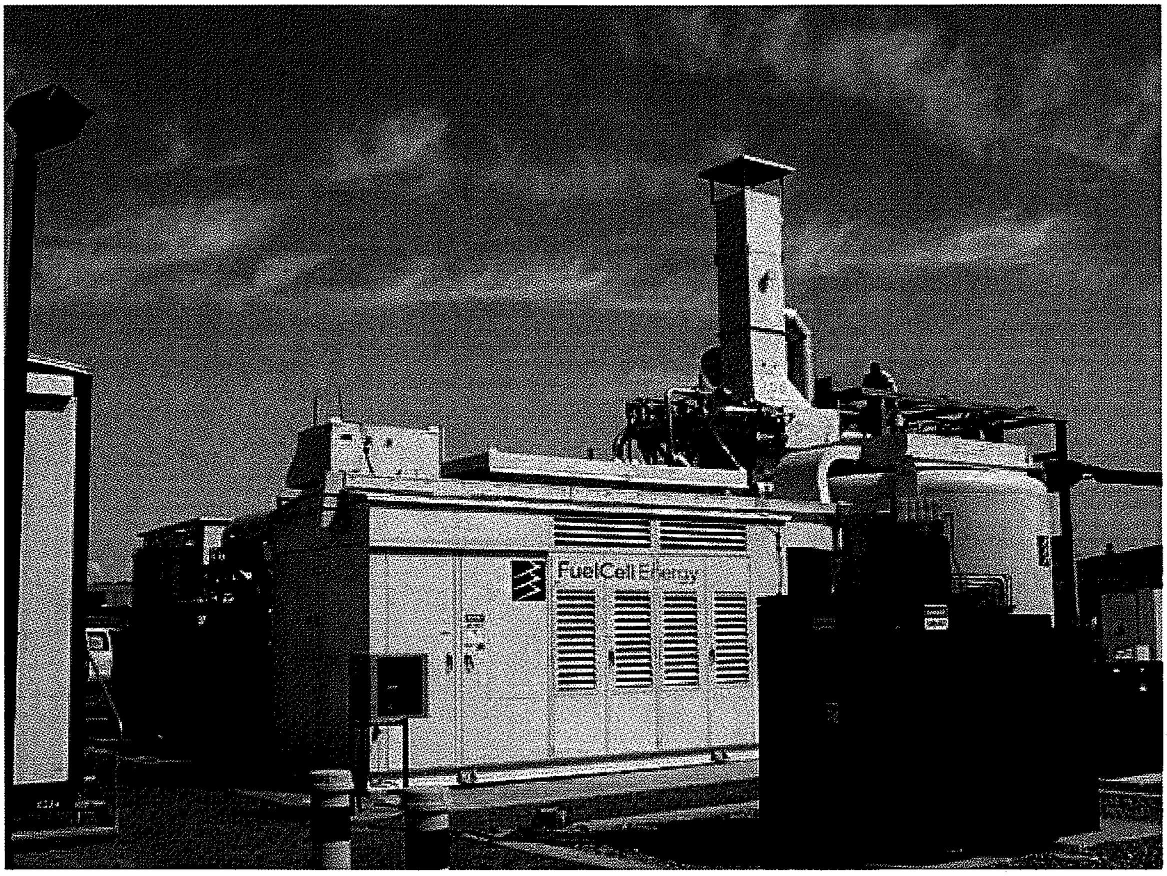
3.0 Fuel Cell System Overview

3.1 Fuel Cell Project Choices Review: This project researched the fuel cell technologies that were commercially available. An original product that was considered was a solid oxide fuel cell (SOFC) from Acumentrics Corp. The estimated cost and availability of this product were the determining factors to not purchase it for this biogas clean up project.

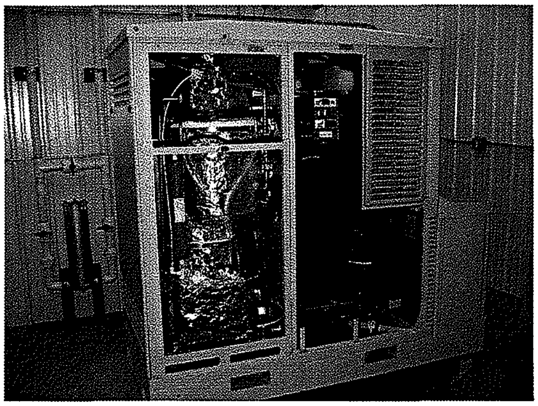
Solid Oxide Fuel Cell, Acumentrics Inc. Westwood Massachusetts

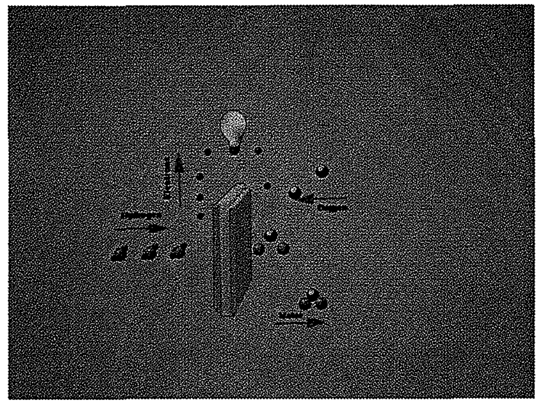


Proton Exchange Membrane (PEM) Fuel Cell, IdaTech, Bend, Oregon



Molten Carbonate Fuel Cell, 1 megawatt, Fuel Cell Energy Inc. Danbury CN





3.2 Plug Power Product Description:

A GenSys™ 5kW proton exchange membrane (PEM) fuel cell from Plug Power of New York was the available commercial product chosen. It is designed for using pipeline natural gas to strip hydrogen from methane (CH_4) through a high temperature catalyst process reformer. The GenSys™ 5 kW fuel cell consumes hydrogen and oxygen to produce electricity and heat. The major components of this combined heat and power system consist of a proton exchange membrane (PEM) fuel cell stack, a fuel processing module (reformer), a 24 volts direct current to 120 volts alternating current inverter, a 2.5 kW battery bank, heat exchangers, a water purification process, and control center. It weighs 2700 pounds. A complete package ready to be installed outside makes this a very useful system for an installation on a farm or at a residence.

The complex software package analysis will start up, monitor the operation, and if necessary shut down the GenSys™ unit. The software outputs include vivid graphic system operation displays and database files that convert to spreadsheets. To understand the level of engineering contained in the GenSys™ Fuel Cell System, note that the Operation Manual is 418 pages in length.

The unit purchased can provide up to 5 kW of continuous load, up to 7.5 kW of peak load with the battery storage energy, and 30,000 Btu's of heat per hour. It is installed in parallel with the electric utility grid and has the capability to provide designated standby loads if the grid goes down.

3.3 Fuel Gas Requirements:

No changes were made to the manufacture delivered reformer, fuel cell, and control hardware or software. This decision established our goal to clean up the biogas to approximately natural gas pipeline quality gas. We needed to increase the methane (CH_4) concentration to 85% (by volume) or better. In addition the carbon dioxide (CO_2) concentration needed reduction to 2%. The high concentration of H_2S of 3500 ppmv in the raw gas greatly affects the life and maintenance of the desulphurization bed filter and reformer. Total sulfur needs to be less than 30 ppmv prior to the fuel cell unit and H_2S needs to be less than 6 ppmv.

3.4 Fuel Gas Supply System:

The compressed natural gas was supplied by Center Point Energy. They made available to us a 3000 PSI portable tank which was sufficient to start up the fuel cell at least three times. We were able to refill the tanks through their fleet and car service station in Minneapolis.

The raw biogas came into the building underground from the main gas line for the Caterpillar genset Building. The incoming 4" line is sufficient to supply several pieces of biogas using equipment. Gas piping for up to four pieces of equipment was installed. A raw gas sampling port for the Bacharach Gas Monitoring system was installed on the main inlet gas line. From there the gas went through the Roots gas meter, a gas compressor, branched for available use by future raw gas processing (i.e. boiler, sterling engine, branched for gas clean up process equipment and then to clean gas uses.

3.5 Operation of the Fuel Cell:

The expected operation of the fuel cell was to start the fuel cell on purchased compressed natural gas. This gas was obtained from Center Point Energy in a small high-pressure tank mounted on a small hand pulled trailer. Once the biogas clean up process was operational and fuel cell stabilized running at 2.5 kW generation output, we would bleed in biogas and shut off the compressed natural gas. We ran the system until the biogas clean up process became ineffective and/or the fuel cell would shut down.

Upon final installation of the fuel cell, it was fired up on compressed natural gas and run for several hours to obtain base line data of the fuel cell fueled by natural gas.

To evaluate our gas preparation system, we cleaned up the biogas using experimental apparatus, and then passed the biogas was through a gas fired garage heater modified to operate at the flow rate in cubic feet and Btu output as the fuel cell. The clean gas content was monitored by the Gemini Biogas system prior to the garage heater and/or fuel cell.

4.0 Project Data Acquisition Systems (DAS)

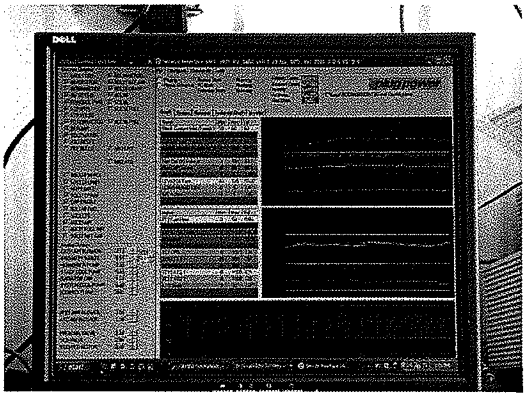
4.1 Data Acquisition System Choices Review:

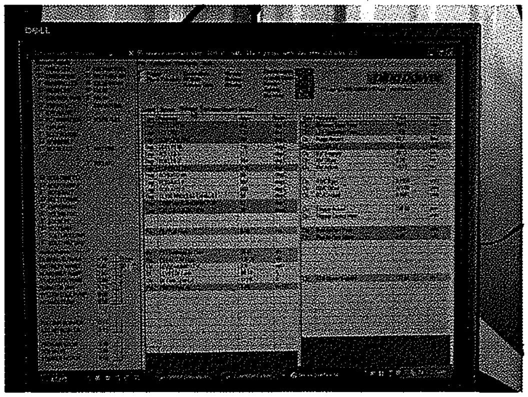
Several research level data acquisition equipment components were identified and priced. This equipment was accurate, expensive, and recalibration requirements were significant. The fuel cell has its own software for its many sensors and operation. A biogas monitoring system from Bacharach of the U.K. was just setting up a distributorship in the U.S and one was ordered for this project. A general data acquisition instrument was also purchased to monitor a multitude of temperature sensors, gas meters, and a humidity sensor installed for the digester and gas pipelines. The general data acquisition system (DAS) from National Instruments has many additional inputs and outputs available for future research projects. The biogas monitoring system will also be applicable for future projects of the University involving methane gas production.

4.2 Plug Power Data Acquisition System:

The Plug Power data acquisition system is of significant size and has plenty of graphics to see approximately twenty-four 10-minute trends. The training course for the Plug Power 5 kW GenSeys™ was a one-week intensive program. The fuel cell with reformer is a complex device and one does need the opportunity to start, operate, and shut down the system several times to understand the water, gas, and electricity flows and phases. Including the multitude of relay switches, motor, pumps, there are lots of temperature sensors combining with the software and its algorithms to determine what state to be in. Startup, humidifier fill, auto thermal oxidizer (ATO) heat up, warm up, running the fuel cells are just a few of the operational states.

The data acquisition system collects over 280 data points and records on a one second, one minute, and five-minute period depending on what state and mode it is in. An example is when a shut down event occurs; the one-second data for five minutes around the event is very useful for diagnostics. Studying the one-minute data gave us ample information to see differences in the early testing biogas cleanup attempts. Learning which data and graphic trends were sensitive to the switch from compressed natural gas to biogas offered hints on if the fuel cell would be able to operate and proceed to the next state

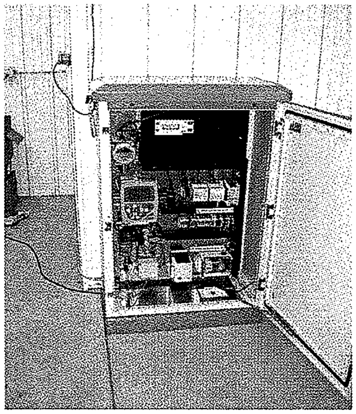




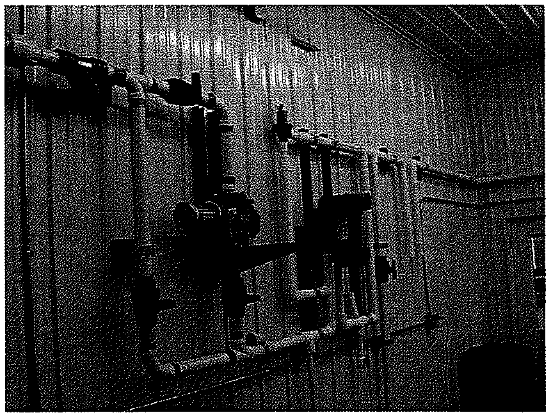
Views of fuel cell processes that may be displayed on the computer monitor.

4.3 Bacharach™ Biogas Monitoring System:

The Bacharach™ Biogas Monitoring System is a single port unit but testing was completed on the raw gases and clean gas by manually switching the tubing from each sample location. The gas data collected included CH_4, CO_2, and H_2S. This instrument also measured gas temperature and pressure data. Sample values were only available for data averaged over a ten-minute period however. This data was downloaded to the computer as generated.



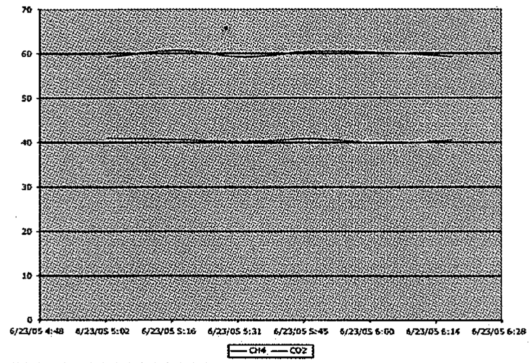
The Bacharach™ Gemini™ gas-measuring instrument



A view of the gas volume meter on the left and the gas blower on the right

The raw biogas coming from the methane digester is primarily 58-60 percent methane and 37-39 percent carbon dioxide. The other gases fluctuating to six percent is water vapor and hydrogen sulfide. Leaks of this raw biogas are quickly evident. The nose responds faster than the general area safety instruments. The biogas pressure came in to the building at 1-3 inch water column pressure. A gas compressor was installed to assure 2 PSI of pipeline pressure to the fuel cell and garage heater.

A garage heater was installed in the building to burn the raw gas for space heating. The heater was operated also for testing the clean up gas to observe how long the clean up processes were effective. The burner orifices were enlarged and an additional hot wire igniter was installed to assure thermostat-controlled start-ups on raw gas.



Computer screen showing the values of methane and carbon dioxide in the gas stream.

C:\Program Files\Fps_COM\FPS_Data_Log_23-06-05.

		CH4	CO2
		%	%
Time/Date	SP	Channel 1	Channel 2
6/23/05 5:03	1	59.3	41
6/23/05 5:18	1	60.8	40.7
6/23/05 5:33	1	59.3	40.2
6/23/05 5:48	1	60.5	40.9
6/23/05 6:03	1	60.2	39.9
6/23/05 6:18	1	59.2	40.5
[illegible]	[illegible]	[illegible]	[illegible]

Computer screen showing the methane and carbon dioxide concentrations that was measured using the Bacharach™ unit.

4.4 National Instruments (NI) Product Description:

Temperature Recording sensors were installed to primarily note what the temperature on a season bases of the manure flow, biogases, and general environment conditions. The NI equipment has enough capacity to monitor the Caterpillar™ genset functions and one additional electrical producing unit or gas process unit. Recording of electrical energy inputs and outputs can eventually be added

The gas meters were industrial grade units that gave a pulse electrical output to record through the NI data acquisition equipment. Three gas meters can be recorded indicating the fuel cell building gas usage, the Caterpillar™ genset building gas usage, and the excess gas going to the flare.

4.5 Dew Point Meter Recording:

A dew point meter was purchased and installed to measure the gas dew point after cleanup and prior to introduction of gas into the fuel cell.

4.6 Safety Monitoring Plan:

The University of Minnesota Environment Group gave us advice in developing an area safety monitoring plan, some air monitoring equipment, and recommendations for equipment to purchase and assure the project staffs safety. Working in the gas piping room attached to the digester was where extreme caution was required. The fuel cell building had the ability to ventilate the spaces quickly. During the operation of the fuel cell and/or garage heater the large garage door and back door and ceiling hatch provided good heat removal and ventilation air.

4.7 Remote Site Access:

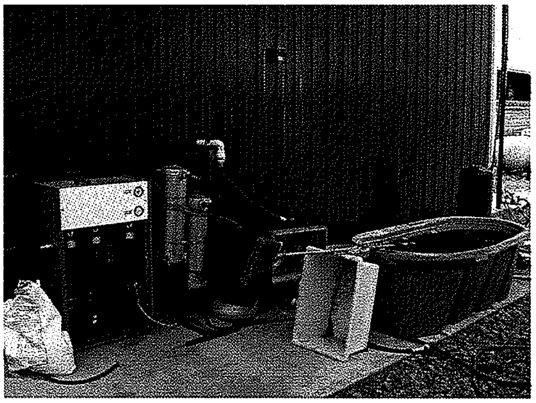
Remote site access to data acquisition system was at the University of Minnesota, St. Paul Campus to a few staff in the Biosystems and Agriculture Engineering Building. This was a very valuable resource to give others ability to solve technical problems in the fuel cell, data acquisition system, and gas clean up process. Cell phones didn't always work at the farm and a computer phone system became the dominant voice communication mode.

4.8 Deficiencies of the Fuel Cell Monitoring System:

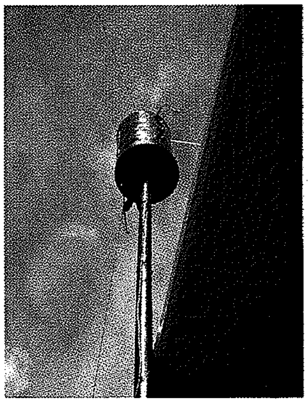
The University of Minnesota was not able to monitor some functions of the fuel cell system. Additional sensors would have been useful. Access to and the ability to adjust (tweak) the control software would have been useful so that various conditions including lower methane concentrations would have been beneficial. Hydrogen sensors would have been useful.

5.0 Biogas Cleanup System:

The clean biogas piping section was modified multiple times to accommodate the different gas cleanup systems. This project used multiple setups to test biogas clean up concepts. Separate and combined testing processes resulted with getting the CH_4 concentration up to the mid 80's percent. The lowest CO_2 concentration was 8 percent. H_2S was reduced under 30 ppmv.



Picture shows the pressure swing absorber on the left, two tanks used for hydrogen sulfide cleanup, the compressor and the water supply tank.



The constructed water column consisted of a 2-inch mild steel pipe approximately 20 foot long. To the top of the pipe was affixed a 2.5 ft diameter water tank.

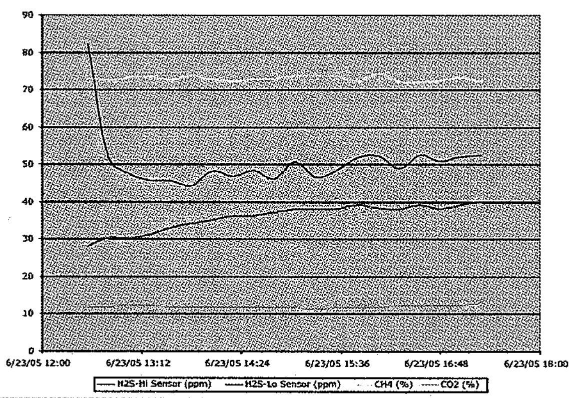
The best-purified biogas was produced using continuous water down flow through a tower at 80 PSI. The gas flowed into the bottom and out the top and then flowed through tubing in an ice bath, finally flowing through a moist wood shavings/iron filing mixture. A 0.5 hp water pressure pump was coupled to a 30-gallon water tank. A 5-hp electric motor ran the gas compressor. The total wattage consumed by the two parasitic loads was not measured, however if both motors were consuming the design horsepower, the expected kilowatts to be consumed would be 4 kW and the fuel cell would only be generating 2.5 kW. This is a negative energy situation, however no optimization was attempted and efficiency will be addressed in future studies.

The biogas had small changes in quality when the water pH or water temperature or water flows changed for the water tower. The biogas was bubbled up the tower while the water flowed down the tower. The best performance was using clean, cold well water with a pH of 7.6 and dumping it versus recycling and then trying to control the pH with lime powder. The temperature in this water recycling system kept rising and pH continually dropped to less than 6 and gas quality would fall in under 3 hours. Introducing fresh cold water became necessary to lengthen effectiveness time. Flowing water through the column and wasting it was the only way to maintain good concentration of CH_4 and low CO_2 for continuous operation. Pumping power at the water well and pressure tanks becomes an added negative energy load to this clean up design.

The ice bath reduced the water vapor in the gas by collecting droplets in the piping within the ice bath system. Collection of water was into a canister. A small refrigeration unit or a deliquescent would eventually replace the use of ice for continuous operation.

The small canister with the wood/iron materials is effective for approximately 3-4 hours. Larger canisters plumbed in combination of parallel and series piping should reduce the H_2S to 20 ppmv or less, lengthen the effectiveness time, and improve the ability of a continuous running system.

The fuel cell also has an internal desulphurization bed filter. The desulphurization bed absorbs mercaptans (sulfur compounds). Its effectiveness is an estimated 6 months based on the 15-ppmv put in to natural gas as an odorant for safety reasons. This project did spend the desulphurization bed filter and install a replacement after 24 hours. The biogas clean up was only able to bring the H_2S to 100-300 ppmv range during most of the test runs. An additional load of the desulphurization bed filter was with the fuel cell running on compressed natural gas, which is approximately another 60 hours.



Gas cleanup results using the water tower

		CH4	CO2	H2S-Hi	H2S-LO
		%	%	ppm	ppm
Time/Date	SP	Channel 1	Channel 2	Channel 1(	Channel 11
6/23/05 12:33	1	73.1	11.8	82.4	27.9
6/23/05 12:48	1	72.5	11.6	52.4	30.2
6/23/05 13:03	1	73.2	12.3	47.5	30.2
6/23/05 13:18	1	73.4	12.2	45.6	31.3
6/23/05 13:33	1	72.6	12	45.7	33.1
6/23/05 13:48	1	73.6	12	44.2	34.3
6/23/05 14:03	1	72.8	11.7	48.2	35.2
6/23/05 14:18	1	72.4	11.9	46.8	36.3
6/23/05 14:33	1	73	11.8	48.4	36.3
6/23/05 14:48	1	72.9	11.8	46.1	37.2
6/23/05 15:03	1	73.7	11.7	50.8	38.2
6/23/05 15:18	1	73.7	11.4	46.7	38.2
6/23/05 15:33	1	73.6	11.7	48.4	38.2
6/23/05 15:48	1	72.4	11.7	51.9	39.2
6/23/05 16:03	1	74.3	12	52.4	38.3
6/23/05 16:18	1	72.4	12.1	48.9	38.2
6/23/05 16:33	1	72.2	12.2	52.6	39.3
6/23/05 16:48	1	72.5	12.4	51	38.2
6/23/05 17:03	1	73.2	12.5	52.1	39.2
6/23/05 17:18	1	72.4	13	52.5	40.2

5.1 Final Water Tower System:

The water tower clean up process consisted of a water pressure regulator, a gas pressure regulator, and a 30 foot 2 inch steel pipe with an expansion tank on top. This process operated at 80 PSI with a counter flow of the gas and water. Cold well water was introduced at the top, biogas at the bottom. The well water was at 55 degree F. and a pH of 7.4 to 7.6. This process also reduced the H_2S to the 300 to 500 ppmv.

The biogas bubbles would interact with the cold water allowing carbon dioxide to absorb into the water under pressure. The CO_2 was released to the atmosphere with the wastewater at atmospheric pressure in the stock tank. The wastewater would warm up to 60 degree F and the pH would drop to 5.4 to 5.6.

Two containers of metal filings/wood shavings clean up process were installed in the piping after the water tower. The biogas would flow through a 50/50 mix by volume of clean, oil free metal filings and wood shavings installed in each canister. A cup of water was added to moisten the wood shavings for improved reaction. This system was used to reduce the sulfur compounds in the biogas. This mixture would start losing its effectiveness after 3 hours. This mixture can be rejuvenated after exposing to air, but was not completed in this project.

The H_2S was reduced from 300-500 ppmv after the water tower to the 25-to 50-ppmv ranges with the two canisters. Earlier tests with only one container reduced it only in the 100-200 ppmv range.

An ice bath clean up process was installed prior to the metal filings/wood shavings canisters. The ice bath had a 10-foot plastic compressor tubing within it to condense out o water vapor in the biogases. The ice bath operated from 35-40 degrees F and we noted the dew point of the gas was down to approximately 50 degrees F.

5.2 Pressure Swing Absorber System:

A pressure swing absorption clean up process was installed and operated prior to the development of the water tower. This equipment was manufactured in Germany and supplied by Donaldson Corp. of Minneapolis. The pressure swing absorber removes water vapor, CO_2 and H_2S. In early experiments we were unable to maintain the gas design pressures needed for the pressure swing absorber. There are two regenerating towers so the unit can purge waste gases. The unit was purging 4-6 cfm of waste gas for every 2 cfm of usable gases. The gas compressor ran continuously under this operation.

When operating in the 40 to 50 PSI range and running raw biogas we were able to reduce the CO_2 levels 5-10 percent supplying a 35% CO_2 biogas. H_2S was reduced from 3000 ppmv to around 100 ppmv. This unit also reduced the water vapor significantly, we were seeing minus 40-50 degree F dew points. Better results should be obtained with gas pressure ranges of 80 to 90 PSI especially with regard to CO_2. Also the pressure swing absorber would do a good job of reducing CO_2 and H_2S if installed after the water tower. Further testing should be conducted.

5.3 Lime Solution Cleanup System:

Our early experiments were with the smaller gas compressor (2-PSI) and a calcium hydroxide (lime) solution clean up process. A saturated solution of water and lime was in a 55-gallon drum and the biogas bubbled through it. We saw significant H_2S reduction in to the 200-300 ppmv range but the effectiveness was only in the 3 to 4 hour time span. System design changes were primarily in retooling the bubbler manifold with improved results. The water scrub clean up processes was pursued instead of attempting to design a rejuvenation process to maintaining an effective saturated solution.

6.0 . Fuel Cell and Internal Combustion Engine Emissions:

Emissions from Haubenschild Caterpillar™ engine generator were compared to Plug Power™ Proton Exchange Membrane (PEM) Fuel Cell (see table below) on March 11, 2005 using biogas in both technologies.

	Engine Generator	Fuel Cell
CO	(800ppmv) 4.18 g/kWh	(<1 ppmv) 0.014 g/kWh
NOx	(2960ppmv) 25.5 g/kWh	(<1 ppmv) <.0023 g/kWh
SO_X	(277ppmv) 3.34 g/kWh	(<1 ppmv) <0.030 g/kWh
$C_X H_Y$	(20460ppmv) 53 g/kWh	(1790 ppmv) 14.5 g/kWh

The data was shown in grams of pollutant emitted per kWh of electricity produced by a specific generator to better compare the emission from the 5kW fuel cell that produces less electricity than the 130kW internal combustion engine. These results show that emissions of carbon monoxide (CO), nitrogen oxides (NOx), sulfur oxides (SOx), and hydrocarbons (CxHy) are minimal in the fuel cell compared to the internal combustion engine. In the fuel cell, many of the pollutants are filtered out in the gas clean up process.

7.0 Education Component of Project

7.1 Tours of the Fuel Cell Research Facility:

There were approximately ten small tours arranged by the members of the U of M team. These involved from 3 to 25 people to a tour. Haubenschild Farms arranged multiple tours during the two-year project. An estimate is that there were 25 tours that visited the farm and saw the research being done on the farm supported by the Legislative Commission on Minnesota Resources.

7.2 Formal Presentations:

There were at least 10 formal presentations to technical audiences by the team using PowerPoint presentations, which included pictures, objectives and results of the research. Written materials other than reports to LCMR were presented at two international professional meetings and were published in the proceedings of those meetings.

7.3 Field Days:

Two field days were held at the farm and information posters were displayed at 3 other field days, meetings and gatherings of farmer groups.

7.4 Specific education and outreach events and publications:

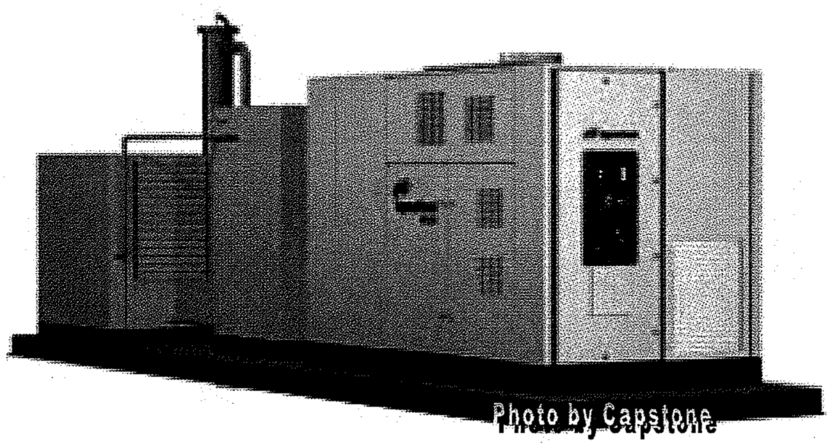
- Air and Waste Management Association Conference and Tour June 21-24, 2005.
- Energy Alley Talk
- Article with CREED through U of M IREE
- H2 Forum Talk
- Presentation of paper "Emissions form Biogas Fueled Engine Generator Compared to a Fuel Cell" at multiple venues.
- Presentation at the 2004 Biocycle Conference in Des Moines, IA

8.0 Microturbine use with Anaerobic Manure Digestion

Beyond fuel cells and internal combustion engines, there are a number of other emerging energy conversion systems that can be used to harness electricity from biogas from anaerobic manure digesters. One such technology is the microturbine, which has been used in a variety of applications using natural gas. Only a handful of manure digesters in the United States have used microturbines as a complement to the energy generation and conversion systems. Some limited research has been undertaken on installations

8.1 Microturbine Facts

Microturbines can be used for both heat and power, just like other energy conversion systems. The turbines can be used in modular units in a series with varying energy outputs. The emissions from the turbines are about the same as from an engine generator set. Dusty conditions can cause problems with the air bearings, which support the turbine. A micro turbine generator coupled to induction generator can be connected to the grid. These are available in 30kW sizes and will match to a digester serving about 200 cows. A ratio of 5-8 cows per kW is reasonable to use in sizing a micro turbine or a generator system.



Microturbine and compressor that could be used to convert biogas to electricity.

8.2 Microturbine Strengths

One strength of a microturbine is the fact that there are less moving parts than internal combustion engines and theoretically this will result in less maintenance. Also, microturbines, like fuel cells, are relatively quiet compared to internal combustion engines. Unlike fuel cells, microturbines are commercially available and have been on the market for a longer period of time.

8.3 Microturbine Weaknesses

A microturbine must have a compressor to raise the pressure of the biogas for the intake. Compressors have serious problems with wet gas so a filter to remove water must be placed ahead of the compressor. Early adopters of micro turbines have had severe problems with compressor failure and problems with heat exchangers to reclaim energy from he exhaust on the micro turbine. Care must be exercised to evaluate the provider of the micro turbine and the compressor system to make sure that it will work. Purchasing an older model of either a compressor or a microturbine is purchasing problems that have not been fixed. A microturbine with compressor and heat recovery unit will cost about $75,000 plus installation.

8.4 Microturbine Applications with Manure Digesters:

The California Polytechnic Institute Agricultural Engineering Department installed a 25 kW microturbine that ran on biogas from a covered lagoon digester. This study compared the energy conversion efficiency of an internal combustion engine vs. that off the microturbine. Initial results showed that the energy conversion efficiencies were 10% and 27% for the internal combustion engine and microturbine respectively.

California Polytechnic Institute Microturbine

Closer to Minnesota, Top Deck Farms in Westgate Iowa installed both a 100 kW internal combustion engine and a 30 kW microturbine to produced electricity from biogas on their dairy farm's manure digester. This project was in cooperation with the Iowa Department of Natural Resources and Iowa State University along with private industry involvement. The cost of the 30 kW Capstone microturbine was approximately $80,000 with installation. In a recent report on this project, the microturbine was found to be quieter and more dependable than the internal combustion engine. Although, the internal combustion engine used had more problems than one would suspect.

Top Deck Farms Microturbine On-farm Application

9.0 Recommendations

For a farm operator considering installing a fuel cell, the recommendation is to wait until the cost of fuel cells has been reduced substantially. Also the pricing structure for electrical purchase by electric distribution companies must change to recognize the value of renewable energy or the incentives for making renewable must be increased.

Additional research is needed in Minnesota to economically solve the gas purification problems that were partially solved by this project. Additional methods of removing hydrogen sulfide and carbon dioxide in an efficient manner will reduce the electrical energy cost and provide a stable output to the fuel cell or other system using the biogas.

10.0 Conclusions

The main goal of the project was to determine if a fuel cell could be operated on the farm with the biogas from the anaerobic digester. In fact the biogas was successfully cleaned up to a level that was sufficient to operate at the stringent specifications of the Plug Power proton exchange membrane (PEM) fuel cell. There is no other documented instance where a PEM fuel cell has been operated successfully on an anaerobic digester on a farm. That said there are still improvements that need to be completed before this will be a viable way to make electricity on most farms. The high cost of the fuel cell used (approximately $70,000 for a 5 kW system) will have to be reduced. However the fuel cell industry is making rapid cuts in the cost of manufacturing costs of fuel cells and these systems may become reasonable in the next decade. The electrical energy used to purify the gas prior to the fuel cell however was more than created by the fuel cell. Modification of the systems and economies of scale will be necessary to make this a positive result. Several potential improvements have been identified and will be incorporated into an improved biogas cleanup system as well as several ideas for improving the gas quality from the digestion process. These will be incorporated in to future research proposals.

The results of this project will be useful to operators who wish to derive electrical energy from the controlled anaerobic treatment of animal manure. However the impact of electrical purchase prices by the electrical distribution companies will guide use of this technology as well as the cost of fuel cells.

The emissions from the fuel cell operating on biogas were much lower than those emitted from the engine generator set operating on the same biogas. The additions to green house gas were greatly reduced. This fuel cell technology would have a significant impact on reducing global warming in the technology could be widely implemented to replace combustion of the biogas either in flares or in engine generator sets.

Appendix C: Power Point Presentations Developed by U of M Staff

rons from Manure

PE, Department of Biosystems and
ineering, University of Minnesota

1

What is Anaerobic Digestion?

Conversion of Organic Matter
by Anaerobic Microbes
Biogas and Manure Effluent

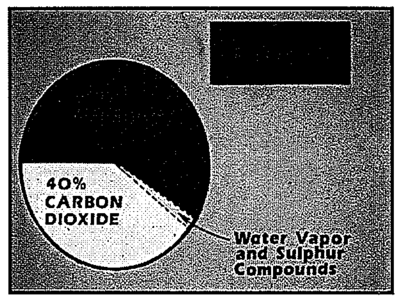
Methane ~ 60%
Carbon Dioxide ~ 40%
Hydrogen sulfide ~ trace

2

Anaerobic Digestion

- Use a heated container to accelerate the degradation of the manure.
- Microorganisms produce a fuel gas and degrade the manure.
- Less odors are produced when compared to non controlled anaerobic digestion

3



Advantages of Digestion

- Total waste management system
  - Pollution control
  - Odor control
  - Nutrient conservation
  - Greenhouse gas reduction

7

Advantages of Digestion

- Energy Production
  - For use as heat
  - For conversion to electricity
  - Combination of both
  - For hot water needs

8

Disadvantages of Digestion

- Is somewhat costly
- Higher management levels required
- Startup is sometimes difficult
- Storage required
  - Cannot store methane as a liquid!!
- Some risk of explosion

9

Uses of Methane Gas

- Household cooking
- House heating
- Water heating
- Electrical generation
- Barn heat
- Making of alcohol fuels

10

Benefits of Methane Generation

- Reducing greenhouse gases
- Only waste management system which generates some energy
- Reduces odors
- Reduces the solids to be disposed

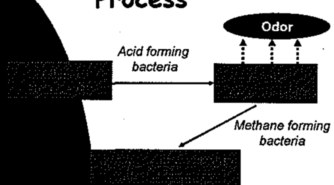
11

Drawbacks to Digestion

- More critical management of system
- Some risks with fuel storage
- Energy recovery system is complex
- More subject to upsets

12

More Details on the Digestion Process

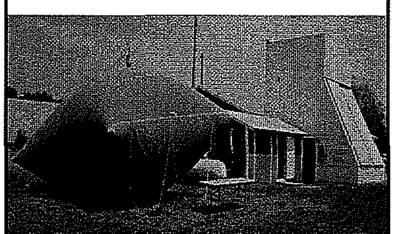


13

Covered Lagoon

- Flexible cover on lagoon or manure storage
- Lowest gas production
- Least "controlled" system
- Longest HRT

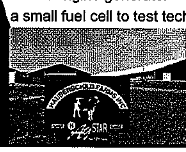
5



16

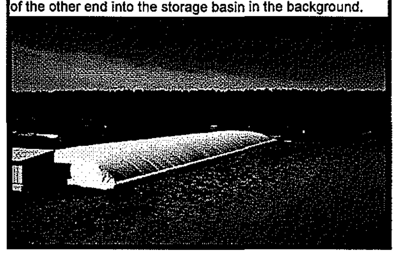
Background

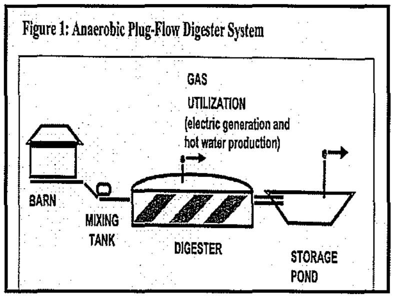
- ...benschild Farms, near Princeton, Minnesota
- ...w dairy farm, 1000 acres of crop land
- ...-flow digester in 1999
- ...eing converted to electricity by 130 kW ...bustion engine generator
- ... a small fuel cell to test technology

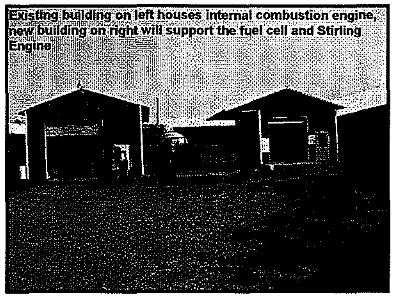


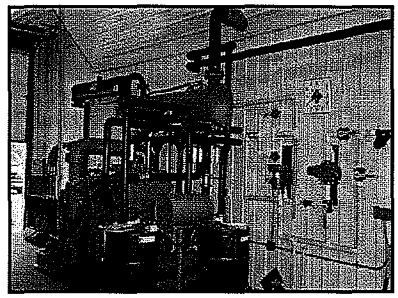
17

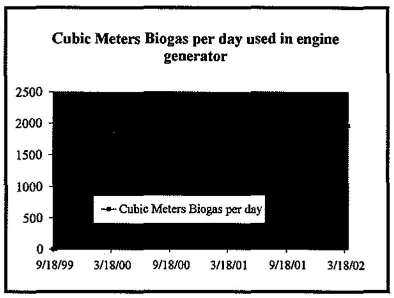
Plug-Flow Digester - A small "plug" of slurry is pumped into one end each day, causing a comparable amount to flow out of the other end into the storage basin in the background.

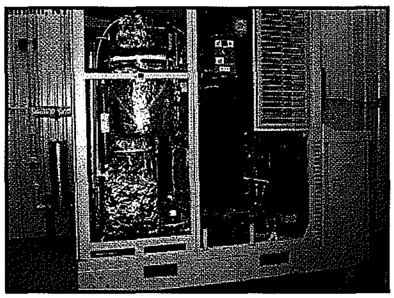


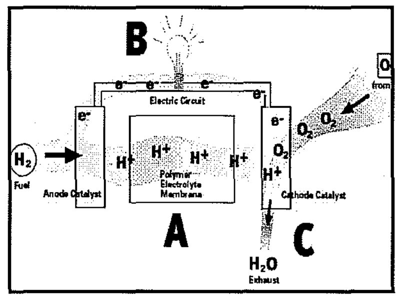












How do fuel cells work

simple electrochemical process.
positive and negative plates allow for a flow of elections.
lectrolyte, carries the hydrogen's protons from one
ode to the other.
trolyte, such as a polymer electrolyte membrane,
s an electron from the proton of a hydrogen atom.
electron travels through a wire to power any electrical

nd electron reunite to form hydrogen and the
combines with oxygen to form water.

25

Challenges

en sulfide removal
concentration 3000-5000 ppm
oncentration < 25 ppb
moval
gas
de removal
entration < 5 ppm

26

Environment and Economic Benefits

ced reliance on fossil fuels as an energy

odors and emissions
roperties of the digested manure are

energy from a renewable resource
rural economy while reducing reliance
s and reducing emission of
gases.

27

Haubenschild Digester

- Biogas production 93ft^3/cow/day
  - (66 ft3/day/1000lb lw)
- Electrical production 4 kWh/cow/day

28

Summary

- Anaerobic treatment will reduce odors and produce some useful energy.
- Systems are more complex than simple storage.

29

Questions

- www.bae.umn.edu/extens/manure/

30

Advancing Utilization of Manure Methane Digester

for this project was recommended by the
e Commission on Minnesota Resources
innesota Environment and Natural
Trust Fund ($204, 375)

31

Other Key Facts

- There is "no" reduction in manure volume
- There is no reduction in manure nutrients
  - Some organic nitrogen is converted to ammonia nitrogen and could be volatilized in the manure storage
- There is no increase in manure nutrients

32

History of Digestion

- First plant built in India in 1859
- Fueled street lamps in England in 1985
- In 1998 an estimated 600 farm-based digesters were in use.
- Estimated 31 digesters are currently in operation on farms in US

33

Terms to Know

- Volatile Solids (VS) - A measure of the weight of solids that is combustible "volatilized" at a temperature of 600 °C. It is reported as a percent of the total weight of the manure sample. Methane production is often based on the volatile solids portion of the manure.

34

Volatile Solids Production

- Dairy = 10 lbs VS per day
- Swine = 8.5 lbs VS per day
- Layer = 12 lbs VS per day

1000 lbs live weight)

ely 50-70% of the VS can be converted.
ls on species and digester design.

35

Temperature considerations

- Psychrophilic <68 °F
- Mesophilic 95-105 °F
- Thermophilic 125-135 °F

36

pH considerations

- Methane forming bacteria require pH of between 6.8 and 7.4

37

Biogas composition

- Methane ~ 60%
- Carbon Dioxide ~ 40%
- Hydrogen sulfide ~ trace

38

Methane is a Fuel Source

- Natural gas is 99% methane
- Methane is about 900 BTU/ft3
- Propane is 2284 BTU/ft3

39

Typical Energy Production

	per 1000 lbs live weight		
s	VS lb/day	Biogas ft^3/day*	Energy BTU/day
	10.0	39	23,400
	8.5	28	16,800
	12.0	37	22,000

/PS-18
ion is typically much higher than
values (often more than twice).

40

Attribute	Fuel Cell	Engine Generator
Capital Cost per kilowatt	High –$10,000 to $12000 Target is $40	Low –$50 to $100
Biogas Cleanup	Needs to be cleaned to strict specifications	Little or none needed
Maturity of Technology	Rapidly emerging	Mature
Greenhouse emissions	Minimal	Carbon dioxide, sulfur dioxide, carbon monoxide, particulates
Noise level of equipment	Very quiet	Very high and sound mitigation necessary
Moving parts to fail	Very few and most at ambient temperature	Many moving parts in hot, challenging environment needing o and cooling
Changes occurring	Changing rapidly with extensive development occurring	Mature and changing slowly
Maintenance cost	Very high because of limited life of fuel cell stack material	Variable depending on the care give to the unit and the durability

12/20/2005 41

Comparison of Fuel Cell and a Genset Utilizing Biogas

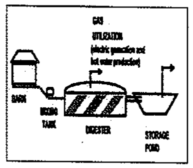
Philip R. Goodrich PE*, David Nelson PE*, Richard Huelskamp*, Dennis Haubenschild**, Matthew Drewitz***, Paul Burns***, David Schmidt PE*, R. Vance Morey*
* Department of Biosystems and Agricultural Engineering, U of Minnesota,** Haubenschild Farms, Princeton MN***Minnesota Department of Agriculture

[1]Other participants in this project include: Amanda Bilik, The Minnesota Project, Verlyn Johnson, Blanca Martinez, BAE and Henry Fischer, East Central Energy.

Background

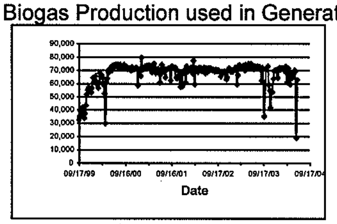
Anaerobic digestion converts volatile organic substances in livestock wastes into methane, carbon dioxide, gaseous contaminants and water vapor. The remaining material is stabilized, reducing odor during storage and land application operations. The energy in the methane can be converted into electrical energy in various ways. The most popular method is an internal combustion engine coupled to an alternating current induction generator connected to the grid. A fuel cell is a newer way to convert the methane into electrical energy which is more challenging

Dennis Haubenschild is an early adopter of anaerobic digestion using AGSTAR (US Environmental Protection Agency) resources to install one at Haubenschild Farms, an 800-cow, 1000-acre dairy farm an hour north of Minneapolis/St. Paul MN. In 1999, the farm installed a heated plug-flow digester with a 135-kilowatt engine/generator to utilize the biogas. The successful operation of this facility (the generator has been running over 98% of the time through July 2004) has drawn many visitors and helped other operations to accept the technology.



SOURCE: Nelson and Lamb

Biogas Production used in Generator



Objective

To demonstrate the feasibility of converting biogas methane to electrical energy using a commercially available fuel cell.

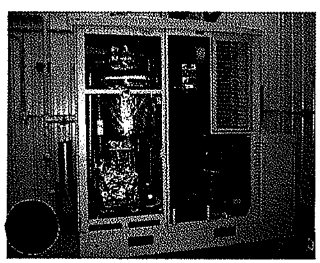
Comparing Electrical Generator Technologies

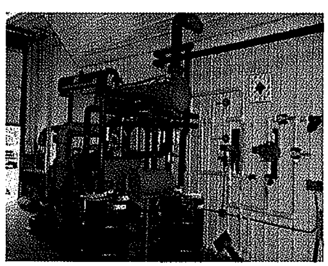
Fuel Cell System

- Cost per kilowatt is very high.
  \$10,000 -->20,000 per kW
- The biogas must be cleaned up to strict specifications. Adds cost and complexity while consuming energy.
- The fuel cell is an emerging technology.
- The greenhouse emissions and particulates are very low.
- The system is very quiet.
- There are few moving parts.
- Cost of maintenance is not yet known.
- The fuel cell technology is continuously improving at a rapid rate.

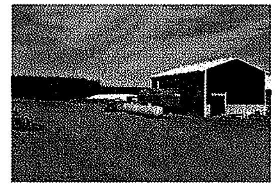
Engine Generator System

- Cost per kilowatt is low.
  \$50 -->100 per kW
- The biogas can be used directly from the digester with no cleanup.
- The fuel cell is mature technology.
- The greenhouse emissions of carbon dioxide, sulfur dioxide carbon monoxide and particulates are significant.
- The noise level is very high and sound mitigation is necessary.
- There are many moving parts, most moving in a hot environment needing oil and cooling
- The technology is mature and changing slowly.

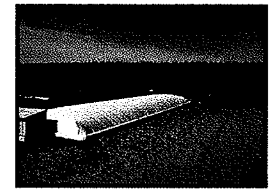




The Haubenschild Farms Digester and Energy Recovery System



Plug-Flow Digester - A small "plug" of slurry is pumped into one end each day, causing a comparable amount to flow out of the other end into the storage basin in the background.



The building at the left houses the 135 kW engine generator and the building on the right houses the fuel cell and instrumentation. One barn is to the right rear of the picture

Challenges to using biogas for a fuel cell

- Hydrogen sulfide removal
  - Initial concentration 3000-5000 ppm
  - Need concentration < 25 ppb
- Moisture removal
  - Need dry gas
  - Dewpoint < -30 degrees Celsius
- Carbon dioxide removal
  - Need concentration < 5 ppm

Emissions from Haubenschild Generator Compared to Plug Power™ Proton Exchange Membrane (PEM) Fuel Cell

Engine Generator Emissions**

1.89 % O_2
0.0796 % CO (796ppm)
0.187 % NOx (1872 ppm)
0.0804 % SO_X (804 ppm)
1.39 % $C_X H_Y$

**Actual tests on Haubenschild Farm Dec 2004

Fuel Cell Emissions*

79 % O_2 and N_2
15.5 % H_2O
4.2% Co_2
<.001% Other
Other = propane,NO_x,SO_x,CO

*Per Plug Power tests

BIOSYSTEMS & AGRICULTURAL ENGINEERING
UNIVERSITY OF MINNESOTA

Advancing Utilization of Manure Methane Digester

Funding for this project was recommended by the Legis[illegible] Commission on Minnesota Resources from the Minnesota Environment[illegible]atural Resources Trust Fund

ure Methane Digester
trical Generation

Goodrich, R. Vance Morey, David
dt, Paul Burns, Matt Drewitz, Dennis
nschild, Amanda Bilek, David Nelson
d Huelskamp

Advancing Utilization of Manure Methane Digester

F or this project was recommended by the
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Background

- well operating digester on an 800 iry herd
- is being converted to electricity by engine generator
- r is producing excess biogas

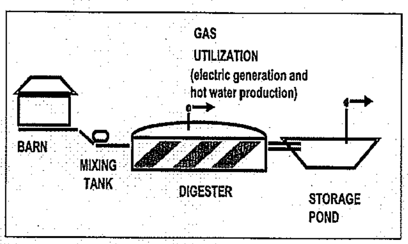
Haubenschild Dairy Farm Energy Production
Princeton, Minnesota

Milk Production + Crop Production + Electrical Production + Future Hydrogen Production

=

Farm Income Diversification

Figure 1: Anaerobic Plug-Flow Digester System



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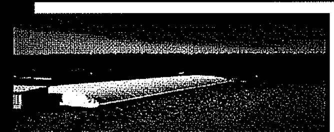

e Digester: To breakdown organic matter in the f oxygen to biogas, which is primarily hane, CO2/carbon dioxide, H2S/hydrogen sulfide, r vapor.

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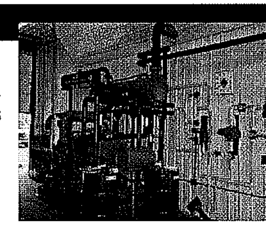
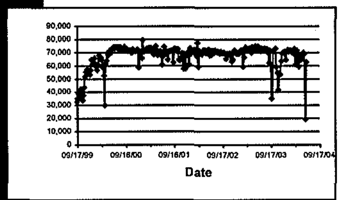


erpiller 3406



Objective

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Procedures to Achieve Objective

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Challenges

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- itial concentration ~3000 ppm
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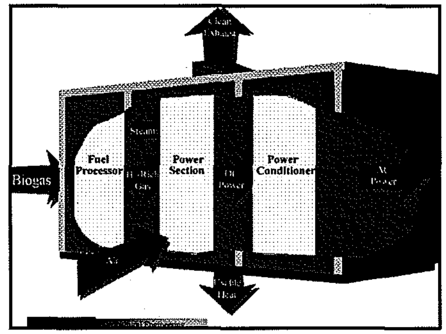
Types of Fuel Cells

- Exchange Membrane -Low temp
- xide -High temperature
- Carbonate -High Temperature



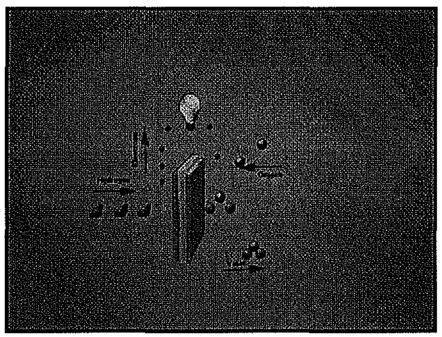
l cell is similar to a car battery in that it

chemical reactions. A fuel cell produces electricity as long as the hydrogen
l source and oxygen passes through it.

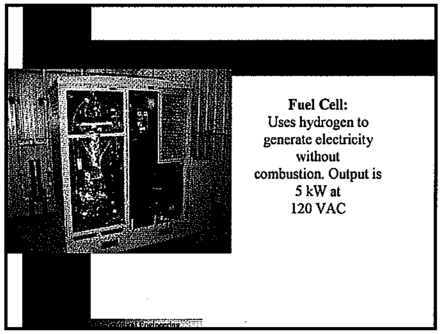
roduced and can be utilized for space heating and hot water needs.

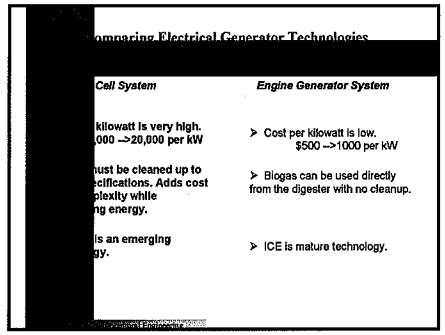
Electricity conversion efficiency is around 25%

gy resources for hydrogen can be biogas, natural gas, propane, anol, ethanol, and other hydrogen based liquids or gases.



The building at the left houses the 135 kW engine generator and the building on the right houses the fuel cell and instrumentation. One barn is to the right rear of the picture


Fuel Cell:
Uses hydrogen to
generate electricity
without
combustion. Output is
5 kW at
120 VAC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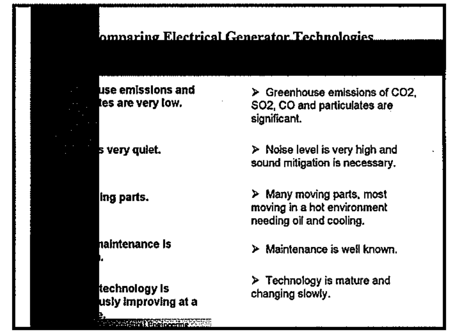
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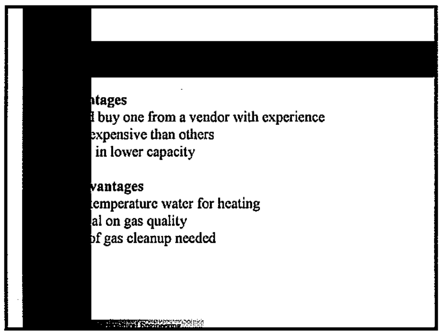
ntages
l buy one from a vendor with experience
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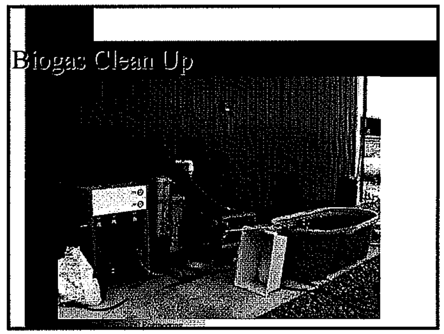
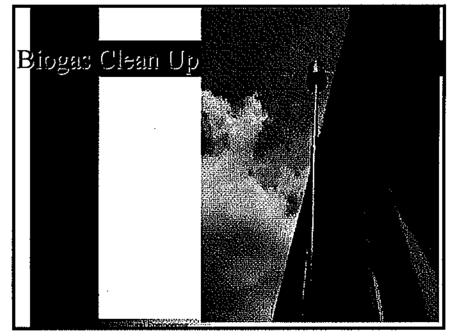

Biogas Clean Up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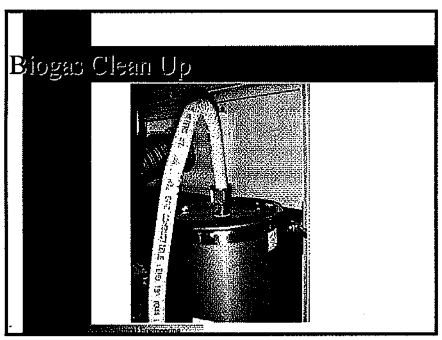
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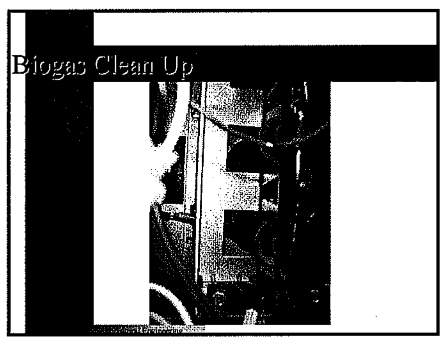
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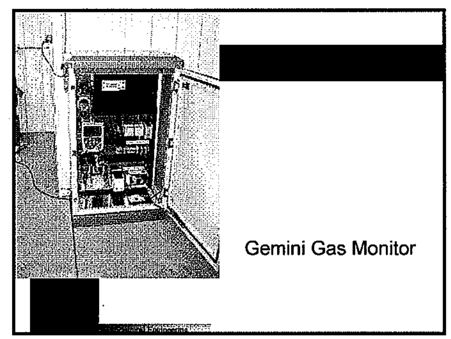
Gemini Gas Monitor

Engine Generator		Fuel Cell
(800ppmv) 4.18 g/kWh	>	(<1 ppmv) 0.014 g/kWh
(2960ppmv) 25.5 g/kWh	>	(<1 ppmv) <.0023 g/kWh
(277ppmv) 3.34 g/kWh	>	(<1 ppmv) <0.030 g/kWh
(20460ppmv) 53 g/kWh	>	(1790 ppmv) 14.5 g/kWh

Energy Production +

Organic Fertilizer +

Net Air Emissions

=

Snergy Income +

Savings +

Environment Impact Reduction

educed reliance on fossil fuels
educed odors and emissions
educed soil and water pollution
upports rural economy

Funding

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- Henry Fischer, East Central Energy.
- Rob Lowen, Plug Power, Inc.
- Jamie Tooley, CES-Landtec Engineering
- Don White, Donaldson Corp
- David Thimsen, EPRI
- Claudio Martinez & Stephan Becerra ,John Deere Co

BIOSYSTEMS & AGRICULTURAL
ENGINEERING
UNIVERSITY OF MINNESOTA

Thank you

Advancing Utilization of Manure Methane Digester
Funding for this project was recommended by the Legislative Commission on Minnesota Resources from the Minnesota Environment and Natural Resources Trust Fund

n Manure

Goodrich PE
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y of Minnesota
MN 55108
n@umn.edu

e Morey, David Schmidt, Paul Burns, Matt
Dennis Haubenschild, Amanda Bilek, David
Richard Huelskamp

Advancing Utilization of Manure Methane Digester

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Outline

- kground
- ective
- at we have done
- y we did it our way
- he results
- ere we go from here

Background

- well operating digester on an 800 iry herd
- is being converted to electricity by engine generator
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Haubenschild Dairy Farm Energy Production
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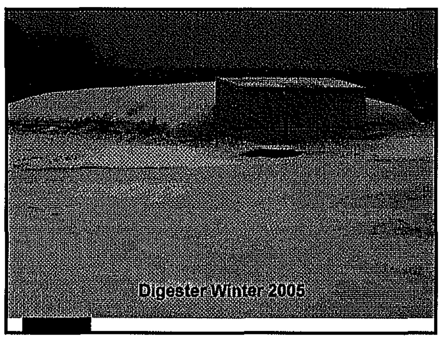
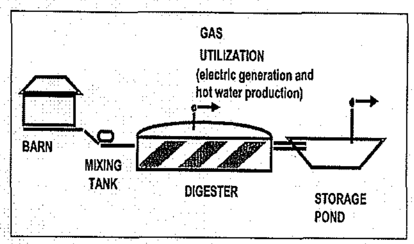


Figure 1: Anaerobic Plug-Flow Digester System



thane Digester

absence of oxygen to
gas, which is
4 --methane,
2 --carbon dioxide,
--hydrogen sulfide,
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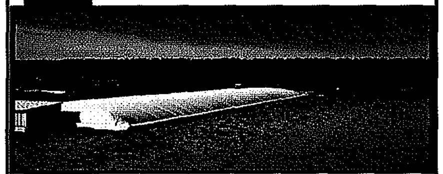

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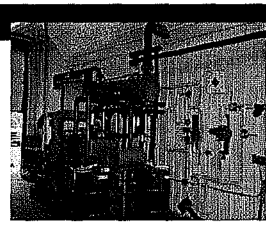

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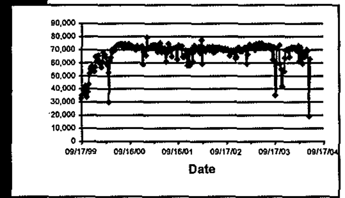

Opportunity

- te side-by-side testing of technology
- e odor reduction benefits of system
- re emissions of two technologies
- ething that had not been done

Objective

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t step may be to produce rogen for farm use from biogas.

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- Exchange Membrane -Low temp
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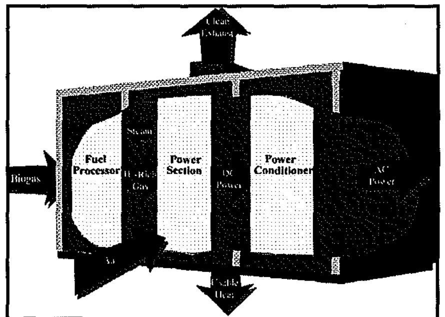
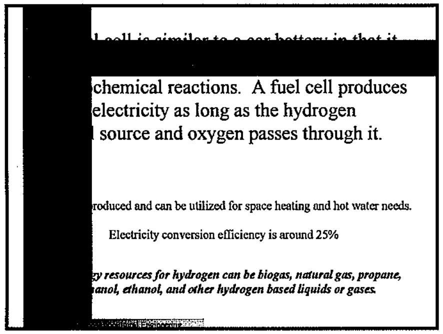
- Carbonate -High Temperature

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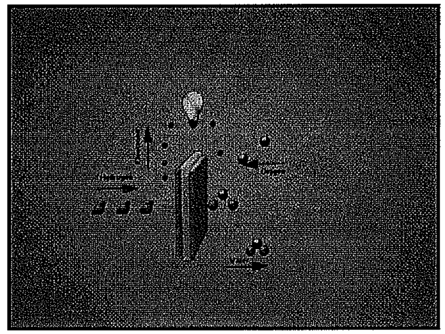

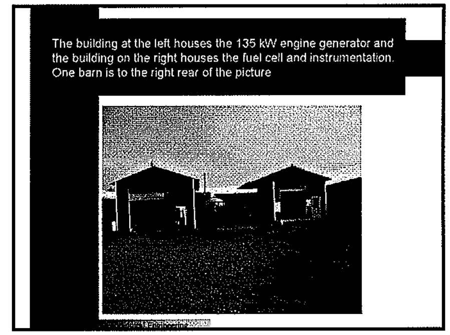
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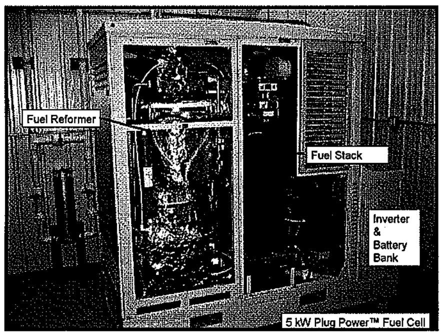
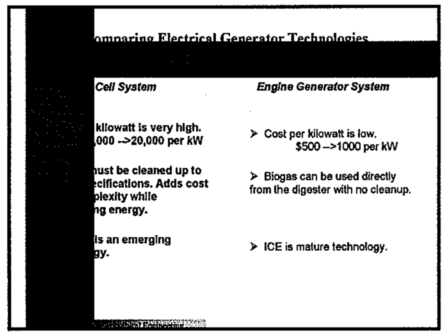

Fuel Reformer
Fuel Stack
Inverter & Battery Bank
5 kW Plug Power™ Fuel Cell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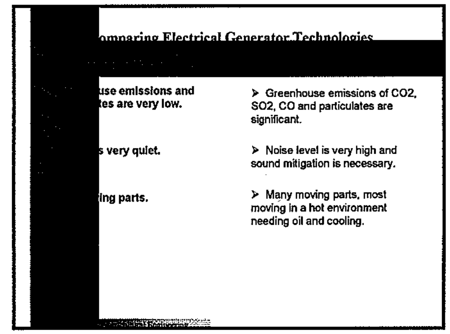
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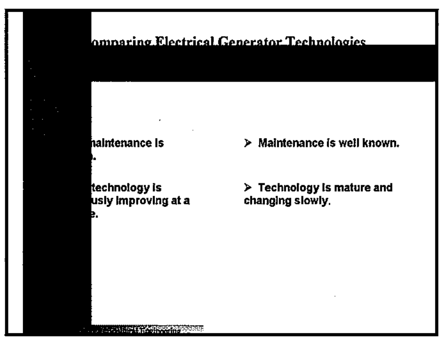
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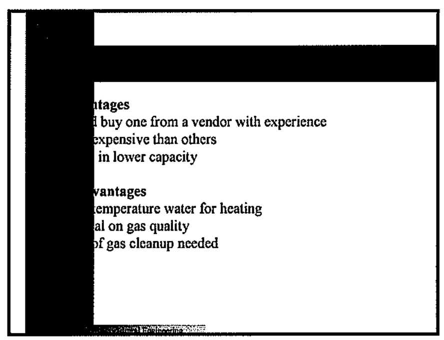
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buy one from a vendor with experience
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in lower capacity
vantages
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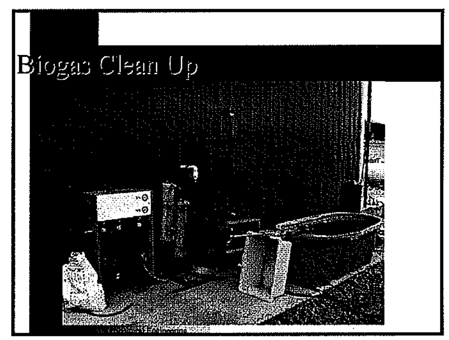
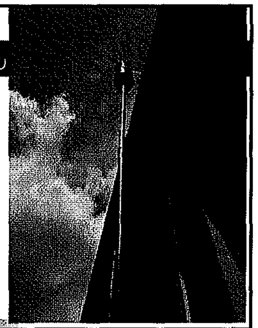
al on gas quality
f gas cleanup needed


Biogas Clean Up

Biogas Clean Up



Biogas Clean Up

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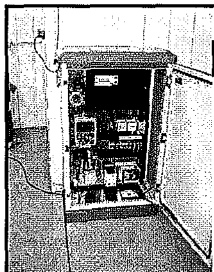

Gemini Gas Monitor

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(20460ppmv) 53 g/kWh	➢ (1790 ppmv) 14.5 g/kWh

Where we are now

- el cell runs ok on cleaned up gas
- ed to get more stable cleanup system
- t getting value for electricity

Where do we go next?

- ress, transport and sell methane
- hydrogen and sell hydrogen
- value and less regulated

conomic Benefits

- educed reliance on fossil fuels
- educed odors and emissions
- educed soil and water pollution
- upports rural economy

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- Dennis Haubenschild from Haubenschild Farms, Princeton MN

atthew Drewitz, Paul Burns, from Minnesota Department of Agriculture

Other participants in this project include:

- Amanda Bilik, The Minnesota Project,
- Verlyn Johnson and Blanca Martinez, BAE
- Henry Fischer, East Central Energy.
- Rob Lowen, Plug Power, Inc.
- Jamie Tooley, CES-Landtec Engineering
- Don White, Donaldson Corp
- David Thimsen, EPRI
- Claudio Martinez & Stephan Becerra ,John Deere Co

BIOSYSTEMS & AGRICULTURAL
ENGINEERING
UNIVERSITY OF MINNESOTA

Thank you

Advancing Utilization of Manure Methane Digester
Funding for this project was recommended by the Legislative Commission on Minnesota Resources from the Minnesota Environment and Natural Resources Trust Fund

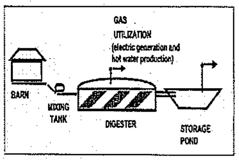
Advancing Utilization of Manure Methane Digester

Funding for this project was recommended by the Legislative Commission on Minnesota Resources from the Minnesota Environment and Natural Resources Trust Fund ($204, 375)

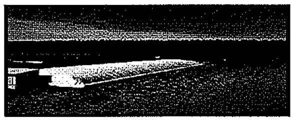
Haubenschild Dairy Farm Energy Production
Princeton, Minnesota

Milk Production + Crop Production + Electrical Production + Future Hydrogen Production
=
Farm Income Diversification

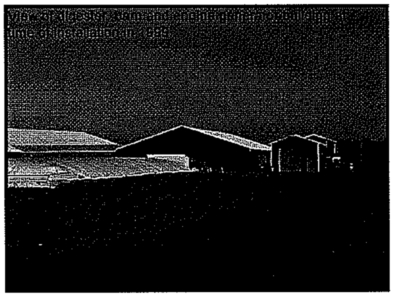
Figure 1: Anaerobic Plug-Flow Digester System



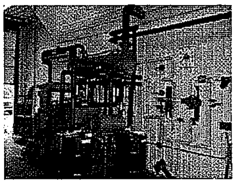
Plug-Flow Digester - A small "plug" of slurry is pumped into one end each day, causing a comparable amount to flow out of the other end into the storage basin in the background.



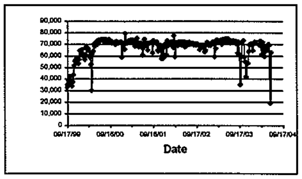
Methane Digester: To breakdown organic matter in the absence of oxygen to biogas, which is primarily CH4/methane, CO2/carbon dioxide, H2S/hydrogen sulfide, and water vapor.



Engine Generator set: Internal combustion engine with 135 kW 240 VAC electrical generator.



Biogas Production Used in Generator

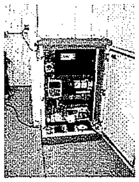


Comparison of Fuel Cell and a Genset Utilizing Biogas

- Philip R. Goodrich PE, David Nelson PE, Richard Huelskamp, David Schmidt PE*, R. Vance Morey from Department of Biosystems and Agricultural Engineering, University of Minnesota.
- Dennis Haubenschild from Haubenschild Farms, Princeton MN
- Matthew Drewitz, Paul Burns, fromMinnesota Department of Agriculture

Other participants in this project include:

- Amanda Bilek, The Minnesota Project,
- Verlyn Johnson and Bianca Martinez, BAE
- Henry Fischer, East Central Energy.
- Rob Lowen, Plug Power, Inc.
- Jamie Tooley, CES-Landtec Engineering
- Don White, Donaldson Corp.



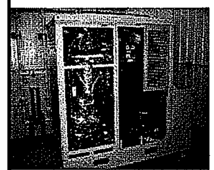
Objective:

To demonstrate the feasibility of converting biogas to electrical energy using a commercially available fuel cell.

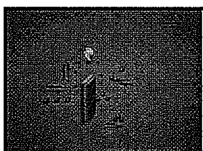
Challenges to using biogas for a fuel cell

- Hydrogen sulfide removal
  - Initial concentration 3000-5000 ppm
  - Need concentration < 25 ppb
- Moisture removal
  - Need dry gas
  - Dewpoint < -30 degrees Celsius
- Carbon dioxide removal
  - Need concentration < 5 ppm

The building at the left houses the 135 kW engine generator and the building on the right houses the fuel cell and instrumentation. One barn is to the right rear of the picture



Fuel Cell:
Uses hydrogen to generate electricity without combustion. Output is 5 kW at 120 VAC



A fuel cell is similar to a car battery in that it produces electricity through electrochemical reactions. A fuel cell produces electricity as long as the hydrogen fuel source and oxygen passes through it.

Heat is also produced and can be utilized for space heating and hot water needs.

Electricity conversion efficiency is around 25%

The energy resources for hydrogen can be biogas, natural gas, propane, methanol, ethanol, and other hydrogen based liquids or gases.

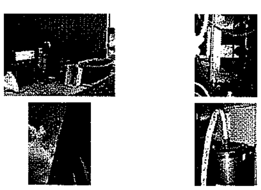
Comparing Electrical Generator Technologies

Fuel Cell System	*Engine Generator System*
➢ Cost per kilowatt is very high. $10,000 –>20,000 per kW	➢ Cost per kilowatt is low. $50 –>100 per kW
➢ Biogas must be cleaned up to strict specifications. Adds cost and complexity while consuming energy.	➢ Biogas can be used directly from the digester with no cleanup.
➢ Fuel cell is an emerging technology.	➢ ICE is mature technology.

Comparing Electrical Generator Technologies

Fuel Cell System	*Engine Generator System*
➢ Greenhouse emissions and particulates are very low.	➢ Greenhouse emissions of CO2, SO2, CO and particulates are significant.
➢ System is very quiet.	➢ Noise level is very high and sound mitigation is necessary.
➢ Few moving parts.	➢ Many moving parts, most moving in a hot environment needing oil and cooling.
➢ Cost of maintenance is unknown.	➢ Maintenance is well known.
➢ Fuel cell technology is continuously improving at a rapid rate.	➢ Technology is mature and changing slowly.

Biogas Clean Up



Emissions from Haubenschild Generator Compared to Plug Power™ Proton Exchange Membrane (PEM) Fuel Cell

	Engine Generator	Fuel Cell
CO	✓ (799ppmv) 4.18 g/kWh	➢ (<1 ppmv) 0.014 g/kWh
NOx	✓ (2963 ppmv) 25.5 g/kWh	➢ (<1 ppmv) <.0023 g/kWh
SO_X	✓ (277 ppmv) 3.34 g/kWh	➢ (<1 ppmv) <0.030 g/kWh
$C_X H_Y$	✓ (2.46 ppmv) 53 g/kWh	➢ (1790 ppmv) 14.5 g/kWh

Energy Production +

Organic Fertilizer +

Net Air Emissions

=

$nergy Income +

$avings +

Environment Impact Reduction

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Thank you

Rich Huelskamp

Advancing Utilization of Manure Methane Digester
Funding for this project was recommended by the Legislative Commission on Minnesota Resources from the Minnesota Environment and Natural Resources Trust Fund

Appendix D: MN Project Final Report to MDA

LCMR Final Report for Minnesota Project
June 30, 2005

The Minnesota Project has integrated the alternative generation project at Haubenschild Family Farms into their outreach and education materials. The Minnesota Project has an educational display that is used when tabling at farm trade shows, agricultural conferences, and other general outreach events. The display has two panels for Minnesota Project's Energizing Agriculture program which summarizes work on cooperative projects involving methane gas recovery for electricity production from anaerobic digesters. A section of this two-panel display contains information and pictures summarizing the cooperative project at the Haubenschild Farm studying alternative electricity production using a fuel cell. The educational display has been used at the following events:

- Midwest Dairy Expo, December 2004
- Steering Committee meeting of the Midwest Agriculture/Energy Network, February of 2005
- Annual meeting of the Sustainable Farming Association of Minnesota, February 2005
- Clean Energy Resource Teams (CERTs) statewide conference, February 2005
- Minnesota Project Board of Directors retreat, April 2005

The educational display containing information on the alternative generation project at Haubenschild Farms will continue to be used in the future at outreach events to continue the general education of the alternative generation project at the Haubenschild Farm.

In April, the Minnesota Project and the Minnesota Department of Agriculture issued a joint press release to publicize the alternative generation project at the Haubenschild dairy. The release went out across the state through the media networks of both the Minnesota Project and Minnesota Department of Agriculture. The release was picked up by a dozen newspapers in Minnesota, a half-dozen Minnesota agricultural publications and internet newsletters and a eight national publications and internet newsletters.

In addition to the education display, the Minnesota Project has updated their website with a wide variety of information pertaining to the alternative generation project. This information can be viewed at www.mnproject.org/index-biogas.html
Information on the website includes funder information, project partners with website links, project objectives and outcomes, educational posters for download, and project fact sheets for download. Pictures of the research site and research equipment are also available. There are plans to add project presentations given by the University of Minnesota to the website.

The Minnesota Project also developed project fact sheets in cooperation with the University of Minnesota and Minnesota Department of Agriculture. There is a fact sheet summarizing project objectives and outcomes, including pictures. There is an additional fact sheet serving as a background piece on fuel cells (functions, purposes, and types). Information for the general fact sheet was obtained from the Clean Energy Resource

Teams (CERTs) and the Minnesota Office of Environmental Assistance. The fact sheets were also produced for print. 500 copies of each were printed and distributed to the University of Minnesota and Minnesota Department of Agriculture. Additional copies can be requested from Amanda Bilek, 651-645-6159 x.5 or abilek@mnproject.org

On June 20, 2005 a project workshop was held at the Haubenschild Farm and Wynett Town Hall, a meeting space adjacent to the farm. There were 40 participants registered to be there, but there was a turnout of 32. A special invite was sent out to 100 members of the agriculture and energy communities. Workshop invitees included agriculture group representatives, state employees at relevant agencies, farmers interested in renewable energy generation, renewable energy advocates, fuel cell industry representatives, and utility representatives. The audience for the day of the workshop included a good cross-section from all of these groups.

The morning portion of the workshop was a project presentation by Phil Goodrich at the University of Minnesota and Dennis Haubenschild. The presentation covered project history and development, challenges, lessons learned and next steps. There was a half-an-hour discussion after the project presentation by presenters and workshop attendees. An additional presentation was given by Ray Davy of Agri-waste. Agri-waste is a company working with a project team at a dairy in Baldwin, WI. The project team is looking at ways to compress methane for use as natural gas. The presentation by Mr. Davy also spurred a good discussion and gave workshop attendees a feel for additional uses of methane gas besides electricity production.

There was a break for lunch and then workshop attendees headed over the farm to take a tour of the farm and the alternative generation equipment. The tour was lead by Dennis Haubenschild, Philip Goodrich, and Rich Hueselkamp. The tour was cut a little short on account for the weather, there were very severe storms in the area that day. However, the workshop participants were educated about how the fuel cell works, how the gas clean-up process functions, the operation of the anaerobic digester and diesel generator set, and day-to-day farm operations.

Overall, the workshop participants had a positive experience and learned a great deal of information about the alternative generation project. Several of the participants made connections with other participants to advance individual projects and made significant work contacts. The Haubenschilds' have had thousands of visitors since the installation of their digester, but at least half of our tour group had not been to the farm before.

Appendix E: Fact Sheets Developed by the MN Project

Fuel Cells

Information for this factsheet provided by:

Minnesota Office of Environmental Assistance, *Common Types of Fuel Cells,* October, 2003

Clean Energy Resource Teams, *Designing a Clean Energy Future: A Resource Manual,* July, 2003

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WWW.MNPROJECT.ORG

MINNESOTA DEPARTMENT OF AGRICULTURE FROM THE FARM TO YOUR FAMILY

UNIVERSITY OF MINNESOTA

The College of Agricultural, Food and Environmental Sciences

Knowledge for a changing world

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

FUEL CELLS ARE ON THE CUTTING EDGE of future technologies and have the potential to reshape our energy future. They use an electrochemical process to turn hydrogen and oxygen into pollution-free electricity and heat. Fuel cells have the potential to make the U.S. an energy independent nation, transforming our economy from one based on imported fossil fuels to a "hydrogen economy" fueled by hydrogen generated with local renewable resources.

Background

Although the first fuel cell prototype was made in England in 1838, the modern version of fuel cell technology was developed as part of the Apollo space program. NASA has demonstrated the commercial viability of fuel cells by continuing to use them to power space flights. Fuel cells can replace internal combustion engines in vehicles, batteries in all sorts of portable devices like cell phones and watches, and can generate electricity and heat for buildings and homes. Fuel cells are modular and can be small enough to fit in a watch or big enough to power large buildings.

The most immediate future applications for fuel cells will be in vehicles and replacing batteries in phones and other mobile electronics. All of the major auto manufacturers have fuel cell vehicles under development and Honda and Toyota began leasing fuel cell cars on a small scale in 2003. Fuel cells are also being used in pilot trials at schools and in city buses in Iceland, the U.S. and European cities. Stationary applications in buildings for heating and electricity are available.

The market potential for fuel cells is estimated at $1.7 trillion by 2020. The private sector is investing $3 billion annually, and investment is growing each year. The high cost of fuel cells still remains a barrier for widespread commercial uses, but expectations are that they will be cost competitive with other technologies by the end of this decade.

Fuel cells can operate at conversion efficiencies as high as 80% for fuel cells running on hydrogen. Fuel cells running on methanol or gasoline are only 40% efficient, but all have the added advantage of producing thermal hot water that can be integrated into a combined heat and power system. This makes them an efficient energy source that can evolve to serve multiple needs.

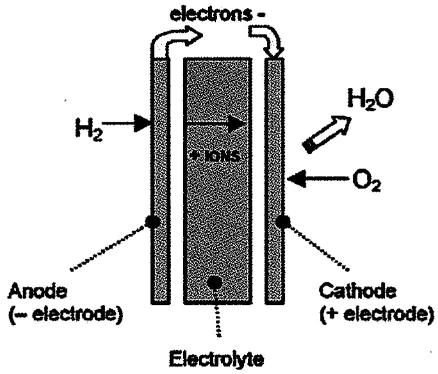
Fuel cells can also provide the added benefit of providing a clean source of energy. Because the energy is generated by a chemical reaction, the electron stream generated from fuel cells is cleaner than streams generated by conventional power plants. For many industries the quality of their power is not of extreme importance, but for some niche applications, such as computer chips, power quality is crucial.

Basics

All fuel cells create electricity through a electrochemical reaction of hydrogen and oxygen. The only by-products of a hydrogen-fueled fuel cell are pure water and heat. Although each type of fuel cell will run a bit differently, they have similar components. All fuel cells have a central electrolyte. An electrolyte is a material that conducts either a positive or a negatively charged atom or molecule (called an ion) from one side of itself to the other. This electrolyte is sandwiched between two electrodes. Like a car battery, a fuel cell has two electrodes: a positive electrode (the cathode) and a negative electrode (the anode). Unlike a car battery, however, the electrodes in the fuel cell contain special metals called "catalysts" that speed the rate of the electrochemical reaction. ***Types of fuel cells vary by the different materials used to make the electrolyte and these catalyst electrodes.***

In a fuel cell, when hydrogen (H) and oxygen (O) atoms come together to form water (H_2O) two electrons are released and are made available to power an external circuit. Although types of fuel cells may differ in the molecular form of the hydrogen and oxygen used to accomplish it this, basic, natural reaction is used in all fuel cells to make water and electricity, As shown in the diagram, hydrogen, (either pure or from some hydrocarbon fuel) and oxygen (from air) enter opposite sides of a fuel cell. An electrochemical reaction occurs at each electrode (at either the anode or the cathode, depending on the type). At the anode, the hydrogen atom loses an electron and its proton (or ion) goes into the electrolyte. The electrolyte is specifically made to conduct ions to the other pole of the fuel cell but not electrons. At the cathode, when two ions enter it from the circuit, these join with an oxygen atom and create a water molecule.

Electrons, directed to flow through a wire from one electrode to the other, power an electrical circuit for use.



Definitions

anode — the negatively charged electrode through which electrons leave a fuel cell

catalyst — a substance, usually a metal present in small amounts, that increases the speed of the reaction in a fuel cell without being consumed in the process.

cathode — the positively charged electrode through which electrons return to a fuel cell.

electrode — the conducting material, or pole, through which an electric current leaves or enters an electrolyte.

electrolyte — the material that conducts ions (positive or negatively charged ions) across the inside of a fuel cell from one of its electrodes to its opposite.

TYPE OF FUEL CELL	EFFICIENCY	OPERATING TEMPERATURE	USE
Proton Exchange Membrane (PEM) or Polymer Electrolyte Membrane (PEMFC)	40% (80%) with cogeneration	175° F	*Transportation* – cars, buses, boats, trains, scooters, bikes, wheelchairs, forklifts *Residential* – household electrical power needs *Portable* – laptop computers, cell phone, medical equipment, robots
Direct Methanol (DMFC)	40%	120 – 150° F	*Portable* – cell phone, laptop computers, vacuum cleaners, highway road signs
Alkali (AFC)	60% (80%) with cogeneration	250 – 500° F	*NASA space program* – space vehicles
Phosphoric Acid (PAFC)	40% (80% with cogeneration)	300 – 400° F	*Landfill/wastewater treatment facilities* – to generate power from methane gas
Solid Oxide (SOFC)	55% (85% with cogeneration)	1,800° F	*Commercial* – utility power plants, airport terminals, public and commercial office buildings, hotels, hospitals
Molten Carbonate (MCFC)	55% (85% with cogeneration)	1,200° F	*Commercial* – utility power plants, airport terminals, schools, office buildings, hotels, hospitals

Alternative Generation Options for Anaerobic Manure Digesters

For more information, please contact:

Philip Goodrich
University of Minnesota
612-625-4215
goodrich@umn.edu

Matt Drewitz
MN Dept. of Agriculture
651-296-3820
Matt.Drewitz@state.mn.us

Amanda Bilek
The Minnesota Project
651.645.6159, ext. 5
abilek@mnproject.org
www.mnproject.org

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MINNESOTA DEPARTMENT OF AGRICULTURE
FROM THE FARM TO YOUR FAMILY

University of Minnesota

The College of Agricultural, Food and Environmental Sciences
Knowledge for a changing world

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

IN 2003, THE MINNESOTA DEPARTMENT OF AGRICULTURE was awarded a grant of $221,000 to conduct fuel cell research using biogas from an anaerobic digester as fuel. Funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative Commission on Minnesota Resources (LCMR).

Project Partners

Dennis Haubenschild, dairy farmer

University of Minnesota Biosystems and Agricultural Engineering Department

Minnesota Department of Agriculture

the Minnesota Project

Contributing Partners

East Central Energy

Great River Energy

John Deere, Inc.

Electric Power Research Institute

Plug Power, Inc.

CES-Landtec Engineering

Donaldson Corporation

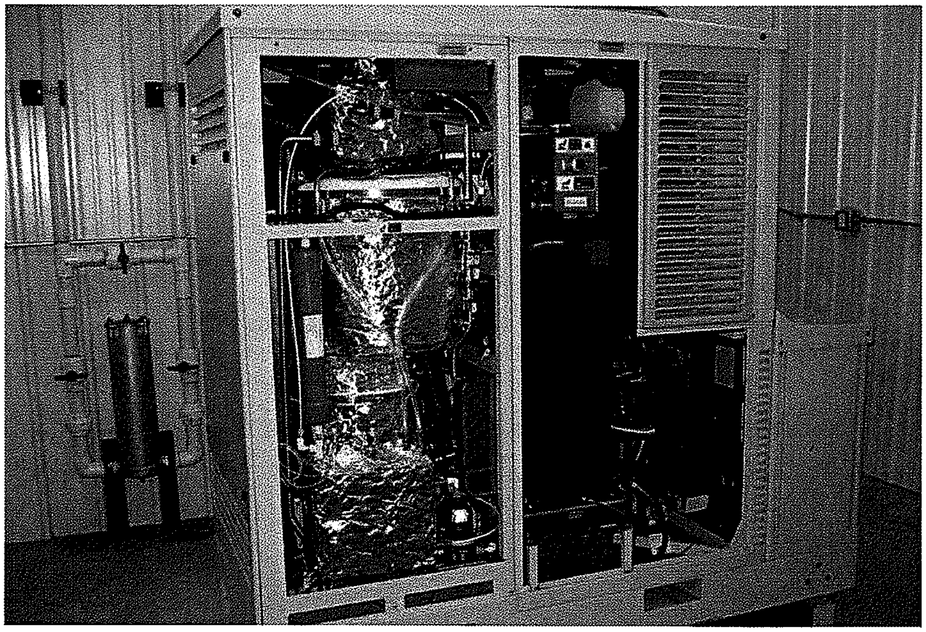
Background on Alternative Generation Test Site

- Haubenschild Farms, near Princeton, Minnesota
- 800-cow dairy farm, 1000 acres of crop land
- Built plug-flow digester in 1999
- Biogas is being converted to electricity by 130 kW internal combustion engine generator
- Digester is producing excess biogas

Environment and Economic Benefits

- Reduced reliance on fossil fuels as an energy source
- Reduced odors and emissions
- Nutrient properties of the digested manure are enhanced, reducing the potential for pollution to water and soil
- Distributed energy from a renewable resource supports the rural economy while reducing reliance on fossil fuels and reducing emission of greenhouse gases

View of Haubenschild barn, digester and engine generator room at time of installation in 1999.



5kW proton exchange membrane (PEM) fuel cell at Haubenschild Dairy Farm

Project Purpose

Investigate the use of alternative technologies for producing electricity from biogas.

Project Focus

Test technologies that have the potential to be more environmentally friendly and easier to maintain than conventional engine generator systems. A fuel cell was selected as the technology to research. Throughout the course of the this project, the University of Minnesota has looked at a number of aspects of employing a fuel cell with an anaerobic digester, which include: fuel cell type, installation and operation, gas clean up, fuel cell emissions, and economic feasibility.

Challenges of Using Biogas for a Fuel Cell

- Hydrogen sulfide removal
  Initial concentration=3000-5000
  parts per million volume basis
  Need concentration < 15 ppmv
  parts per million volume basis
- Moisture removal
  Need dry gas
- Carbon dioxide removal
  Need concentration < 50,000
  parts per million volume basis

Project Execution

A small portion of biogas from the existing plug-flow anaerobic manure digester on the Haubenschild dairy farm was routed into a new research building that housed the fuel cell, gas clean up equipment, and monitoring equipment. A 5kW proton exchange membrane (PEM) fuel cell purchased from Plug Power, Inc. was used for the research project.

University of Minnesota researchers (Dr. Phil Goodrich, Rich Huelskamp, David Nelson, and David Schmidt) worked on developing and implementing the gas clean-up process and monitoring strategy for the project.

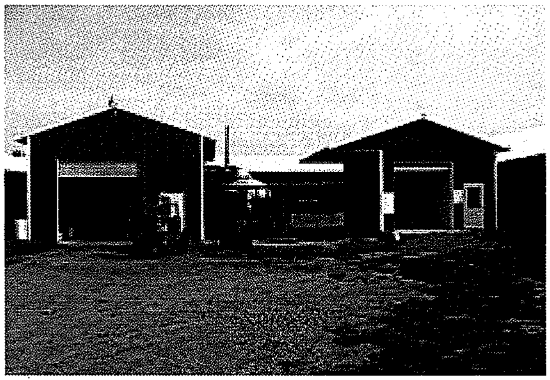
The greatest challenge of this project was cleaning the biogas of impurities (carbon dioxide, hydrogen sulfide, and water vapor) so the biogas could be effectively used in the fuel cell and its reformer.

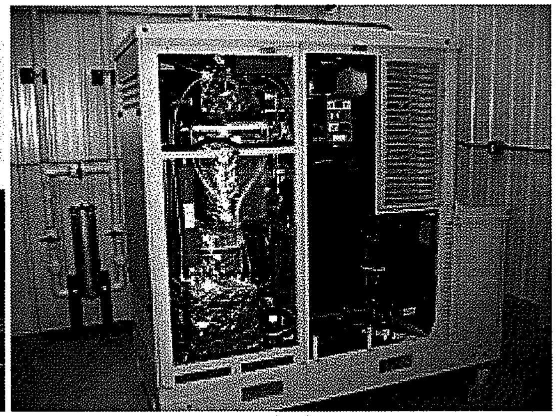
In January 2005, the fuel cell was operated on compressed natural gas and in February 2005, the fuel cell was operated on biogas for the first time. Since then the gas cleanup system has been continually modified to decrease the contaminants in the fuel and to develop a more reliable gas quality, the fuel cell has been used to test the purified gas intermittently. The fuel cell has operated continuously for periods up to 10 hours at a time. Data has been collected on the performance of the fuel cell and also the emissions given off during operation when using biogas. The emissions from the fuel cell exhaust are essentially non-detectable. The researchers are working to make the cleanup equipment system more reliable to provide a stream of quality methane for the fuel cell, thereby increasing the energy that can be produced with this clean energy converter.

Appendix F: MN Project Website Information

Communities Agriculture Energy Emerging Issues
State Policy Federal Policy Clean Energy Resource Teams
Farm Energy/Biogas Energy Publications Links
Haubenschild Digester Digester Resources/Links

Advancing Utilization of Manure Methane Digester


Existing engine generator building on left, alternative generation research building on the right housing 5kW fuel cell.


5kW fuel cell using hydrogen to generate electricity without combustion.

A grant made to the Minnesota Department of Agriculture, from the Natural Resources Trust Fund, as recommended by the Legislative Commission on Minnesota Resources (LCMR), enabled the University of Minnesota Department of Biosystems and Agricultural Engineering to complete dual research objectives at Haubenschild Farms.

1. Evaluate alternative technologies for generating electricity from biogas that are more environmentally friendly and easier to maintain than an internal combustion engine.
2. Identify compatible waste streams that will enhance the adoption of manure digestion technology.

Project Partners

Haubenschild Farms, Dennis Haubenschild

University of Minnesota, Department of Biosystems and Agricultural Engineering, http://www.bae.umn.edu/

Minnesota Department of Agriculture, www.mda.state.mn.us/feedlots/digester.htm

the Minnesota Project, www.mnproject.org/indexs-biogas.html

Contributing Partners

East Central Energy, http://www.eastcentralenergy.com/

Great River Energy, http://www.greatriverenergy.com/

John Deere, Inc. www.deere.com/en_US/deerecom/usa_canada.html

Electric Power Research Institute, http://www.epri.com/

Plug Power, Inc. http://www.plugpower.com/

CES-Landtec Engineering, http://www.ces-landtec.com/

Donaldson Corporation, www.donaldson.com/en/index.html

Project Materials

Fuel cell basics fact sheet, 96 KB PDF

Alternative generation project fact sheet, 163 KB PDF

Manure to hydrogen poster 48 KB Powerpoint

Manure to power production poster 1 MB Powerpoint

Haubenschild farm project poster 658 KB Powerpoint

Comparison of fuel cell and genset utilizing biogas poster 4 MB Powerpoint

Introduction to anaerobic digestion and fuel cells 5 MB Powerpoint

Advancing Utilization of Manure Methane Digester project presentations

- Hydrogen Hydrogen and Electrons from Manure 8.5 MB Powerpoint
- Project overview, 8.5 MB Powerpoint or 7 MB Powerpoint

Air and waste management research paper, 568KB Word Document

Appendix G: MDA Anaerobic Digester Web Page

MINNESOTA DEPARTMENT OF AGRICULTURE
FROM THE FARM TO YOUR FAMILY

Anaerobic Manure Digestion Information and Resources

Anaerobic manure digestion for animal agriculture has come into the main stream in recent years in the United States. Other countries in Asia and Europe have used this technology in one form or the other for centuries in small applications, but it hasn't been until the last 30 years that this technology has been used widely on a commercial scale.

Livestock producers across the country have been researching this technology and some have established anaerobic manure digesters on their own farms. As the technology improves, the relative risk of having a manure digester will decrease and the efficiency of the system will increase.

To help answer some of the basic questions involving Anaerobic Manure Digestion, the Minnesota Department of Agriculture has developed this web page to provide some answers about anaerobic manure digestion and information resources on this technology. The information has been broken into the following categories:

- FAQs about Anaerobic Manure Digestion for Livestock Operations
- Minnesota Department of Agriculture LCMR project entitled, "Advancing Utilization of Manure Methane Digester Electrical Generation "
- Case Study: Haubenschild Dairy
- Annotated Bibliography of Anaerobic Manure Digester Reports
- Reference and Resources for Anaerobic Manure Digesters

FAQs about the MDA Methane Digester Loan Program

The MDA developed the Methane Digester Loan Program in 1998 to help supplement the funds needed for livestock producers in Minnesota to begin installing digesters on their farms. This loan program has helped one dairy farmer in Minnesota install manure digester. One additional farm has been conditionally approved for a loan. The criteria for the Methane Digester Loan are listed below (also, see Session Laws 2002, 41B.049):

What is the purpose of Methane Digester Loan Program?
To help finance the purchase of necessary equipment and the construction of a system that will use manure to produce electricity. The State of Minnesota has established a revolving loan fund to appropriate funds for this program.

Who is eligible for loans for manure methane digester technology?
To be eligible for a loan under this section a borrower must:

- locate the projects and use the equipment and practices on a farm in Minnesota;
- provide evidence of financial stability;
- demonstrate an ability to repay the loan;
- provide evidence that the practices implemented and capital assets purchased will be properly managed and maintained; and
- a borrower who has previously received a loan under this program is prohibited from receiving another methane digester loan.

What are the terms and criteria of the methane digester loan program?

- The Rural Finance Authority (RFA) of the Minnesota Department of Agriculture may participate with a local lender or make a direct loan to a farmer who is eligible for the biogas loans.
- Loans made under this program are currently no-interest loans.
- Application for a loan participation or direct loan must be made on forms prescribed by the RFA.
- No loan participation or direct loan may exceed $250,000.

- Standards for loan amortization shall be set by the RFA not to exceed ten years.
- Security for the loans must be a personal note executed by the borrower and whatever other security is required by the eligible lender or the RFA.
- No loan proceeds may be used to refinance a debt existing prior to application.
- Loans under this program may be used as a match for Federal loans or grants.
- There is a $100 non-refundable application fee due with the application.

For more information, please contact Gary Blahosky at 651-296-4985 at the Minnesota Department of Agriculture.

Methane Digester Loan Application (PDF: 191 KB / 7 pages)

Applications or inquires by mail are to be sent to:

Rural Finance Authority
Minnesota Department of Agriculture
90 West Plato Blvd.
St. Paul, MN 55107-2094

LCMR Project: Using a Fuel Cell to Generate Electricity from Manure

In 2003, the Legislative Commission on Minnesota Resources (LCMR) awarded the MDA a $221,000 grant to research the project entitled, **"Advancing Utilization of Manure Methane Digester Electrical Generation"**. The MDA will be working with the University of Minnesota (U of M) Biosystems and Agricultural Engineering Department, The Minnesota Project, and farmer Dennis Haubenschild to complete the objectives of this project. The U of M will be testing the efficacy of using a fuel cell to produce electricity from biogas; The Minnesota Project will be assisting with the education component of the project; and Dennis Haubenschild will be assisting the U of M by monitoring and performing daily maintenance on the fuel cell.

This project will investigate the utilization of manure methane technologies through the use of a fuel cell and microturbine generators and through the use of alternative waste streams to be digested with manure. The purpose of this project is to: 1) evaluate alternative technologies for generating electricity from bio-gas that are more environmentally friendly and easier to maintain than internal combustion engines and, 2) identify compatible waste streams that will enhance the adoption of manure digestion technology. Deliverables for this project will include: 1) data collection and analysis of the feasibility of the use of a fuel cell with a manure digester, 2) report on microturbine feasibility from literature and published reports, and 3) a report on compatible waste streams.

Case Study: Haubenschild Dairy Manure Digester, Princeton, MN

The following was reproduced from the Executive Summary of the publication entitled, "Final Report: Haubenschild Farms Anaerobic Digester, August 2002" developed by The Minnesota Project

Haubenschild Farms is a 1000-acre, family owned and operated dairy farm near Princeton, Minnesota. In 1998 the owners were planning to increase the size of their operations, and considered the possibility of installing an anaerobic manure digester. They knew that this type of system could result in environmental benefits while offering a return on their investment. Some of the key expected benefits of an anaerobic digester are:

- Odor control
- Renewable energy production
- Pathogen reduction
- Greenhouse gas reduction
- Reduction in total oxygen demand of the treated manure (total oxygen demand is a measure of potential impact on aquatic systems)

Haubenschild Farms applied for and was selected as an AgSTAR "Charter Farm," one of 13 such farms selected nationwide to demonstrate farm-scale anaerobic digestion technologies. AgSTAR is a joint program of the U.S. Environmental Protection Agency, U.S. Department of Energy and U.S. Department of Agriculture, designed to promote the use of anaerobic digestion systems. In addition to the AgSTAR program, the Haubenschild Farms project received assistance from the Minnesota Department of Agriculture, Minnesota Department of Commerce and the Minnesota Office of Environmental Assistance. With financing complete, construction of the digester was started in the summer of 1999 and completed in October of the same year. Total construction cost of the digester and generator system was about $355,000.

The Haubenschild Farms digester is a covered 350,000-gallon concrete tank installed in the ground, with suspended heating pipes to heat the manure inside the digester where bacteria breaks down the manure, creating methane. A 135-kilowatt engine-generator set is fueled with methane captured from the digester. The hot water to heat the digester is recovered from the engine-generator's cooling jacket. Barn floor space is also heated with the recovered heat. The digested effluent, odor reduced, flows to a lined storage pond where it is kept until it can be injected or broadcast spread on fields for crop production.

When the digester was started, it was processing manure from about 425 dairy cows, which was about half of its total design capacity of 1000 cows. In 2000, Haubenschild Farms built a second free stall barn and has expanded to a current size of about 750 cows. Since startup in the fall of 1999, the biogas output of the digester steadily increased to about 65,000 cubic feet by May 2000. Currently, more biogas is being produced than can be used by the engine-generator, so it is hard to estimate exactly how much biogas is being produced. The Haubenschilds are considering adding generation capacity to utilize the excess biogas. Approximately 70,000 cubic feet/day of biogas is used by the engine generator; the rest is currently flared. With 425 cows, the biogas output per cow was almost twice projections – with 750 cows, the output per cow has come down somewhat to about 40 percent above projections. Haubenschild's cows are producing about 50 percent more manure per cow than the digester was engineered for, which somewhat explains the high biogas production per cow.

The sale of the electricity generated is an important benefit of the project. Before the digester was built, Haubenschild Farms entered into a power purchase contract proposed by the local electric cooperative, East Central Energy, who greeted the project with enthusiasm and offered Haubenschild Farms a very favorable contract. Since the expansion of the milking herd size from 425 to about 750 cows in the summer of 2000, the digester has been producing enough electricity to provide all the electric needs on-farm, plus enough surplus electricity to power about 75 additional homes.

The building and operation of the Haubenschild Farms project has offered several key lessons for future digesters:

- Payback of 5 years on investment is possible
- A good time to install a digester is when changing or expanding operations
- Electric utility cooperation is important
- Active management is crucial for stable digester and engine operation
- Digester design and engineering expertise is key
- There are barriers to financing digester systems
- Cooperative agency participation reduces the barriers to a project's success
- Manure collection method and collection frequency are important. For more information, contact Minnesota Project.

References and Resources

Annotated Bibliography of AD Resources and References

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 o f 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.

Additional References and Web Sites

US EPA AgSTAR Program. This program is a joint venture between EPA, USDA, and DOE and provides resources and technical assistance on AD.

University of Adelaide, Australia, Paul Harris: Introduction to Biogas. This web site has some basic info on ADs and how they work.

Canadian Agri-Food Research Council: Manure Net. This is a very useful website developed by the Canadian Government. This website information on AD in the United States, Canada, Europe, Asia, and Australia.

University of Wisconsin Extension: Discovery Farms Program. The Discovery Farms program in Wisconsin developed a publication (A3766) in 2001 entitled ***Anaerobic Digesters and Methane Production...Questions that need to be asked and answered before investing your money***. This publication is very germane to Minnesota's issues involved with AD.

Biogas Works: This web site has numerous links to manure digester sites and information.

RCM Digesters: This website has a lot information on AD and shows examples of digesters installed, including the Haubenschild Farm manure digester in Princeton, MN.

Agricultural Utilization Research Institute (AURI) in Minnesota, in conjunction with RCM digesters, developed a quick checklist to determine if a livestock producers operation would be a candidate for AD.

University of Minnesota Biosystems and Agricultural Engineering: David Schmidt, staff engineer with the U of M, has developed a web site devote to manure and odor management. The web site has information on manure digesters as well.

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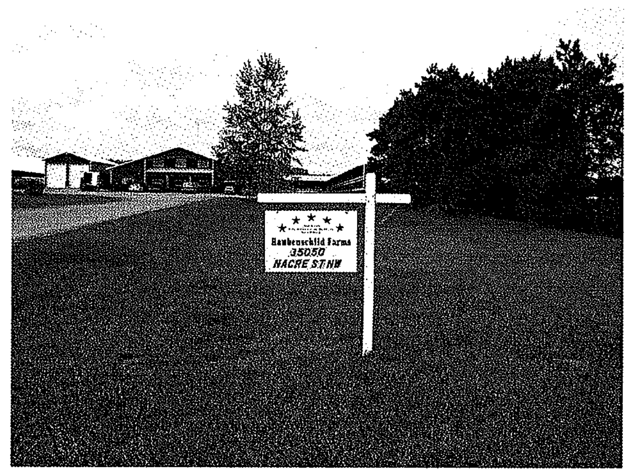
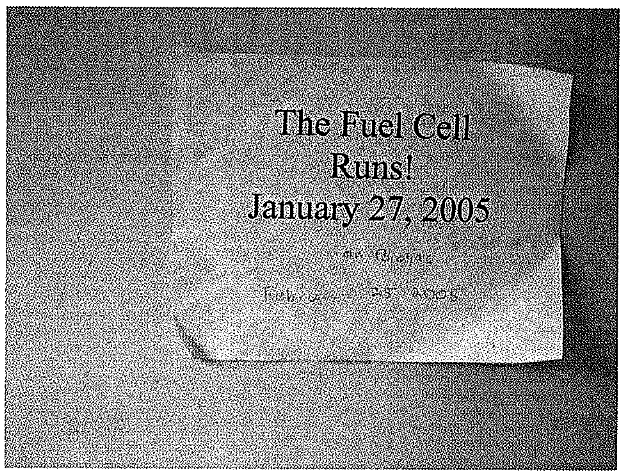
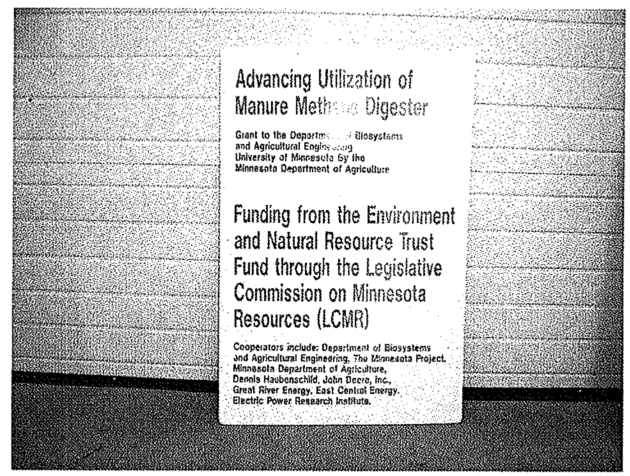
Appendix H: LCMR Project Photos (Power Point)

Haubenschild Farm: LCMR Project Research Site Location (Princeton, MN)

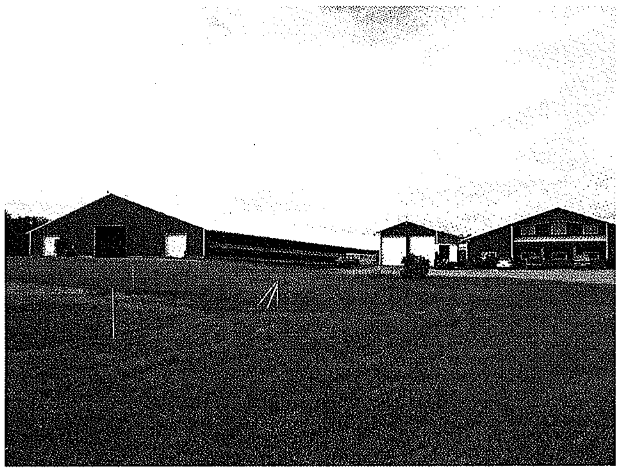




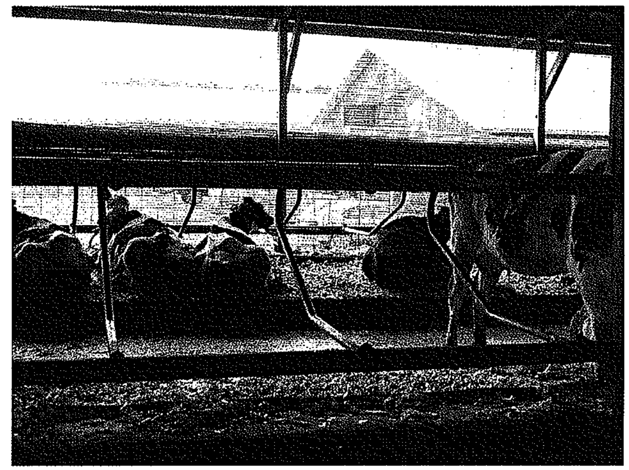


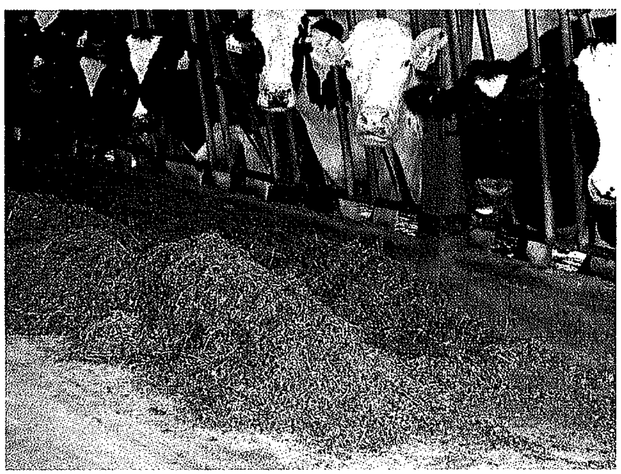
Haubenschild Operation

Haubenschild Dairy



Cows resting on newspaper bedding



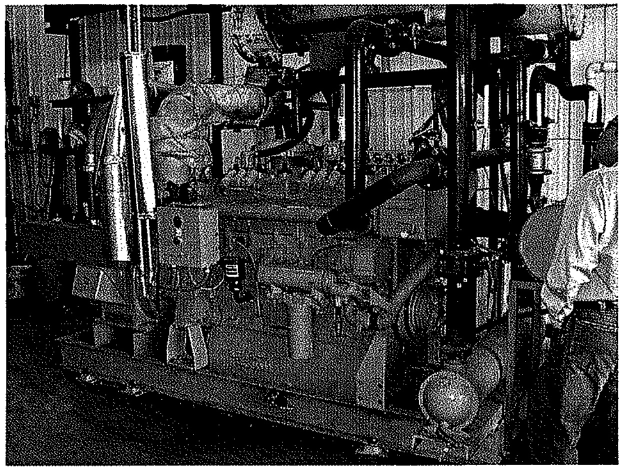


Cows Eating in Barn

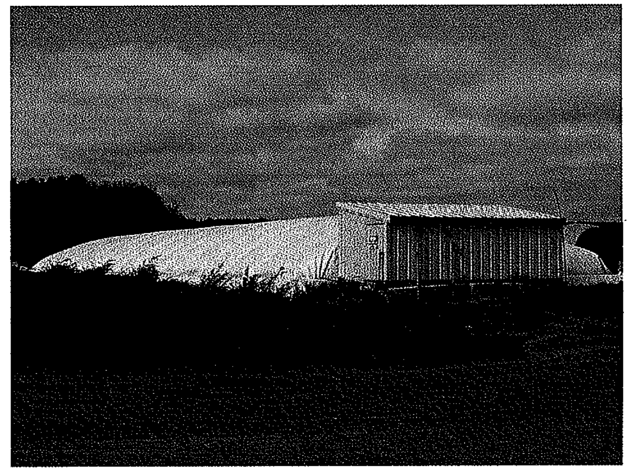
Dry Cows on Pasture

Digester and Existing Genset

130 kW Catepillar Engine Generator



Anaerobic Manure Digester



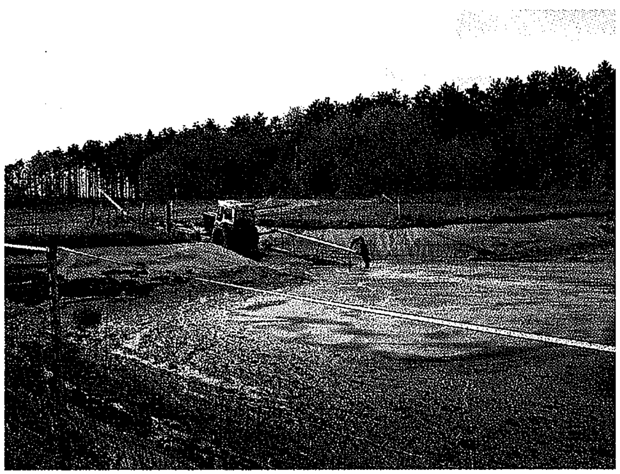
Biogas Flare

Manure Storage Basin with Liner

Manure Handling and Land Application

Manure Tank Applicator

Alfalfa Field for Manure Application



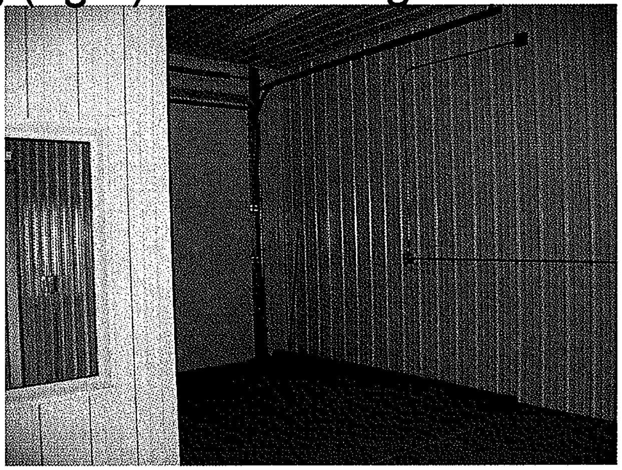
Manure Pump and Agitator

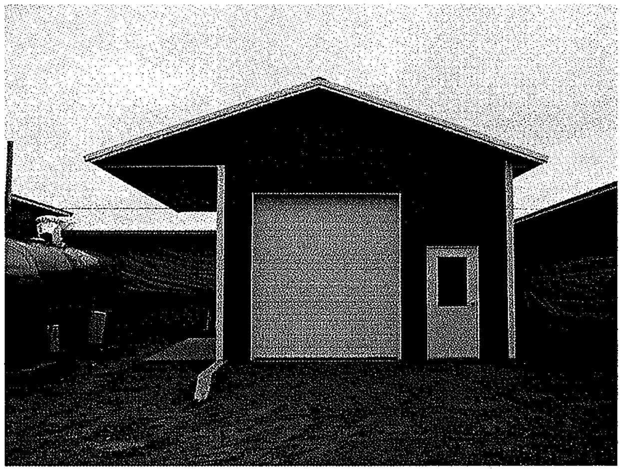
Corn Field for Manure Application

Fuel Cell Research Facility Funded By John Deere Inc.

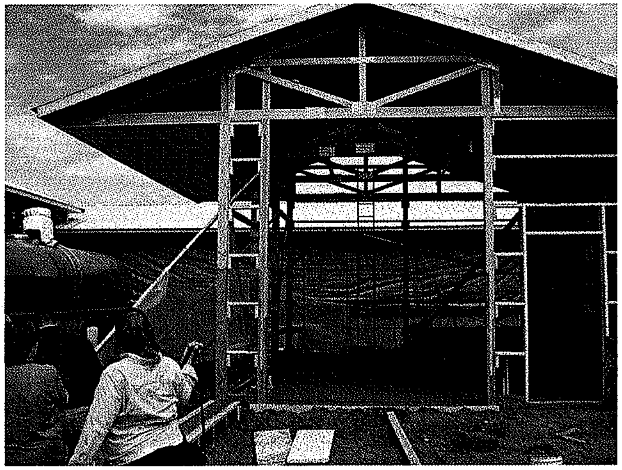
Existing Generator Building (left) and New Building (right)

Building Interior



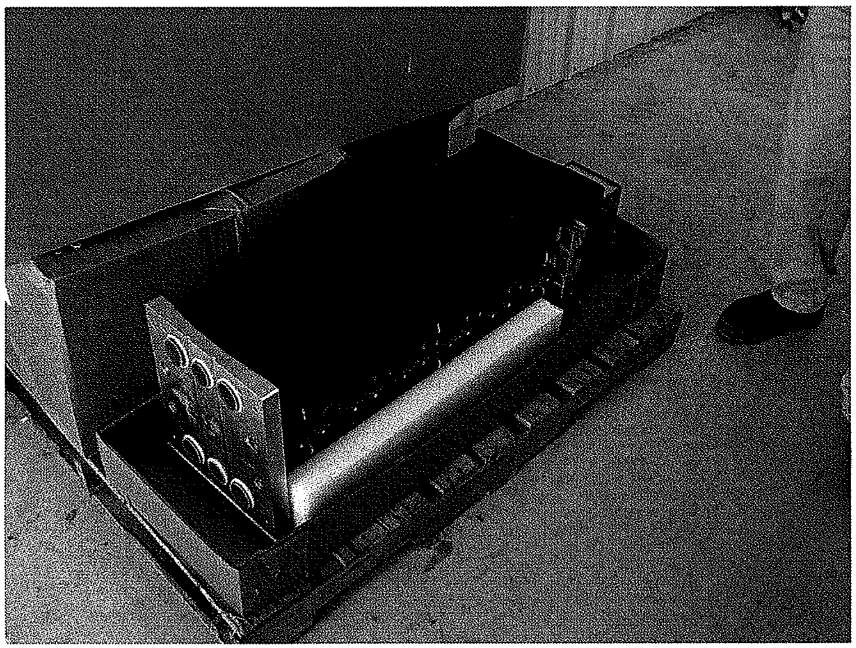


Finished Building

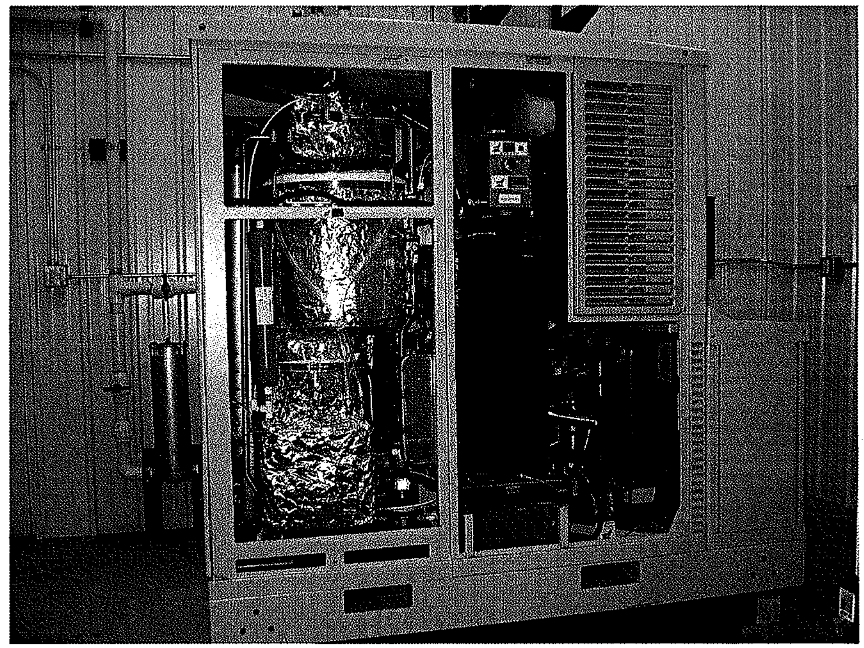


Construction of Building

Fuel Cell Delivery (September 2004)



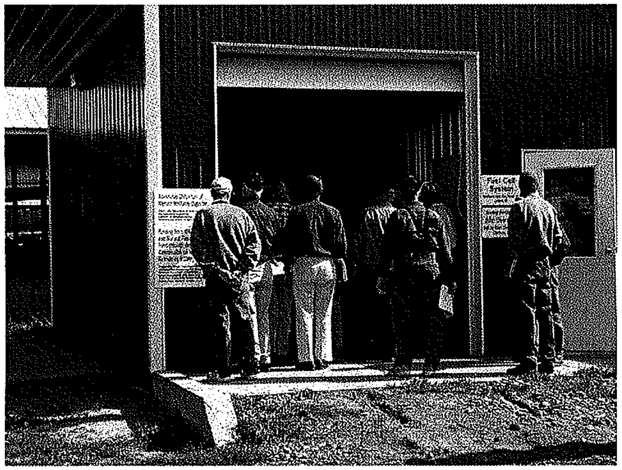
Fuel Cell Stack in Crate



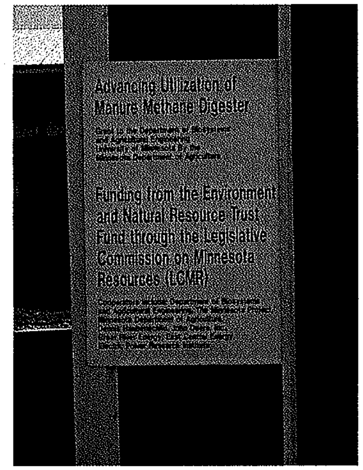
Fuel Cell after Delivery

Sept. 30, 2004 field day (NRCS Project and LCMR Project)

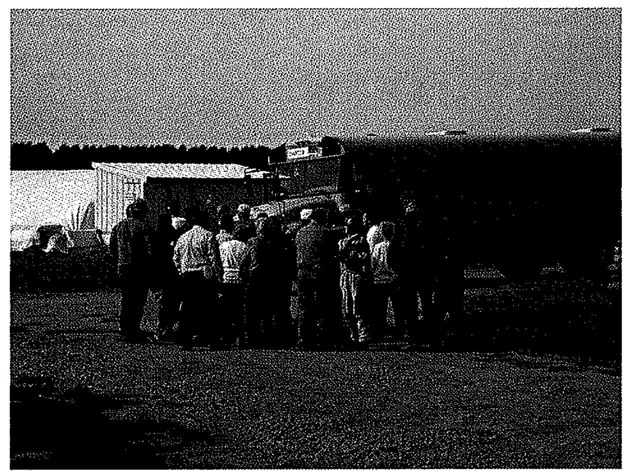
Participants Learning about Fuel Cells



LCMR Project Sign



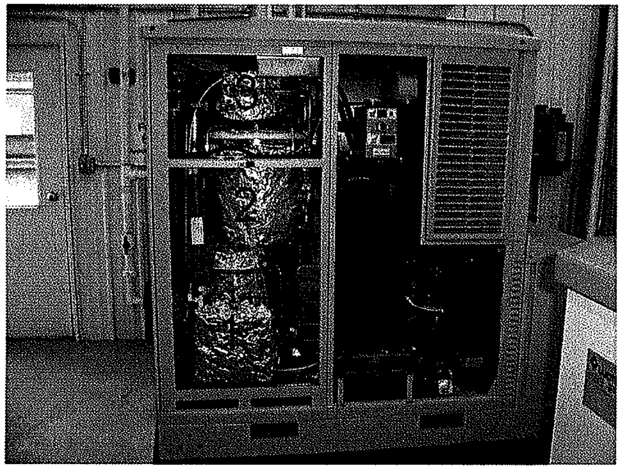
Dave Nelson (U of M) Speaking



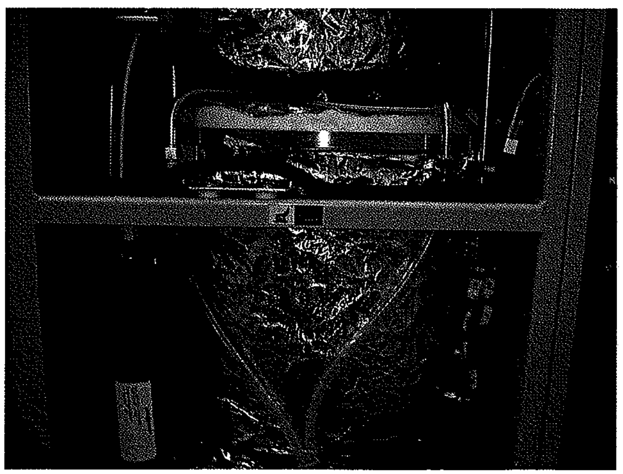
Dennis H. Speaking to Participants

Fuel Cell and H2 Reformer

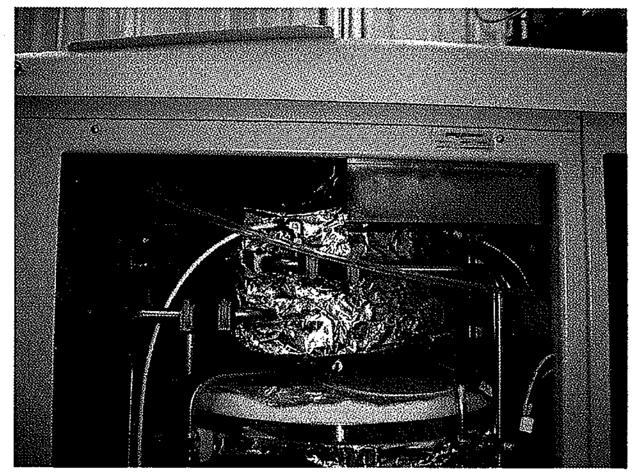
Fuel Cell with Side Panel Off



Stage 1 H2 Reformer (1)



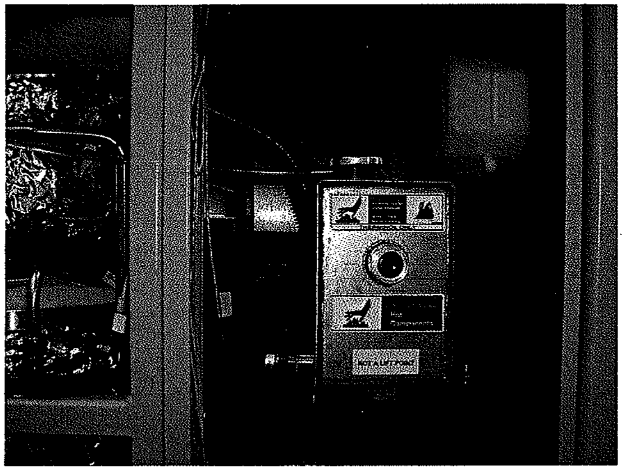
Stage 2 H2 Reformer (2)



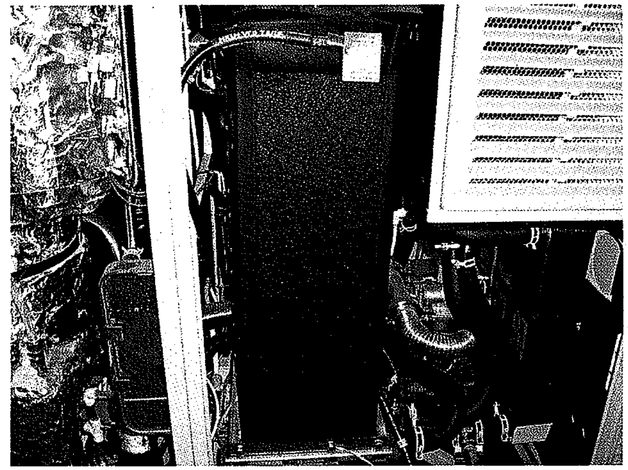
Stage 3 H2 Reformer (3)

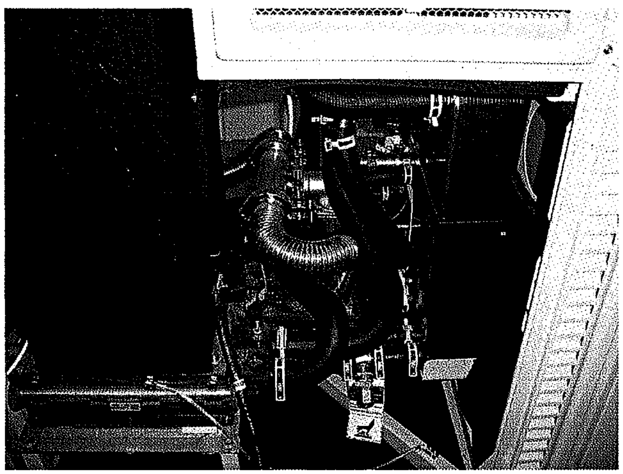
Fuel Cell Stack Components

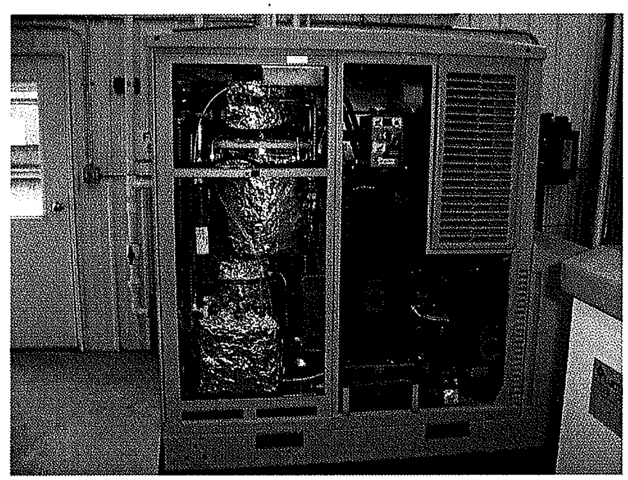
Reformed Gas Enters Fuel Cell Stack (4)



Fuel Cell Stack (5)

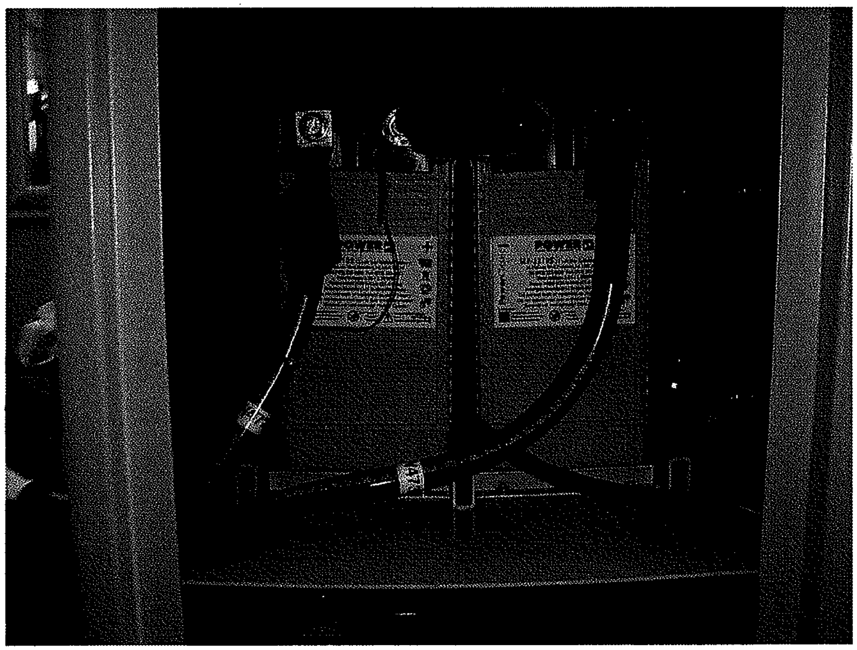






Electrical Generation, Water Processing, and Emissions from Fuel Cell Stack (6)

Fuel Cell Battery and Run Indicator Light

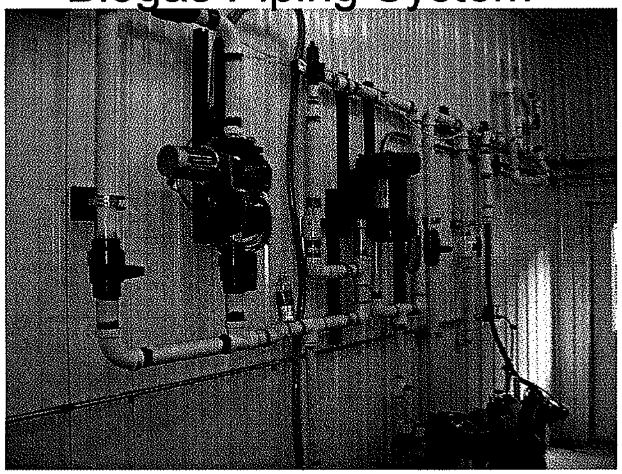


Batteries for Energy Storage

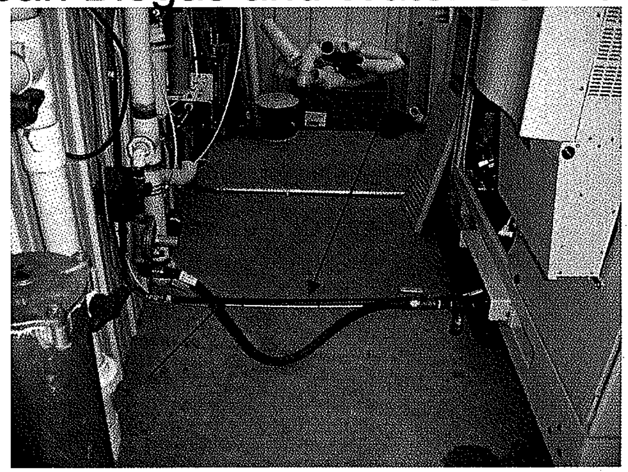
Indicator Light on Fuel Cell

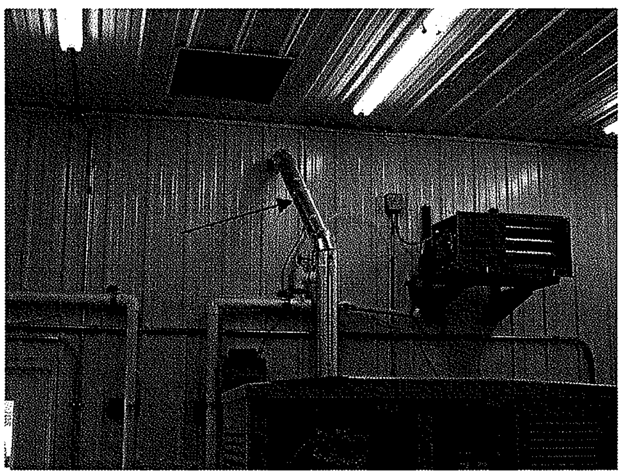
Gas Piping System In the Fuel Cell Research Facility

Biogas Piping System

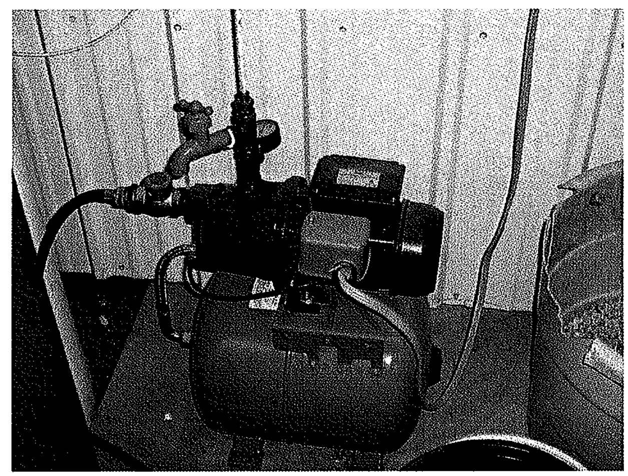


Clean Biogas and Water Connections





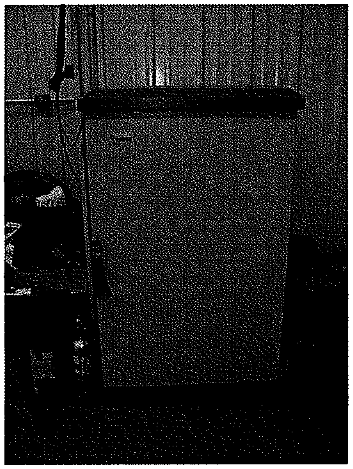
Vent for Fuel Cell Emissions



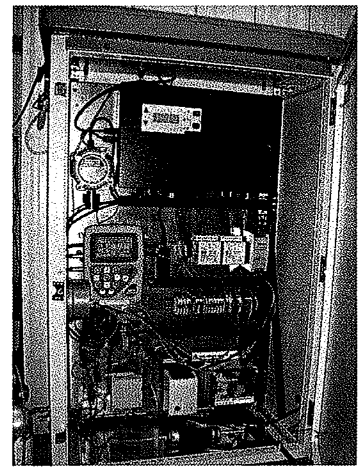
Biogas Compressor Pump

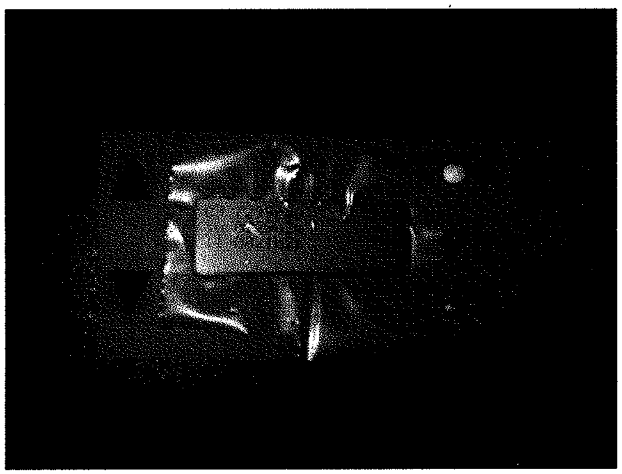
Biogas Air Quality Monitoring System

Biogas Monitor (exterior)

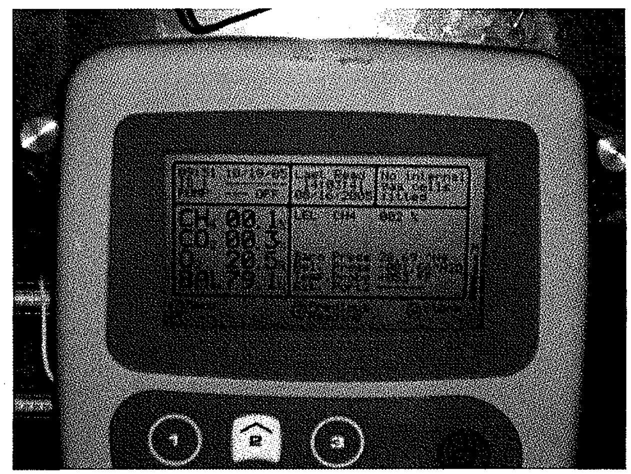


Biogas Monitor (inside)





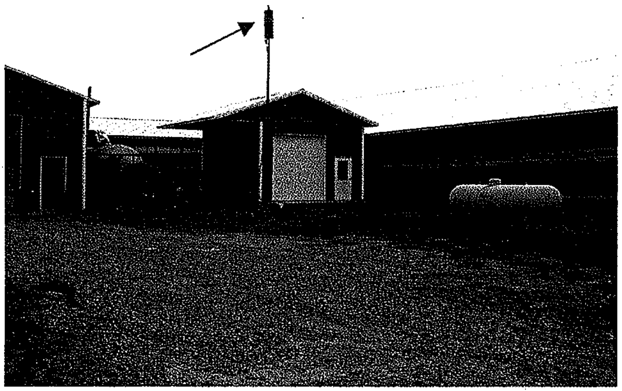
Biogas Air Quality Readings



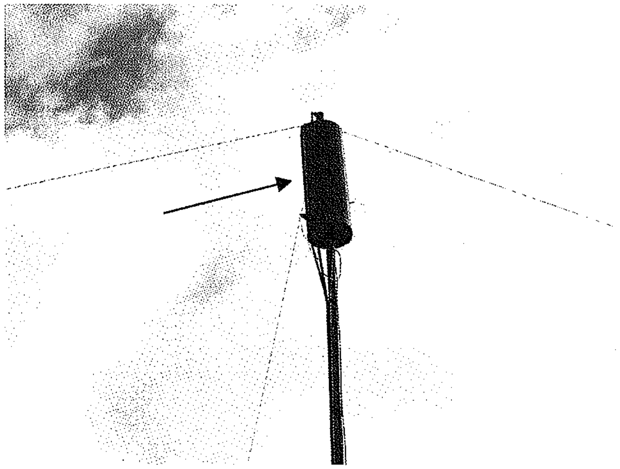
Ambient Air Monitor

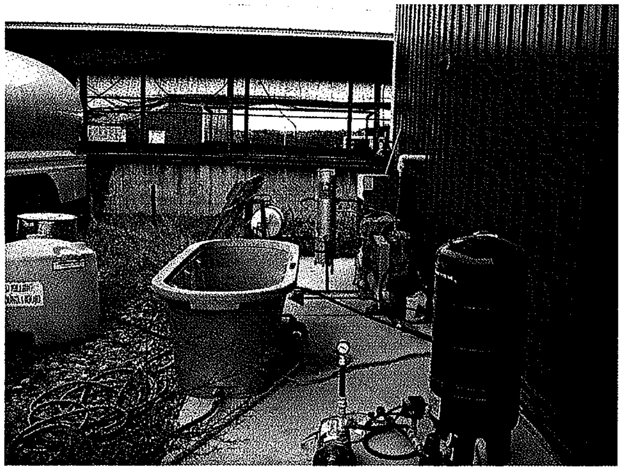
Water Tower Biogas Clean Up System

Water Tower next to Building

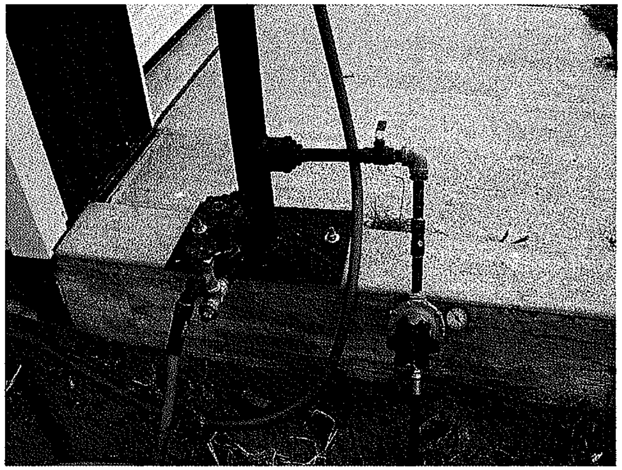


Water Tower (close-up)



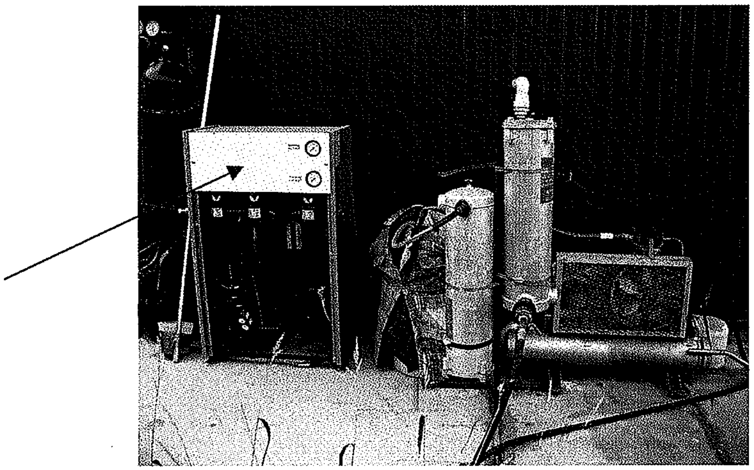


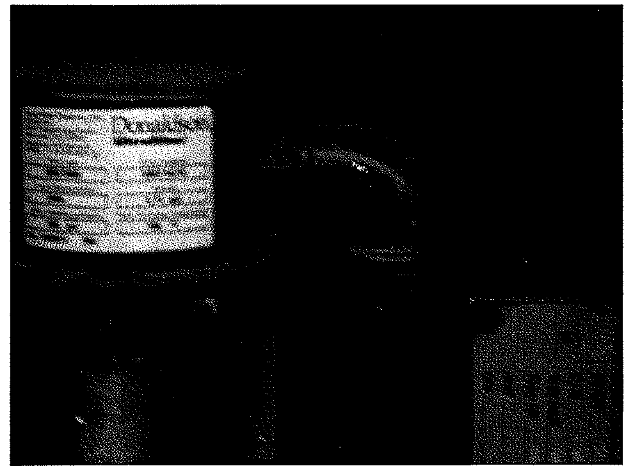
Water Recirculation System

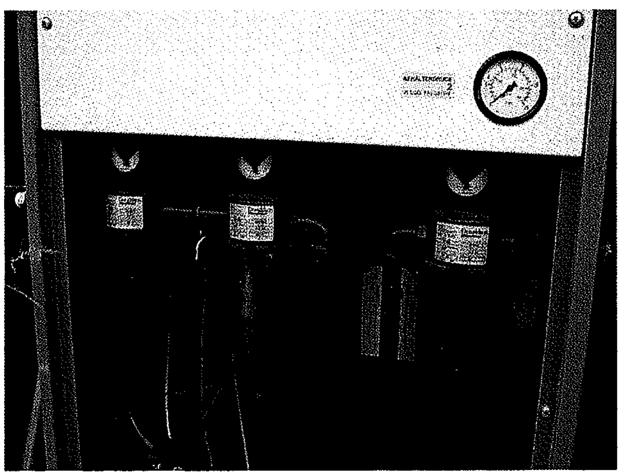


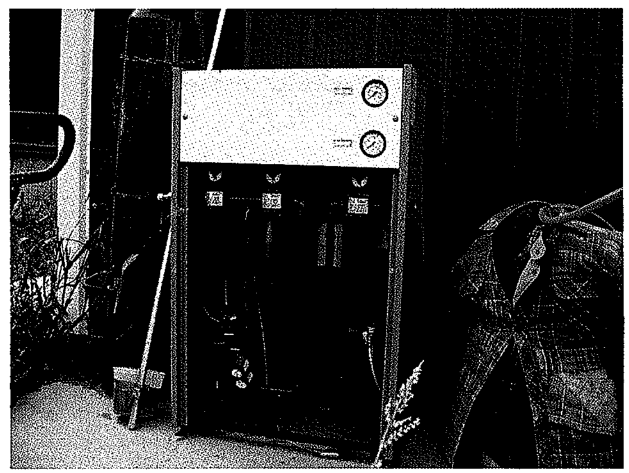
Water Tower Base and Water Shut Off Valyes

Pressure Swing Absorber Biogas Clean Up System





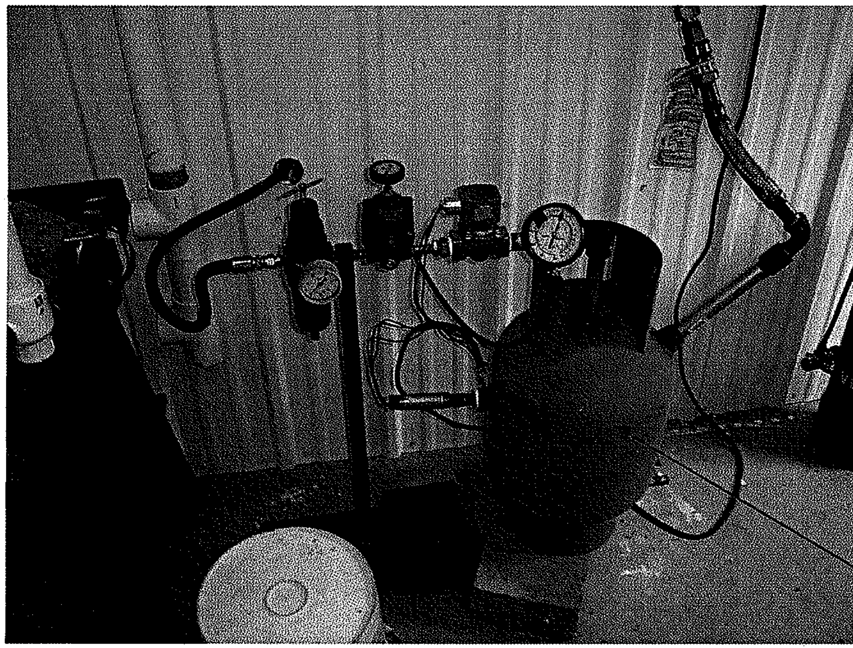




Donaldson Pressure Swing Absorber (CO_2 cleanup)

Hydrogen Sulfide Clean Up of Biogas (Iron Scrubber)

Iron Fillings for Scrubber

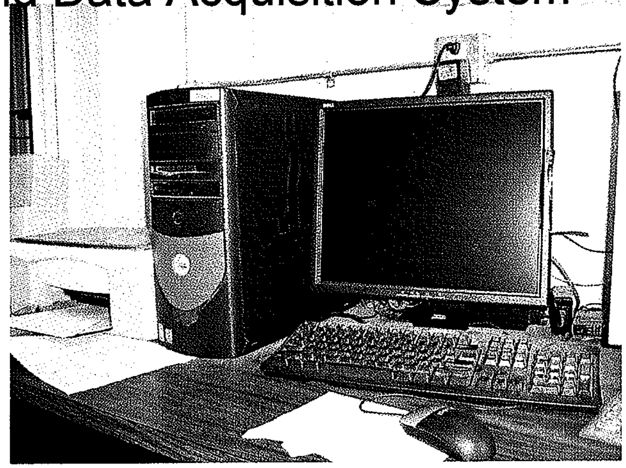


Iron Scrubber to take H2S out of Biogas

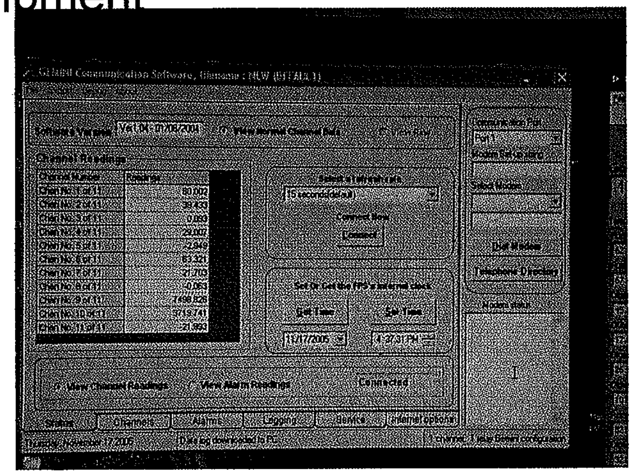
Steel Wool for Scrubber

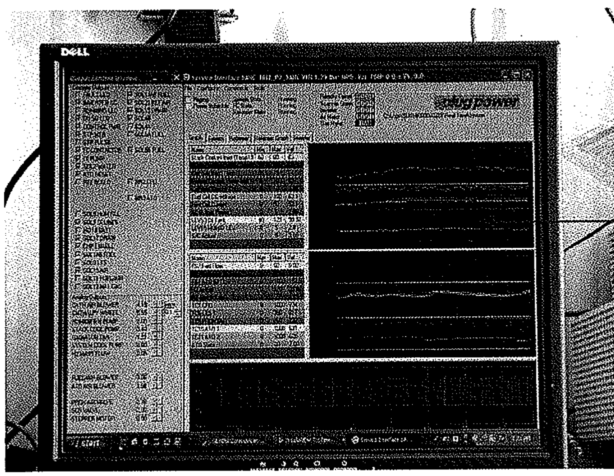
Data Acquisition System

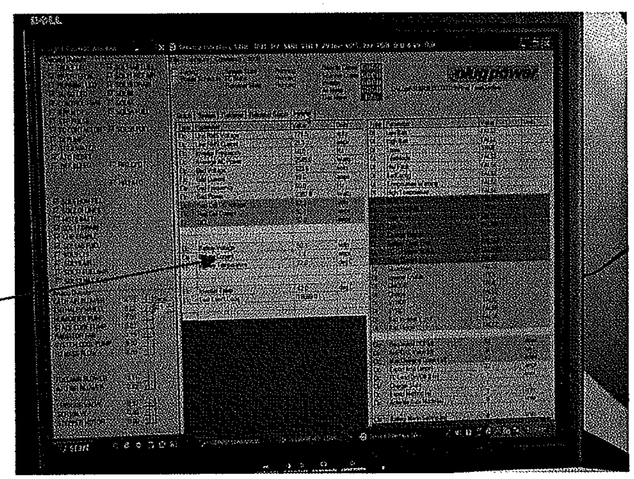
Computer that Controls the Fuel Cell and Data Acquisition System



Readout from Biogas Quality Monitoring Equipment



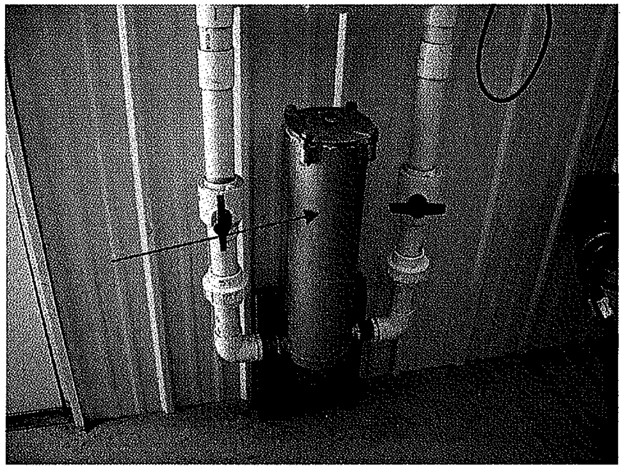




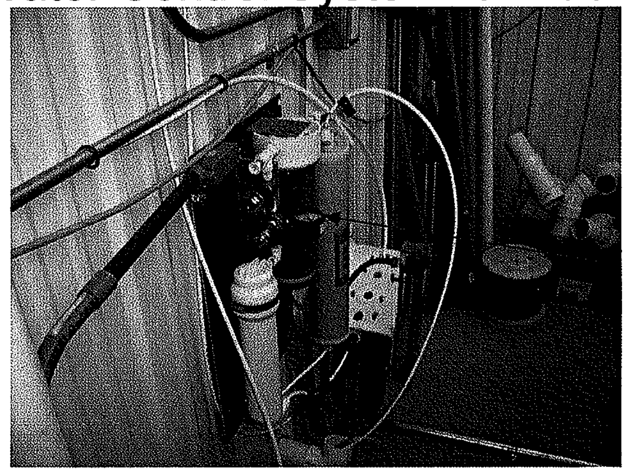
Plug Power Fuel Cell Software Readouts and Output

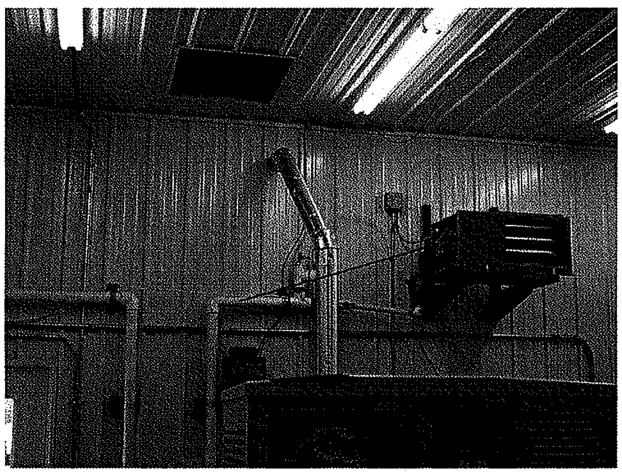
Additional Gas and Water Monitoring Systems

Desiccator for Biogas

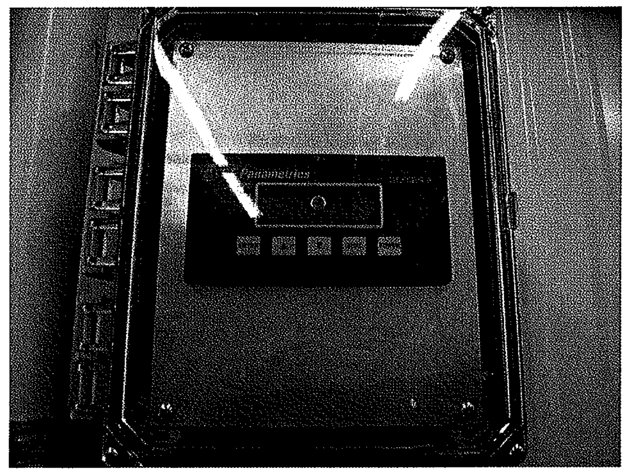


Water Control System for Fuel Cell





Natural Gas Heater for Testing Biogas



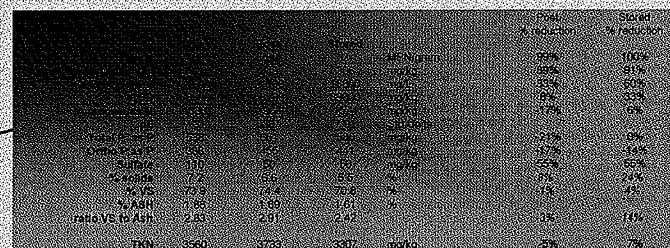
Natural Gas Heater Controls

Appendix I: Poster Displays Developed for LCMR Project

Producing Renewable Energy and Reducing Greenhouse Gases

To

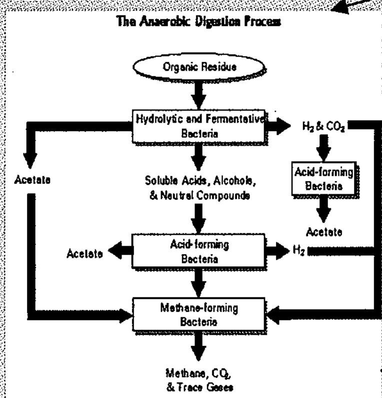
Solve Today's Agriculture Waste Management Issues



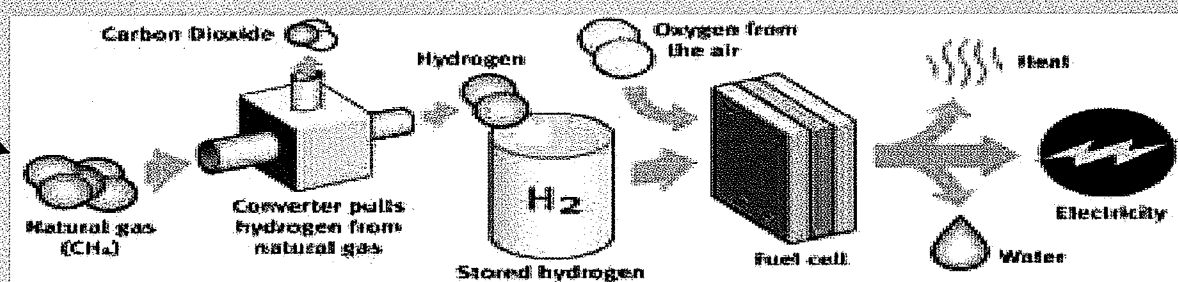
			Stored		Post % reduction	Stored % reduction
[illegible]	[illegible]	[illegible]	[illegible]	MPN/gram	99%	100%
[illegible]	[illegible]	[illegible]	[illegible]	mg/kg	89%	91%
[illegible]	[illegible]	[illegible]	[illegible]	mg/L	[illegible]	60%
[illegible]	[illegible]	[illegible]	[illegible]	mg/kg	8%	33%
[illegible]	[illegible]	[illegible]	[illegible]	mg/kg	17%	6%
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
Total P as P	[illegible]	[illegible]	[illegible]	mg/kg	-21%	0%
Ortho P as P	[illegible]	455	[illegible]	mg/kg	-17%	-14%
Sulfate	110	50	60	mg/kg	55%	55%
% solids	7.2	6.6	5.5	%	8%	24%
% VS	73.9	74.4	70.8	%	-1%	4%
% ASH	1.88	1.69	1.61	%		
ratio VS to Ash	2.83	2.91	2.42		-3%	14%
TKN	3560	3733	3307	mg/kg	-5%	7%

Manure Analysis

Pre = reception pit
Post = after digester
Store = in lagoon

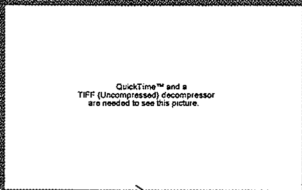


www.biogasworks.com



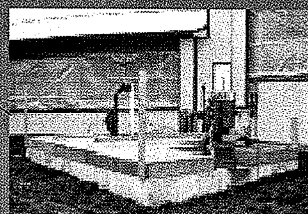
www.moea.state.mn.us

Anaerobic Digestion



For livestock producers that are seeking new ways to deal with manure from their operation in a safe, efficient, and sustainable way.

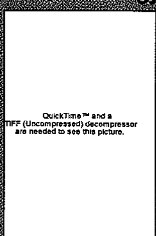
Reception/Mixing Pit



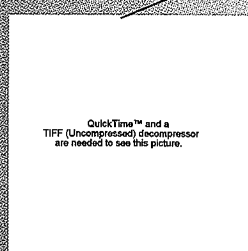
Anaerobic process

The conversion of waste into value added products

Energy Source or Pollutant?



	[illegible]
Animal weight	[illegible]
Biogas cuft/day	[illegible]
Btu/day	[illegible]
KWh/day	[illegible]



Storage -90 to 300days

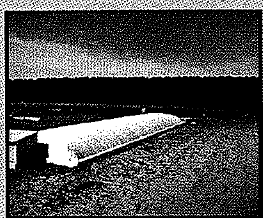
Ready for Plant Uptake

Anaerobic digestion is the breakdown of organic matter in the absence of oxygen,with biogas being given off in the process. This process occurs naturally in swamps and stagnant dirty water. Biogas is made up primarily of methane (55 – 80%) and carbon dioxide (10 – 45%). It can also contain significant amounts of hydrogensulfide, (up to 3500 parts per million).

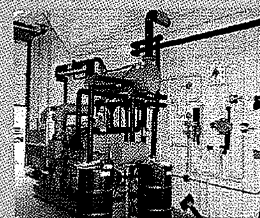
Haubenschild Dairy Farm Energy Production
Princeton, Minnesota

Milk Production + Crop Production + Electrical Production + Future Hydrogen Production = Farm Income Diversification

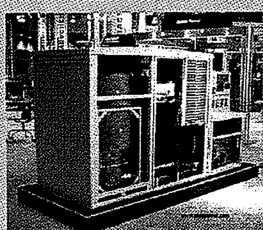
Haubenschild Farm Energy Production Technologies



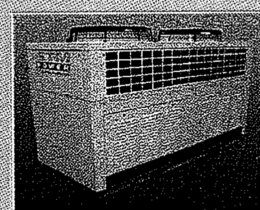
Methane Digester: To breakdown organic matter in the absence of oxygen to produce biogas, which is primarily methane and carbon dioxide with some hydrogen sulfide.



Engine Generator set: Internal combustion engine with 135 kW 240 VAC electrical generator.

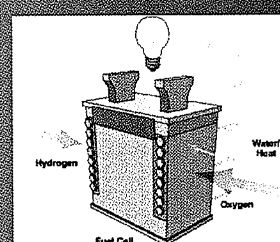


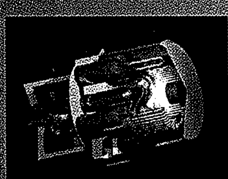
Fuel Cell: Uses hydrogen to generate electricity without combustion. Output is 5 kW at 120 VAC



Sterling Engine: External combustion engine with 55 kW 240 VAC generator.

A fuel cell is similar to a car battery in that it produces electricity through electrochemical reactions. A fuel cell produces electricity as long as the hydrogen fuel source and oxygen passes through it. The byproduct of this process is water vapor. The energy resources for hydrogen can be biogas, natural gas, propane, methanol, ethanol, and other hydrogen based liquids or gases. Heat is also produced and can be utilized for space heating and hot water needs. Electricity conversion efficiency is around 25% and up to 80% with the use of the waste heat. See www.eere.energy.gov/hydrogenandfuelcells/fuelcells/basics.html for information.





A sterling engine contains a sealed gas system (similar to refrigeration) that expands and contracts to "move" a piston. The sterling engine uses external heat exchangers to expand the gas. Another heat exchanger cools the internal gas and this gas compression causes the piston to return for the internal gases to expand again. Electricity conversion efficiency is around 30% and up to 80% with the use of the waste heat. See www.sesusa.org for information.

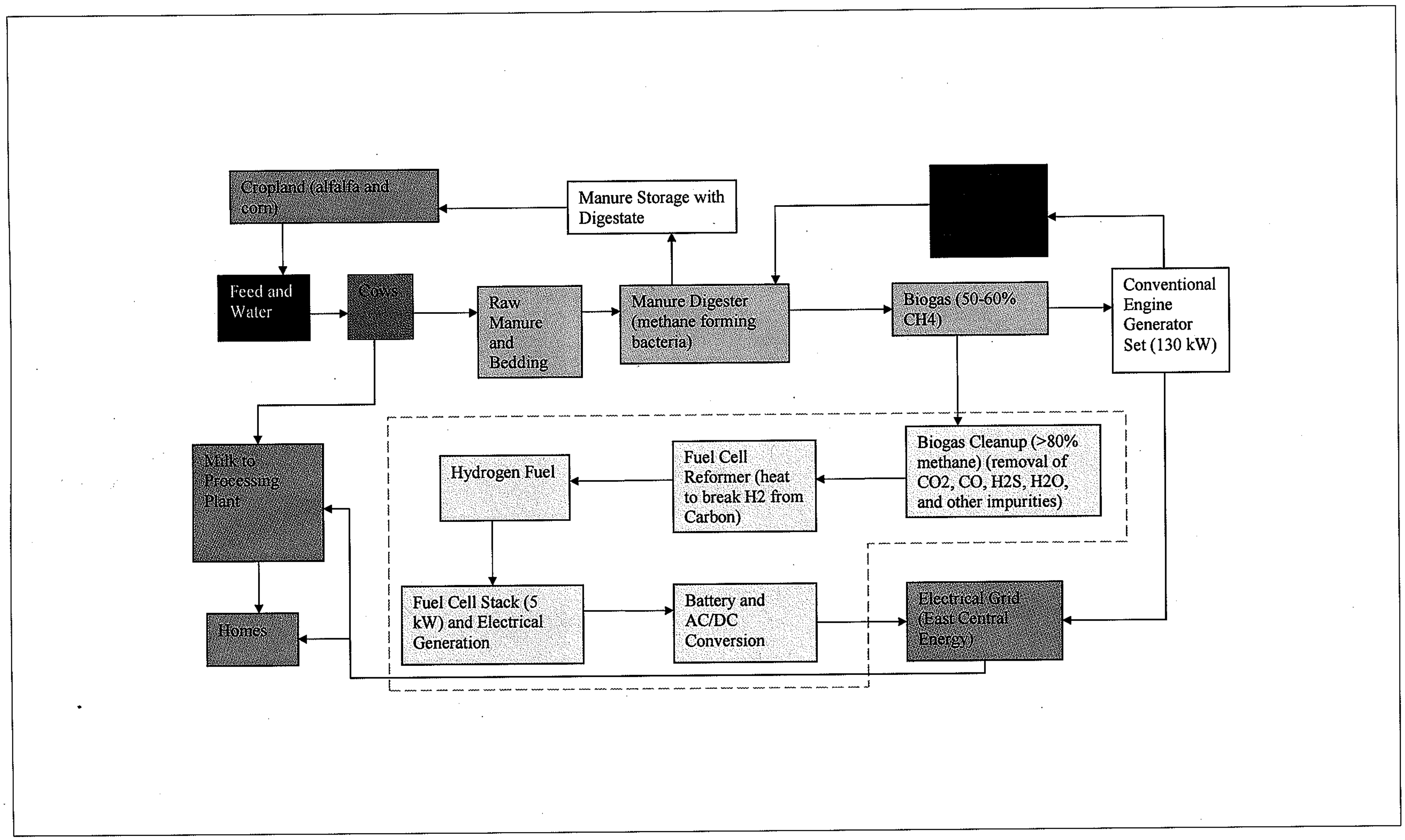
Energy Production + Organic Fertilizer + Reduced Air Emissions =

Savings + Environment Impact Reduction

Appendix J: Anaerobic Digester Energy Flow Diagram with Fuel Cell

Date: August 22, 2005

Energy Flow in the Haubenschild Manure to Methane and Hydrogen System



Developed by Matt Drewitz, MDA-ARMD

Appendix K: Articles and Papers on Fuel Cell

Emissions from Biogas Fueled Engine Generator Compared to a Fuel Cell

Paper # 634

Philip R. Goodrich PE, Richard J. Huelskamp, David R. Nelson PE, David Schmidt PE, R. Vance Morey, Department of Biosystems and Agricultural Engineering, University of Minnesota, 1390 Eckles Avenue, St. Paul, MN 55108,

Dennis Haubenschild, Haubenschild Dairy, 7201 349th Avenue NW, Princeton MN, 55371,

Mathew Drewitz, Paul Burns, Minnesota Department of Agriculture, 90 West Plato Blvd., St. Paul MN, 55107.

ABSTRACT

A highly successful biogas project on a Minnesota 800-cow dairy has been operating for five years. This paper compares the emissions of a conventional combustion engine coupled with an induction generator (genset) producing electricity for the grid with a fuel cell using the same biogas. The greenhouse emissions from the fuel cell are minimal compared with the internal combustion engine. Emissions of nitrogen oxides (NOx), carbon monoxide (CO), sulfur dioxide (SO_2) were less than detection limits and total hydrocarbons (THC) were only 1,790 ppmv or 14.5 g/kWh$_e$. Average genset emissions at 103 kW were NOx = 2,963 ppmv or 25.5 g/kWh$_e$, CO = 799 ppmv or 4.18 g/kWh$_e$, THC = 2.46 % or 53 g/kWh$_e$, SO_2 = 277 ppmv or 3.34g/kWh$_e$.

This is the first side-by-side comparison of these two different ways of converting the biogas to marketable distributed energy. The advanced treatment of the digester provides beneficial treatment for manure including organic loading reduction, odor reduction and enhanced handling characteristics. The engine generator (135 kW) has been operational more than 97% of the time during the first 5 years of operation. The fuel cell is a 5 kW proton exchange membrane fuel cell (PEM) from Plug Power™ of Latham New York. The anaerobic digester and fuel cell forms a system that reduces greenhouse gases and odors while recycling the nutrients to the soil and at the same time produces renewable distributed energy reducing fossil fuel use and reducing the need for long transmission lines.

INTRODUCTION

Anaerobic digestion converts volatile organic substances in livestock manure into methane (CH_4), carbon dioxide (CO_2), gaseous contaminants and water vapor. The remaining material is stabilized, reducing odor during storage and land application operations. The increasing regulation of animal production systems to reduce the risk of water pollution is affecting farming operations. Expansion of existing animal raising operations and upgrades to existing operations are being required to meet new permit regulations and even to meet criteria that have normally not been applied to agricultural operations. Anaerobic digestion is one method that is being considered to reduce odors and that may provide a positive return to the farm.[1] The energy in the CH_4 can be converted into electrical energy in various ways. The most popular method is an internal combustion engine coupled to an alternating current induction generator connected to the grid. A fuel cell is a more challenging new method to convert the methane into electrical energy.

Dennis Haubenschild was an early adopter of anaerobic digestion using AGSTAR[2] (US Environmental Protection Agency) resources at Haubenschild Farms, an 800-cow, 400-hectare dairy farm locate approximately 85 km north of Minneapolis, MN. In 1999, the owner installed a heated plug-flow digester with a 135-kilowatt engine/generator to utilize the biogas. The successful operation of this facility (the generator has been running over 97 % of the time through July 2004) has drawn many visitors and encouraged others to accept the technology.[3]

The EPA estimates in 2000 of CH_4 from combustion of biofuels was 4% of the world load to the atmosphere and the global anthropogenic N_2O budget in 2000 was only 1% from biomass fuel.[4] Therefore more efficient conversion would reduce the greenhouse gas loading, but is a small part of the estimated greenhouse gas contribution.

TWO CONVERSION METHODS OF BIOGAS TO ELECTRICAL ENERGY AT HAUBENSCHILD DAIRY

Objective of the research

The primary objective of the research project was to demonstrate the feasibility of converting biogas CH_4 to electrical energy using a commercially available fuel cell as an alternative to the conventional engine generator system.

Comparing electrical conversion technologies

A comparison in table 1 identifies the strengths and weaknesses of the two electrical generator technologies systems in place on the Haubenschild digester.

Table 1. Comparison of fuel cell and engine generator conversion of biogas to electrical energy

Attribute	Fuel Cell	Engine Generator
Capital Cost per kilowatt	High --$10,000 to $12000 Target is $40	Low --$50 to $100
Biogas Cleanup	Needs to be cleaned to strict specifications	Little or none needed
Maturity of Technology	Rapidly emerging	Mature
Greenhouse emissions	Minimal	Carbon dioxide, sulfur dioxide, carbon monoxide, particulates
Noise level of equipment	Very quiet	Very high and sound mitigation necessary
Moving parts to fail	Very few and most at ambient temperature	Many moving parts in hot, challenging environment needing oil and cooling
Changes	Changing rapidly with	Mature and changing slowly

occurring	extensive development occurring	
Maintenance cost	Very high because of limited life of fuel cell stack material	Variable depending on the care given to the unit and the durability

There are significant differences in the capital costs of the two systems. The future fuel cell system may be comparable in cost to the engine generator set, but is not comparable now. The risks of the newer fuel cell because of unknown maintenance costs and durability indicate the fuel cell system may not yet be the system of choice even though the emissions are much lower.

Published emission data[5] from a Caterpillar (Model 3306 ST) IC engine with a rated nominal power output of 100 kW (15.5 °C, sea level) operating on animal manure produced biogas are available for one large swine operation.[4] Nitrogen oxide (NO_x) emissions at 45 kW were 5.44 g/kWh and decreased as power output decreased. Carbon monoxide (CO) emissions averaged 26.3 g/kWh at 45 kW and exceeded the analytical range of the CO analyzer at the lower loads (greater than 10,000 ppm). Hydrocarbon (THC) emissions were also very high. Total hydrocarbon concentrations were above the analyzer range (10,000 ppm as CH_4) and therefore not reported. Using an on-site gas chromatograph and flame ionization detector, analysts were able to quantify CH_4 emissions at an average of 50.8 g/kWh at 45 kW. CH_4 emissions increased to a high of 68.0 g/kWh at the 30 kW. Emissions of SO_2 averaged 10.4 g/kWh at 45 kW and increased at lower loads.

Fuel cell emissions were available for an International Fuel Cell Corporation PC25 TM 200 kW phosphoric acid fuel cell operating on landfill gas.[6] The average emissions were measured as follows (dry gas, corrected to 15 % O_2): NO_x = 0.12 ppmv or 0.29 g/hr, SO_2 = non detectable (0.23 ppmv detection limit) or <0.78 g/hr, and CO = 0.77 ppmv or 1.15 g/hr.

Fuel cell emissions were available for a Plug Power Fuel cell operating on natural gas at a residential home in upstate New York.[7] The fuel cell, gas composition and electrical output were very similar to the fuel cell tested on the Haubenschild digester. The average emissions at 2.57 kW were measured as follows (dry gas, corrected to 15 % O_2): NO_x = <0.25 ppmv or <5.76×10^{-4} g/kWh_e, CO = 0.19 ppmv or 2.74×10^{-3} g/kWh_e, THC= 509 ppmv or 4.13 g/kWh_e, CH_4 = 494 ppmv or 4.00 g/kWh_e

Experimental setup

The testing was accomplished at the Haubenschild digester in Princeton, MN. The digester producing the biogas was a plug flow digester described in the report by Nelson and Lamb.[8] Figure 1 shows the manure digester in winter when the test was done. The engine is a Caterpillar model 3406 attached to a generator with a capacity of about 135 kW, (150 kW on natural gas) to produce the electricity. The engine, originally designed for commercial natural gas usage, required retrofitting with larger orifice carburetor valves and a large regulator but was otherwise unchanged. The fuel for both the genset and the fuel cell were produced by the digester and a branch in the piping from the digester assured that the gas was the same for both systems. The gas for the genset passes through one Roots™ fuel meter and the biogas for the fuel cell passes through a separate Roots™ fuel meter.

Figure 1: The Haubenschild Dairy plug flow digester, which generated the biogas

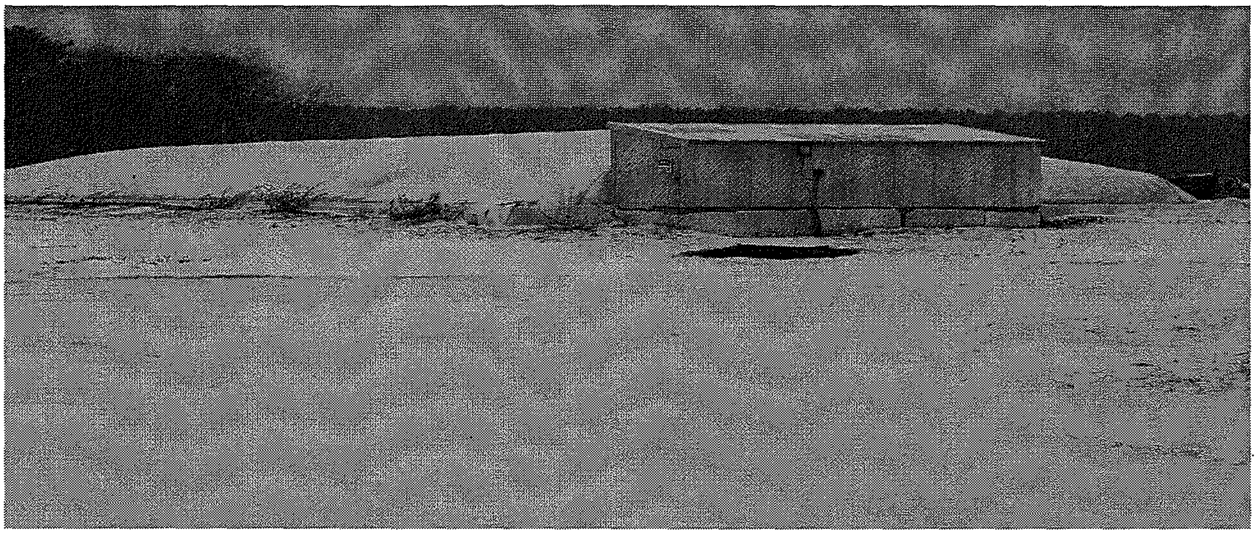


Figure 2 shows the engine generator set in the generator building. Figure 3 shows the Plug Power Fuel Cell located in the U of M research building adjacent to the generator building.

Figure 2: The 130 kW engine generator set operating on biogas from the digester

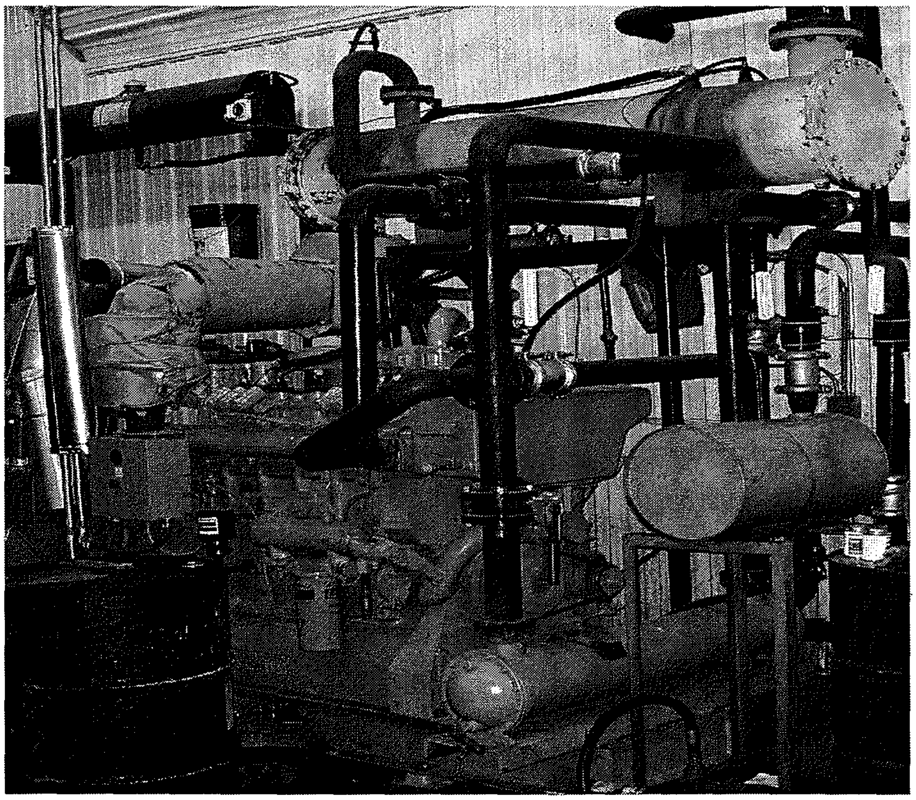
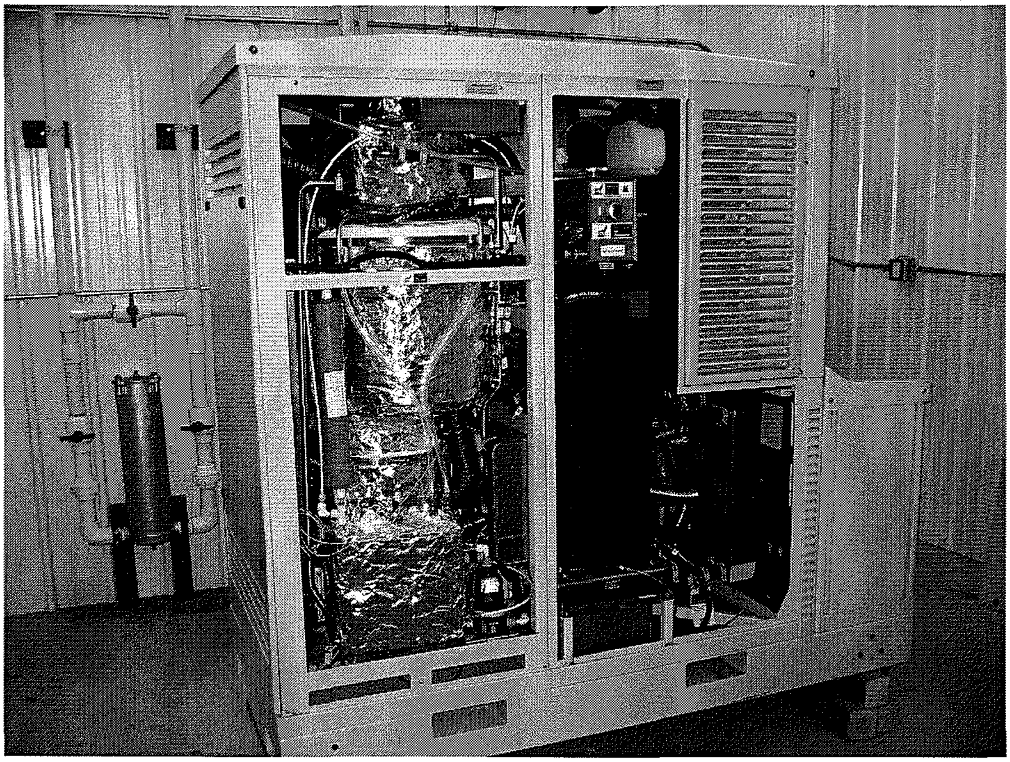


Figure 3: The Plug Power™ proton exchange membrane (PEM) fuel cell



A technician from the University of Minnesota Center for Diesel Research using the EPA emissions test protocol[9] CTM-0307 titled "Determination of Nitrogen Oxides, Carbon Monoxide, and Oxygen Emissions from Natural Gas-Fired Engines, Boilers and Process Heaters Using Portable Analyzers" performed the tests. The instrument used was an ECOM KL[10] and was calibrated prior to use with EPA protocol span gases. "The KL sample conditioning system consists of a high flow pump, a temperature regulated heated sample line, a thermoelectric Peltier gas cooler with moisture trap, and a peristaltic pump"[11]. The NO cal gas was 972 ppm, NO_2 96.7 ppm, CO 2419 ppm, SO_2 198 ppm, and 476 ppm propane for the THC Cell. Sensors for all gases were electrochemical except for a Pellister sensor was used for THC measurements. The calibration gases were from National Specialty Gases. Data was logged at 10-second intervals by the instrument.

The engine generator, which had been operating continuously for several months, was tested in the morning and the fuel cell in the afternoon of the same day. The test probe was inserted into a port in the genset exhaust pipe about 2 ft from the exhaust heat exchanger of the engine. Test data was collected during four 10 min periods in 2 hrs. The engine generator had been emission tested previously when the fuel cell was not operational to obtain some preliminary data about the efficiency of the engine generator set. The fuel cell emissions were tested only on one day because of the cost of the field tests.

The fuel cell was started in the morning and progressed through the 3 hrs start up process using natural gas from a natural gas cylinder. Then the shift was made to biogas fuel preprocessed by a pressure swing absorber operated at 60 psi with an approximate cycle of 50 % bypass to remove carbon dioxide and hydrogen sulfide. The probe was inserted in a port in the stack about two feet above the top of the fuel cell cover.

The fuel cell was operated at output 2.5 kW_e and the data collected for a one-hour period on natural gas and then for one hour on the cleansed biogas. Only emissions data when operating on the cleansed biogas are presented. However the data are comparable for the natural gas period.

Results

Emissions from Haubenschild generator

The average emissions at 103 kW were measured as follows (dry gas, corrected to 15 percent O_2): NO_x = 2,963 ppmv or 25.5g/kWh_e, CO = 799 ppmv or 4.18g/kWh_e, THC = 2.46 ppmv or 53g/kWh_e, SO_2 = 277 ppmv or 3.34g/kWh_e

Table 2 Concentrations measured during four ten-minute sampling periods on 103 kW genset

Mean Time	**11:02**	**10:35**	**11:11**	**11:35**	**Average**
Concentration (dry measurements)					
O_2(%)	**3.0**	**3.8**	**2.6**	**2.4**	**2.93**
CO(ppm)	**777**	**791**	**812**	**816**	**799**
NO(ppm)	**2840**	**2580**	**2975**	**2970**	**2841**
NO_2(ppm)	**122**	**151**	**115**	**98**	**121**
NO_x(ppm)	**2962**	**2731**	**3090**	**3068**	**2963**
SO_2(ppm)	**244**	**222**	**315**	**329**	**277**
THC(%)	**2.28**	**2.47**	**2.57**	**2.54**	**2.46**

Each value in table 2 is the average of 60 samples in each ten-minute period.

Emissions from Plug Power™ 5 kW proton exchange membrane (PEM) fuel cell

Throughout the test average emissions at 2.50 kW were measured as follows (dry gas, corrected to 15 % O_2): NO_x <1 ppmv or <. 0023g/kWh_e, CO <1 ppmv or 0.014g/kWh_e, THC = <100 ppmv or 0.81g/kWh_e, SO_2 <1 ppmv or <0.030 g/kWh_e

Table 3 Concentrations measured during four ten-minute sampling periods on 5 kW fuel cell

Mean Time	**13:29**	**13:44**	**13:59**	**14:14**	**Average**
Concentration (dry measurements)					
O_2(%)	**3.0**	**3.8**	**2.6**	**2.4**	**2.93**
CO(ppm)	**<1**	**<1**	**<1**	**<1**	**<1**
NO(ppm)	**<1**	**<1**	**<1**	**<1**	**<1**
NO_2(ppm)	**<1**	**<1**	**<1**	**<1**	**<1**
NO_x(ppm)	**<1**	**<1**	**<1**	**<1**	**<1**
SO_2(ppm)	**<1**	**<1**	**<1**	**<1**	**<1**
THC(%)	**<.01**	**<.01**	**<.01**	**<.01**	**<.01**

Each value in table 3 is the average of 60 samples in each ten-minute period

Discussion of results

The emissions from the fuel cell were much lower than from the engine generator. The emissions of nitrogen oxides (NO_x) were less than the minimum detection level for the test whereas the genset produced 25.5 g/kWh_e. The emissions of carbon monoxide (CO) were also less than the minimum detection level for the test whereas the genset produced 4.18g/kWh_e. Total hydrocarbons (THC) for the fuel cell were less than 0.81g/kWh_e compared to the 53g/kWh_e for the genset. Sulfur dioxide (SO_2) was less than the detection limit of 1 ppm or <0.030 g/kWh_e. These data compare favorably with those reported by EPA for the Plug Power fuel cell in Lewiston New York, however they used a more sensitive ambient air instrument for the low levels of CO and NO_x. They did not report SO_2 emissions. The SO_2 emissions from the phosphoric acid fuel cell were reported as less than detectable. The CO levels for all fuel cells were essentially less than detectable. A probable reason for the very low emissions is that the fuel cell is highly controlled process optimized to reduce emissions to meet California emission standards. The genset is a combustion process not optimized to reduce emissions nor is the genset computer controlled.

Conclusions

The emissions of NO_x, CO, THC, and SO_2 from the fuel cell are much less than from the engine generator. The main reason is that the biogas is used directly in a combustion process in the engine generator and the fuel cell system first removes some of the carbon dioxide and then the methane is converted to hydrogen by the auto thermal reformer in an efficient optimized process. The pressure swing absorber gas cleanup process, prior to introducing the gas to the fuel cell, removes almost all (15 ppm H_2S remains of original 5000 ppm) of the critical contaminant gas. The CO_2 is decreased from 40% to 10%. A biofilter will be used to collect and recycle the hydrogen sulfide into the soil along with the filter material. The biofilter is not expected to sequester the carbon dioxide and that will be ultimately released to the local atmosphere.

Acknowledgments

Funding for this project was recommended by the Legislative Commission on Minnesota Resources from the Minnesota Environment and Natural Resources Trust Fund. John Deere Inc. provided funds to build the research structure where the fuel cell and instrumentation are housed on the Haubenschild farm. The able assistance of Verlyn Johnson, Darrick Zarling and Blanca Martinez has helped immensely as well as the support of Marcia Haubenschild. The Minnesota Project, the Department of Biosystems and Agricultural Engineering, University of Minnesota, East Central Energy, Great River Energy, Electric Power Research Institute, Donaldson Inc, LandTec Inc, and others have provided continuing support to this project.

Keywords

Methane, Biogas, Fuel Cell, Anaerobic Digestion, Greenhouse Gas, Emissions, Manure, Dairy, Energy Conversion, Renewable Energy, Odors

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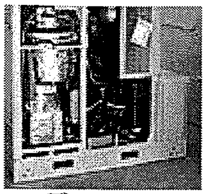

MINNESOTA DAIRY RUNS HYDROGEN FUEL CELL ON BIOGAS

BioCycle June 2005, Vol. 46, No. 6, p. 58

Demonstration project with university researchers involves cleaning biogas to develop renewable energy options for farmers.

A MINNESOTA dairy - the Haubenschild family farm near Princeton - is making history by becoming the first demonstration project in the world to run a hydrogen fuel cell from the biogas captured from cows. For five years, as reported in BioCycle, the Haubenschilds have been operating an anaerobic digester to process manure from their cows (now numbering 900) as well as recycled newspaper used as bedding. The hydrogen fuel cell is the latest innovative project on the farm. Once the biogas from the digester is cleaned, it is converted to hydrogen fuel which produces electricity in the fuel cell.

In 2003, the Minnesota Department of Agriculture (MDA) was awarded a grant ($221,000) to conduct fuel cell research using digester biogas as fuel. According to Matt Drewitz of the MDA, funding for this project was provided by the Minnesota Environment and Natural Resources Trust Fund as recommended by the Legislative Commission on Minnesota Resources (LCMR). Along with the MDA, Haubenschild, the University of Minnesota Biosystems and Agricultural Engineering Department, and the Minnesota Project are all partners in this project. The purpose is to investigate use of alternative technologies for producing electricity from biogas produced from livestock. The project focus was on technologies that have the potential to be more environmentally friendly and easier to maintain than conventional engine generator systems. The fuel cell was selected as the technology to research. Through this project, the University of Minnesota has looked at a number of aspects of employing a fuel cell with anaerobic digestion, which include: fuel cell type, installation and operation, gas clean up, fuel cell emissions, and economic feasibility.

A small portion of biogas from an the existing plug flow anaerobic manure digester on the Haubenschild dairy farm was routed into a research building that housed the fuel cell, gas clean up equipment, and monitoring equipment. A 5 kW proton electron membrane (PEM) fuel cell (Plug Power Inc.) was used for the research project. University of Minnesota researchers (Dr. Phil Goodrich, Rich Huelskamp, and David Nelson) worked on developing and implementing the gas piping and monitoring strategy. The greatest challenge was cleaning the biogas of impurities (H2O, CO2, and H2S) so it could be safely used in the fuel cell and its reformer. In January, 2005, the fuel cell was operational on pure natural gas and in February, 2005 the fuel cell was run on biogas for the first time. At this point, the fuel cell has only been run intermittently on biogas for a few hours at a time. Data has been collected on the performance of the fuel cell and also the emissions given off during operation when using biogas. The University of Minnesota researchers are anticipating running the fuel cell continuously for longer durations in the near future. For more information, contact Dr. Phil Goodrich with the University of Minnesota at goodrich@tc.umn.edu.

"Expansion of energy harvesting and conversion to rural areas will bring business expansion, jobs and continued vitality," says Goodrich. "Fuel cells and anaerobic digestion are part of this opportunity. Hydrogen may be one of the primary drivers of the economy within 10 years, since it is clean, can be stored, and does not pollute the atmosphere."

For further details, Matt Drewitz of the Minnesota Department of Agriculture can be contacted at (651) 296-3820; Dr. Philip Goodrich of the University of Minnesota at can be e-mailed Goodrich@tc.umn.edu.

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News Release

For Immediate Release: Tuesday, May 10, 2005

Contacts: Curt Zimmerman, Communications Coordinator, 651-296-6456
Amanda Bilek, Minnesota Project Outreach and Education Coordinator, 651-645-6159, Ext. 5

MINNESOTA DAIRY FARM'S COWS PRODUCING ENERGY AS WELL AS MILK

Hydrogen fuel cell project uses biogas from manure digester

ST. PAUL, Minn. - A Minnesota dairy farm is making history by becoming the first demonstration project in the world to run a hydrogen fuel cell from the biogas captured from dairy cows. The project is being conducted at the Haubenschild family farm near Princeton.

For five years, the Haubenschilds have been operating an anaerobic digester—a system that collects manure to capture methane gas for conversion to electricity. The addition of the hydrogen fuel cell is the latest innovative project on the farm.

The anaerobic manure digester produces biogas, which is composed of methane, carbon dioxide, water vapor, and trace gases. Once the biogas from the manure digester is cleaned, the biogas is converted to hydrogen fuel, which produces electricity in the fuel cell. Hydrogen is seen as an attractive alternative to fossil fuels since it doesn't release carbon dioxide or harmful greenhouse gases.

The demonstration project is the first of its kind and was a cooperative venture among the Minnesota Department of Agriculture (MDA), Haubenschild Farms, the University of Minnesota Department of Biosystems and Agricultural Engineering, and the Minnesota Project. Funding for the fuel cell project was provided by the Environmental and Natural Resources Trust Fund though the Legislative Commission on Minnesota's Resources (LCMR). MDA Senior Planner Matt Drewitz is assisting in the demonstration project.

"The LCMR funds have allowed the State of Minnesota to further develop renewable energy opportunities for farmers in Minnesota," said Drewitz. "The MDA is fortunate to work with Haubenschild Farms on this innovative project."

This purpose of this project is to investigate the feasibility of using fuel cell technology on a working farm. University of Minnesota researchers have been able to run the fuel cell on biogas intermittently and are working towards running the fuel cell on biogas continually. The fuel cell is a proton electron membrane (PEM) and produces 5 kilowatts of electrical power. A fuel cell of this size is ideal for research purposes but not large enough to power the dairy or produce electricity for sale. Dr. Philip Goodrich is conducting the research on this innovative project for the University of Minnesota, College of Agriculture, Food, and Environment Sciences (COAFES).

-more-

"The expansion of energy harvesting and conversion to rural areas will bring business expansion, jobs and continued vitality to rural Minnesota," said Dr. Goodrich. "Fuel cells and anaerobic digestion are part of this opportunity. Hydrogen may be one of the primary drivers of the economy within 10 years. Hydrogen is clean, can be stored, and does not pollute the atmosphere."

Cleaning the gas so it can be used by the fuel cell is the one of the greatest challenges for this experiment. Trace gas such as hydrogen sulfide can damage the fuel cell, so it is important that impurities are removed. The University of Minnesota researchers are experimenting with a number of low-cost systems for cleaning the biogas.

Demonstration projects using ethanol and wind energy in the production of hydrogen fuel are being tested in renewable energy projects across the country. For more information on this project, contact the MDA's Matt Drewitz, at (651) 296-3820, or Dr. Philip Goodrich, with the University of Minnesota at (612) 625-4215 or Goodrich@tc.umn.edu.

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This release is available on the MDA website at: www.mda.state.mn.us

Volume 7. Number 4. Summer, 2004

THE STREAM

(Technical tools and Hands-on help for Education re a Solar Theme to Renew the Environment Across Minnesota)

www.creedproject.org www.mres-solar.org

Combined Newsletter of the
Communities for Responsible Energy/Environment Demonstration (CREED) Project & the Minnesota Renewable Energy Society (MRES)

U OF M'S INITIATIVE FOR RENEWABLE ENERGY & THE ENVIRONMENT (IREE)

THE INITIATIVE

Dick Hemmingsen

The University of Minnesota Initiative for Renewable Energy and the Environment (IREE) has as it's mission "to promote statewide economic development, sustainable, healthy, and diverse ecosystems, and national energy security through the development of bio-based and other renewable resources and processes."

The U of M's IREE addresses the need to reduce our state's and nation's dependence on nonrenewable, fossil fuel-based sources of energy and products and to improve the health and sustainability of our global ecosystems. IREE will capitalize on the substantial renewable resources in Minnesota as well as the unique strengths of the University of Minnesota and the state to facilitate efforts in research, collaboration, and policy development.

Currently, IREE's funded projects involve more than 50 University faculty, representing 25 departments across 5 colleges, with over 15 industrial, governmental, or other educational institution partners.

CLUSTERS OF ACTIVITY:
A primary goal of the IREE is to

U of M's IREE: Cont. on p.8.

CONTENTS

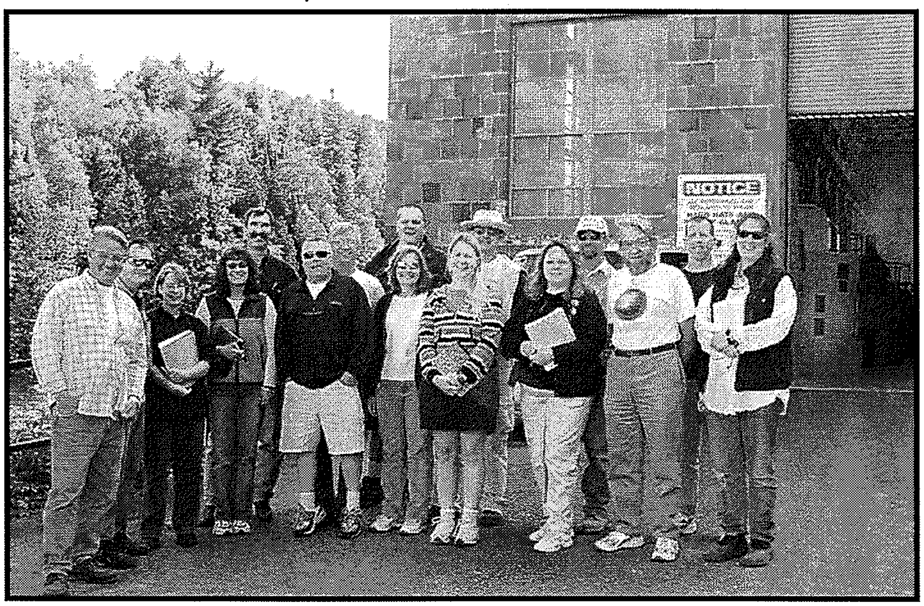

Fig.1. DSRFE Group at Minnesota Power's Thomson Hydro-Electric Generating Station. (See News Item #2 on p6)

THE STREAM

Vol. 7. #4. SUMMER 2004

Combined Newsletter of the Communities for Responsible Energy/Environment Demonstration (CREED) Project and the Minnesota Renewable Energy Society (MRES).

Published bimonthly.

The views expressed in articles and letters in this publication are not necessarily those of the editors or of the Boards of Directors of the CREED Project and/or MRES. All correspondence, letters to the editors, requests for copies and other matters should be addressed to:-

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e-mail: <rogeraiken@creedproject.org>.

Comments, letters and contributory articles are encouraged. **The annual subscription for mailed hard copy is $15, (students $10) for six issues. Back copies of the "THE STREAM" are available from the above address for $3 a copy. The e-mail version is FREE.**

RECENT BACK ISSUE TOPICS:-

Vol./#	Date	Topic
5/1	Winter 02	Laws of Thermodynamics.
5/2	Spring I 02	Renewable Projects in MN.
5/3	Spring II 02	Shortage of Tech. Grads.
5/4	Summer 02	Ren. Projects in MN Part 2.
5/5-6	Fall I/II 02	Efficient Envir Friendly Trnspn.
6/1	Winter 03	Ren. Projects in MN Part 3.
6/2	Spring I 03	Teacher Assocns. on E. Edn.
6/3	Spring II 03	Minn. EERE Industry #1.
6/4	Summer 03	Minn. EERE Industry #2.
6/5	Fall I 03	Minn. EERE Industry #3.
6/6	Fall II 03	Minn. EERE Industry #4.
7/1	Winter 04	Minn. EERE Industry #5.
7/2	Spring I 04	CREED's New Programs.
7/3	Spring II 04	Minn. EERE Industry #6.

MEETINGS

CREED's Board recently voted to change the frequency of Board meetings from monthly to quarterly. The detailed work of the organization will now be managed by Finance, Education, Newsletter, Tours, and E85 Hybrid Subcommittees, Our next full Board meeting will be held on **Saturday, December 4, 2004** at **1300** at the home of new Board Chair Rich Huelskamp, 28609 Walnut Run Way, Red Wing, and will include a tour of his home. For more information, call him at 651-301-3271, or Secretary/Treasurer, Valdi Stefanson, 651-762-4015, Executive Director, Tom Abeles, 612-823-3154 or Newsletter Editor, Roger Aiken, 651-644-8318.

MRES Board Meetings are held on the **second Thursday** of each month at **1900 hours** (7:00 p.m.) at **Whole Builders Cooperative,** 2928 5th Ave. S., Minneapolis, MN 55408. For more information call Chair, David Boyce, 952-445-7270, or Treasurer, Ralph Jacobson, 612-623-3246.

Board meetings of both our organizations are open to the general public and visitors are welcome.

MEMBERSHIPS

CREED and MRES are two independent organizations with their own separate Boards of Directors. They pool their resources and expertise to publish this bimonthly newsletter. Each has several levels of membership.

CREED:

CREED is a Minnesota based 501(c)(3) nonprofit organization whose mission is to:-

"Educate Minnesotans about the impact of energy supply, conversion and use on our environment/ economic prosperity through 3E (Energy, Environment, Economy) materials and demonstration of sustainable technologies and life-styles."

CREED has two types of membership; individual and corporate, with several levels within each type to cater to the comfort levels of different people and businesses. These are:-

INDIVIDUAL MEMBERSHIP:-

Community:	$25 to $49.
State:	$50 to $99.
Regional:	$100 to $249.
Continental:	$250 to $499.
Global:	$500 and above.

CORPORATE MEMBERSHIP:

Bronze:	$500 to $999.
Silver:	$1000 to $2499.
Gold:	$2500 to $4999.
Platinum:	$5000 and above.

These memberships have been instituted to enable people interested in and dedicated to Energy Education to find an organizational home and volunteer their time and expertise to one or more of our programs. People and Organizations contributing to CREED's membership are acknowledged in issues of "THE STREAM".

We gratefully acknowledge the support of the following who are current with their memberships:-

CORPORATE:
Platinum Level:
Great River Energy.
Gold Level:
Minnesota Power
Bronze Level:
Discern Engineering, LLC

INDIVIDUAL:
Regional Level:
Roger Aiken, George Anderson, David Boyce, Michael Eckhardt, Rich Huelskamp, Chuck Koestler, Patricia Ann Richards, Bob Swanson.
State Level:
Bill Butler, Mark & Lorraine Francis, Keith Harris, Jim Harrison, Bruce Odegaard, Lyle Olson, Valdi Stefanson.
Community Level:
Bob & Lee McLane, Carl McNally, Jim Mecklenburg, Jon Olds, Stephan Peter, Kathleen Sekhon, Wally Swentko, Gina Vermilyea, Joel Weisberg.

MRES:

Established in 1978, the MRES is a Minneapolis-based non-profit organization committed to developing awareness and use of renewable energy resources across Minnesota. MRES is the state chapter of the American Solar Energy Society, the leading national nonprofit working to promote renewable energy. Over its 25 year history, MRES has become among Minnesota's more respected sources for expertise on renewable energy technologies and development. Twice, in 1983 and again in 1995, MRES was chosen to host the annual ASES conference bringing solar experts from across the country to Minneapolis. MRES local chapter memberships are as follows:-

Individual:	$30
Student & Senior:	$15
Family:	$45
Businesses:	$100
Corporate:	$500

All MRES members receive a free subscription to the newsletter.

FEEDBACK

*(fĕd΄bak΄), the process of returning part of the output of a system to the input, either to oppose the input (**negative feedback**) or to aid the input (**positive feedback**)*

Letters to the Editor are welcomed. This is an open forum for your views and/or disagreements. However neither the Editors nor Boards of Directors of CREED and MRES will necessarily endorse your statements.

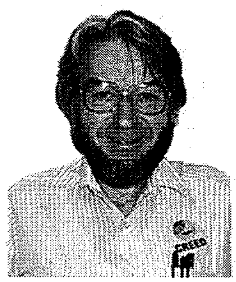
George Anderson <ganderson@crowniron.com>, writes on Thurs, 2 Sept. 2004

Roger,

Nice job - made my article and the others look good! Incidentally, you may wish to look up PureChoice on the web and try to get an article from them. It is a company I have some recent investment in, because it is a very interesting product: sensors in one or even each room of a house, lab, office, etc. and connection via internet to provide real time and history of air quality. At any moment the manager can go on the web and see the CO_2, CO, °F, humidity, volatiles for every sensor he has access to worldwide - with graphs going back days or weeks if a question arises. Lots of interesting potential: Within minutes of someone entering a building the CO_2 rises on a steady climb - and security people are interested in this. Obviously the air conditioning and vent systems of schools can be varied to optimize energy while keeping volatiles from computers or CO_2 under control - one school even caught a sudden and major spike in CO during school hours when a 'propane buffer' (??) malfunctioned. Formaldehyde tends to spike one sensor when some types of carpet are being installed. A remote lake cabin can be monitored for temperature, moisture (we once had a water pipe develop pinholes in mid-winter and moisture went sky-high), CO, etc. - perhaps a bit costly for that, but really accurate and comprehensive! Upscale apartments or homes may want one or more. Schools and offices are the big expected market. How about defense labs? Aircraft? Ship hulls?

Indoor air quality is a big deal and these guys have a potential hit product already with a proven installed base. The product, with appropriate patents and cost reduction curve, is the brainchild of PureChoice in Lakeville, Bryan Reichel CEO.

FROM THE DESK OF THE EDITOR:



Earlier this year I attended a Society of Automotive Engineers' (SAE) meeting at the U. of M., along with some of the final year Mankato students who had been working on my Prius hybrid to see whether it could run on E85 fuel. The topic addressed at the meeting was "The Production of Hydrogen by the Autothermal Reforming of Ethanol". and the speaker was Regents Professor Lanny Schmidt of the Department of Chemical Engineering and Materials Science. I intuitively sensed that this process was a breakthrough that held great promise for our transportation future, and I was not disappointed when, during question time Prof. Schmidt pointed out that not only was this a way to rise to the challenge of a new hydrogen economy paradigm, but also to do it from renewable fuels to reduce our dependence on foreign oil. Furthermore he pointed out that of all the convenient liquid renewable fuels, only ethanol came close to being able to be readily produced in quantities that could make a substantial impact on the transportation equation with existing technologies.

And so the germ of the idea for this issue of "THE STREAM" was born. It was quickly discovered that Lanny Schmidt and his students' research was just one small part of a much greater renewable energy initiative underway at the U. of M.. Researchers here have known for some time that the economy of our country and in particular that of the Upper Midwest is extremely vulnerable to supplies of oil from overseas and especially from the Middle East. Consequently a group of researchers and administrators was formed to collectively focus the University's expertise in a multi-disciplinary fashion on this challenge. The outcome of this effort is called the **Initiative for Renewable Energy and the Environment** or the **IREE**. Starting on page 1. you will find Dick Hemmingsen's overview of this initiative, with a list of the projects which are currently being funded by cluster.

Two of the research projects under the initiative are described in this issue. They are Lanny Schmidt's Renewable Hydrogen from Ethanol by Autothermal Reforming project and Prof. Jane Davidson's Low Cost Polymer Solar Water Heating research. The former has as its goal the development of a technology to reduce our dependence on foreign oil for transportation, the latter, a means to make the economic penetration of solar hot water heating systems into the market widespread. Since hot water represents about 18% of the energy used by the Residential and Commercial sectors of this country and well designed solar systems can contribute up to 75% of this energy, the potential for savings in both natural gas and electricity is large.

Rich Huelskamp and Phil Goodrich's article on the Haubenschild Fuel Cell project at Princeton is not officially part of the IREE - it is funded with LCMR money - but it nevertheless fits right in with the overall IREE aim to use energy more efficiently. An existing 135kW engine-generator set using methane from the anaerobic digestion of manure from Dennis Haubenschild's 800 cow dairy operation, is being supplemented with a 5kW Plug Power PEM fuel cell and a 55kW Stirling Engine Generator. Funds for this second technology are coming from a consortium of East Central Power, Great River Energy and Electric Power Institute. One of the goals of the project is to compare these two technologies in terms of their increased efficiency in the conversion of methane into electricity.

I will be interested in getting your feedback with respect to these articles and your thoughts for their future commercial development. Also cast your eye through the list of other research projects underway at the U. and give me you suggestions for a future issue of "THE STREAM". And keep your comments on what is happening in the News, both popular and scientific flowing in. This is your publication.

Sincerely, Roger G. Aiken.

UPCOMING MEETINGS AND EVENTS

1. BOARD MEETINGS:

NOVEMBER 2004:-
CREED: There will be no Board meeting in November.
MRES: Thursday 11, 1900 hrs at Whole Builders Cooperative.

DECEMBER 2004:-
CREED: Saturday 4, 1300 hrs at the home of new Board Chair Rich Huelskamp, 28609 Walnut Run Way, Red Wing. This will be a chance for CREED's full Board and anyone else interested in visiting Rich and Ellen's new energy efficient home, which was showcased in the previous issue of this publication, to see what they have accomplished. **Don't miss this wonderful opportunity.**
MRES: Thursday 14, 1900 hrs at Whole Builders Cooperative.

2. C.E. COURSES IN THE RENEWABLE ENERGY CERTIFICATE SERIES AT HAMLINE UNIVERSITY FOR TEACHERS:

FALL 2004:
2.1. Energy Basics: SCED 6080-14861. Two Saturdays November 13 & 27, 8:00 a.m.-5:30 p.m. plus additional on line hours: Energy definitions, units and dimensions. Classifications by type and form. Energy flow. Energy sources. Energy conversion and the laws of thermodynamics. Energy end use and end use sectors. Site visits to a refuse derived fuel facility and a coal burning electric power station.

SPRING 2005:
2.2. Energy Basics: SCED 6080-34840. Two Saturdays February 19 & March 5, 8:00 a.m.-5:30 p.m. plus additional on line hours: This will be a repeat of the Fall Course.

2.3. Solar Direct: SCED 6078-34878. Two Saturdays April 9 & 30, 8:00 a.m.-5:30 p.m. plus additional on line hours: Solar radiation, and the thermal and photovoltaic applications of solar energy. Energy balance of the sun-earth-atmosphere system. Pollution of the atmosphere, Global Warming. Site visits to homes and buildings utilizing solar collectors and energy efficient building design.

Each course is worth 2 C.E. Semester Graduate Credits. Classes comprise two Saturdays of contact time 8:00 a.m. to 5:30 p.m. preceded by course lecture and homework assignments to be posted on Hamline's "blackboard" web site one week before each class.

For further information contact:-
Content- Roger Aiken, 651-644-8318 or <rogeraiken@creedproject.org>
Registration- Renee Wonser, CGEE 651-523-2419 or <rwonser@gw.hamline. edu> **or** Brenda Erickson, CGEE 651-523-2591 or <berickson08@hamline.edu>.

3. "DISCOVERING SCIENCE ON THE RANGE IN THE FIELD OF ENERGY":

TEACHERS ON THE IRON RANGE PLEASE TAKE NOTE!!

We are tentatively planning now for a sequel to cover those aspects of energy which we did not cover in our recently concluded course. The sequel will cover the topics of wind, biomass (production, conversion and use), new energy technologies, energy policy and energy entrepreneurship. Tentative dates are: **Monday 11 to Friday 15, July & Sunday 14 to Thursday 18, August , 2005.** at the Laurentian Environmental Center, Britt, MN. Mark these dates on your calendars for next year. Preference will be given to teachers from Northeastern Minnesota, but others may apply.

For further information contact:- Roger Aiken, 651-644-8318 or <rogeraiken@creedproject.org>

4. NATIONAL TECH PREP CONFERENCE, 2004:

Wednesday 13 - Saturday 16 October, 2004. at the Minneapolis Convention Center.
Tech Prep has been creating student successes for over a dozen years. It is a partnership (secondary-post-secondary-business), a process for teaching and learning, and a curriculum structure. It is effective because students' potential for academic and career success is enhanced when they are motivated to learn in the context of career pathways that are interesting to them. Tech Prep is "useful academics" in action. Please consider attending as well as sharing with our Nation, the wonderful education programs we have in Minnesota.

For further information call NTPN at 800-518-1410 ext. 276

5. MRES 2004 SOLAR TOUR REUNION:

Wednesday 20 October, 2004. 1800 hrs. at Innovative Power Systems, 1153 16th Avenue S.E., Mpls.This will be a time for solar building owners and tour guides to compare notes, describe the reactions and comments of visitors and assess the level of success of the recent tour of solar homes and buildings.

For further information contact Gina Vermilyea at 651-653-0742 or <ginamariezz@aol.com>.

6. MINNESOTA SCIENCE TEACHERS ASSOCIATION FALL CONFERENCE:

Friday October 22, 2004. at Burnsville Senior High School, 600 E. Highway 13, Burnsville, MN.
MnSTA invites you to their Conference, "South of the River" Keynote speakers are to be announced soon! Go to <http://www.mnsta.org/conferences/fall/FC04/index.php> to learn more about the conference schedule, speakers and their presentations.

For further information contact <nancy.houtkooper@richfield.k12.mn.us> or <leila.youakim@anoka.k12.mn.us>.

7. 2004 ROCHESTER WELLNESS FAIR:

Tuesday October 26, 2004. 1600-2000 hrs. at Mayo High School, Rochester.
Each year the Rochester School District holds a Wellness Fair for all staff and teachers in their district. This year their Wellness Fair, to be held at Mayo High School, will include an Energy Component.

For further information contact Rich Huelskamp at 651-301-3271 or <rich@sunswarmth.com>.

8. INTERNATIONAL SOLAR CITIES CONGRESS 2004:

Sunday 14 to Thursday 18 November, 2004. at Daegu - Republic of Korea.
The event will enable the world to meet for the purpose of developing major policies for sustainable urban development. Korea is giving great attention to renewable energy because its dependence on fossil fuel is very high. Daegu aspires to be a leader in this regard by expanding its development of renewable energy technologies. The Daegu Congress 2004 will be an opportunity to let the world know how important it is to establish effective urban programs and international standards for the use of renewable energy systems and high-efficiency energy technologies. At this Congress, International Solar Cities will be able to meet and develop a common agenda for our future.

Directions: On-line registration and downloadable registration forms are available. Please complete the Registration Form and send it to the Conference secretariat via fax +82-2-3402-0589 or e-mail <iscc@ioconvex.com>.

Cost: Early Registration Costs: - Member of organizer, sponsor and supporter: $200 USD, Non-Member: $350 USD, Student: $100 USD Accompanying Person: $100 USD.

For more information contact: Prof. Jong-dall Kim Executive Director Event Website: <http://www.solarcity2004.or.kr/index.asp>, email:<jdkim@knu.ac.kr>, Tel.: +82 53 950 6323, Fax: +82 53 950 6324.

✂ ☎ ✂ ☞ NEWS ITEMS ✍ ✉ ✈ ✂

1. CHANGES ON CREED'S BOARD:

After having served as the CREED Board Chair since its inception in 1997, **Robert (Bob) Swanson** has stepped down from that position but stays on the Board as its Vice Chair. The Chair position has now been taken over by Board member **Rich Huelskamp**. Citing the pressure of their work and teaching duties and consequently their inability to attend Board meetings, resignations have been received and accepted from **Keith Anderson**, **Kathleen Sekhon** and **Jeff Ylinen**. However they will remain as non-voting advisory or Associate Board members. Associate Board member **Stephan Peter** has asked that his name be removed completely from the Advisory role. He remains as a paid up regular member of the CREED Organization. The new line up of CREED officers, board members and staff is now as follows:-

Officers:-

Chair, Rich Huelskamp; Vice Chair, Bob Swanson; Secretary/Treasurer, Valdi Stefanson; Executive Director; Tom Abeles.

Board (Voting Members):-

Roger Aiken, Lyle Bradley, Rich Huelskamp, Lyle Olson, Valdi Stefanson, Bob Swanson.

Board (Non Voting Advisory Members):-

Tom Abeles, Keith Anderson, Gary Connett, Lisa Daniels, Tracy Fredin, Bob Hanson, Mark LaLiberte, Emily Moore, Kathleen Sekhon, Jeff Ylinen.

Staff:-

Executive Director, Tom Abeles, Lead Instructor/Newsletter Editor, Roger Aiken, Web Master, Will Nabors, Web Site Developer, Jon Olds, Newsletter Co-Editor/Tours Organizer, Bill Butler.

2. "DISCOVERING SCIENCE ON THE RANGE IN THE FIELD OF ENERGY":

Sixteen teachers from schools on the Iron Range in N.E. Minnesota participated in CREED's DSRFE Project, funded by the Minnesota Higher Education Services Office (HESO) under their Improving Teacher Quality (ITQ) Program. They attended two weeks of instruction in energy while living in at the Laurentian Environmental Center (LEC) in Britt, Minnesota. We are now entering the second phase of the project, during which we will be visiting the teachers in their own classrooms helping them to integrate this material into their curriculums and to devise evaluation methods to track the progress being made by their students. We will be applying for a follow on grant from HESO for 2005 to complete the instruction of the EERE material that we offer to teachers through the 10 Credit Series of courses at Hamline University. See "Upcoming Meetings and Events" #3 on page 5..

3. E85 HYBRID CHALLENGE PROJECT:

This project is a co-operative joint initiative between CREED, The American Lung Association of Minnesota's (ALAMN) Clean Fuels Program and Minnesota State University-Mankato's Automotive and Manufacturing Engineering Department. Having successfully completed Phase IA of the project to demonstrate that a Toyota Prius Hybrid vehicle can run successfully on E85 fuel, the partnership is now applying for funds to embark on Phase IB

Phase IB will develop a solution to the problem of "cold" starts in Minnesota winters and expand the data collection to ascertain what other modifications can be carried out to optimize the vehicle's performance. This program is being carried out during fall semester at MSU-Mankato. Additionally, CREED will develop a program promoting the E-85 hybrid. This will include "wrapping" the Prius for display in community meetings, workshops, seminars, development of literature appropriate for distribution, including an Internet site and an online discussion forum for students and others interested in discussing opportunities for E-85 and the hybrid. Preliminary, in state, tours to promote the program to the community and to create visibility for ethanol in general and the combined hybrid concept.

Phase II The "Proofing" Phase will have as its objective the design of a conversion in sufficient detail that it will be possible for automotive programs from high schools through universities to engage in such conversions while at the same time gaining knowledge on the servicing and maintenance of these vehicles for the general public. These materials will be used to provide guidelines for a national competition or "E85 HYBRID CHALLENGE" for students in these institutions. Students would convert a hybrid into an optimized flexible fuel vehicle to compete in a variety of classes.

Phase III The "Challenge" Phase will comprise a closed course, cross country "race" for E-85 hybrid vehicles. Each vehicle will be a conventional "street" vehicle which has been optimized by a team of students from various automotive programs or from dealerships. Each vehicle will be fully equipped with monitoring instruments which are connected to an Internet site. Each team will start from their home base but traverse the same closed course within a given time period. All vehicles will be trackable, 24X7 by accessing the Internet site.

For further information contact Tom Abeles 612-823-3154 <tpa55407@yahoo.com> or Roger Aiken 651-644-8318 <rogeraiken@creedproject.org> at CREED; Tim Gerlach 651-223-9577 <tim.gerlach@alamn.org> at ALAMN; or Bruce Jones 507-389-6700 <bruce.jones@mnsu.edu> at MSU-Mankato.

5. COLORADO'S RENEWABLE ENERGY STANDARD (RES):

The Union of Concerned Scientists has asked us to publicize that this November, Colorado voters will become the first in the U.S. to vote on a renewable electricity standard (RES), requiring utilities to use 10% renewable energy by 2015, including 4% of that amount from solar energy. A win in Colorado, a conservative state with a major fossil fuel industry, will strengthen the hands of advocates working in other state legislatures, open the door for other renewable energy ballot initiatives, and build momentum for a federal RES. But Xcel Energy, one of the largest utilities in the country, and other utility & fossil fuel interests, plan to spend $10 million to defeat the initiative, blanketing the airwaves with misleading ads. This is a campaign that renewable energy advocates everywhere cannot afford to lose. Please send a letter to Xcel Energy's CEO urging the company not to stand between Colorado and cheaper, cleaner, safer electricity. Use the following as a guide:

[Dear Mr. Brunetti,

I'm writing to ask you to reconsider Xcel Energy's opposition to the Colorado Renewable Energy Initiative.

Renewable energy is the way of the future and Colorado's climate makes it ideally suited to be a leader in renewable energy. The adoption of a state renewable electricity standard will improve energy security, reduce air pollution, stabilize electric rates and help Colorado become a world leader in renewable energy technology.

Now is the time for Xcel to lead the way. Instead of investing over a billion dollars in new coal plants in Colorado, Xcel can be a leader and support the Renewable Energy Initiative.

Thank you for your time.

Sincerely,]

See <http://www.ucsaction.org/ctt.asp?u=34701&l=53146> or <http://www.ucsaction.org/ctt.asp?u=34701&l=53012>.

6. VIDEO REVIEW:

THE END OF SUBURBIA: Oil Depletion and the Collapse of The American Dream: Gregory Greene, Director, 2004.

Milton Takei, of Toronto's Electric Wallpaper, suggests that professors might consider having their students watch Gregory Greene's new video, "The End of Suburbia: Oil Depletion and the Collapse of the American Dream". The video points out how the United States used its post-Second World War wealth to construct unsustainable suburbs which required an extensive highway system for automobiles. It discusses the possibility that the world may have already reached the peak, or plateau, in global oil production (one commentator said that we would only know in hindsight). I recently saw a cartoon which summarized what would be the economic effects of the video's conclusions: the world economy is in the hospital, but wakes up, and feeling fine, checks out, only to walk into the path of a speeding truck with the label, "oil prices."

The video makes the connection between the fighting in Iraq and oil. However, I think that it underestimates the future danger of countries fighting wars over oil supplies. Ikuo Hirata discusses the possible effects of the new generation of small nuclear weapons that some in Washington wish to develop: "The current nuclear nonproliferation regime has functioned on the assumption that the nuclear powers would keep scaling down their arsenals without ever using them. The development of usable nuclear weapons would invalidate the assumption, possibly turning the nuclear nonproliferation treaty into a dead letter" ("Hiroshima Must Not Be Forgotten," *Nikkei Weekly* [English language], 9 August 2004, p.29).

I believe that an implication of the article is that if the nuclear nonproliferation treaty becomes a dead letter, then Japan would also be no longer bound by it. Japan's economy is, of course, highly dependent on oil imports. Hirata is a deputy chief editorial writer of *The Nihon Keizai Shimbun* (*Japan Economic Journal*), the Tokyo equivalent of the *Wall Street Journal*.

The video does not mention the phenomenon of "white flight" whereby white people moved to the U.S. suburbs to escape the central cities. Too many middle class people see the suburbs as havens within which they are safe from the violence of poor people and people of color. "We're literally stuck up a cul-de-sac in a cement SUV without a fill-up" - James Howard Kunstler.

Since World War II North Americans have invested much of their newfound wealth in suburbia. It has promised a sense of space, affordability, family life and upward mobility. As the population of suburban sprawl has exploded in the past 50 years, so too the suburban way of life has become embedded in the American consciousness. Suburbia, and all it promises, has become the American Dream.

But as we enter the 21st century, serious questions are beginning to emerge about the sustainability of this way of life. With brutal honesty and a touch of irony, The End of Suburbia explores the American Way of Life and its prospects as the planet approaches a critical era, as global demand for fossil fuels begins to outstrip supply. World Oil Peak and the inevitable decline of fossil fuels are upon us now, some scientists and policy makers argue in this documentary. The consequences of inaction in the face of this global crisis are enormous. What does Oil Peak mean for North America? As energy prices skyrocket in the coming years, how will the populations of suburbia react to the collapse of their dream? Are today's suburbs destined to become the slums of tomorrow? And what can be done NOW, individually and collectively, to avoid The End of Suburbia ?

Hosted by Barrie Zwicker. Featuring James Howard Kunstler, Peter Calthorpe, Michael Klare, Richard Heinberg, Matthew Simmons, Michael C. Ruppert, Julian Darley, Colin Campbell, Kenneth Deffeyes, Ali Samsam Bakhtiari and Steve Andrews. Directed by Gregory Greene. Produced by Barry Silverthorn. Duration: 78 minute

To order your copy on DVD or VHS go to URL<http://www.endofsuburbia.com/>.

U of M's IREE: Cont. from p.1.
harness the strengths of University expertise and, along with public and private partners, apply them to creative solutions in renewable energy. The success of the IREE will be dependent on the organization and deployment of our faculty expertise around clusters of activities leading to significant impacts at the "project" level. Fostering an environment where multi- and interdisciplinary thinking and projects can easily occur will be the key to accomplishing this goal. Funded clusters cover the following areas:

FUNDED PROJECTS BY CLUSTER:

1. Demonstration Projects.
*Solar/Hydrogen Fuel Cell Project.
*Science Museum of Minnesota's Prairie Maze: A Demonstration Project on Renewable Energy and the Environment.
*The University of Minnesota Renewable Energy Research and Demonstration Center at Morris.

2. Bio-Energy and Bio-Products Cluster.
*Using Genomics to Increase Soybean Biodiesel Yield.
*Membrane Electrode Assemblies for Microbial Fuel Cells Able to Oxidize Ethanol.
*Investigation of a Thin, Multi-Layer Latex Coating Photobioreactor for Optimal Light Adsorption and Hydrogen Evolution using Non-Growing Rhodopseudomonas palustris Mutants.
*Development of Research Infrastructure for Hybrid Poplar Biomass Production in Minnesota.
*Making Biodiesel from Crop Residues.
*Moisture Degradation Kinetics of Poly Lactic Acid (PLA) Products.
*Combustion Studies of Biomass-Derived Oil Sprays.
*Using Genomics Tools to Manipulate Carbon Partitioning to Increase Crop Yields of Biofuels and Biobased Products.
*Synthesis and Properties of Polyesters using 3-Hydroxy Propionic Acid (3HP) as the Primary Building Block.
*Genetic Basis of Biomass Accumulation in the Model Plant Arabidopsis Thaliana Grown in Ambient and

Elevated CO_2 Environments.
*Production of Bio-energy and Bio-products from Alfalfa and Willow.
*Functional Genomics of Bacterial Energetics.
*Development of a Biorefining Model for Corn Processing.
*Value-added Technologies for Utilization of Crop Byproducts and Residues.

3. Conservation & Energy Efficient Systems Cluster.
*Energy Efficient Roof and Attic Design: A Feasibility Study.
*Application of Hybrid Wind-Solar Electricity Generation in Western Minnesota.
*Renewable Roof for Residential Buildings.
*Integrated Building Systems for Energy Efficiency and Renewables.
*Intelligent Building Control with Renewable Energy Sources and Distributed Passive Wireless MEMS Sensors.
*Next Generation Solar Heating Systems.

4. Hydrogen Cluster.
*Quantum Chemistry Studies of Hydrogen Storage by Metal Organic Frameworks.
*The Study of Photoelectrochemical Processes for Hydrogen Production.
*Catalysts and Electrode Structures for Electrochemical Oxidation.
*Investigation of Composite Coatings for Photo Biochemical Generation of Hydrogen from Carbo-hydrates.
*Reforming Ethanol and Biodiesel to Produce Hydrogen.
*Hydrogen Production Infrastructure Analysis.

5. Policy, Economics & Ecosys-tems Cluster.
*Bringing Energy Efficient Hybrid Vehicles to Market - Decision Making by Corporations, Governments, and Consumers.
*Energy Alley Research Workgroup.
*Energy from Grass: Integrating Directed Class Research with Additional Research Topics.
*Clean Energy Resource Teams (CERTs) Project.
*Full Cost Accounting of Renewable Energy Systems.
*Sustainable Fuel-Sourcing Systems for Biomass Energy Production: Two Minnesota Case Studies.

For more information on the projects check the IREE web-site <http://www.iree.umn.edu> or contact the IREE Director, Dick Hemmingsen at 612-625-2263 or <hemmings@umn.edu>.

ETHANOL'S ROLE IN THE HYDROGEN ECONOMY

Gregg Deluga and Lanny Schmidt

The Hydrogen Economy is an economy based on the universe's most abundant resource. Hydrogen is the molecule that creates the power of the sun; the energy produced is non-polluting and gives the earth life. Hydrogen is also the molecule of choice in rocket fuel, due to its high energy. However, only the fuel cell holds the promise of converting hydrogen into electricity in an efficient, safe manner.

A fuel cell is a device that converts chemical energy into electrical energy through an electrochemical reaction. This means a fuel cell works like a battery that never runs out as long as fuel is fed to it. The fuel cell works as follows. In the middle is an electrolyte, a very specialized material; it allows protons to pass through it while being an

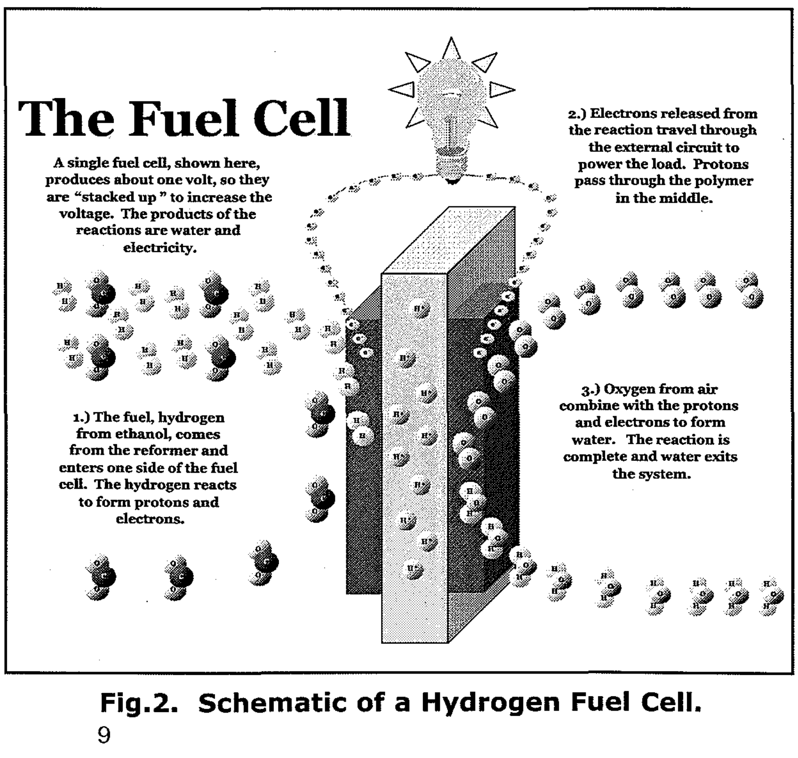


Fig.2. Schematic of a Hydrogen Fuel Cell.

insulator. This insulator forces the electrons through the external wire. This wire is hooked up to the electrical load, but can only draw power if the chemical reactions on both sides of the electrolyte are proceeding fast enough. The reaction on one side is hydrogen on platinum, converting hydrogen to protons and electrons. On the other side oxygen from air is reacting with protons, and the electrons on platinum to create water. So, that's it – hydrogen and air reacting to create electricity and water, a fuel cell.

This also sets up a problem – where does the hydrogen come from? Hydrogen is found on the earth only in bound form, water being the most common (H_2O). Hydrogen can be found in coal, natural gas, gasoline, oil, grass, and crop waste just about everywhere. Anything that is alive or was alive at one time contains hydrogen, but not in a useable form – the hydrogen must be extracted. The most common method of extracting hydrogen is called steam reforming. This is where, for example, natural gas and steam are heated to very high temperatures, and the hydrogen is extracted and separated in very large oil refinery type equipment. This hydrogen, normally called industrial hydrogen, is used mostly in the creation of ammonia for fertilizer. The other large application is for hydrocracking to make gasoline and hydrosulfurization to clean the noxious sulfur out of gasoline and diesel fuel. The amount of energy it takes to heat up the natural gas and steam makes more emissions per unit of energy than the efficiency gains available from the hydrogen produced. In other words, the hydrogen produced this way pollutes instead of cleaning our environment.

ETHANOL AND THE UNIVERSITY OF MINNESOTA:
A new process, recently discovered in the University of Minnesota's Department of Chemical Engineering and Material Science, holds promise to solve the problem of delivering hydrogen to fuel cells. In the process, ethanol and water mixtures are fed to an automotive fuel injector. The fuel injector sprays the 103-proof mixture into a reactor where it vaporizes and mixes with air. The mixture of ethanol, air, and water then touches a catalyst, Rhodium-Ceria. The catalyst initiates a chemical reaction in which the mixture is spontaneously heated from boiling temperature (95°F) to 1500 °F in a matter of 1/1000 of a second. As the chemical reaction proceeds, all the hydrogen is extracted from the ethanol along with a little bit extra from the accompanying water. This gas stream isn't quite ready for a fuel cell – it needs to be "cleaned up" a bit to remove any carbon monoxide, a poison to fuel cells. In the same reactor, an extra bit of catalyst, Platinum-Ceria, is added downstream.

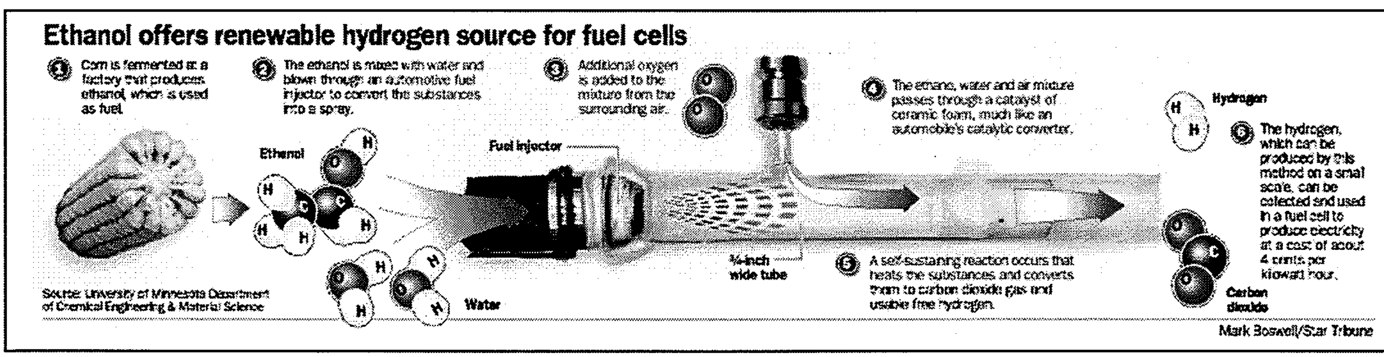


Fig.3. Renewable Hydrogen from Corn Derived Ethanol.

Gregg Deluga, scientist and lead author on the "Science" paper, (Renewable Hydrogen from Ethanol by Autothermal Reforming, G. A. Deluga, J. R. Salge, L. D. Schmidt and X. E. Verykios, Science, Feb. 13, 2004: pp. 993-997.) was asked why there was so much interest. "I feel like this is a scientific breakthrough that most people can relate to and understand. The media has picked up on the fact the 'Hydrogen Economy' is coming, but most people really don't understand what it is all about or how it will work," Deluga said. "Now, people understand you can use ethanol in a car today and it gives about 30 miles to the gallon. Someday, when fuel cells become economical, you could still fill up the car, but be converting the ethanol to hydrogen and getting many more miles to the gallon. People understand what ethanol is and are not afraid of it.

The breakthrough comes from a unique mix of reactor design, catalysts, and a little luck. Ethanol is flammable when it is mixed with air; however, if you flow ethanol and air fast enough, a flame can never form – like trying to light a candle on a windy day. The catalyst, a mix of the exotic metals Rhodium and Cerium, is commonly used in automotive catalytic converters. "I read about the catalytic converters and thought that's kind of close to what we want to do here, so I tried it," Deluga said. After many failed attempts, a few extra tricks were figured out and three years of work paid off in the summer of 2003. Deluga says hydrogen was extracted from ethanol in such great quantities; it was "off the charts."

This chemical reactor – about the size of a corn cob, interestingly enough – is known as a millisecond contact time auto-thermal reformer. It has been a research topic in Professor Lanny Schmidt's laboratory at the University of Minnesota for about 15 years. "This all started about 10, 15 years ago with methane and natural gas. We found a way to make synthesis gas a thousand times faster than anyone else," Schmidt said. His research has continued to develop to include hydrogen production for fuel cells in the past few years. "This invention points to a way to make renewable hydrogen that may be economical and available today," Schmidt, a University of Minnesota Regent's professor, said.

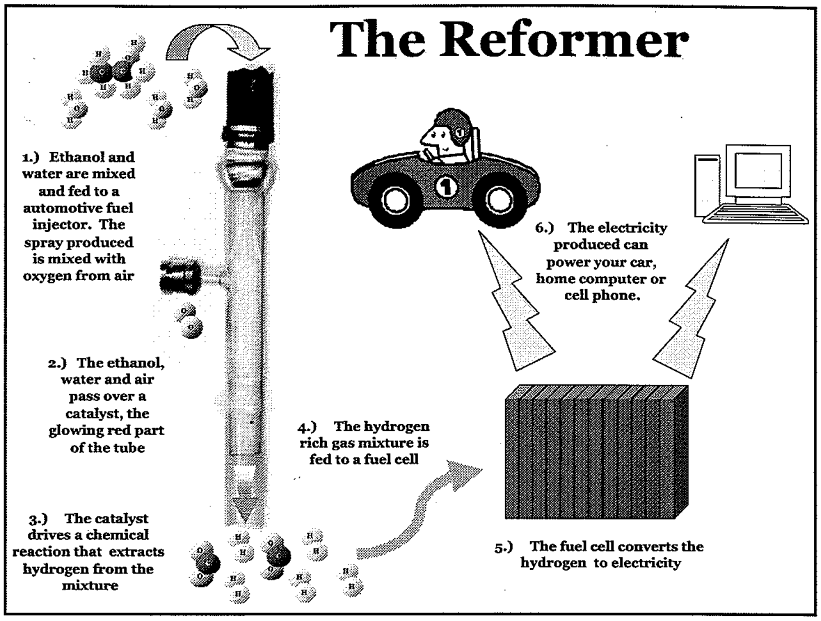


Fig.4. Schematic of the Reformer.

The researchers see an early use for their invention in remote areas, where the installation of new power lines is not feasible. People use ethanol to power small hydrogen fuel cells in their basements. The average home uses about 2 kW normally and at peak times closer to 7 kW. The fuel cell system in the basement would be about the size of a standard washer and dryer. The tank outside, while depending on how much electricity is used, would hold the approximately two gallons of ethanol needed per day. The system could provide electricity and a little extra heat for the home.

The current process uses fuel grade ethanol mixed with water. This small detail makes the discovery even more beneficial to ethanol producers. In the future, instead of converting all the ethanol to anhydrous (fuel grade) ethanol, some could be left with water in the stream. This eliminates a large energy and expense category for the ethanol producers. The last bits of water that must be removed from ethanol to make it fuel grade are the most expensive. This means the ethanol processor now has a more efficient and economical plant. The process could also be extended to biodiesel fuels, the researchers said. Its benefits include reducing dependence on imported fuels, reducing carbon dioxide emissions (because the carbon dioxide produced by the reaction is stored in the next year's corn crop), and boosting rural economies.

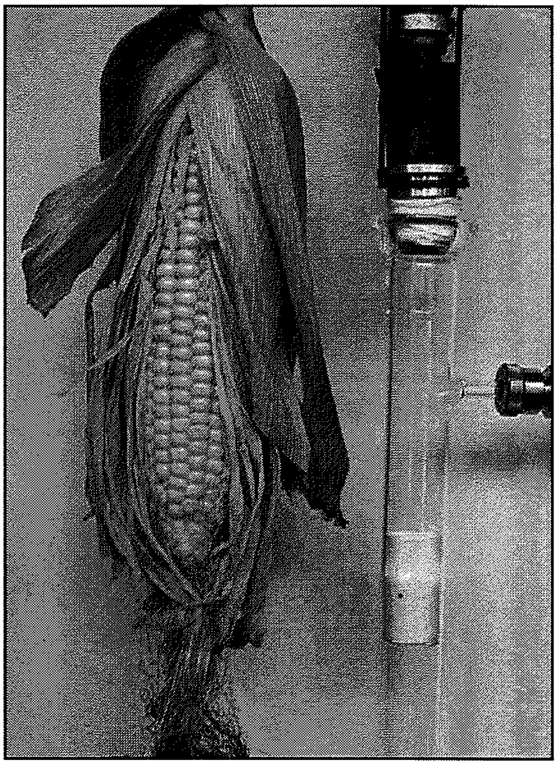


Fig.5. Photograph of a glowing auto-thermal chemical reactor used to convert ethanol into hydrogen along side of an ear of corn, the raw material to produce ethanol.

"The H_2 economy means cars and electricity powered by hydrogen," Schmidt said. "But hydrogen is hard to come by. You can't pipe it long distances. There are a few hydrogen-fueling stations, but they strip hydrogen from methane – natural gas – on site. It's expensive, and because it uses fossil fuels, it increases carbon dioxide emissions, so this is only a short-term solution until renewable hydrogen is available."

Ethanol is easy to transport and relatively nontoxic. It is already being produced from corn and used in car engines on a large scale. But when used instead to produce hydrogen for a fuel cell, the whole process is nearly three times as efficient. That is, a bushel of corn would yield three times as much power if its energy were channeled into hydrogen fuel cells rather than burned along with gasoline.

"We can potentially capture 50 percent of the energy stored in sugar (in corn), whereas converting the sugar to ethanol and burning the ethanol in a car would harvest only 20 percent of the energy in sugar," Schmidt said. "Ethanol in car engines is burned with 20 percent efficiency, but if you used ethanol to make hydrogen for a fuel cell, you would get 60 percent efficiency."

So what does the future hold? When will everyone be driving fuel cell-powered ethanol cars? James Salge, co-author on the paper and graduate student at the University of Minnesota, said, "The efficiency of the reformer needs to be improved a bit. We are currently 80 percent there – I want to find a way to get that last 20 percent. I would also like to look into using ethanol for chemical production. We recently made some plastic precursors out of biodiesel, and maybe we can make similar products out of ethanol," Salge said. As the three scientists and good friends joked about the future of ethanol and fuel cells, it was clear that the future was hard to predict. This was an enabling technology for the hydrogen economy, but when will that economy happen? That, Deluga said, is as much a political decision as a scientific one.

Gregg Deluga was a research scientist and Lanny Schmidt is a Regents professor in the Department of Chemical Engineering and Materials Science at the University of Minnesota. Gregg may be reached at 615-235-1389 or <deluga@cems.umn.edu>. Lanny at 612-625-9391 or <schmidt@cems.umn.edu>.

UNIVERSITY OF MINNESOTA FUEL CELL PROJECT

Rich Huelskamp and Phil Goodrich

This project is installing a Proton Exchange Membrane (PEM) fuel cell using biogas as the energy resource to generate renewable energy based electricity. The manure from 800 cows at the Haubenschild Dairy Farm near Princeton, MN will generate the methane gas. The University of Minnesota's primary goals are to research/develop a biogas clean up system and monitor the system to evaluate efficiency and greenhouse gas emissions.

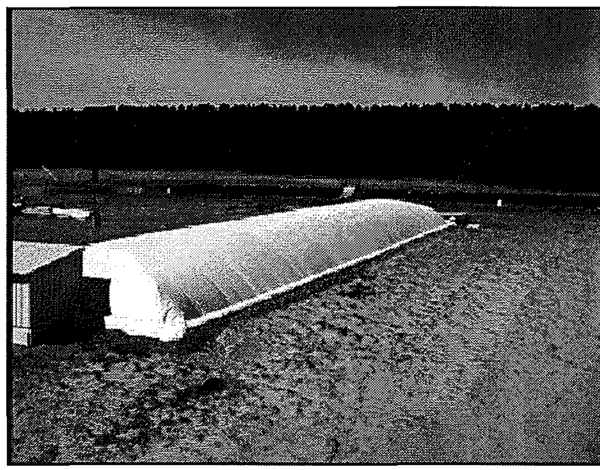


Fig.6. The Haubenschild operation.

The Legislative Commission on Natural Resources (LCMR) is providing funding for this project. Project cooperators include the Department of Biosystems and Agricultural Engineering, the Minnesota Project, the Minnesota Department of Agriculture, Dennis Haubenschild, John Deere Inc., Great River Energy, East Central Electric, and the Electric Power Research Institute. Philip Goodrich PE, Department of Biosystems and Agricultural Engineering is the principal investigator. Information from this project will be made available to the public on a website.

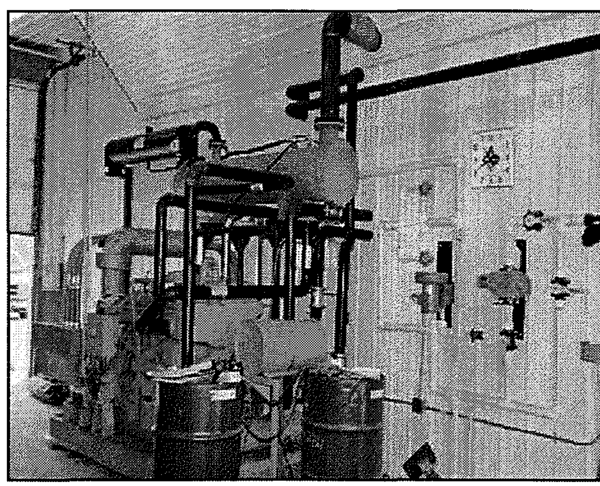


Fig.7. The Engine-Generator Set.

In 1999, Dennis Haubenschild accomplished a business goal of turning manure into:

* An energy resource.
* A higher value fertilizer.
* A land spreading application with significant reductions in odors.
* A promising economic opportunity to diversify the family income.

With planning, financial, and design assistance of state and federal agencies, Dennis was able to install a methane digester and engine generator set to produce cow power. The engine driven 135 kW electric generator is producing enough electricity for use on the farm and to distribute through East Central Electric's utility lines to supply approximately 10 neighboring farms/homes.

Over time Mr. Haubenschild improved the performance of the anaerobic digester so excess methane gas was being flared off. His options to make use of the excess gas were to consider another combustion engine/generators set or use it in a gas-fired boiler.

The Minnesota Department of Agriculture recommended seeking funds to conduct biogas cleanup research for use in a hydrogen powered fuel cell and/or a biogas fueled sterling engine. Sufficient industry and government support came together for both technologies. A 5 kW Plug Power PEM fuel cell was recently delivered and will be in operation before winter.

The electricity generated will be fed into the utility grid for East Central Electric's Green Power Program. Utility customers volunteer to pay an additional $1.5045 per 100 kWh to support installations like Dennis's renewable energy based electricity.

Biogas is primarily made of 55-80% methane, 10-45% carbon dioxide, and up to 3500 parts per million hydrogen sulfide. Anaerobic digestion is the breakdown of organic matter in the absence of oxygen with the biogas being given off in the process. This process occurs naturally in swamps and stagnant dirty water. The solids and excess liquids from the digester are stored in a plastic lined storage pond and then injected into crop producing fields. The solids and liquids are biologically ready for plant absorption of the nutrients.

The biogas cleanup equipment will separate out the hydrogen sulfide and carbon dioxide. This will increase the percent of methane to 90-95% and will lengthen the operational life of the fuel cell. The reduction of carbon dioxide and hydrogen sulfide in the biogas clean up will improve the purity of the hydrogen gas that the reformer component of the fuel cell generates.

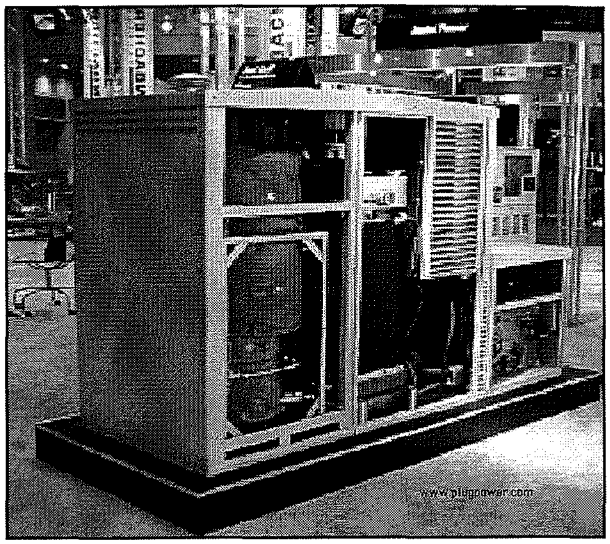


Fig.8. 5kW Plug Power PEM Fuel Cell.

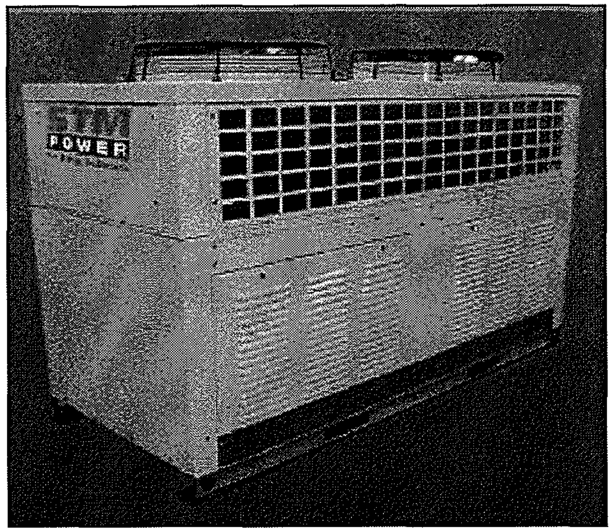


Fig.9. 55kW STM Power Stirling Engine.

In a companion project funded by East Central Power, Great River Energy and Electric Power Institute, a 55 kW sterling engine made by STM Power will arrive in November.

No biogas cleanup is being initially planned for the sterling engine. A sterling engine (also called a heat engine contains a sealed gas system (similar to refrigeration equipment) that expands and contracts to "move" a piston. The sterling engine uses external heat exchangers to expand the gas. Another heat exchanger cools the internal gas and this gas compression causes the piston to return for the internal gases to expand again. Electricity conversion efficiency is around 30% with total energy conversion up to 80% when waste heat is used for other processes. See <www.seusa.org> for more information.

Producing renewable energy generated electricity and heat with the net benefit of reduced greenhouse gases is an excellent method to solve some of today's agriculture waste management issues. Livestock producers that are seeking new ways to deal with manure from their operation in a safe, efficient, and sustainable way can consider anaerobic digesters. Reducing their environmental impact, improved fertilizer qualities of the manure, and a diversified income will result.

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DEVELOPMENT OF LOW-COST POLYMER SOLAR WATER HEATING SYSTEMS

Jane Davidson and Lorraine Francis

A team of professors and students at the University of Minnesota is collaborating with scientists at the National Renewable Energy Laboratory (NREL), two US solar manufacturers and several polymer manufacturers to develop a new type of solar water heating system made of plastic. The replacement of glass and metal components with plastic is expected to reduce the costs of hardware, shipping and installation and make solar water heating more affordable. The US Department of Energy has recently stated a goal of a 50% cost reduction of solar water heating systems with the objective of increasing market penetration. Currently only 1 percent of US homes use solar energy to heat water. The energy to heat water represents about 18% of the energy use in US buildings. The University of Minnesota team includes Professors Jane Davidson, Sue Mantell and Frank Kulacki in the Department of Mechanical Engineering and Professor Lorraine Francis in the Department of Chemical Engineering and Materials Science. The research of these professors and their graduate students addresses some of the key challenges in using polymers in solar systems. Their work is aimed at assuring high thermal efficiency and appropriate selection and testing of candidate polymer materials.

The design currently being studied is a system intended for mild climates where freezing temperatures are rare. The polymer system is a modification of the conventional Integral Collector Storage (ICS) water heating system. ICS systems are currently used throughout the world in regions where freezing is not severe. The ICS system is relatively simple because it does not require pumps or controls for operation. The collection and storage functions of the system are combined in a single component. Designs of these systems vary but the general configuration is a water tank, or interconnected tanks, that contains pressurized potable water and is usually made of copper. The exterior of the copper tank absorbs the sun's radiant energy. The copper tank is either enclosed in an insulated box with a transparent low-iron glass cover (called the glazing) or in evacuated glass tubes. When the homeowner turns on the hot water, the cold city water flows into the ICS and the solar heated water is pushed out the top. The solar heated water may be supplied directly to the faucet or to the conventional water heater. In most homes, a conventional electric or gas water heater is used as a backup to the solar system. Solar energy usually provides 50 to 75 percent of the hot water. Typical solar water heaters have 2 to 6 m2 of collector area, and 190 to 450 liter water storage tanks.

The new low-cost ICS system uses polymer components. A sketch of a generic polymer ICS system is shown in Fig. 10. The ICS is a relatively thin-walled polymer vessel that contains water at atmospheric pressure. A polymer heat exchanger is immersed in the storage fluid. Instead of the household water flowing directly into the storage water, it passes through a heat exchanger before it is delivered at the faucet. Because the flow is triggered by the homeowner turning on the hot water faucet, no mechanical pump is needed. The heat exchanger is needed to protect the polymer vessel from rupture or de-formation due to the pressure of the household water supply. The glazing to protect the polymer storage vessel and to re-duce thermal losses to the ambient air is also polymer. Scientists at NREL have been working on selection of the best glazing materials. A laminate construction made of polycarbonate with a thin acrylic Korad® film to protect the polycarbonate and collector vessel from solar ultraviolet UV light is recommended. This laminate has shown excellent UV-screening properties, has good transmittance across the solar spectrum and is expected to maintain its properties even after long exposure to sunlight and elevated operating temperatures.

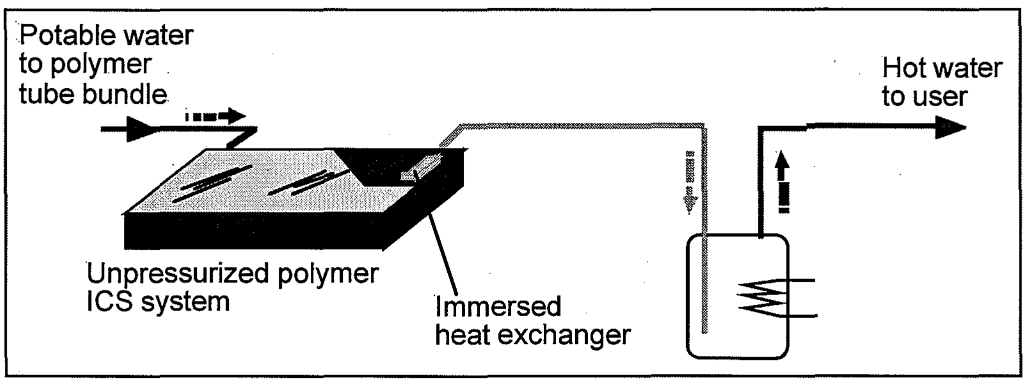

Fig.10. Generic polymeric Unpressurized Integral Collector Storage system under development in the US for mild climates.

Research at the U. of M. has focused on design of the heat exchanger and evaluation of materials for the storage vessel and heat exchanger. Heat exchangers are not a new technology, but the immersion of the heat exchanger in a thin insulated vessel which is exposed to radiant energy and placed on an inclined roof poses a transient natural convection heat transfer problem that has not been studied in the past. Professor Davidson's Solar Energy Laboratory at the University of Minnesota is recognized as the premier facility in the US to measure performance of solar heat exchangers (Fig. 11). Professors Davidson and Kulacki and their student Dr. Wei Liu have evaluated several polymer prototypes in this facility. From the extensive data base, they developed empirical heat transfer correlations that solar manufacturers can use to select heat exchangers for their systems. One of the important findings is that the tubes of the heat exchanger can be packed tightly into the storage vessel and still maintain relatively high heat transfer rates. In fact, the natural circulation flow that develops in the thin ICS storage vessel has been shown to enhance heat transfer rates over what might be expected if the heat exchanger were immersed in a large tank. Students Yan Su and Vishard Ragoonanan are looking at methods to further improve performance.

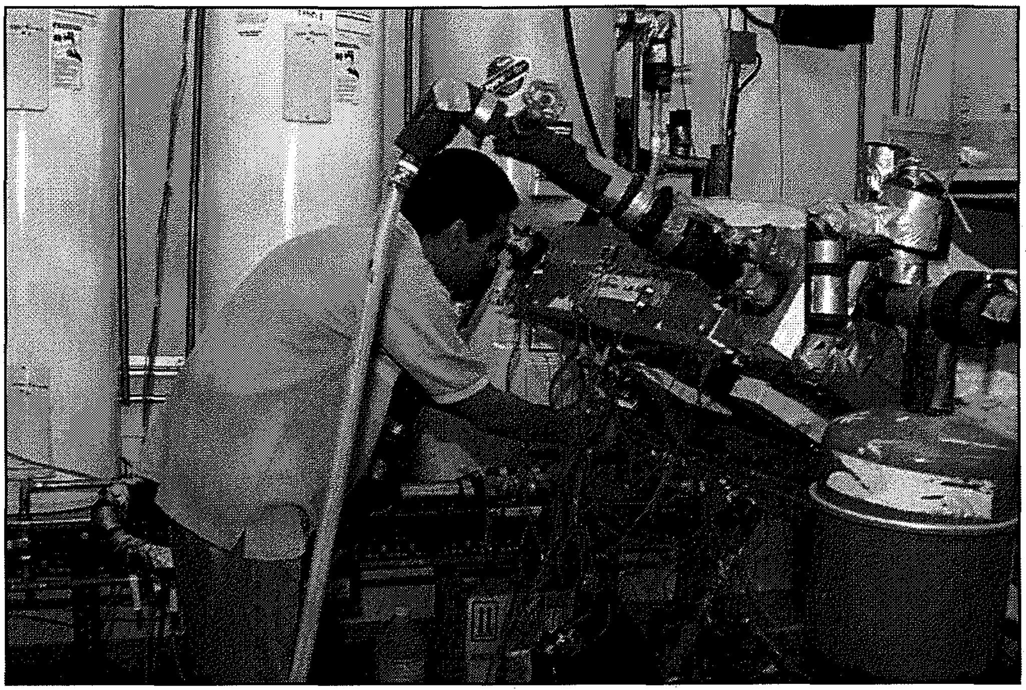

Fig.11. The University of Minnesota's Solar Energy Laboratory is recognized as the premier US facility for evaluation of novel solar heat exchangers. Solar energy is simulated with electric resistance heaters allowing testing even in the snowy Minnesota winter.

The University of Minnesota has evaluated candidate materials either proposed by industry or polymer manufacturers for the solar vessel and the heat exchanger. Both the propensity of candidate materials to form scale in hard water and the mechanical behavior of materials in potable water are being evaluated. Professors Susan Mantell and Davidson and students, Dr. Chunhui Wu and Andy Freeman, have evaluated the long-term mechanical behavior of polymers in hot chlorinated water. When a polymer is exposed to an oxidative environment like potable water, degradation such as chain scission and cross-linking can occur. These changes on the molecular level can result in an undesirable change in mechanical properties (lower strength and increased creep compliance) on the macroscopic level. Water absorption can also change the macroscopic mechanical behavior of the material. As part of a potable hot water system, polymer components can be exposed to temperatures as high as 82°C and oxidation reduction potential (ORP) levels as high as 500 mV. (The oxidative reduction potential (ORP) of water is a measure of the total oxidizing potential.) Mechanical properties such as creep compliance, creep rupture strength and ultimate tensile strength have been measured for polybutylene, polysulfone, nylon 6,6, and semiaromatic nylon. With the exception of nylon 6,6, these materials have been identified as potential heat exchanger materials.

Professor Lorraine Francis is leading the effort to understand how minerals in hard water used in many locations affect the polymer tubes in the heat exchanger. When water flows through tubes and pipes, calcium carbonate ($CaCO_3$) as well as other compounds may form on the tube walls. This process is referred to as scaling. In solar systems, scaling can reduce heat transfer due to the additional conductive resistance across the calcium carbonate layer, and increase the fluid pressure drop due to narrowing of the flow passage. There is a large body of research documenting the effects of scaling on metal heat transfer surfaces; however, data on scaling rates in polymer tubes are limited and the materials and conditions studied do not match those for polymer-based solar collectors and heat exchangers. Student Yana Wang carried out qualitative measurements of scaling rates, and observation of surface morphology of nylon 6,6, high temperature nylon, polybutylene, polypropylene, Teflon, and copper tubes placed in a heat exchanger with highly supersaturated water flowing through the tubes provide convincing evidence that polymers, like copper, are likely to scale if these materials are used in an open-loop heat exchanger where the working fluid is supersaturated with respect to calcium carbonate (Fig. 12). The ultimate aim of on-going experiments is to understand the mechanism by which polymers scale so that strategies can be developed to avoid scaling. Of key interest are chemical differences between polymers, which influence their interaction with water, the mechanism of calcium carbonate nucleation, and scale morphology, and structural differences, which may impact calcium carbonate nucleation and adhesion. Student Patti Sanft is currently exploring these issues using an optical method for monitoring scale.

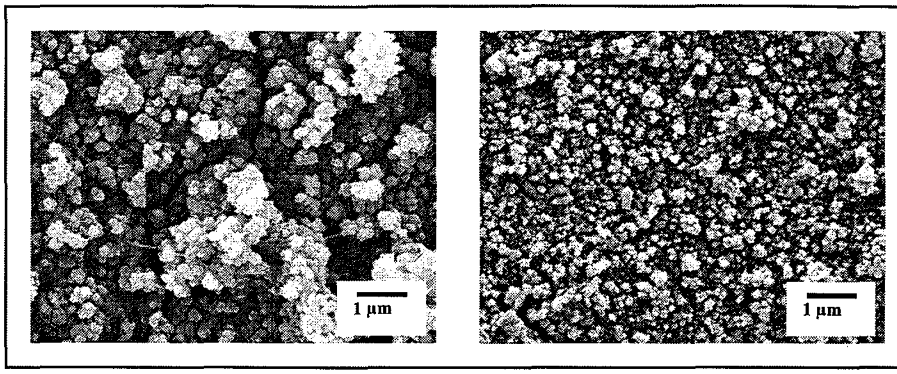

Fig.12. Scanning electron images of scale formation on nylon 6,6, polybutylene (PB) and copper after 1660 hours in a heat exchanger. On-going work at the University of Minnesota seeks to understand the mechanism by which polymers scale so that strategies can be developed to avoid scaling.

Two solar manufacturers have used the work at the University of Minnesota to help design polymer ICS solar water heaters. Systems are being tested on selected homes in California. In the near future it is hoped that the technology can be extended to colder climates like Minnesota.

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BILL BUTLER'S EDGE ACADEMY COLUMN

For this issue Bill brings us an article written by Mark Clayton, a Staff writer for The Christian Science Monitor. See <http://www.csmonitor.com/cgi-bin/encryptmail.pl?ID= CDE1F2EBA0C3ECE1F9F4EFEE&url= /2004/0902/p14s01-sten.html>.

A VORACIOUS EARTH

Some regions - especially in Asia - are overusing their renewable resources.

It's the region of the world that leaves the biggest human footprint. It gobbles up 80 percent of the crop and other plant resources it produces each year. If things don't change, its ecological survival looks iffy. Surprisingly, it's not the United States. It's a swath of Asia that sweeps from India to China. And it leads to a startling question: If these areas of the world are nearing an ecological budget deficit, can they sustain their growth much longer?

"Some regions of the world ... consume far beyond 100 percent of what their local ecosystems can provide," says Taylor Ricketts, director of the Conservation Science Program at the World Wildlife Fund in Washington, an author of a recent study on ecological imbalances. "These areas are being subsidized by other ecosystems. They're on a form of life support." These findings stem from a map built by Dr. Ricketts and his colleagues which shows mankind's ecological footprint for each square mile of Earth's inhabited zones. This geographical representation, published in the journal *Nature* in June, defies conventional wisdom about consumption, while illustrating the dramatic effect of population density.

The calculation works this way: First, add up all the planet's sun energy converted to organic carbon by plants each year and call it "net primary production" or NPP - about 56 billion tons worth. Now, subtract the portion that human beings use - all the carbon in materials people consume from cotton in clothes to wood in homes to corn flakes and milk in a bowl of cereal. Ricketts figures that the world's 6.3 billion people appropriate up to a third of the world's NPP a year. While that average sounds sustainable, it disguises key geographical imbalances (and ignores energy use and land-cultivation used in other human-foot-

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Fig. 13. Views from the Second Week of the "Discovering Science on the Range in the Field of Energy" Course for Teachers at the Laurentian Environmental Center.

print calculations).

For example, most of Siberia effectively uses 0 percent of its local NPP. By contrast, North America uses 23 percent. Surprisingly, that's still less than the worldwide average. North Americans aren't consuming less. They eat up 5.4 tons of carbon per year compared with a modest 1.2 tons for residents of south central Asia. But that part of Asia is far more populous - 1.3 billion people - and more densely packed than North America. As a result, that region consumes enough goods to require 1.6 billion tons of NPP per year or about 80 percent of the carbon output of that area, the study shows. That's the present picture. If developing nations boost consumption to match industrialized countries, overall human appropriation of NPP would rise 75 percent, Ricketts and his group calculates.

That shift is already happening, argues Norman Myers, a visiting professor of environmental science at Oxford University and coauthor of a new book, *"The New Consumers."* More than 1 billion people in 20 developing and transitional nations have recently become wealthy enough to begin consuming like Americans. Already, they own one-fifth of the world's automobiles. By 2010, they could own a third. "The road the planet is heading down with all these new consumers will be enormously and gloriously unsustainable," Dr. Myers says in an telephone interview from Oxford, England. "If these consumers want to buy a lot of computers and gadgets - on the whole, that's OK.... But when it comes to cars, the environmental costs are huge."

Unlike Ricketts and company, Myers factors energy into his equation. Worldwide, the average human footprint is 2.28 hectares (5.4 acres), but Earth only has a biocapacity of 1.9 hectare per person, he says, citing a World Wildlife Fund Living Planet Report. That leaves a 0.38 hectare deficit per person. In China, the deficit is more acute: 0.5 hectares per person. China's population is a major part of 1.1 billion new consumers worldwide with purchasing power equivalent to more than $6 trillion. Those consumers will buy as many as 800 million cars by 2010 and use a quarter of all electricity in their respective countries - generated by fossil fuels, Myers reports.

On the plus side, this consumer trend could be muted or reversed, he says. More efficient technologies could be adopted in developing nations - hybrid or electric-car technology instead of SUVs, for instance. And, there's also the possibility a different ethic, voluntary simplicity, could develop en masse along the way. "Surveys show that a lot of people are finding that life doesn't get better with consumption of more and more goodies - that life should offer more than just another trip to the shopping mall," he says.

Not everyone is quite so concerned. Steven Hayward, a resident scholar with the American Enterprise Institute acknowledges models of global human consumption can be useful, but their predictions are often wrong in the long run. "They are essentially taking a static snapshot of the resource profile of the whole world," he says. "When you run that out in a straight line way, any snapshot will generally present an unsustainable conclusion." For instance, a century ago the New England landscape had been turned into farm land and denuded of trees, which were burned for heat. Today, New England has been reforested. As the price of resources goes up, humanity will adjust, shift to other resources, he says.

At least some places take the consumption footprint issue seriously. By cutting its use of natural gas and diesel and increased recycling, Santa Monica, Calif. recently shrank its ecological footprint by 5.7 percent to 20.9 acres per person over 10 years, according to Redefining Progress, a nonprofit group focused on sustainability. Unless that happens more broadly, though, humanity's footfall on the environment will get ever heavier, predicts Paul Ehrlich, a Stanford University professor of environmental studies. In his new book *"One with Nineveh: Politics, Consumption, and the Human Future,"* he calls for a wholesale reassessment of human consumption. In 2000, for instance, the US used about 23 percent of the world's energy despite having less than 5 percent of its population. The US has about one quarter of all the cars in the world. And much of its consumption affects other regions through its massive imports - cutting Indonesian forests, for instance. "We humans are not living on our income, we are living on our capital - our agricultural soils, our underground water, and our biodiversity," Dr. Ehrlich says.

Humanity does have a chance to save itself, because population growth has moderated. Also, economists and ecologists are working to gauge the total costs of consumption more accurately. A $2 gallon of gasoline is really $6 because it carries $4 of unpaid environmental costs, he says. "We could do enormously better on energy efficiency with technologies we already have in hand.... Unfortunately, as far as consumption goes, we're still hog wild in the wrong direction."

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Appendix L: Dataset Examples from Fuel Cell and Monitoring Software

C:\Program Files\Fps_COM\FPS_Data_Log_23-06-05.csv

Time/Date	SP	CH4 % Channel 1	CO2 % Channel 2	O2 % Channel 3	Bar. Press Hg Channel 4	Gas Press " w.c. Channel 5	Gas Temp Deg F Channel 6	Air Temp Deg C Channel 7	NA Channel 8	NA Channel 9	H2S-Hi ppm Channel 1	H2S-LO ppm Channel 11
6/23/2005 5:03	1	59.3	41	0.4	28.7	-1.9	80.9	34.5	0	7793.2	2961.9	7.5
6/23/2005 5:18	1	60.8	40.7	0.3	28.6	-1.9	80.8	34.5	0	7781.9	2969.6	6.5
6/23/2005 5:33	1	59.3	40.2	0.2	28.7	-1.4	80.1	34.2	0	7770.3	2994.5	0.4
6/23/2005 5:48	1	60.5	40.9	0.3	28.7	-2	79.6	33.7	0	7799.9	2970.9	0.5
6/23/2005 6:03	1	60.2	39.9	0.2	28.7	-2.2	79.4	33.3	0	7769.8	2966.3	0.4
6/23/2005 6:18	1	59.2	40.5	0.1	28.7	-2.2	79.1	32.8	0	8196.3	4253	54.6
6/23/2005 6:33	1	94.7	23.2	0.1	28.6	49.4	81.4	32.4	0	8305.1	495.1	101
6/23/2005 6:48	1	72.1	24.4	0.1	28.7	48.9	83.3	32.3	0	8256.7	300.6	101
6/23/2005 7:03	1	69.2	24.5	0.1	28.7	44.7	84.4	32.1	0	8245.7	245.1	99.8
6/23/2005 7:18	1	67.4	23.2	0.2	28.6	42.4	87.1	32.2	0	8222.2	180.9	81.8
6/23/2005 7:33	1	69.1	20.9	0.2	28.6	42.1	90.5	32.4	0	8178.8	166.6	71
6/23/2005 7:48	1	70.2	17.7	0.2	28.6	39.7	87.7	32.6	0	8129.2	152.6	60.5
6/23/2005 8:03	1	70	17.4	0.1	28.6	36	90.3	32.7	0	8100.4	147.1	53.5
6/23/2005 8:18	1	67.3	21.5	0.2	28.6	33.2	90.9	32.9	0	8126.1	151.2	50.3
6/23/2005 8:33	1	65.7	28.3	0.1	28.6	31	90.4	33.1	0	8166	177.5	47.2
6/23/2005 8:48	1	61.6	37.7	0.1	28.7	29.4	90	33.3	0	8239.3	209.3	44.5
6/23/2005 9:03	1	60.8	38.8	0.1	28.6	26.8	89.4	33.3	0	8209.2	235.7	41.5
6/23/2005 9:18	1	60.5	38	0.2	28.6	28.9	89.3	33.5	0	8246	286.5	39.2
6/23/2005 9:33	1	64.8	30.1	0.3	28.6	26.4	90	33.7	0	8143.8	244	37.3
6/23/2005 9:48	1	68.5	22.4	0.2	28.6	29.5	89	33.7	0	8061.2	217.3	35.4
6/23/2005 10:03	1	68.6	19.3	0.2	28.6	26.4	90.4	33.9	0	8049.6	191.6	33.5
6/23/2005 10:18	1	70.4	17.1	0.2	28.6	52.1	90.3	34	0	8216.6	215.8	29.3
6/23/2005 10:33	1	70.9	15.6	0.2	28.6	51.7	88.9	34.2	0	8197.3	302.6	28.3
6/23/2005 10:48	1	71	14.7	0.3	28.6	51.6	88.8	34.3	0	8188.5	308.9	27.8
6/23/2005 11:03	1	71.8	13.7	0.2	28.6	51.6	88.2	34.5	0	8174.1	317.1	27.2
6/23/2005 11:18	1	72.3	12.8	0.2	28.6	33.8	88.3	34.6	0	8167.6	264.9	26.3
6/23/2005 11:33	1	71.8	12	0.2	28.6	34.9	86.1	34.8	0	8032.4	165.2	26.3
6/23/2005 11:48	1	72.7	12.3	0.3	28.6	33.9	92.1	34.9	0	8040.9	146.6	27.3
6/23/2005 12:03	1	74.3	12	0.4	28.6	-2.2	92	35.2	0	7564.4	142.1	16.3
6/23/2005 12:18	1	33.1	4.7	6.3	28.6	46.6	93.1	35.5	0	8112.1	203.5	28.2
6/23/2005 12:33	1	73.1	11.8	0.4	28.5	38.4	93.1	35.7	0	8036.9	82.4	27.9
6/23/2005 12:48	1	72.5	11.6	0.3	28.6	50.3	92.8	36.1	0	8009.8	52.4	30.2
6/23/2005 13:03	1	73.2	12.3	0.4	28.6	40.6	92.1	36.4	0.1	8044.2	47.5	30.2
6/23/2005 13:18	1	73.4	12.2	0.3	28.6	48.8	93.7	36.6	0.1	8096.5	45.6	31.3
6/23/2005 13:33	1	72.6	12	0.2	28.6	42.1	94.3	36.9	0.1	8042.3	45.7	33.1
6/23/2005 13:48	1	73.6	12	0.3	28.5	40.7	94.2	37.2	0	8012.9	44.2	34.3
6/23/2005 14:03	1	72.8	11.7	0.4	28.6	38.2	94.6	37.5	0	7998.2	48.2	35.2
6/23/2005 14:18	1	72.4	11.9	0.3	28.6	35.3	95.1	37.7	0.1	7974.8	46.8	36.3
6/23/2005 14:33	1	73	11.8	0.3	28.6	39.8	95.2	38	0.1	7974.1	48.4	36.3
6/23/2005 14:48	1	72.9	11.8	0.3	28.6	33.2	95.3	38.3	0	7939.8	46.1	37.2
6/23/2005 15:03	1	73.7	11.7	0.3	28.5	30.8	96.1	38.6	0	7929.8	50.8	38.2
6/23/2005 15:18	1	73.7	11.4	0.5	28.6	32.7	97.3	38.8	0	7924.2	46.7	38.2
6/23/2005 15:33	1	73.6	11.7	0.4	28.6	30.9	98.1	39.1	0.1	7931.9	48.4	38.2
6/23/2005 15:48	1	72.4	11.7	0.4	28.5	29.3	98.2	39.4	0.1	7905.2	51.9	39.2
6/23/2005 16:03	1	74.3	12	0.4	28.6	26.9	94.3	39.7	0.1	7884.6	52.4	38.3
6/23/2005 16:18	1	72.4	12.1	0.6	28.6	29.2	98.3	39.8	0	7858.9	48.9	38.2
6/23/2005 16:33	1	72.2	12.2	0.5	28.5	25.9	99.3	40.1	0.1	7861.9	52.6	39.3
6/23/2005 16:48	1	72.5	12.4	0.5	28.5	35.1	97.4	40.4	0	7931.7	51	38.2
6/23/2005 17:03	1	73.2	12.5	0.5	28.5	37.1	95.4	40.6	0.1	7954.1	52.1	39.2
6/23/2005 17:18	1	72.4	13	0.5	28.5	34.5	96.9	40.9	0.1	7939.9	52.5	40.2

Notes:
Ice bath was 39 to 40 Deg F, Water tank was 55-59 Deg. F,
Outlet water had pH of 5.6 to 5.8, Water tank pH was 7.6
Water flow rate varied from 3 to 4 gallons per minute
Water tower gas pressure varied from high 60's to 75 PSI

	1	2	3	4	5	6	7	8	9	10
1	Service Int Ver PDB: 0-0-6 VS: 0.0									
2	integer dat	standard date	SOL2 WATER	ATO	REF	SOL6	SOL7 DI LINES	MOT8	SOL17 DRAIN FUEL	CHP
3			FILL (NC)	RESET	BLEED (LAB)	HUM FILL	DRAIN (NO)	BATT COMP	PROCESSOR 2 (NO	ENABLE
4										
5										
6	1.12E+09	5/19/2005 1:32	0	1	0	1	1	0	1	1
7	1.12E+09	5/19/2005 1:32	0	1	0	1	1	0	1	1
8	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
9	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
10	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
11	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
12	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
13	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
14	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
15	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
16	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
17	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
18	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
19	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
20	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
21	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
22	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
23	1.12E+09	5/19/2005 1:33	1	1	0	0	1	0	1	1
24	1.12E+09	5/19/2005 1:33	1	1	0	0	1	0	1	1
25	1.12E+09	5/19/2005 1:33	1	1	0	0	1	0	1	1
26	1.12E+09	5/19/2005 1:33	1	1	0	0	1	0	1	1
27	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
28	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	1
29	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	0
30	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	0
31	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	0
32	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	0
33	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	1	0
34	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	0	0
35	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	0	0
36	1.12E+09	5/19/2005 1:33	0	1	0	1	1	0	0	0

	11	12	13	14	15	16	17	18	19
1									
2	SOL1AB	SOL9 LTS	SOL19 AIR	SOL11 FUEL/AIR	SOL12 NAT	SOL14AB FUEL	SOL21	SOL15 DRAIN FUEL	SOL4B CATHODE
3	FUEL	WATER (NC)	BLEED (NC)	SHUTOFF (NC)	GAS PURGE (NC	BLOCK (NC)	REF AIR	PROCESSOR 1 (NO	AIR VALVE HOLD
4									
5									
6	1	0	1	0	0	1	1	1	1
7	1	0	1	0	0	1	1	1	1
8	1	0	1	0	0	1	1	1	1
9	1	0	1	0	0	1	1	1	1
10	1	0	1	0	0	1	1	1	1
11	1	0	1	0	0	1	1	1	1
12	1	0	1	0	0	1	1	1	1
13	1	0	1	0	0	1	1	1	1
14	1	0	1	0	0	1	1	1	1
15	1	0	1	0	0	1	1	1	1
16	1	0	1	0	0	1	1	1	1
17	1	0	1	0	0	1	1	1	1
18	1	0	1	0	0	1	1	1	1
19	1	0	1	0	0	1	1	1	1
20	1	0	1	0	0	1	1	1	1
21	1	0	1	0	0	1	1	1	1
22	1	0	1	0	0	1	1	1	1
23	1	0	1	0	0	1	1	1	1
24	1	0	1	0	0	1	1	1	1
25	1	0	1	0	0	1	1	1	1
26	1	0	1	0	0	1	1	1	1
27	1	0	1	0	0	1	1	1	1
28	1	0	1	0	0	1	1	1	1
29	0	0	0	0	0	0	0	1	0
30	0	0	0	0	0	0	0	1	0
31	0	0	0	0	0	0	0	1	0
32	0	0	0	0	0	0	0	1	0
33	0	0	0	0	0	0	0	1	0
34	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0

	20	21	22	23	24	25	26	27	28	29	30	31
1												
2	SOL4A CATHODE	SOL5A FUEL	SOL5B FUEL	HR2 CPO	HR3 ATO	FAULT	INVERTEF	RUNNING	SU SD	CONTROL	STP MTR	STP
3	AIR VALVE PULL-IN	VALVE PULL-IN	VALVE HOLD	HEATER	HEATER	LED	AC LED	LED	LED	PWR LED	DIRECTION	PULSE
4												
5												
6	0	0	1	0	0	0	1	0	1	1	1	0
7	0	0	1	0	0	0	1	0	1	1	1	0
8	0	0	1	0	0	0	1	0	1	1	1	0
9	0	0	1	0	0	0	1	0	1	1	1	0
10	0	0	1	0	0	0	1	0	1	1	1	0
11	0	0	1	0	0	0	1	0	1	1	1	0
12	0	0	1	0	0	0	1	0	1	1	1	0
13	0	0	1	0	0	0	1	0	1	1	1	0
14	0	0	1	0	0	0	1	0	1	1	1	0
15	0	0	1	0	0	0	1	0	1	1	1	0
16	0	0	1	0	0	0	1	0	1	1	1	0
17	0	0	1	0	0	0	1	0	1	1	1	0
18	0	0	1	0	0	0	1	0	1	1	1	0
19	0	0	1	0	0	0	1	0	1	1	1	0
20	0	0	1	0	0	0	1	0	1	1	1	0
21	0	0	1	0	0	0	1	0	1	1	1	0
22	0	0	1	0	0	0	1	0	1	1	1	0
23	0	0	1	0	0	0	1	0	1	1	1	0
24	0	0	1	0	0	0	1	0	1	1	1	0
25	0	0	1	0	0	0	1	0	1	1	1	0
26	0	0	1	0	0	0	1	0	1	1	1	0
27	0	0	1	0	0	0	1	0	1	1	1	0
28	0	0	1	0	0	0	1	0	1	1	1	0
29	0	0	0	0	0	0	1	1	0	1	1	0
30	0	0	0	0	0	0	1	1	0	1	1	0
31	0	0	0	0	0	0	1	1	0	1	1	0
32	0	0	0	0	0	0	1	1	0	1	1	0
33	0	0	0	0	0	0	1	1	0	1	1	0
34	0	0	0	0	0	0	1	1	0	1	1	0
35	0	0	0	0	0	0	1	1	0	1	1	0
36	0	0	0	0	0	0	1	1	0	1	1	0

	32	33	34	35	36	37	38	39	40	41	42
1											
2	FC	DI	System Coolant	Stack Coolant	Stack Coolant	Cathode	Enclosure	Electronics	TC12	TC1 CPO	TC2A
3	CONTACTOF	PUMP	Pump Inlet (Temp10)	Inlet (Temp13)	Outlet (Temp12	Inlet (Temp1)	(Temp4)	Enclosure	CPO IN		CPO OUT
4								(Temp5)			
5											
6	1	0	61.61	62.92	67.7	63.98	29.01	26.14	479.28	774.6	702.44
7	1	0	61.61	62.92	67.7	63.98	29.01	26.14	479.28	774.6	702.44
8	0	0	61.55	62.88	67.73	63.96	29.01	26.2	479.65	788.72	702.21
9	0	0	61.55	62.88	67.73	63.96	29.01	26.2	479.65	788.72	702.21
10	0	0	61.52	62.88	67.71	64.01	29.05	26.25	481.24	801.15	702.16
11	0	0	61.52	62.88	67.71	64.01	29.05	26.25	481.24	801.15	702.16
12	0	0	61.54	62.86	67.69	64.1	29.07	26.29	482.4	823.54	702.07
13	0	0	61.54	62.86	67.69	64.1	29.07	26.29	482.4	823.54	702.07
14	0	0	61.56	62.87	67.64	64.23	29.09	26.36	483.89	841.6	701.62
15	0	0	61.56	62.87	67.64	64.23	29.09	26.36	483.89	841.6	701.62
16	0	0	61.56	62.87	67.64	64.23	29.09	26.36	483.89	841.6	701.62
17	0	0	61.58	62.89	67.5	64.38	29.14	26.35	485.12	861.33	701.33
18	0	0	61.58	62.89	67.5	64.38	29.14	26.35	485.12	861.33	701.33
19	1	0	61.6	62.93	67.4	64.62	29.19	26.41	485.94	892.74	701.93
20	1	0	61.67	63	67.25	64.72	29.21	26.43	485.61	914.82	702.42
21	1	0	61.67	63	67.25	64.72	29.21	26.43	485.61	914.82	702.42
22	1	0	61.67	63	67.25	64.72	29.21	26.43	485.61	914.82	702.42
23	1	1	61.68	63.07	66.98	64.83	29.22	26.45	483.03	951.37	703.16
24	1	1	61.68	63.07	66.98	64.83	29.22	26.45	483.03	951.37	703.16
25	1	1	61.67	63.15	66.75	64.88	29.23	26.43	477.44	977.58	703.8
26	1	1	61.67	63.15	66.75	64.88	29.23	26.43	477.44	977.58	703.8
27	1	0	61.68	63.14	66.41	64.87	29.23	26.45	474.55	1016.08	704.94
28	1	0	61.68	63.14	66.41	64.87	29.23	26.45	474.55	1016.08	704.94
29	0	0	61.63	63.17	66.16	64.88	29.25	26.45	472.6	1038.8	705.62
30	0	0	61.63	63.17	66.16	64.88	29.25	26.45	472.6	1038.8	705.62
31	0	0	61.63	63.17	66.16	64.88	29.25	26.45	472.6	1038.8	705.62
32	0	0	61.6	63.16	65.87	64.76	29.25	26.48	475.98	1063.99	704.76
33	0	0	61.6	63.16	65.87	64.76	29.25	26.48	475.98	1063.99	704.76
34	0	0	61.61	63.15	65.72	64.58	29.26	26.47	484.22	1073.46	702.55
35	0	0	61.61	63.15	65.72	64.58	29.26	26.47	484.22	1073.46	702.55
36	0	0	61.57	63.16	65.56	64.15	29.25	26.47	491.34	1079.4	698.47

	43	44	45	46	47	48	49	50	51	52	53	54	55
1													
2	TC4	TC5	TC6	TC9	TC18	TC10	TC11	TC13B	TEMP14A	CJC COLD	Cathode	LEVS1	Spare
3	LTS IN	LTS 1	LTS 2	PROX OUT	ATO IN	ATO 1	ATO 2	PROCESS	HUMIDIFEI	JUNCTION	Air Flow	Stack	Stack
4								EXHAUST	TOP		(FS1)	Coolant	Voltage
5													
6	204.7	213.37	204.92	118.72	50.15	591.07	615.26	50.68	80.73	31.84	0.84	1	7.78
7	204.7	213.37	204.92	118.72	50.15	591.07	615.26	50.68	80.73	31.84	0.84	1	7.78
8	205	213.41	205.11	118.66	49.9	590.1	614.13	50.72	80.76	31.9	0.84	1	7.04
9	205	213.41	205.11	118.66	49.9	590.1	614.13	50.72	80.76	31.9	0.84	1	7.04
10	205.57	213.64	205.04	118.8	49.33	587.39	613.9	50.75	80.64	31.94	0.84	1	7.53
11	205.57	213.64	205.04	118.8	49.33	587.39	613.9	50.75	80.64	31.94	0.84	1	7.53
12	205.71	213.57	204.91	118.79	49.11	582.81	612.93	49.94	80.53	31.89	0.84	1	7.44
13	205.71	213.57	204.91	118.79	49.11	582.81	612.93	49.94	80.53	31.89	0.84	1	7.44
14	206.09	213.7	205.11	119.15	46.61	558.28	611.8	51.44	80.61	31.89	0.85	1	6.7
15	206.09	213.7	205.11	119.15	46.61	558.28	611.8	51.44	80.61	31.89	0.85	1	6.7
16	206.09	213.7	205.11	119.15	46.61	558.28	611.8	51.44	80.61	31.89	0.85	1	6.7
17	206.23	214.03	205	119.21	44.52	516.94	610.1	55.2	80.54	31.89	0.86	1	7.77
18	206.23	214.03	205	119.21	44.52	516.94	610.1	55.2	80.54	31.89	0.86	1	7.77
19	206	214.37	204.8	118.58	42.57	468.69	605.69	56.88	80.66	32.02	0.86	1	7.14
20	206.23	214.7	204.63	119.1	38.77	395.47	583.32	62.24	80.91	32.03	0.87	1	7.64
21	206.23	214.7	204.63	119.1	38.77	395.47	583.32	62.24	80.91	32.03	0.87	1	7.64
22	206.23	214.7	204.63	119.1	38.77	395.47	583.32	62.24	80.91	32.03	0.87	1	7.64
23	206.34	215.1	204.48	119.22	37.08	353.85	551.95	64.88	81.46	31.87	0.87	1	7.61
24	206.34	215.1	204.48	119.22	37.08	353.85	551.95	64.88	81.46	31.87	0.87	1	7.61
25	206.97	215.8	204.32	118.78	36.54	311.93	492.62	67.9	81.98	31.88	0.87	1	7.67
26	206.97	215.8	204.32	118.78	36.54	311.93	492.62	67.9	81.98	31.88	0.87	1	7.67
27	207.97	216.3	204.34	118.84	35.69	296.22	451.92	69.74	82.86	32.14	0.87	1	7.21
28	207.97	216.3	204.34	118.84	35.69	296.22	451.92	69.74	82.86	32.14	0.87	1	7.21
29	208.35	216.61	204.36	119.24	35.5	278.53	395.32	72.15	83.35	32.12	0.87	1	7.67
30	208.35	216.61	204.36	119.24	35.5	278.53	395.32	72.15	83.35	32.12	0.87	1	7.67
31	208.35	216.61	204.36	119.24	35.5	278.53	395.32	72.15	83.35	32.12	0.87	1	7.67
32	208.36	217.03	204.6	118.91	32.98	262.96	360.62	74.86	83.42	32.09	0.88	1	7.65
33	208.36	217.03	204.6	118.91	32.98	262.96	360.62	74.86	83.42	32.09	0.88	1	7.65
34	207.15	217.67	204.51	118.73	29.07	221.45	307.93	77.48	83.55	32.13	0.88	1	6.88
35	207.15	217.67	204.51	118.73	29.07	221.45	307.93	77.48	83.55	32.13	0.88	1	6.88
36	206.13	217.98	204.44	118.37	28.19	188.32	274.92	80.12	83.78	32.11	0.88	1	7.24

	56	57	58	59	60	61	62	63	64	65	66	67	68	69
1														
2	Spare Stack	LEVS5	LEVS3	Ref Station	FS2	Ext	FS3	FS4 ATO	PRES5	CATH AIR	ENTHALP'	HUMIDIFIEF	STACK	RADIATOF
3	Current	HUMID	DI Tank	CO Sensor	Fuel	Fuel	Reformer	Air Flow	Fuel Air	BLOWER	WHEEL	PUMP	COOL	FAN
4	(CUR1)	LEV			Flow	Flow	Air Flow						PUMP	
5														
6	0.3	2.9	50.88	6.08	0	0.52	57.89	87.44	1.13	4.15	3.38	7	3.45	1.17
7	0.3	2.9	50.88	6.08	0	0.52	57.89	87.44	1.13	4.15	3.38	7	3.45	1.17
8	0.31	2.9	50.53	6.75	0	0.51	57.26	89.51	1.19	3.96	3.38	7	3.56	1.14
9	0.31	2.9	50.53	6.75	0	0.51	57.26	89.51	1.19	3.96	3.38	7	3.56	1.14
10	0.32	2.85	50.3	6.83	0	0.54	55.54	89.12	1.75	3.75	3.38	7	3.65	1.13
11	0.32	2.85	50.3	6.83	0	0.54	55.54	89.12	1.75	3.75	3.38	7	3.65	1.13
12	0.36	2.86	50.32	5.97	0	0.51	54.16	141.99	2.95	2.8	3.38	7	3.89	1.12
13	0.36	2.86	50.32	5.97	0	0.51	54.16	141.99	2.95	2.8	3.38	7	3.89	1.12
14	0.46	2.85	50.42	5.94	0	0.54	51.83	464.79	4.83	2.8	3.37	7	4.37	1.12
15	0.46	2.85	50.42	5.94	0	0.54	51.83	464.79	4.83	2.8	3.37	7	4.37	1.12
16	0.46	2.85	50.42	5.94	0	0.54	51.83	464.79	4.83	2.8	3.37	7	4.37	1.12
17	0.54	2.85	50.42	5.87	0	0.53	49.29	500.28	6.08	2.8	3.37	7	4.77	1.14
18	0.54	2.85	50.42	5.87	0	0.53	49.29	500.28	6.08	2.8	3.37	7	4.77	1.14
19	0.61	2.85	50.27	6.08	0	0.49	52.7	743.07	8.1	2.8	3.36	7	4.9	1.17
20	0.7	2.77	50.39	5.87	0	0.53	59.66	966.95	11.92	2.8	3.36	7	4.9	1.21
21	0.7	2.77	50.39	5.87	0	0.53	59.66	966.95	11.92	2.8	3.36	7	4.9	1.21
22	0.7	2.77	50.39	5.87	0	0.53	59.66	966.95	11.92	2.8	3.36	7	4.9	1.21
23	0.74	2.73	50.44	5.86	0	0.5	69.38	877.12	14.23	2.8	3.35	7	4.83	1.24
24	0.74	2.73	50.44	5.86	0	0.5	69.38	877.12	14.23	2.8	3.35	7	4.83	1.24
25	0.71	2.76	50.3	5.86	0	0.51	75.98	795.18	14.88	2.8	3.35	7	4.75	1.28
26	0.71	2.76	50.3	5.86	0	0.51	75.98	795.18	14.88	2.8	3.35	7	4.75	1.28
27	0.74	2.83	50.33	6.08	0	0.51	77.42	796.39	15.12	2.8	3.35	7	4.83	1.28
28	0.74	2.83	50.33	6.08	0	0.51	77.42	796.39	15.12	2.8	3.35	7	4.83	1.28
29	0.79	2.89	50.28	6.59	0	0.52	59.23	965.35	12.41	0	0	7	0	0
30	0.79	2.89	50.28	6.59	0	0.52	59.23	965.35	12.41	0	0	7	0	0
31	0.79	2.89	50.28	6.59	0	0.52	59.23	965.35	12.41	0	0	7	0	0
32	0.78	2.98	50.36	6.59	0	0.5	11.58	1420.63	10.08	0	0	7	0	0
33	0.78	2.98	50.36	6.59	0	0.5	11.58	1420.63	10.08	0	0	7	0	0
34	0.85	3	50.32	5.89	0	0.53	2.63	1481.55	7.46	0	0	0	0	0
35	0.85	3	50.32	5.89	0	0.53	2.63	1481.55	7.46	0	0	0	0	0
36	0.84	3.14	50.39	6.73	0	0.5	0.45	1020.34	3.99	0	0	0	0	0

	70	71	72	73	74	75	76	77	78	79	80	81
1												
2	SYSTEM	H2 MASS	FUEL/AIR	ATO AIR	PROX AIR	SCR	STEPPER	Reformer	Reformer LEV2	System LEV1	System LEV2	General
3	COOL	FLOW	BLOWER	BLOWER	VALVE	VALVE	MOTOR	LEV1 Alarm	Alarm Timer	Alarm Timer	Alarm Timer	Alarm
4	PUMP	CONTROLLER						Timer				Timer
5												
6	8	0	2.69	1.84	2.09	0	0	0	0	0	0	0
7	8	0	2.69	1.84	2.09	0	0	0	0	0	0	0
8	8	0	2.63	1.83	2.09	0	0	0	0	0	0	0
9	8	0	2.63	1.83	2.09	0	0	0	0	0	0	0
10	8	0	2.59	1.95	2.6	0	0	0	0	0	0	0
11	8	0	2.59	1.95	2.6	0	0	0	0	0	0	0
12	8	0	2.57	3.05	2.1	0	0	0	0	0	0	0
13	8	0	2.57	3.05	2.1	0	0	0	0	0	0	0
14	8	0	2.55	3.72	2.1	0	0	0	0	0	0	0
15	8	0	2.55	3.72	2.1	0	0	0	0	0	0	0
16	8	0	2.55	3.72	2.1	0	0	0	0	0	0	0
17	8	0	2.55	3.09	2.1	0	0	0	0	0	0	0
18	8	0	2.55	3.09	2.1	0	0	0	0	0	0	0
19	8	0	3.18	5.59	2.1	0	0	0	0	0	0	0
20	8	0	3.49	5.14	2.09	0	0	0	0	0	0	0
21	8	0	3.49	5.14	2.09	0	0	0	0	0	0	0
22	8	0	3.49	5.14	2.09	0	0	0	0	0	0	0
23	8	0	3.57	4.6	2.09	0	0	0	0	0	0	0
24	8	0	3.57	4.6	2.09	0	0	0	0	0	0	0
25	8	0	3.57	4.59	2.08	0	0	0	0	0	0	0
26	8	0	3.57	4.59	2.08	0	0	0	0	0	0	0
27	8	0	3.53	4.63	2.08	0	0	0	0	0	0	0
28	8	0	3.53	4.63	2.08	0	0	0	0	0	0	0
29	5	0	0	8	0	10	0	0	0	0	0	0
30	5	0	0	8	0	10	0	0	0	0	0	0
31	5	0	0	8	0	10	0	0	0	0	0	0
32	5	0	0	8	0	10	0	0	0	0	0	0
33	5	0	0	8	0	10	0	0	0	0	0	0
34	0	0	0	0	0	10	0	0	0	0	0	0
35	0	0	0	0	0	10	0	0	0	0	0	0
36	0	0	0	0	0	10	0	0	0	0	0	0

	82	83	84	85	86	87	88	89	90	91	92	93	94
1													
2	ESTOP	Alarm	Cat Blw	ATO Blw	Fuel/Air Bl	Stack Pump	System Coolant	Radiator	Stack	TEMP10	T13	T10	Enthalpy
3	Timer	Override	Feedback	Feedback	Feedback	Feedback	Pump Feedback	Fan	Current	Setpoint	Integral	Integral	Wheel
4		Timer						Feedback	Offset		Term	Term	Base
5													
6	0	0	92	33	58	7	0	4	-0.1	61.77	61.6	267.27	1.35
7	0	0	92	33	58	7	0	4	-0.1	61.77	61.6	267.27	1.35
8	0	0	92	33	58	7	0	4	-0.1	61.77	61.6	267.27	1.35
9	0	0	92	33	58	7	0	4	-0.1	61.77	61.6	267.27	1.35
10	0	0	87	32	56	7	0	4	-0.1	61.84	61.6	267.06	1.35
11	0	0	81	36	55	7	0	4	-0.1	61.89	61.61	266.83	1.35
12	0	0	81	36	55	7	0	4	-0.1	61.89	61.61	266.83	1.35
13	0	0	81	36	55	7	0	4	-0.1	61.89	61.61	266.83	1.35
14	0	0	73	66	54	7	0	4	-0.1	61.88	61.61	266.59	1.34
15	0	0	63	83	54	7	0	4	-0.1	61.9	61.61	266.35	1.34
16	0	0	63	83	54	7	0	4	-0.1	61.9	61.61	266.35	1.34
17	0	0	63	83	54	7	0	4	-0.1	61.9	61.61	266.35	1.34
18	0	0	63	83	54	7	0	4	-0.1	61.9	61.61	266.35	1.34
19	0	0	57	71	54	7	0	4	-0.1	61.8	61.62	266.16	1.34
20	0	0	57	112	65	7	0	4	-0.1	61.69	61.62	266.06	1.34
21	0	0	57	112	65	7	0	4	-0.1	61.69	61.62	266.06	1.34
22	0	0	58	114	80	7	0	4	-0.1	61.52	61.62	266.1	1.33
23	0	0	58	114	80	7	0	4	-0.1	61.52	61.62	266.1	1.33
24	0	0	58	114	80	7	0	4	-0.1	61.52	61.62	266.1	1.33
25	0	0	58	103	81	7	0	4	-0.1	61.45	61.62	266.24	1.33
26	0	0	57	103	80	7	0	4	-0.1	61.33	61.61	266.52	1.33
27	0	0	57	103	80	7	0	4	-0.1	61.33	61.61	266.52	1.33
28	0	0	57	103	80	7	0	4	-0.1	61.33	61.61	266.52	1.33
29	0	0	57	105	80	7	0	4	-0.1	61.28	61.61	266.73	1.33
30	0	0	57	105	80	7	0	4	-0.1	61.28	61.61	266.73	1.33
31	0	0	50	167	35	7	0	4	-0.1	61.28	61.61	266.73	1.33
32	0	0	50	167	35	7	0	4	-0.1	61.28	61.61	266.73	1.33
33	0	0	50	167	35	7	0	4	-0.1	61.28	61.61	266.73	1.33
34	0	0	45	191	18	7	0	4	-0.1	61.28	61.61	266.73	1.33
35	0	0	45	191	18	7	0	4	-0.1	61.28	61.61	266.73	1.33
36	0	0	40	149	10	7	0	4	-0.1	61.28	61.61	266.73	1.33

	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110
1																
2	Enthalpy	Stack	Low	Low	Low	Low Cell	High	High Cell	Cell	Cell	Cathode	Cathode	Cathode	H2	H2	H2
3	Wheel	Pump	Cell	Cell	Cell #	Voltage	Cell #	Voltage	Average	Ratio	Stoichs	Stoich	Blower	Demand	Actual	Target
4	Offset	Offset	Trip	Alert							Calc	Offset	Setpoint			
5																
6	2.03	0.89	0	1	42	0.24	46	0.69	0.59	0.4	3.71	0	253.26	38.26	44.08	38.43
7	2.03	0.89	0	1	42	0.24	46	0.69	0.59	0.4	3.71	0	253.26	38.26	44.08	38.43
8	2.03	0.89	0	1	42	0.24	46	0.69	0.59	0.4	3.71	0	253.26	38.26	44.08	38.43
9	2.03	0.89	0	1	42	0.24	46	0.69	0.59	0.4	3.71	0	253.26	38.26	44.08	38.43
10	2.03	0.89	1	1	42	0.04	46	0.71	0.58	0.06	4.26	0	230.59	38.26	43.03	70.65
11	2.03	0.89	0	0	88	0.91	20	0.98	0.95	0.96	3.87	0	230.59	38.26	41.97	70.65
12	2.03	0.89	0	0	88	0.91	20	0.98	0.95	0.96	3.87	0	230.59	38.26	41.97	70.65
13	2.03	0.89	0	0	88	0.91	20	0.98	0.95	0.96	3.87	0	230.59	38.26	41.97	70.65
14	2.03	-0.23	0	0	88	0.92	35	0.99	0.96	0.96	10	0	6.12	38.26	40.16	106.54
15	2.03	-1	0	0	81	0.93	5	0.99	0.96	0.96	10	0	6.12	38.26	38.22	106.54
16	2.03	-1	0	0	81	0.93	5	0.99	0.96	0.96	10	0	6.12	38.26	38.22	106.54
17	2.03	-1	0	0	81	0.93	5	0.99	0.96	0.96	10	0	6.12	38.26	38.22	106.54
18	2.03	-1	0	0	81	0.93	5	0.99	0.96	0.96	10	0	6.12	38.26	38.22	106.54
19	2.03	-1	0	0	59	0.94	73	1	0.96	0.97	10	0	6.12	56.41	37.64	70.65
20	2.02	-1	0	0	88	0.92	73	1	0.96	0.96	10	0	6.12	56.41	43.23	70.65
21	2.02	-1	0	0	88	0.92	73	1	0.96	0.96	10	0	6.12	56.41	43.23	70.65
22	2.02	-1	0	0	74	0.94	5	0.99	0.96	0.97	10	0	6.12	56.41	49.91	70.65
23	2.02	-1	0	0	74	0.94	5	0.99	0.96	0.97	10	0	6.12	56.41	49.91	70.65
24	2.02	-1	0	0	74	0.94	5	0.99	0.96	0.97	10	0	6.12	56.41	49.91	70.65
25	2.02	-1	0	0	6	0.93	50	0.99	0.96	0.97	10	0	6.12	56.41	57.12	70.65
26	2.02	-1	0	0	66	0.93	50	0.99	0.96	0.96	10	0	6.12	56.41	59.72	70.65
27	2.02	-1	0	0	66	0.93	50	0.99	0.96	0.96	10	0	6.12	56.41	59.72	70.65
28	2.02	-1	0	0	66	0.93	50	0.99	0.96	0.96	10	0	6.12	56.41	59.72	70.65
29	2.02	-1	0	0	88	0.92	50	0.99	0.96	0.96	0	0	6.12	56.41	60.68	78.5
30	2.02	-1	0	0	88	0.92	50	0.99	0.96	0.96	0	0	6.12	56.41	60.68	78.5
31	2.02	-1	0	0	88	0.93	50	0.98	0.96	0.97	0	0	6.12	56.41	17.78	78.5
32	2.02	-1	0	0	88	0.93	50	0.98	0.96	0.97	0	0	6.12	56.41	17.78	78.5
33	2.02	-1	0	0	88	0.93	50	0.98	0.96	0.97	0	0	6.12	56.41	17.78	78.5
34	2.02	-1	0	0	66	0.93	5	0.98	0.96	0.97	0	0	6.12	56.41	3.43	78.5
35	2.02	-1	0	0	66	0.93	5	0.98	0.96	0.97	0	0	6.12	56.41	3.43	78.5
36	2.02	-1	0	0	66	0.93	50	0.99	0.96	0.97	0	0	6.12	56.41	0	78.5

	111	112	113	114	115	116	117	118	119	120	121	122	123	124
1														
2	H2	H2	H2	H2 Stoich	H2 Stoich	H2 Stoich	DCL	DCL	System	Required	AC Output	Stack DC	Corrected	Battery
3	Stoich	Stoich	Stoich	Dyn Floor	Dyn Ceiling	Low Power	Base	Offset	Pwr	AC Power	Power	Power	Batt Voltage	SOC
4	Calc	Target	Offset			Offset			Setting					(SARC)
5														
6	1.61	1.2	0.01	1.2	1.4	0	58.78	-6.54	0	2.5	2.35	2247.84	49.81	61
7	1.61	1.2	0.01	1.2	1.4	0	58.78	-6.54	0	2.5	2.35	2247.84	49.81	61
8	1.61	1.2	0.01	1.2	1.4	0	58.78	-6.54	0	2.5	2.35	2247.84	49.81	61
9	1.61	1.2	0.01	1.2	1.4	0	58.78	-6.54	0	2.5	2.35	2247.84	49.81	61
10	1.8	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	2.27	1937.22	49.67	87
11	1.76	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	2.27	1937.22	49.67	87
12	1.76	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	2.27	1937.22	49.67	87
13	1.76	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	2.27	1937.22	49.67	87
14	10	1.9	0.01	1.2	1.4	0	98	-6.54	0	4	1.97	0	50.37	87
15	10	1.9	0.01	1.2	1.4	0	98	-6.54	0	4	1.65	4.71	49.95	74
16	10	1.9	0.01	1.2	1.4	0	98	-6.54	0	4	1.65	4.71	49.95	74
17	10	1.9	0.01	1.2	1.4	0	98	-6.54	0	4	1.65	4.71	49.95	74
18	10	1.9	0.01	1.2	1.4	0	98	-6.54	0	4	1.65	4.71	49.95	74
19	10	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	1.45	0	50.2	74
20	10	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	1.32	0	49.82	76
21	10	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	1.32	0	49.82	76
22	10	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	1.18	0	49.71	81
23	10	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	1.18	0	49.71	81
24	10	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	1.18	0	49.71	81
25	10	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	0.99	4.78	49.6	61
26	10	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	0.91	0	49.59	63
27	10	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	0.91	0	49.59	63
28	10	1.26	0.01	1.2	1.4	0	98	-6.54	0	4	0.91	0	49.59	63
29	10	1.4	0.01	1.2	1.4	0	98	-6.54	0	0	0.79	0	49.56	67
30	10	1.4	0.01	1.2	1.4	0	98	-6.54	0	0	0.79	0	49.56	67
31	10	1.4	0.01	1.2	1.4	0	98	-6.54	0	0	0.73	0	49.68	63
32	10	1.4	0.01	1.2	1.4	0	98	-6.54	0	0	0.73	0	49.68	63
33	10	1.4	0.01	1.2	1.4	0	98	-6.54	0	0	0.73	0	49.68	63
34	10	1.4	0.01	1.2	1.4	0	98	-6.54	0	0	0.67	0	49.72	67
35	10	1.4	0.01	1.2	1.4	0	98	-6.54	0	0	0.67	0	49.72	67
36	0	1.4	0.01	1.2	1.4	0	98	-6.54	0	0	0.44	0	49.35	55

	125	126	127	128	129	130	131	132	133	134	135	136	137
1													
2	System	Next Stoich	AC Export	AC Export	Charge	System	Air Flow	Fuel Flow	Estimated	DI Tank	CPO	CPO	Cascaded
3	Efficiency	Reduction	State	Limit	Needed	Config	Meter	Meter	Fuel Flow	Start Lvl	Delay	Setpoint	CPO
4					Voltage	uration	Temp	Temp					Setpoint
5													
6	16.75	56.4	0	6	46.5	2	23.45	0	17.99	64.14	9.33	756.51	756.51
7	16.75	56.4	0	6	46.5	2	23.45	0	17.99	64.14	9.33	756.51	756.51
8	16.75	56.4	0	6	46.5	2	23.45	0	17.99	64.14	9.33	756.51	756.51
9	16.75	56.4	0	6	46.5	2	23.45	0	17.99	64.14	9.33	756.51	756.51
10	13.16	900	0	6	46.5	2	23.5	0	17.56	64.14	9.33	756.53	756.53
11	13.16	899	0	6	46.5	2	23.45	0	17.13	64.14	5.54	756.55	756.56
12	13.16	899	0	6	46.5	2	23.45	0	17.13	64.14	5.54	756.55	756.56
13	13.16	899	0	6	46.5	2	23.45	0	17.13	64.14	5.54	756.55	756.56
14	0	896.6	0	6	46.5	2	23.45	0	16.39	64.14	5.54	756.66	756.66
15	0	894.2	0	6	46.5	2	23.45	0	15.6	64.14	5	756.8	756.8
16	0	894.2	0	6	46.5	2	23.45	0	15.6	64.14	5	756.8	756.8
17	0	894.2	0	6	46.5	2	23.45	0	15.6	64.14	5	756.8	756.8
18	0	894.2	0	6	46.5	2	23.45	0	15.6	64.14	5	756.8	756.8
19	0	891.8	0	6	46.5	2	23.4	0	15.36	64.14	5	756.73	756.73
20	0	889.4	0	6	46.5	2	23.45	0	17.64	64.14	5	756.48	756.48
21	0	889.4	0	6	46.5	2	23.45	0	17.64	64.14	5	756.48	756.48
22	0	887	0	6	46.5	2	23.45	0	20.37	64.14	5	756.23	756.2
23	0	887	0	6	46.5	2	23.45	0	20.37	64.14	5	756.23	756.2
24	0	887	0	6	46.5	2	23.45	0	20.37	64.14	5	756.23	756.2
25	0	885.6	0	6	46.5	2	23.4	0	23.31	64.14	5	755.98	755.98
26	0	885.6	0	6	46.5	2	23.5	0	24.38	64.14	5	755.53	755.53
27	0	885.6	0	6	46.5	2	23.5	0	24.38	64.14	5	755.53	755.53
28	0	885.6	0	6	46.5	2	23.5	0	24.38	64.14	5	755.53	755.53
29	0	885.6	0	6	46.5	2	23.5	0	24.77	64.14	0	0	755.17
30	0	885.6	0	6	46.5	2	23.5	0	24.77	64.14	0	0	755.17
31	0	885.6	0	6	46.5	2	23.8	0	7.26	64.14	0	0	755.17
32	0	885.6	0	6	46.5	2	23.8	0	7.26	64.14	0	0	755.17
33	0	885.6	0	6	46.5	2	23.8	0	7.26	64.14	0	0	755.17
34	0	885.6	0	6	46.5	2	23.8	0	1.4	64.14	0	0	755.17
35	0	885.6	0	6	46.5	2	23.8	0	1.4	64.14	0	0	755.17
36	0	885.6	0	6	46.5	2	24.8	0	0.16	64.14	0	0	755.17

	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153
1																
2	Cascaded	CPO	CPO Fuel	SOL9	LTS	Reformer	LTS	Purge	S/C	KW	KW	KW	KW	O2/C	O2/C	O2/C
3	CPO	Slope	Flow	Duty	Cycle	State	Reduction	Amount	Actual	Setpoint	Offset	Actual	Override	Base	Offset	Actual
4	Offset		Correction	Offset	State	Timer	Timer									
5																
6	31.51	13.5	0	0	1	3600	0	80.67	3.59	9.35	0	10.77	0	0.5955	0	0.6709
7	31.51	13.5	0	0	1	3600	0	80.67	3.59	9.35	0	10.77	0	0.5955	0	0.6709
8	31.51	13.5	0	0	1	3600	0	80.67	3.59	9.35	0	10.77	0	0.5955	0	0.6709
9	31.51	13.5	0	0	1	3600	0	80.67	3.59	9.35	0	10.77	0	0.5955	0	0.6709
10	31.53	13.5	0	0	1	3600	0	80.67	3.6	9.35	0	10.52	0	0.5955	0	0.6711
11	31.56	13.5	0	0	1	3600	0	80.67	3.55	9.35	0	10.26	0	0.5955	0	0.6709
12	31.56	13.5	0	0	1	3600	0	80.67	3.55	9.35	0	10.26	0	0.5955	0	0.6709
13	31.56	13.5	0	0	1	3600	0	80.67	3.55	9.35	0	10.26	0	0.5955	0	0.6709
14	31.66	26.35	0	0	1	3600	0	80.67	3.56	9.35	0	9.81	0	0.5955	0	0.671
15	31.8	26.35	0	0	1	3600	0	80.67	3.56	9.35	0	9.34	0	0.5955	0	0.6708
16	31.8	26.35	0	0	1	3600	0	80.67	3.56	9.35	0	9.34	0	0.5955	0	0.6708
17	31.8	26.35	0	0	1	3600	0	80.67	3.56	9.35	0	9.34	0	0.5955	0	0.6708
18	31.8	26.35	0	0	1	3600	0	80.67	3.56	9.35	0	9.34	0	0.5955	0	0.6708
19	31.73	37.76	0	0	1	3600	0	80.67	3.54	13.78	0	9.2	0	0.6152	0	0.6698
20	31.48	37.76	0	0	1	3600	0	80.67	3.44	13.78	0	10.56	0	0.6152	0	0.6684
21	31.48	37.76	0	0	1	3600	0	80.67	3.44	13.78	0	10.56	0	0.6152	0	0.6684
22	31.2	44.61	0	0	1	3600	0	80.67	3.41	13.78	0	12.2	0	0.6152	0	0.6667
23	31.2	44.61	0	0	1	3600	0	80.67	3.41	13.78	0	12.2	0	0.6152	0	0.6667
24	31.2	44.61	0	0	1	3600	0	80.67	3.41	13.78	0	12.2	0	0.6152	0	0.6667
25	30.98	44.61	0	0	1	3600	0	80.67	3.4	13.78	0	13.96	0	0.6152	0	0.6646
26	30.53	52.81	0	0	1	3600	0	80.67	3.56	13.78	0	14.59	0	0.6152	0	0.6608
27	30.53	52.81	0	0	1	3600	0	80.67	3.56	13.78	0	14.59	0	0.6152	0	0.6608
28	30.53	52.81	0	0	1	3600	0	80.67	3.56	13.78	0	14.59	0	0.6152	0	0.6608
29	30.17	0	0	0	1	0	0	80.67	3.63	13.78	0	14.83	0	0.6152	0	0.6592
30	30.17	0	0	0	1	0	0	80.67	3.63	13.78	0	14.83	0	0.6152	0	0.6592
31	30.17	51.17	0	0	1	2	0	80.67	4.53	13.78	0	4.34	0	0.6152	0	0.6587
32	30.17	51.17	0	0	1	2	0	80.67	4.53	13.78	0	4.34	0	0.6152	0	0.6587
33	30.17	51.17	0	0	1	2	0	80.67	4.53	13.78	0	4.34	0	0.6152	0	0.6587
34	30.17	0	0	0	1	4	0	80.67	0.97	13.78	0	0.84	0	0.6152	0	0.6749
35	30.17	0	0	0	1	4	0	80.67	0.97	13.78	0	0.84	0	0.6152	0	0.6749
36	30.17	0	0	0	1	4	0	80.67	1.16	13.78	0	0	0	0.6152	0	0.8175

	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168
1															
2	O2/C	Stepper	Stepper	Prox	Prox Air	Prox Air	ATO	ATO	ATO Air	ATO Air	ATO Air	ATO	Estimated	ATO	ATO
3	Measured	Actual	Control	Delay	Flow Base	Flow	KW	Amp	Correction	Rate	Estimate	Blower	ATO Blw	Setpoint	Blower
4			Mode			Offset	Scale	Scale		Correction		Setpoint	Voltage		Floor
5															
6	2	200	1	118.75	2.31	-0.22	80	10	-142.77	0	232.08	89.31	2.98	600	85.28
7	2	200	1	118.75	2.31	-0.22	80	10	-142.77	0	232.08	89.31	2.98	600	85.28
8	2	200	1	118.75	2.31	-0.22	80	10	-142.77	0	232.08	89.31	2.98	600	85.28
9	2	200	1	118.75	2.31	-0.22	80	10	-142.77	0	232.08	89.31	2.98	600	85.28
10	2	200	1	118.75	2.31	-0.22	80	10	-120.02	0	232.08	112.05	2.98	600	112.1
11	2	196	1	118.75	2.31	-0.22	80	10	-120.02	0	232.08	112.05	2.98	600	112.1
12	2	196	1	118.75	2.31	-0.22	80	10	-120.02	0	232.08	112.05	2.98	600	112.1
13	2	196	1	118.75	2.31	-0.22	80	10	-120.02	0	232.08	112.05	2.98	600	112.1
14	2	196	1	118.75	2.31	-0.22	80	10	0	0	415.75	415.75	2.99	600	294.8
15	2	188	1	118.75	2.31	-0.22	80	10	0	0	415.75	415.75	2.99	600	294.3
16	2	188	1	118.75	2.31	-0.22	80	10	0	0	415.75	415.75	2.99	600	294.3
17	2	188	1	118.75	2.31	-0.22	80	10	0	0	415.75	415.75	2.99	600	294.3
18	2	188	1	118.75	2.31	-0.22	80	10	0	0	415.75	415.75	2.99	600	294.3
19	2	188	1	118.75	2.31	-0.22	80	10	0	0	851.81	851.81	4.6	600	433.5
20	2	188	1	102.91	2.31	-0.22	80	10	0	0	851.81	851.81	4.6	600	433.5
21	2	188	1	102.91	2.31	-0.22	80	10	0	0	851.81	851.81	4.6	600	433.5
22	2	188	1	102.91	2.31	-0.22	80	10	-0.84	-19.91	851.81	831.06	4.6	600	433.5
23	2	188	1	102.91	2.31	-0.22	80	10	-0.84	-19.91	851.81	831.06	4.6	600	433.5
24	2	188	1	102.91	2.31	-0.22	80	10	-0.84	-19.91	851.81	831.06	4.6	600	433.5
25	2	172	1	102.91	2.3	-0.22	80	10	-2.1	-42.77	851.81	806.94	4.5	600	433.1
26	2	172	1	102.91	2.3	-0.22	80	10	-7.64	-48.62	851.81	795.54	4.39	600	433.5
27	2	172	1	102.91	2.3	-0.22	80	10	-7.64	-48.62	851.81	795.54	4.39	600	433.5
28	2	172	1	102.91	2.3	-0.22	80	10	-7.64	-48.62	851.81	795.54	4.39	600	433.5
29	2	156	1	102.91	2.3	0	0	0	0	0	0	0	4.44	650	433.5
30	2	156	1	102.91	2.3	0	0	0	0	0	0	0	4.44	650	433.5
31	2	156	1	102.91	2.3	0	0	0	0	0	0	0	4.44	650	433.5
32	2	156	1	102.91	2.3	0	0	0	0	0	0	0	4.44	650	433.5
33	2	156	1	102.91	2.3	0	0	0	0	0	0	0	4.44	650	433.5
34	2	156	1	102.91	2.3	0	0	0	0	0	0	0	4.44	650	433.5
35	2	156	1	102.91	2.3	0	0	0	0	0	0	0	4.44	650	433.5
36	2	156	1	102.91	2.3	0	0	0	0	0	0	0	4.44	650	433.5

	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183
1															
2	ATO Stb	ATO	ATO 1	ATO 2	ATO	System	FC	Reformer	DI Tank	Batt Comp	Humid	Radiator	Radiator	Stack I	FC Air
3	Fine Timer	Cal	Slope	Slope	State	State	State	State	Level Cntl	Fan Cntl	Fill Cntl	Coolant	Cooling	Coolant	Stoich
4		Status										Pump Cntl	Fan Cntl	Pump Cnt	Calc
5															
6	0	0	0.23	-0.25	7	51	30	40	0	1	1	1	1	1	1
7	0	0	0.23	-0.25	7	51	30	40	0	1	1	1	1	1	1
8	0	0	0.23	-0.25	7	51	30	40	0	1	1	1	1	1	1
9	0	0	0.23	-0.25	7	51	30	40	0	1	1	1	1	1	1
10	600	0	-0.2	-0.19	7	51	30	40	0	1	1	1	1	1	1
11	589	0	-0.85	-0.1	7	51	30	40	0	1	1	1	1	1	1
12	589	0	-0.85	-0.1	7	51	30	40	0	1	1	1	1	1	1
13	589	0	-0.85	-0.1	7	51	30	40	0	1	1	1	1	1	1
14	577	0	-2.84	-0.25	7	51	30	40	0	1	1	1	1	1	1
15	565	0	-7.08	-0.27	7	51	30	40	0	1	1	1	1	1	1
16	565	0	-7.08	-0.27	7	51	30	40	0	1	1	1	1	1	1
17	565	0	-7.08	-0.27	7	51	30	40	0	1	1	1	1	1	1
18	565	0	-7.08	-0.27	7	51	30	40	0	1	1	1	1	1	1
19	600	0	-13.5	-0.56	7	51	30	40	0	1	1	1	1	1	1
20	593	0	-23.33	-2.23	7	51	30	40	0	1	1	1	1	1	1
21	593	0	-23.33	-2.23	7	51	30	40	0	1	1	1	1	1	1
22	600	0	-26.4	-4.67	7	51	30	40	0	1	1	1	1	1	1
23	600	0	-26.4	-4.67	7	51	30	40	0	1	1	1	1	1	1
24	600	0	-26.4	-4.67	7	51	30	40	0	1	1	1	1	1	1
25	600	0	-27.65	-10.04	7	51	30	40	0	1	1	1	1	1	1
26	600	0	-20.15	-11.42	7	51	30	40	0	1	1	1	1	1	1
27	600	0	-20.15	-11.42	7	51	30	40	0	1	1	1	1	1	1
28	600	0	-20.15	-11.42	7	51	30	40	0	1	1	1	1	1	1
29	600	0	0	0	0	104	54	51	0	0	0	0	0	0	0
30	600	0	0	0	0	104	54	51	0	0	0	0	0	0	0
31	600	0	0	0	0	104	54	51	0	0	0	0	0	0	0
32	600	0	0	0	0	104	54	51	0	0	0	0	0	0	0
33	600	0	0	0	0	104	54	51	0	0	0	0	0	0	0
34	600	0	0	0	0	107	55	54	0	0	0	0	0	0	0
35	600	0	0	0	0	107	55	54	0	0	0	0	0	0	0
36	600	0	0	0	0	107	55	54	0	0	0	0	0	0	0

	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198
1															
2	Cathode	Enthalpy	H2 DCL	H2 DCL	Stack	AC	Battery	Load	Fuel/Air	Stepper	LTS Water	ATO	ATO	Prox	Humidifier
3	Blower	Wheel	Calc	Control	Recovery	Export	Maintenance	Following	Blower	Mtr Cntl	Temp Cntl	Blower	Lean	Valve	Pump Cntl
4	Cntl	Cntl			Cntl	Cntl	Cntl		(KW) Cntl			Cntl	Cntl	Cntl	
5															
6	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
7	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
8	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
9	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
10	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
11	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
12	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
13	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
14	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
15	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
16	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
17	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
18	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
19	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
20	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
21	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
22	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
23	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
24	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
25	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
26	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
27	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
28	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215
1																	
2	SCR	H2 Mix	Cascaded	Remote	Scanner	Inverter	Air	Gas	Paging	Power	Low	High	Spare	Test	HW	Bad	Temperature
3	Cntl	Cntl	CPO	Comm	Comm		Meter	Meter		Schedule	Batt	Batt		Mode	Fault	Config	Warning
4																	
5																	
6	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
7	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
8	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
9	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
10	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
11	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
12	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
13	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
14	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
15	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
16	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
17	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
18	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
19	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
20	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
21	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
22	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
23	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
24	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
25	1	0	1	1	1	1	1	0	1	0	0	0	1	0	0	0	0
26	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
27	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
28	1	0	1	1	1	1	1	0	0	0	0	0	1	0	0	0	0
29	0	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0
30	0	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0
31	0	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0
32	0	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0
33	0	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0
34	0	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0
35	0	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0
36	0	0	0	1	1	1	1	0	0	0	0	0	1	0	0	0	0

	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231
1																
2	High	RUN	DCDC	High	Low	Charger	Battery	FC	Over	Shutdown	Inverter	CMODE	Charge	SYNC0	SYNC1	Bad
3	Temperature		ENABLE	V_in	V_in	Enable	Temp Error	Contactor	Current		Enable					Inverter
4								Status								V_out
5																
6	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
7	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
8	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
9	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
10	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
11	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
12	0	1	1	0	0	1	0	1	0	0	1	1	0	1	0	0
13	0	1	1	0	0	1	0	1	0	0	1	1	0	1	0	0
14	0	1	1	0	0	1	0	1	0	0	1	1	0	1	0	0
15	0	1	1	0	0	1	0	1	0	0	1	1	0	1	0	0
16	0	1	1	0	0	1	0	1	0	0	1	1	0	1	0	0
17	0	1	1	0	0	1	0	1	0	0	1	1	0	1	0	0
18	0	1	1	0	0	1	0	1	0	0	1	1	0	1	0	0
19	0	1	1	0	0	1	0	1	0	0	1	1	0	1	0	0
20	0	1	1	0	0	1	0	1	0	0	1	1	0	1	0	0
21	0	1	1	0	0	1	0	1	0	0	1	1	0	1	0	0
22	0	1	1	0	0	1	0	1	0	0	1	1	0	1	0	0
23	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
24	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
25	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
26	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
27	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
28	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
29	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
30	0	1	1	0	0	1	0	0	0	0	1	1	0	1	0	0
31	0	1	0	0	0	1	0	0	0	0	1	1	0	1	0	0
32	0	0	0	0	0	1	0	1	0	0	1	1	0	1	0	0
33	0	0	0	0	0	1	0	1	0	0	1	1	0	1	0	0
34	0	0	0	0	0	1	0	1	0	0	1	1	0	1	0	0
35	0	0	0	0	0	1	0	1	0	0	1	1	0	1	0	0
36	0	0	0	0	0	1	0	1	0	0	1	1	0	1	0	0

	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246
1															
2	Bad	Line RMS	Line RMS	Inverter	Average	Grid	Grid	Grid	Grid	Fuel Cell	Fuel Cell	DCL	Charge	DCDC	Battery
3	FSync	Voltage	Current	Frequency	AC Power	Voltage	Current	Frequency	Power	DC voltage	Current		Control	Limit	Voltage
4														Value	
5															
6	0	121.8	19.7	59.98	2436	124.3	18.6	59.98	2277	50.4	46.5	52	0	1023	49.1
7	0	121.8	19.7	59.98	2436	124.3	18.6	59.98	2277	50.4	46.5	52	0	1023	49.1
8	0	122	19.3	59.98	2382	124.3	18.3	59.98	2229	50.4	44.6	52	0	1023	49
9	0	122	19.3	59.98	2382	124.3	18.3	59.98	2229	50.4	44.6	52	0	1023	49
10	0	122	19.3	59.98	2382	124.3	18.3	59.98	2229	50.4	44.6	52	0	1023	49
11	0	121.8	18.6	59.99	2257	124.1	16.9	59.99	2114	49.8	38.9	52	0	1023	48.6
12	0	120.8	16.3	59.99	1976	123.1	14.9	59.99	1827	46.8	0	47	0	0	47
13	0	120.8	16.3	59.99	1976	123.1	14.9	59.99	1827	46.8	0	47	0	0	47
14	0	120.8	16.3	59.99	1976	123.1	14.9	59.99	1827	46.8	0	47	0	0	47
15	0	120.3	14.2	59.99	1751	122.8	13.3	59.99	1606	47	0	47	0	0	47.3
16	0	120.3	14.2	59.99	1751	122.8	13.3	59.99	1606	47	0	47	0	0	47.3
17	0	120	12.6	59.98	1541	122.6	11.5	59.98	1404	47.2	-0.1	47	0	0	47.4
18	0	120	12.6	59.98	1541	122.6	11.5	59.98	1404	47.2	-0.1	47	0	0	47.4
19	0	119.8	11	59.99	1324	122.3	9.9	59.99	1180	47.2	0	45	0	0	47.4
20	0	119.8	11	59.99	1324	122.3	9.9	59.99	1180	47.2	0	45	0	0	47.4
21	0	119.8	11	59.99	1324	122.3	9.9	59.99	1180	47.2	0	45	0	0	47.4
22	0	119.5	9.9	59.99	1191	122.3	8.4	59.99	1066	47.4	0	44	0	0	47.6
23	0	119.3	8.6	59.99	1058	121.8	7.3	59.99	930	47.7	0	40	3	0	47.8
24	0	119.3	8.6	59.99	1058	121.8	7.3	59.99	930	47.7	0	40	3	0	47.8
25	0	119.3	8.6	59.99	1058	121.8	7.3	59.99	930	47.7	0	40	3	0	47.8
26	0	119.3	7.6	59.99	916	121.8	6.4	59.99	797	47.9	0	37	3	0	47.9
27	0	119.3	6.6	59.99	806	121.6	5.5	59.99	677	48	0	35	3	0	48
28	0	119.3	6.6	59.99	806	121.6	5.5	59.99	677	48	0	35	3	0	48
29	0	119.3	6.6	59.99	806	121.6	5.5	59.99	677	48	0	35	3	0	48
30	0	119.3	6.6	59.99	806	121.6	5.5	59.99	677	48	0	35	3	0	48
31	0	119	6.1	59.99	721	121.6	5.1	59.99	586	48	0	34	0	1023	47.9
32	0	119.5	5.6	59.99	652	122.1	4.3	59.99	530	47.6	0	33	0	0	48
33	0	119.5	5.6	59.99	652	122.1	4.3	59.99	530	47.6	0	33	0	0	48
34	0	119.5	4.4	59.99	495	122.1	3.2	59.99	372	48.2	0	33	0	0	48.6
35	0	119.5	4.4	59.99	495	122.1	3.2	59.99	372	48.2	0	33	0	0	48.6
36	0	119.5	4.4	59.99	495	122.1	3.2	59.99	372	48.2	0	33	0	0	48.6

	247	248	249	250	251	252	253	254	255	256
1										
2	Battery	Battery	Total	Battery	Inverter	Last Event	Battery	System	Requested	AMPDAC
3	Current	Temp	Amp	SOC	Temp	Code	Mode	Mode	DCL (d)	Value (d)
4			Seconds							
5										
6	-16.6	26	0	0	40	18689	2	18	52.13	0
7	-16.6	26	0	0	40	18689	2	18	52.13	0
8	-16.1	26	0	0	40	18689	2	18	47.13	0
9	-16.1	26	0	0	40	18689	2	18	47.13	0
10	-16.1	26	0	0	40	18689	2	18	47.13	0
11	-21.3	26	0	0	40	18689	2	18	47.13	0
12	-67.3	26	0	0	40	18689	2	18	47.13	0
13	-67.3	26	0	0	40	18689	2	18	47.13	0
14	-67.3	26	0	0	40	18689	2	18	47.13	0
15	-55.9	26	0	0	40	18689	2	18	47.13	0
16	-55.9	26	0	0	40	18689	2	18	47.13	0
17	-50.4	26	0	0	40	18689	2	18	45.13	0
18	-50.4	26	0	0	40	18689	2	18	45.13	0
19	-48.4	26	0	0	40	18689	2	18	45.13	0
20	-48.4	26	0	0	40	18689	2	18	43.13	0
21	-48.4	26	0	0	40	18689	2	18	43.13	0
22	-42.2	26	0	0	40	18689	2	18	41.13	0
23	-37.6	26	0	0	40	18689	2	18	38.13	0
24	-37.6	26	0	0	40	18689	2	18	38.13	0
25	-37.6	26	0	0	40	18689	2	18	38.13	0
26	-33.8	26	0	0	40	18689	2	18	35.13	0
27	-31.2	26	0	0	40	18689	2	18	33.13	0
28	-31.2	26	0	0	40	18689	2	18	33.13	0
29	-31.2	26	0	0	40	18689	2	18	33.13	0
30	-31.2	26	0	0	40	18689	2	18	33.13	0
31	-35.5	26	0	0	40	4096	2	18	33.13	0
32	-34.4	26	0	0	40	8208	2	18	33.13	0
33	-34.4	26	0	0	40	8208	2	18	33.13	0
34	-15.9	26	0	0	40	8208	2	18	33.13	0
35	-15.9	26	0	0	40	8208	2	18	33.13	0
36	-15.9	26	0	0	40	8208	2	18	33.13	0

Appendix M: Waste Streams Report

Opportunities, Constraints, and Research Needs for Co-digestion of Alternative Waste Streams with Livestock Manure in Minnesota

November 23, 2005
Minnesota Department of Agriculture
Agricultural Resources Management and Development Division

This report partially fulfills the objectives of the project "Advancing Utilization of Manure Methane Electrical Generation" which was funded through the Legislative Commission of Minnesota Resources and the Natural Resources Trust Fund

Section 1: Introduction

Anaerobic manure digestion (AD) is a technology that has been around for centuries, but only until recently has it become a main stream technology in the United States. Anaerobic digestion was developed and modified by a number of researchers in Europe and Asia to address the treatment of human wastes and to produce gas cooking and heating, and energy use (Persson et al, 1979). Many larger scale digesters receiving manure and other waste streams have been installed in the last 30 years throughout Europe. India has installed thousands of very small ADs, along with some larger industrial applications (Persson et al, 1979) (Lusk, 1998). In the United States, the adoption of AD has been very slow and has been hindered by high capital costs and past system failures. In just the last 5 years, a critical mass of ADs has been implemented on farms across the country. These systems tend to focus on the digestion of dairy manure and have been located on-site of relatively large farms. Unlike Europe, centralized ADs have only been developed in a few special circumstances in the United States.

In the State of Minnesota, there are currently only two farm scale ADs that are fully operational, with both of them located on dairy farms. Interest is high among livestock producers who would like to install an AD, but the interest has not matched the implementation of the technology. Alternative biomass waste streams to combine with manure in the AD process may be one strategy to move the development of this technology forward in Minnesota. Minnesota has an abundance of biomass, whether naturally occurring or bi-products of industrial processes, that may be suitable for addition to AD systems. The amount of energy produced by AD of manure in Minnesota is only a small fraction of the entire energy use of the State (Hinds, 2003), but co-digestion of manure with alternative waste streams will help enhance this renewable energy generation technology.

The purpose of this report is to identify potential waste streams in Minnesota that could be combined with manure to enhance biogas production and increase revenues of an AD system. Canada (Monreal, Barclay, and Rousselle, 2004) and Australia (Lake, 1996) have looked at this topic abroad and some Midwestern States in the U.S. are also beginning these types of investigations. This report investigated current research and information pertaining to this topical area and has identified research and knowledge gaps that exist. No new research, whether economic, technical, or scientific, was undertaken for the preparation of this report.

Section 2: Criteria for Mixing Manure with Alternative Waste Streams

The focus of this report is on the alternative waste streams that can be co-digested with manure. Manure AD is becoming more prevalent in the United States and there is a great potential for its use by Minnesota's animal agriculture industry.

The following section gives a brief overview of various aspects of AD.

What is Anaerobic Manure Digestion?

Anaerobic manure digestion is a biochemical process by which organic matter is decomposed by bacteria in the absence of oxygen, producing methane and other byproducts. The complete mixture of this gas is called biogas. Biogas can be used for heating, as fuel for engine generators that produce electricity, or flared into the atmosphere. Biogas consists of a mixture of methane, carbon dioxide, and other trace gases (ex. hydrogen sulfide).

The following is the chemical formula for AD (Frear, Fuchs, Wallman, 2004):

Organic Matter + H20 + Bacteria (Acidogenic/Methanogenic) → CH4 + CO2 + NH3 + H2S

Anaerobic digestion occurs in sealed vessels (digesters) that do not contain oxygen. Two types of digesters used to digest animal manure and other compatible waste streams are: mesophilic and thermophilic. Mesophilic AD is accomplished at temperatures of approximately 30-35 Celsius (body temperature) and requires a retention time of the digestate for 15-30 days in the digester. Thermophilic AD occurs at higher temperatures that typically exceed 55 Celsius. Thermophilic AD has a shorter retention time (12-14 days) and may be able to destroy a larger number of pathogens (European Anaerobic Digestion Network, 2005). The drawbacks of thermophilic are that they are sometimes more costly to run and more complicated than thermophlic digesters.

What Factors Impact the Production of Biogas from Manure and Other Organic Waste Streams?

The digestion of manure and the biogas produced is variable depending upon factors such as the type of manure (liquid vs. solid), animal species, and the type of feed the animals are consuming. This variability of the AD of manure will also be variable depending on the types of other organic waste streams that are being co-digested. The rate and efficiency of the anaerobic digestion process is controlled by the following factors (Burke, 2001):

- The type of waste being digested,
- Its concentration,
- Its temperature,
- The presence of toxic materials,
- The pH and alkalinity,
- The hydraulic retention time,
- The solids retention time,
- The ratio of food to microorganisms,

- The rate of digester loading,
- And the rate at which toxic end products of digestion are removed.

What Waste Characteristics are Important for AD and Biogas Production?

The most important constituents of wastes for AD are to have high levels of volatile solids, such as celluloses and hemi-celluloses. Most volatile solid compounds convert to biogas readily through the AD process. Although, lignin does not break down very well through AD, hence waste streams with high lignin content are may result inefficient AD and low biogas production. The more efficient the biogas production, the higher the methane content of the biogas will be. Biogas is typically 55-65% methane and 35-45% carbon dioxide (Burke, 2001).

What are the Drawbacks of Co-digestion of Different Waste Streams?

There are numerous constraints and obstacles for co-digesting manure with alternative waste streams. Economic, political, regulatory, and technical barriers have to be considered when determining the feasibility of using a particular waste stream with manure.

Rudolf Braun developed the following list of constraints for co-digestion of wastes in his paper *Potential of Co-digestion, limits and Merits* (Braun, 2002):

- Increased digester effluent chemical oxygen demand (COD)
- Additional Pretreatment requirements
- Increased mixing requirements
- Wastewater treatment requirements
- High utilization degree required
- Decreasing availability and rates
- Hygienisation requirements
- Restrictions of land use for digestate
- Economically critical dependent on crop costs and yield

There is a lack of literature, specifically in the United States, that characterizes the digestibility of a number of the waste streams described in the previous section of this report. In the mid-1990s, the State of Michigan developed a report of the potential for using agricultural wastes for biomass energy (Falvey, 1996). This report was fairly favorable to their potential, but did not go into specifics about manure digestion and waste streams that could be used effectively together for co-digestion. Studies need to be conducted in States like Michigan and Minnesota to determine which waste streams are suitable for AD with livestock manures. Future research is needed to fully understand if these wastes indeed are feasible for livestock producers to use with manure digesters. One of the most important aspects to consider are what waste streams will help enhance biogas production of AD with manure. In some cases, high strength biological wastes added to a manure AD system may be problematic for the integrity of the digester. Also, the consistency and frequency of the wastes entering the manure AD is important and could be detrimental to the entire system is not managed correctly.

Economics is a key factor that may inhibit the use of certain waste streams for being used in a livestock AD system. The margins in modern agriculture are very tight and economics plays a large role in every decision a farmer makes. One of the most underlying limiting economic factors will be transportation costs. For example, in a livestock operation, transportation of manure to fields for land application is carefully incorporated into the size of the operation, method of application, and manure storage type and size.

Some waste streams will need further treatment (sterilization) or permitting before they can legally be used on a livestock operation. These types of wastes may have significant benefits for co-digestion with manure, but may have additional added costs and may require a higher level of management by the livestock producer. Most of the work investigating wastes, such as offal from slaughter plants, have been undertaken in Europe and other counties. Because of that fact, further analysis would need to be taken to determine if this type of waste could realistically be incorporated in the manure AD system in Minnesota.

What are the Benefits of Co-digestion of Different Waste Streams?

Manure is a valuable resource to Minnesota farmers, whether it is used as a fertilizer or for producing energy. AD is one of many types of treatment systems that can enhance the value of the manure. A report from the South Jutland University Denmark presents a number of benefits of with AD of manure and co-digestion of bio wastes (Holm-Nielsen and Al Seadi, 1998):

- Cost savings for farmers
- Improved fertilizer efficiency
- Reduced greenhouse gas emissions
- Cost effective and environmentally sound waste recycling
- Reduction of Odors
- Reduction of flies
- Potential pathogen reductions
- Renewable Energy production

In addition, Braun has documented the benefits of co-digestion of multiple substrates, such as manure and other waste streams (Braun, 2002):

- Improved nutrient balance and digestion
- Equalization of particulate, floating, settling, acidifying, etc. wastes, through dilution by manure or sewage sludge
- Additional biogas collection
- Possible gate fees for waste treatment
- Additional fertilizer (soil conditioner) reclamation

- Renewable biomass ("Energy Crops") disposable for digestion in agriculture

The economic benefit of increased biogas production from the co-digestion of manure with other waste streams is probably the largest benefit. Research has shown that some waste streams have the ability to enhance biogas production from AD systems with manure (citation). Because of the limited amount of research for this area, it important that future studies be undertaken to further quantify the synergistic effects of other waste streams on biogas production from manure digesters. Economic benefits are not limited to increased biogas production. Tipping fees collected by farmers taking these other waste streams could also be another source or revenue for the livestock operation. There are also cost savings to businesses and industry producing these alternative waste streams. Digesting these waste streams with manure as a means of waste treatment in some cases will be much less expensive than treating the waste by other methods.

Manure management is very important for livestock operators in Minnesota. Manure digestion has many inherent benefits that make the manure easier to handle, enhance the fertilizer value, and reduce the odors. Adding other waste streams to improve any of these properties will be a benefit to the livestock producer. In some instances, livestock producers with AD systems also have incorporated manure composting into their operation. The manure composting may occur after the digestion process. If composting is an economic and environmental initiative of the operation, it may be possible to add certain waste streams to the manure that will aid in the composting process.

What are the Primary Waste Streams that can be digested with Manure?

The following are the major identified sources (see section 3 for more detail) of organic waste streams that could be combined with manure in AD:

- Food Industry
- Grain Industry
- Paper and Pulp Industry
- Domestic Wastes
- Livestock Wastes
- Crop Residues

Most manure digesters in the US have only one source of substrate; animal manure from dairy, swine, or poultry. In other countries with a more mature AD industry and more constraints on disposal of organic wastes, mixing or co-digesting manure with other types of waste streams has been common place. In the US, dairy manure has been the prominent source for manure digestion. Manure from swine and poultry has been digested also, but success has been limited. With more livestock operations undertaking manure digestion, alternative waste streams for co-digestion may be important in their development and feasibility.

Section 3: Sources of Waste Streams in Minnesota Potentially Suitable for Manure Digestion

Minnesota is blessed with numerous biomass resources that can be used for a variety of purposes, such as fuel for cars and trucks and biogas for producing electricity and heat. Minnesota Governor Tim Pawlenty has signed into law measures that will double the amount of ethanol in gasoline in Minnesota. "This bill strengthens our rural economy, improves our air quality and reduces our unhealthy dependence on foreign oil," said Governor Pawlenty, "It also puts our state at the leading edge of a very promising industry. We truly are on our way to becoming the Saudi Arabia of renewable fuels (May 10, 2005)". For Minnesota to be successful in implementing a larger number of AD on livestock operations across the State, it will be important that other waste streams than manure be identified and incorporated into these future systems. This section reviews a number of wastes streams, or more appropriately referred to as "resources", that may have potential for co-digestion with manure.

Food Industry:

Breweries: Anaerobic digestion of brewery waste may be a potential option for digestion with manure. In Minnesota, there is a modest brewery industry that remains, but the majority of the industry is located in the Twin Cities metropolitan area. The Schells Brewery in New Ulm, MN is located in a more rural area and may be a possible source of brewery waste. Brewery waste can be rather dilute and this may be a drawback for its use as a waste stream to combine with manure for AD. The Anheuser-Busch company, which has a large fluidized bed digester it uses for AD of their brewery waste, the total solids was about 1%. In this instance, the digester provides a cost savings by producing energy on-site and also by reducing the effluent concentration that is sent to the waste water treatment plant (Riggle, 1996). For this type of waste to be feasible farms to combine with manure in AD, it would be important to determine: 1) availability of the waste in MN, 2) dilution of the substrate, 3) transportation costs involved, and 4) type of digester needed for AD.

Potato Processing: Minnesota has a long history with the potato production industry and is a leading production State of this commodity. Potatoes are produced in the Red River Valley, Central, and Southwestern MN. Potato waste, which varies in type and consistency, could be used as waste stream to combine with manure for AD. Wastes such as spoiled potatoes, rejected potato chips, and wastewater are possibilities. The limiting factors for use of this waste stream would be: 1) proximity to livestock farms to the processing facilities, and 2) the consistency of the waste stream. In the recent past, there was a proposal to design an AD for a Minnesota dairy farm that would include this waste stream, but this project never came to fruition.

Sugar Beet Processing: The Sugar Beet industry in MN is located primarily in the Red River Valley and in SW part of the State. Wastes such as spoiled sugar beets and byproducts of the sugar refining process could be potential waste steams for AD with manure. Like the potato industry, it would be important to have livestock operators in close proximity to the processing plants. The density of livestock operations is much higher in SW MN than the Red River Valley, so a feasibility analysis would need to be conducted to determine if this waste stream is plausible. Another issue, which would relate to potatoes as well, is ensuring that the material in the waste stream was void of inert materials such as soil. Inert materials accumulate in digesters and eventually compromise the integrity of the AD system if it is not managed properly.

Dairy Processing: Minnesota is the 7th largest producer of milk from dairy cows in the United States, with h approximately 6,500 dairy farms. Dairy farms are located throughout the State, but the largest concentrations are in Southeastern and Central Minnesota. Minnesota has a significant dairy processing industry that produces fluid milk, butter, cheese, yogurt, ice cream, and other dairy products. With this variety of products being produced, an equal variety of waste streams associated with dairy processing may be available for AD. Dairy processing facilities are located in both major population centers and in rural areas of the State. Currently, some dairy processing plants are using AD for treating their own wastes on site, which reduces their treatment costs and effluent discharges to waste water treatment plants. Also, at least one dairy processing plant is producing ethanol from their waste streams (Riggle, 1996). The nature of dairy wastes, with high volatile organics and biochemical oxygen demand (BOD), makes them ideal for AD.

One advantage to dairy processing plants is the relatively close proximity of some plants to livestock operations that potentially could install manure digesters. To further the understanding of the scope to which dairy processing waste could be used for AD with manure, the following information should be analyzed: 1) geographic information system (GIS) analysis of location of livestock facilities to dairy processing plants, 2) ratio of manure to different dairy processing wastes in AD that result in optimum biogas production and digestate treatment, and 3) economic costs of transporting dairy processing wastes to on-farm manure digesters.

Meat Processing and Rendering Facilities: Minnesota has meat processing plants for the swine, chicken, turkey, and beef industry. Processing facilities are predominantly in southern MN, with another contingent of poultry processing facilities in Central and North Central, MN. In Europe, wastes from meat processing plants and slaughter houses (abattoirs) are commonly mixed with municipal sludge and manure waste streams in biogas plants (Braun, 2002). One of the main concerns with digestion of this type of waste stream is animal disease transmission. This has been amplified by the proliferation of bongiform encephalitis (BSE) in the United Kingdom and other countries. Therefore, it is necessary to pasteurize the wastes at an elevated temperature after AD to ensure that digestate is free of diseases and pathogens that may be harmful to animal populations.

Catering, Institutional, Domestic, and Restaurant Wastes: This waste stream is another source of wastes that may have potential for AD with manure. Comprised mostly of wastes produced through the food preparation process, these organic waste streams are becoming increasingly problematic for disposal in landfills and treatment by WWTPs.

This is most notable in Europe, which has resulted in separate collections just for this waste stream (CADDET Centre for Renewable Energy, 2000). Many European countries have incorporated this waste stream into AD from biogas plants, some of which are using manure. Researchers from Cornell University in New York State have conducted a study that has looked at the inclusion of food waste with manure and have documented the observed benefits (Scott and Ma, 2004). Research conducted in Switzerland found that the addition of vegetable waste improved and accelerated the AD process (Edelmann, Engeli, and Gradenecker, 2000). In Minnesota, it will be important to understand the amount of theses wastes that could be available for AD with manure and if it would be economically feasible to do so.

<u>Grain Industry</u>:

Ethanol Plants with Wet and Dry Distillers Grains: The ethanol industry has been in development over the last twenty years. Minnesota has a number of ethanol plants and will be potentially adding more and larger plants in the next few years. From the process of distilling ethanol from corn, a product called distillers grain is produced. There are many uses for distillers grain, the most prominent use is for animal feed. Distillers grain is sold as feed in both a wet and dry form. Because many livestock operations are already using distillers grain for feed, it may have the potential as an additional waste stream for a manure digester. Economic analysis of using distillers grain as strictly an AD waste stream, versus an animal feed has not been determined. Also, the performance of distillers grain as an additional to an AD system needs to be investigated.

Damaged Grains: In Minnesota, a small percentage of grain (corn, soybeans, and small grains) is damaged and determined to be unfit for sale. This may be because of improper storage, fire, or other unforeseen circumstances. This grain is usually disposed of by land application to agricultural fields or by putting it into a landfill. Because of this waste streams limited value, it may be an economical waste to digest with manure. There is a need to determine if further treatment is needed for the damaged grain before it enters a digester. Because the condition of the damaged grains is variable, this could impact the consistency of biogas production from this waste stream.

Biodiesel Plants: In Minnesota, biodiesel production is in its infancy, but there are plans for the development of this industry in the near future. Bio-products from the biodiesel production process may a waste stream to digest with manure. Distance from livestock facilities, digestibility of the bio-products, and the cost of hauling the waste will all be factors in determining if this is viable AD waste stream.

Soybean Processing: Minnesota is one of the largest producers of soybean oil and meal in the United States. Investigations on the technical and economic feasibility of using the bi-products from this industry for AD with manure need to be made.

Grain Milling Wastes: The grain milling industry has historically been a very important part of Minnesota's economy. This industry was exemplified with the flour mills industry located in Minneapolis, MN in the early 1990's. This industry continues to be a major industrial sector in Minnesota and is another source of organic waste streams that could be used to co-digest with manure. Location to animal agriculture (transportation costs) and the biological strength of wastes from this industry will be important in determining the viability of using this waste for AD with manure.

Paper and Pulp Industry:

Newspaper and Recycled Paper: Newspaper and recycled paper is an abundant waste stream source that is ubiquitous across the State of Minnesota. In Minnesota, the Haubenschild Dairy has used newspaper bedding as a supplemental waste stream for their manure digester. More research is needed to determine the synergistic effects co-digesting newspaper with manure.

Paper Mill Processing: Minnesota has a significant paper milling and logging industry. It is not apparent that paper mill waste is a good source for AD. This industry is located in Northern MN, where livestock operations that would have the potential for manure digestion are not very prevalent. If this waste stream is plausible for AD with manure, the economics of transporting this waste stream to livestock facilities would need to be determined.

Domestic Wastes:

Human Waste Sludge: In United States, as well as in Minnesota, it is common for municipal waste sludge to be treated with AD. The biogas collected is used for both creating electrical energy and for driving boilers for heating. The co-digestion of manure and human sludge has been accomplished in Europe. This has not been the case in the United States. Analysis is needed that looks into the scientific and political reasons (health concerns, regulations) in Minnesota that would allow or prohibit the co-digestion of human sludge and manure.

Yard Wastes: Yard wastes from gardens and grass clippings from lawns are two waste streams that have potential for AD. Both of these waste streams are available seasonally in MN. Currently, an increasing percentage of this material from residential areas is collected, composted, and reused. This material has been used for AD in European biogas plants. One of the issues associated with this waste is inert material such as soil and wood chips, can be problematic for AD. Also, the energy value of this waste may potentially be low, and the cost of transporting this material will need to be analyzed.

Livestock Wastes:

Mixing Manure from Multiple Species: The majority of AD systems being incorporated into livestock operations in the Midwest are being deployed on dairy operations. In Minnesota, two dairy farms are currently use AD and a handful more will be starting up manure AD systems in the coming years. Dairy manure is very suitable for AD and has been a successful venture for a number of dairy farmers. Minnesota has a strong dairy industry, but also has very robust swine and poultry industries as well.

Swine and poultry manure has more challenges for AD than does dairy manure and the use of alternative wastes streams for co-digestion with manure is very important. There is a need to determine the efficacy of mixing swine and poultry manures together or to mix with other species of manure (dairy, beef) to increase the feasibility of AD.

Residue from Poultry Manure Incineration: Minnesota's first poultry manure incineration plant is going on-line in the very near future. It is not know whether the residual wastes produced from the incineration process is a valuable waste stream to be digested with manure.

Crop Residues:

Corn Stover: Nearly half of Minnesota's cropland is planted into corn. With this large amount of corn being harvested, a large amount of corn stubble (stover) is left behind. This stubble is very important for protecting the soil from erosion from soil and wind. In recent years, the interest in harvesting some of this material for energy production has increased. It is believed that some stubble can be removed without reducing the environmental benefits it provides to the soil. Ethanol production is one of the main ideas for an end use to corn stubble. Analysis is needed to determine the cost effectiveness, technical feasibility, and environmental impact of mixing corn stubble with manure for AD.

Alfalfa or other Legumes: Alfalfa is grown primarily in regions of Minnesota where dairy are prevalent. Alfalfa is not just an important feed for livestock in Minnesota, but is also very good for the environment. Alfalfa is very good at helping reduce soil erosion on steep sloping land and it also helps build soil structure. With losses in cattle numbers in recent years, the amount of alfalfa in Minnesota has steadily decreased. Anaerobic digestion of alfalfa with manure could potential help in developing a new market for this crop and help restore the number of acres planted to it in the future. Research has been conducted that found that alfalfa did increase the biogas production of manure when it was co-digested with it (Kaparaju et al., 2002) Economic and scientific analysis is needed to determine if this is a feasible concept on working farms.

Switch Grass and Small Grains: In Iowa, the Bluestem Biomass process is an example of the use of a native grass for the production of biogas through AD. This is a promising project that may shed light on the efficacy of mixing this type of biomass with manure for AD. For small grains such as wheat and oats, the stubble left behind after harvest may be an optional resource for co-digestion with manure. Small grains are grown primarily in the Red River Valley in NW Minnesota and in areas where cattle are raised. The feasibility of using this material as a co-digestate will depend on many economic factors of collecting and transporting the material. Using the material as bedding, at least for cattle operations, should help with the economics of using it for AD.

Section 4: Research Needs

Anaerobic digestion of manure has been around for centuries and research has been increasing in this field. Unfortunately, there is little research that has been done on working farms in Midwestern states on alternative waste streams for co-digestion. In order for AD to continue to develop in Minnesota, it is important that on-going research is undertaken and keeps in line with the implementation of the technology.

The following are focus areas for research on co-digestion of alternative waste streams with manure from livestock operations in Minnesota:

- **Analyze Available Substrates:** There is a lack of technical research on a variety of available waste streams and their ability to be digested with or without manure. Continued work, beyond this report, is needed to identify available substrates and waste streams for co-digestion with manure.
- **Conduct Bench-top Studies with Small Scale Manure Digesters:** Initial research should involve lower-cost bench-top studies to look at the efficacy of alternative waste streams. These types of studies will allow for experimental control and reproducibility of testing.
- **Conduct Real World Tests with Operational Digester:** Continue to cooperate with farmers on research on manure digesters in Minnesota. Also, determine the plausibility of constructing a research manure digester at the University of Minnesota campus or at one of the Research and Outreach Centers.
- **Economic Analysis:** The University of Minnesota Applied Economic Department has been continually working on economic analysis pertaining to the adoption of AD by Minnesota livestock producers. It is important that this research continues and that economic benefits and constraints for introducing alternative wastes for co-digestion of manure be considered.
- **Decision Matrix Development:** A user friendly decision tool or matrix would be very helpful to assist livestock producers in determining what types of waste streams would be most compatible for mixing with specific types of animal manures.
- **Producer Adoption:** Producer surveys and outreach efforts need to be undertaken to determine which alternative waste streams livestock producers with AD systems are willing to work with.
- **Policy Implications:** The regulatory community (US EPA, MPCA, BAH, MDH, MDA) must be involved in determining what waste streams legally can be used by livestock producers on their farms. Permitting and reporting requirements need to be documented and assimilated into a guidance document on use of alternative waste streams in AD.
- **Funding Resources:** Funding sources for research need to be identified and time-lines for application for funds need be outlined. Also, cost share and grant funds for manure digesters must be documented and winnowed into a central document.
- **Continue CERTs Project Work:** It is important that the Clean Energy Resource Teams (CERTs) initiative continue and that the information compiled by this

group is updated and amended periodically. Through this effort, researchers will be better to connect with agricultural producers that may be interested in AD.

The University of Minnesota and the Minnesota Department of Agriculture will be cooperating on a future LCMR project that will be focusing primarily on the feasibility of multiple farm anaerobic manure digestion systems. Within this study, a limited amount of research will be conducted looking at a few wastes streams that may be beneficial to multiple farm manure digesters in Minnesota.

Section 5: European Model and Examples of Co-Digestion of Manure in Biogas Plants

In Europe, the development of biogas plants that co-digest manure with other wastes has been aggressive over the last two decades. This has resulted because of economic, social, and environmental pressures. The Kyoto Protocol, which requires counties to meet 1990 levels of green house gases, is a very significant driver (Ireland EPA, 2005). In counties like Denmark, with a relatively large livestock population and with a small land base, the development of biogas plants was needed. Many of these plants have been subsidized by their national government in order to make them economically viable. The following is a summary of some of the efforts co-digesting manure with alternative waste streams to produce biogas from a few counties in Europe:

Denmark: Denmark has been a world leader in AD development and implementation, especially for generating manure to electricity systems. One of the driving forces in Denmark is their goal of having 33% of their total energy produced derived from renewable energy sources by the year 2030. It is believed that that the biogas production in Denmark will be increasing by a factor of 10 by the year 2020. Manure is estimated to be about 80% of the biogas potential in Denmark (Anegelidaki and Ellegaard, 2005).

Co-digestion of manure with other organic wastes is common place in Denmark. It is the experience in Denmark that co-digestion of wastes help increase biogas production, which in turn results in a greater energy yield. Manure acts as a beneficial carrier substrate for other types of wastes streams and if beneficial for the following reasons: 1) manure is a good solvent for drier waste streams, 2) manure acts a pH buffer, 3) manure contains nutrients needed for bacterial growth, and 4) manure is helpful in diluting concentrated waste streams (Anegelidaki and Ellegaard, 2005).

As of 2000, there were 20 biogas plants that were operational in Denmark, which mostly involve the digestion of animal manures. These AD systems use both mesophilic (37 Celsius) and thermophilic (53 Celsius) systems for producing biogas and do not resemble counterpart systems being installed in the U.S. for livestock operations. Some of the individual AD systems are primarily a mesophilic system with a final thermophilic phase to reduce pathogens in the waste stream. The University of Southern Denmark has compiled data on individual biogas plants and has developed a very good publication that details how each plant works (Al Seadi, 2000).

United Kingdom: The United Kingdom (UK), like Denmark, has had government initiatives driving the AD and renewable energy industry. Notably, the "Climate Change Levy" and the "Renewable Obligation" (Monnet, 2003) are UK energy initiatives that are helping the development of AD. Although, the application of AD in the UK has not been as wide spread as other European countries. Regulations are driving the use of renewable energy and environmental beneficial technology like AD. One area of focus is the co-digestion of manure with animal bi-product wastes. The UK has promulgated strict regulations for the disposal of animal bi-products in the wake of the Mad Cow Disease outbreak in the early 2000's. These regulations impact AD of this material to ensure that the digestate is free of any dangerous pathogens (Monnet 2003) (Papadimitriou and Stentiford, 2003). In addition, greenhouse gas reductions in the Kyoto protocol and other directives of the European Union on waters quality have put pressure on the UK to work toward developing more AD systems (Ireland EPA, 2005).

Sweden: The use of AD in Sweden has increased greatly in the 1990s. Like the UK and other European counties, regulation is the impetus behind the adoption of this technology. Specifically, the ban on the land filling of organic wastes, phosphorus reduction regulations, and the Kyoto protocol requirements for Sweden has given AD an outlet for those waste steams to be handled and processed (Nordberg, 2002). Also, the inability to use animal bi-products in feed in Sweden has made slaughterhouse and associated wastes available for AD. Manure is the primary feedstock for most of the biogas plants, so other waste streams co-digested are secondary substrates (Nordberg and Edstrom, 2002). A good example of a Swedish AD plant is the Kristianstad plant that processes a number of wastes. This plant takes in organic wastes such as municipal household organics, distillery bio sludge, abattoirs (animal slaughter plants), liquorice, vegetable wastes (carrots, potatoes), and manure (swine, cattle, poultry). All of these waste streams are processes and co-digested in very efficient manner. The digestate is land applied to near-by farmer fields (Caddet Centre for Renewable Energy, 2000).

Germany: Germany, along with other counties in Europe, has been using AD plants for manure since WWII (Lusk, 1998). As of 2000, Germany had a total of 44 biogas plants that have a processing capacity of 1.2 Million metric tons of bio-waste streams. In total, Germany processes 8 million metric tons of bio wastes, but 85% of those wastes are composted rather than treated through AD. Most of the larger biogas plants in Germany use co-digestion of animal waste, human sewage, and food and processing wastes. Typically, a low solids waste stream is used for these types of plants (Kranert and Hillebrecht, 2000). This is in contrast to Austria which has numerous biogas plants, but there is very little if any co-digestion taking place (Holm-Nielsen and Al Seadi, 1998). Biogas plants that utilize a variety of waste streams will have both an AD and a composting element in the bio waste processing scheme. For example, the Biogenes Zentrum Peine biogas plant built in the late 1990's separates waste streams high in lignin and cellulose that do not digest well and they are composted. Waste streams more suitable for AD are separated and digested (Kranert and Hillebrecht, 2000).

Section 6: Applied Concept in Minnesota: Haubenschild Dairy

The Haubenschild Dairy, near Princeton, MN, milks approximately 800 (900) cows and has been successfully operating an anaerobic manure digester system since 1999. The manure digester is a plug-flow system and the biogas that is collected is run through a CAT 3406 engine generator set that produces 130kW of electricity. Since the outset, the Haubenschild Dairy has co-digested manure with shredded newspaper. The newspaper is first used as bedding and incorporated with the manure before it enters the digester. The new paper is brought to the farm in bulk from the local (who is it) and is finely shredded into bedding with a conventional bale shredder. In recent years, the Haubenschild Dairy has also been taking small amounts of dairy processing waste and incorporating that into the manure digestion stream.

The Haubenschild Dairy has far exceeded the biogas production per cow that was initially projected for the dairy. University of Minnesota researchers believe that this has occurred because of three things: 1) Haubenschild dairy's management of the digester, 2) the precise herd and feed management, and 3) the use of the shredded newspaper as bedding. The University of Minnesota researchers believe that the synergistic effects of the manure and the shredded newspaper combined in the manure digester have resulted in the above normal biogas production at this facility. If additional funding becomes available, a small research study may be undertaken to scientifically document this finding.

Section 7: Conclusion

Minnesota is a leader in renewable energy and is in support of AD systems for livestock operations. For Minnesota to continue its leadership role in AD, it is important that additional livestock operations incorporate AD into the management systems in the near future. To do so, it may be necessary for livestock operations to digester other waste streams with their manure. Economic, environmental, and social issues will guide the use of alternative waste streams with AD of manure. This report is one of many steps needed to help understand this issue and give guidance to livestock producers in Minnesota.

The major findings of this report are:

- Europe is leading the world in AD of manure and alternative waste streams.
- Minnesota industries produce an abundance of organic waste streams that have the potential for use in AD with manure from Minnesota livestock farms.
- There is very limited research and documentation that specifies which waste streams are the most technically and economically feasible for AD with manure.
- The potential economic impact of fully utilizing alternative waste streams with AD of manure seems to be great, but economic analysis must be done to quantify this information.
- Research needs specified in this report must be examined and prioritized by stakeholders involved in AD in MN.
- Livestock producers need readily accessible information on alternative waste streams for AD with manure.

This report was developed by the Minnesota Department of Agriculture Agricultural Resources Management and Development Division for the project "Advancing Utilization of Manure Methane Digester Electrical Generation", which was funded by the Legislative Commission on Minnesota Resources (LCMR) via the Natural Resources Trust Fund.

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