Anaerobic Digester Technology Applications in Animal Agriculture -A National Summit

June 2 – 4, 2003

Hilton North Raleigh Hotel

Raleigh, North Carolina

Water Environment Federation
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PAPER PRESENTERS AND TITLES

Tom Christensen and Ted Payseur, National Summit Co-chairs, Recap of the Summit-- Anaerobic Digester Technology Applications in Animal Agriculture,

Dennis A. Burke, High Rate Anaerobic Digestion of Dilute Animal Waste for Maximum Gas Production

Ron Donlan, Cove Area Renewable Energy Products.

Tom Dorr, Rural Development Perspective

Earl Dotson, How Can Digesters fit into a Producers Environmental Plan?

Prince Dugba, Conversion of Swine Manure into Bio-Diesel Using Anaerobic Digesters

Robert Foster, Case Study—An integrated approach to dairy waste handling

Ronald K. Frobel, Large Anaerobic Digester Containments using EPDM Rubber Geomembranes

Sam Ghosh, An Alternative and Innovative Approach to Anaerobic Digestion of Dairy Manure

C.L Hansen, Demonstration of the Induced Blanket Reactor for Anaerobic Treatment of Dairy and Swine Manure

Adrian Hanson, Producing Energy and Soil Amendment from Agricultural Wastes

Scott Inglis, Complete Mix Mesophilic Anaerobic Digester in Western New York

Barry Kintzer, NRCS, Historical Perspectives on Anaerobic Digester Conservation Practice Standards

Richard Kohn, National Academy of Sciences Report—Recommendations on Air Emissions and Animal Agriculture

Glen Lindgren, Inland Empire's Regional Plant #5 Anaerobic Digester for Dairy Waste: Comparative Performance and Concepts for Improvement

Richard Mattocks, Anaerobic Digesters at Dairies in Cold Climates

Mark Meech, Verification of Innovative Treatment Technologies in Animal Waste Management Programs

Frank Humenik, Anaerobic Lagoon with an Impermeable Cover for Reduction of Odor and Ammonia Volatilization

Carlos Monreal, Co-Generation Using Animal Waste

Mark Moser, A Dozen Successful Swine Waste Digesters

Carl Nelson and William Lazarus, Assessing Environmental and Economic Performance of Biogas Systems

Kurt Roos, Comparative Environmental Benefits of Anaerobic Digesters

Kurt Roos, U.S. EPA AgStar Program, U.S. Experiences with Anaerobic Digestion of Animal Wastes—Technologies, Trends and the AgStar Program

Joe Rudek, Ammonia Deposition and Air-water Interface Issues

Leland Saele, NRCS, USDA Anaerobic Digester Ambient Temperature (Code 365) Conservation Practice Standard

Leland Saele, NRCS, USDA Anaerobic Digester Controlled Temperature (Code 366) Conservation Practice Standard

Leland Saele, NRCS, USDA Waste Facility Cover (Code 366) Conservation Practice Standard

Jason C. H. Shih, Thermophilic Anaerobic Digestion: Theory, Practice and Benefits

Jose Sifontes, SEBAC, A New Technology for the Sustainable Processing of Animal and Agricultural Wastes

Fred Soroushian, Application of Phased Digestion for Cluster Dairies

Arthur A. Teixeira, Sequential Batch Anaerobic Composting (SEBAC®) For Organic Solid Waste Management

W. James Wells, Design, Construction and Start-up of Two Large Covered Anaerobic Digesters Treating Swine Manure (10,000 sows and 108,000 Finishers)

Carol E.Whitman, Waste-to-Energy: An Opportunity for Electric Power and Agriculture

Ann C. Wilkie, Anaerobic Digestion of Flushed Dairy Manure

C. Mike Williams, Anaerobic Digester Applications for "Environmentally Superior Technology": Research Status and Future Perspective

Todd Williams, Differences Between Using Anaerobic Digestion for Dairy Manure and Using it for Municipal Solids

George Wiltsee, Clean and Reliable Power and Heat from Digester Gas

Ping-Yi Yang, Design and Analysis of an Anaerobic Bio-nest Reactor

Ruihong Zhang, Anaerobic Phased Solids Digester for Biogasification of Agricultural and Food Wastes

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Water Environment Federation
601 Wythe Street
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www.wef.org

June 2, 2003

Dear Colleague,

Addressing the environmental stewardship needs of America's livestock and poultry producers is a public policy priority. With approximately 250 million dry tons of animal manure produced yearly in the United States, and a growing percentage of it produced on fewer, larger, and more geographically concentrated farms, there is increasing scrutiny on animal agriculture's potential impact on the Nation's natural resources. The array of potential environmental issues has grown and livestock and poultry producers are challenged more than ever to comply with resource protection requirements promulgated through a number of Federal and State statutes.

Today, animal agriculture is responding affirmatively to many varied issues, ranging from environmental and public health to biosecurity to economic concerns. Environmental stewardship in animal agriculture is not a new idea, nor has it been neglected. Indeed, most livestock and poultry producers have been among agriculture's most active adopters of conservation technologies, practices, and systems. Yet, the challenges continue, driven by a number of factors including increasing demand for animal agriculture products, changing economic conditions, the advent of new technologies, a dynamic natural environment, and development pressures bringing population centers into closer proximity to animal production.

Innovative technologies and approaches are needed in order to make advances on the Nation's most difficult environment challenges in animal agriculture. One technology that has demonstrated potential to help mitigate the impacts of animal manure on air and water resources, while producing other benefits such as energy, is anaerobic digestion. This technology has the potential to fit seamlessly fit into production systems, and to provide both economic and environmental benefits.

This conference serves as a vehicle to discuss the application of anaerobic digestion technology in a systems approach to animal manure management. Through this conference, we plan to explore technology and implementation issues, economic and market development needs, environmental improvement opportunities, and lessons learned. We also hope to identify and clarify the appropriate roles for natural resource, agricultural, environmental, and rural development public entities in the facilitating further development and greater adoption of this technology.

We welcome you to Raleigh, North Carolina and thank you for the insights and contributions you will bring to this conference.

Sincerely,

Tom Christensen, USDA NRCS
Ted Payseur, Water Environment Federation
Conference Co-Chairs

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PHOENIX Process Equipment Co. Table 3
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PHOENIX Process Equipment Co. designs, manufactures and markets systems for dewatering biological process wastewater. Equipment includes belt filter presses, table thickeners and reverse osmosis units for liquid/solid separation and water purification.

US EPA/AgSTAR Table 7
15802 Moncure Dr.
Montclair, VA 22026
AgStar is an outreach program designed to increase the use of appropriate digester systems at reduced risk.

USDA - NRCS Table 12
5601 Sunnyside Ave.
Beltsville, MD 20705
USDA - NRCS display on farm bill programs. Publications relating to animal feeding operations and CNMP's will be available.

National Biosolids Partnership Table 11
601 Wythe Street
Alexandria, Virginia 22314
The National Biosolids Partnership provides support to the Nation's municipal wastewater treatment plants for the appropriate management of residuals

Cyclus EnviroSystems Table 16
6007 Hill St.
Olympia, WA 95816
Engineers and constructors of high rate anaerobic digestion processes for municipal, ndustrial and agricultural wastes.

U.S. EPA Climate and Waste Program Table 15
1200 Pennsylvania Ave., NW (5306W)
Washington, DC 20460
Educational materials regarding, climate impacts from solid waste.

CONTINUING EDUCATION UNITS/PROCEEDINGS

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Participants who attend the full conference and document attendance at each session will be awarded CEUs. CEUs are calculated at a rate of 1.0 CEU for every 10 hours of participation.

In order to have a CEU certificate mailed, attendees must have the Request for CEU form stamped at each session they attend and they must return the completed CEU form to the Registration desk. Information concerning CEUs is available by sending your request to WEF c/o CEU Coordinator by FAX to 1-703-684-2413.

PROCEEDINGS

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Recap of the Summit-- Anaerobic Digester Technology Applications in Animal Agriculture

Today, manure management is a challenge. Proper facilities have to be built and managed. And there must be encouragement for ways to maximize the value of manure as a source of fertilizer, energy, and other value-added products.

Most farmers believe in doing the job right to protect natural resources. The challenge is to get the job done in the context of maintaining profitability. For many of us, the water quality problem has been pretty much under control for quite a while now. Success with regard to water quality may have led us to think we had solved the manure management challenge.

Attention is moving to agriculture and other watershed sources of pollution. People expect more of agriculture, including livestock and poultry operations, all the time.

Expectations are related to odor control, greenhouse gases and climate change. People want all industries, including agriculture, to do their part to limit greenhouse gas emissions. In some cases, agriculture has not taken action fast enough, and regulation remains a possibility.

Indeed, some regulation is already here, for example, EPA's Revised CAFO Rule that addresses water quality.

And, some regulation is being considered. Based on a 2003 National Academy of Sciences report, EPA is looking to define feasible regulations on air emissions from animal feeding operations.

These new and potential regulations are indicators that the old methods for handling manure aren't enough. That's why it is time to look at additional technologies, such as anaerobic digesters--a relatively efficient way to treat manure, while virtually eliminating objectionable odors and the loss of greenhouse gases.

Voluntary Versus Regulatory

Regulation is not the best scenario because it can have unintended consequences: compliance raises the cost of production; production moves state-to-state, region-to-region, or country-to-country to avoid these costs; geographic areas with lots of regulation lose economically, the environment loses because production takes place in localities with lower standards.

We have already seen some of these adverse results in the livestock and poultry industries.

So, what is the other scenario? In the regulatory scenario, society demands environmental improvements, and the producer bears the costs. In the voluntary scenario, the market helps the producer recoup his or her costs. When people develop an expectation, industry, government, and others develop market-based incentives for voluntary action that can result in cleaner water and cleaner air, producer profits, and an economy that stays in America. Everybody wins.

Anaerobic digesters can play a role in either scenario. Either way, digesters help to control odors, reduce greenhouse gas emissions, and provide a rich nutrient source with reduced pathogens.

Making Digesters Viable

Digester technology is not new. Digesters have been around for decades, and several countries in Europe are making extensive use of them. In this country, installation of on-farm digesters is not generally accepted as being economically feasible.

What is relatively new is the idea that America needs to rely more on digester technology to reach its environmental goals. For this idea to become a reality, we must meet three conditions:

1. Digesters must be inexpensive and reliable enough to make economic sense in more operations.

2. We must have viable markets for the products of digestion.

3. We must have incentives to bring down the cost to producers and to launch the technology.

Incentives

First, look at incentives. One thing NRCS does is administer USDA's incentive programs for conservation. As you know, the 2002 farm bill includes an increase of $18.5 billion for conservation, which opens up many more options for many more producers. The farm bill also places more emphasis on livestock and poultry operations, which is good news for all of you.

The single largest program for conservation on working lands is the Environmental Quality Incentives Program, or EQIP, with $9 billion to invest over ten years. Sixty percent of this investment is designated for livestock and poultry environmental stewardship.

There are a few instances where the EQIP program or other USDA programs have been used to help producers with part of the costs of digesters. Fairly general conservation practice standards have been used to cover this kind of work.

Today, we unveil three new conservation practice standards specifically for digesters. These are performance standards that lay out expectations for the performance of the technology but do not prescribe or endorse a particular vendor's product.

One of the standards is for manure facility covers for new lagoons and to retrofit existing lagoons. The second standard is to build new ambient temperature digesters. The third standard is to build new controlled temperature digesters.

These standards were published April 29 in the Federal Register. The final conservation practice standards will be published as soon as the comments have been incorporated into the text. They then will be available on-line in the USDA electronic Field Office Technical Guide.

These new standards will have two major benefits. They will make it easier for producers to fit anaerobic digesters into their EQIP contracts as part of a comprehensive nutrient management plan. And, they will make it easier for producers to use technical service providers to plan and construct digesters.

USDA NRCS will be working much more with technical service providers to deliver conservation assistance to producers. For digesters, this means engineering consultants and consulting firms. We are talking with some of the professional engineering societies about memorandums of understanding that will allow us to certify members of these societies as technical service providers.

We have set aside $20 million this year for the use of technical service providers. With these technical standards in place, digesters will be an ideal practice for technical service providers with this expertise.

State Conservationists also set the cost-share rates within their states. We have a backlog of applications for all our major conservation programs, so it is important that we use cost-share rates properly as incentives, not as entitlements.

To promote equity across States and regions, we are requiring that State Conservationists sign off on cost share lists that include practices with rates of over 50 percent and Regional Conservationists sign off on contracts larger than $100,000. These policies are not intended to prohibit higher cost-share rates or larger contracts. Rather, they are intended to give everyone a chance at participating and encourage fiscal responsibility. .

USDA also is supporting activities in the areas of biomass and bioenergy. Farmers and ranchers are eligible for loan guarantees for renewable energy systems, including anaerobic digesters under the Rural Business and Industry Programs administered by Rural Development. Loans can be for farm- or ranch-level systems or to buy stock in cooperatives established to process agricultural commodities.

Also, USDA is funding Biomass Research and Development, including demonstration projects, with $14 million this year through 2007. A request for proposals was published in March, with proposals due the middle of May.

But incentives such as federal funding would go farther if cost and a better market were being met.

Costs

Digesters are not cheap, and the technology needed to capture the energy from a digester drives up the cost even more.

EQIP can help meet these costs. The maximum contract size under EQIP is $450,000; however, we cannot offer many contracts that large and still meet the needs of enough producers. The sale or use of value-added products from digestion also can help producers cover the costs of installing digesters.

But helping meet the costs is not enough. We also need to bring down the total cost of digesters, both large and small, to make this technology affordable for more and more producers. The cost and efficiency of digesters reminds me of the ethanol industry 20 years ago.

Bringing down the cost involves technology, production, experience, and installation variables, which are things entrepreneurs, universities, and corporations can help. I know that the formula that made ethanol cost competitive can do the same for digesters.

Markets

In terms of markets, there is much to be done. The fact is, there are fewer than 300 digesters now being used in agriculture in this country to produce usable energy – as opposed to burning off-gases. If there were better markets, that number could be in the tens of thousands.

The collected biogas from anaerobic digesters is typically 60-70 percent methane, which is a valuable energy resource. The challenge is to build a market for this methane.

We are not far enough along in being able to market the effluent from digesters. Effluent from the digester process is a valuable source of nitrogen that can improve our agricultural productivity. It also is low in pathogens.

To maximize this market, we need to do two things.

The first is feed management -- particularly in the beef and dairy industries -- to produce a product that is better balanced in nutrients. For example, many farms that fertilize with today's manure are max-ing out on phosphorus, limiting the amount of manure they can apply. Feed management will produce effluent that is more useful on-farm.

The second is to improve the economics of manure management in holistic ways that take into account all costs, including production, storage, and transportation of the marketable products of digestion, be they methane or effluent.

Developments in all these areas will help make it profitable to manage manure.

Producers need to work closely with their local utility regulators to make them aware of barriers to creating markets for electricity generated using products of digestion. Working together with utility companies themselves also can build markets. One example is the plan in Oregon to build centrally located generators, with the utility company brokering the hauling and disposal of solids.

Today, we have a new era of cooperation between EPA, USDA, and others to create a Federal regulatory environment that takes into account both environmental needs and the economic realities of agricultural production. The new CAFO rule is an example of this cooperation.

Producers and producer organizations need to work at the State level to help create this same kind of cooperation.

This summit brings together the nucleus for solution. The various presentations covered the technology and keys to the cost and market place that will help anaerobic digester technology take its place in the conservation arena. We have learned that

- Developments in digester technology can help bring down both the cost of digesters and the cost of associated technologies to capture and use the products of digestion.

- Markets for the products of digestion can be developed through development of private sector partnerships,

- Creation of a flexible, business friendly regulatory environment and closer cooperation between government and the private sector is a key ingredient.

- And, finally, we know that the appropriate use of incentives, direct and indirect, can help producers recoup some of the costs of producing clean air and clean water.

Success in these areas is not just desirable, it is essential to creating the kind of voluntary, market-based approach to air and water quality that we need.

We have 250 million dry tons of manure a year out there to use properly, and a public that is increasingly intolerant of degraded air and water quality. If we producers and others don’t put our heads together and manage manure through the voluntary approach, then we will have to live with the possibility of greater regulatory influence. And that is a future I think we would all like to avoid.

ABSTRACT

High Rate Anaerobic Digestion of Dilute Animal Waste for Maximum Gas Production
By
Authors: Dennis A. Burke, PE

Keywords: High Rate Digestion, Liquid-Solids Separation, Dairy Manure, Contact Process, Stabilization Process, AGF Process, Pasteurization, Disinfection

Economical high rating anaerobic digestion technologies have been developed and applied throughout the world for the treatment of warm soluble wastes. These include the UASB process and a variety of anaerobic filters. Thermophilic digestion requires twice the heat of mesophilic digestion. Consequently, thermophilic digestion of dilute cold waste is not particularly feasible. The other commonly used high rate anaerobic processes are not suitable for the digestion of cold particulate slurries such as animal waste.

Upwards of 60% of the large dairies in warm climates, such as California, use flush systems. A large number of dairies throughout the United States have converted to sand bedding to enhance animal health and milk production. Removal and recycle of bedding sand requires dilution of the waste. In the past the use of flush systems, or sand bedding prevented the application of anaerobic digestion processes. The application of new high rate anaerobic digestion processes, for dilute waste slurries, is essential to minimize noxious gas emissions from confined animal operations.

This paper discusses 10 years of research and application of high rating anaerobic digestion and separation technologies for dilute dairy manure. Research on the separation and concentration of dilute dairy manure from flush system waste, for subsequent anaerobic digestion is presented. The products of this process are clean sand for reuse, clean disinfected flush water for recycle, and concentrated organic slurry for anaerobic digestion. Research on the application of the anaerobic contact stabilization process of dairy manure is also presented. This 12-month project achieved 65% conversion of particulate and soluble COD to gas using a 16-day HRT. Finally, the results of four years of full-scale operation of the AGF pasteurization process and the application of the AGF process to the 3,500-milk cow Fair Oaks Dairy, which utilizes sand bedding, are presented.

C.A.R.E. Products

Cove Area Renewable Energy

A Solution For Agriculture Today and Tomorrow

Southern Alleghenies Resource Conservation & Development Council and Partners

Project Intent

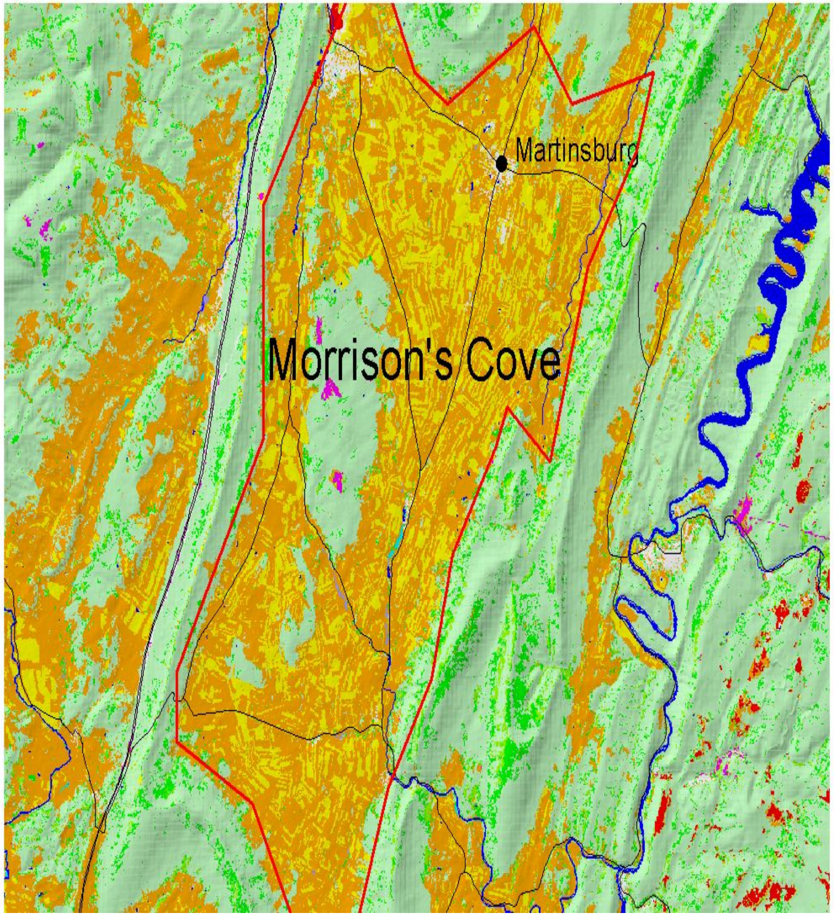
- Keep small farms profitable
- Preserve agricultural integrity
- Collect manure from farmers for regional approach
- Improve groundwater
- Protect public drinking water supply
- Foster communication between ag and non ag sector
- Reduce odor complaints

What is C.A.R.E.

- Products produced by farmers who care about their community and the environment
- Products include methane, carbon dioxide, electricity, bedding, compost, vermicompost, vermicompost tea, fertilizer brine and pure water.

Morrison's Cove Overview

- Located in the Appalachian Ridge & Valley
- 26miles^2 or 67km^2 watershed
- 11,000 residents
- Martinsburg water supplies 2,300 people

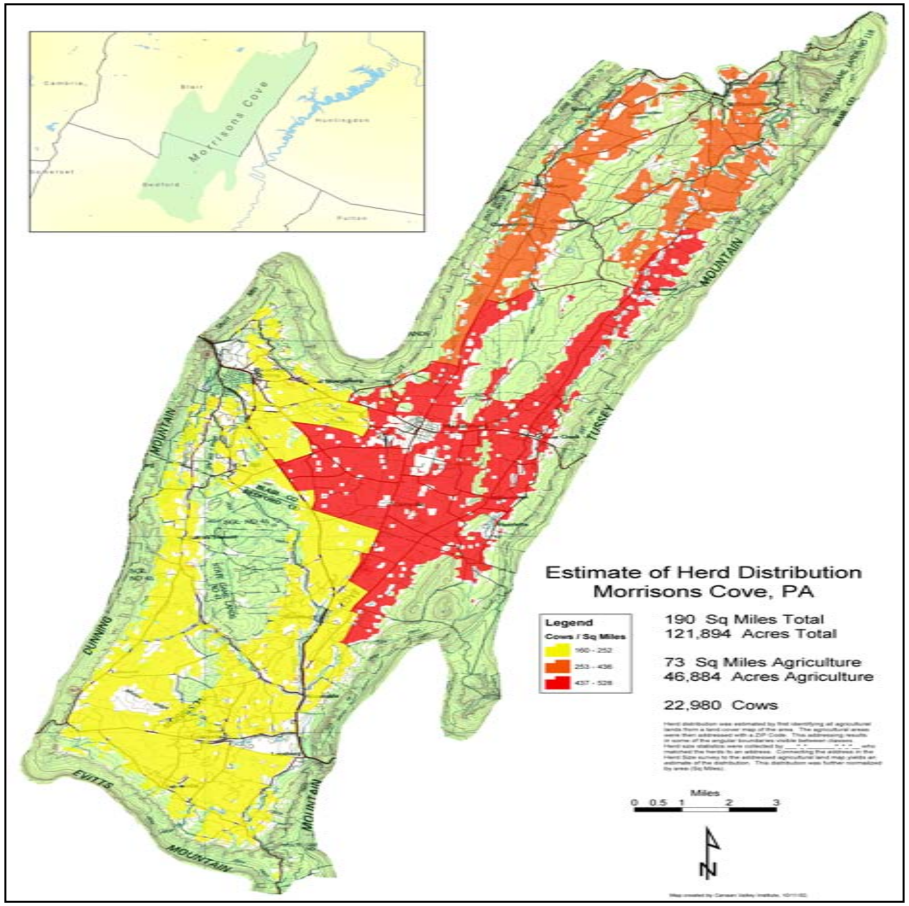


Karst Geology

Morrison’s Cove Agriculture

- 25O farms

  (250 separate management plans_
- 25,000 Cows
- 95% streams in agricultural land



A Typical Watershed Scene

Regulatory Climate

- EPA TMDL (Total Maximum Daily Loads) 2 Animal Units Per Acre
- Animal Unit= 1000 lbs (450Kg)

Let's Calculate It

- 25,000 cows at 1200 lbs/head (540Kg) equals 30 million lbs live animal weight (1.35 Million Kg)
- 30,000 animal units in 16,640 acre watershed
- Land usage leads to noncompliance

Nitrate Levels in Public Water Supply

- Current 9ppm with noncompliance at 10ppm
- Additional $1,491
- $500,000 to reduce nitrates

Groundwater Study Rationale

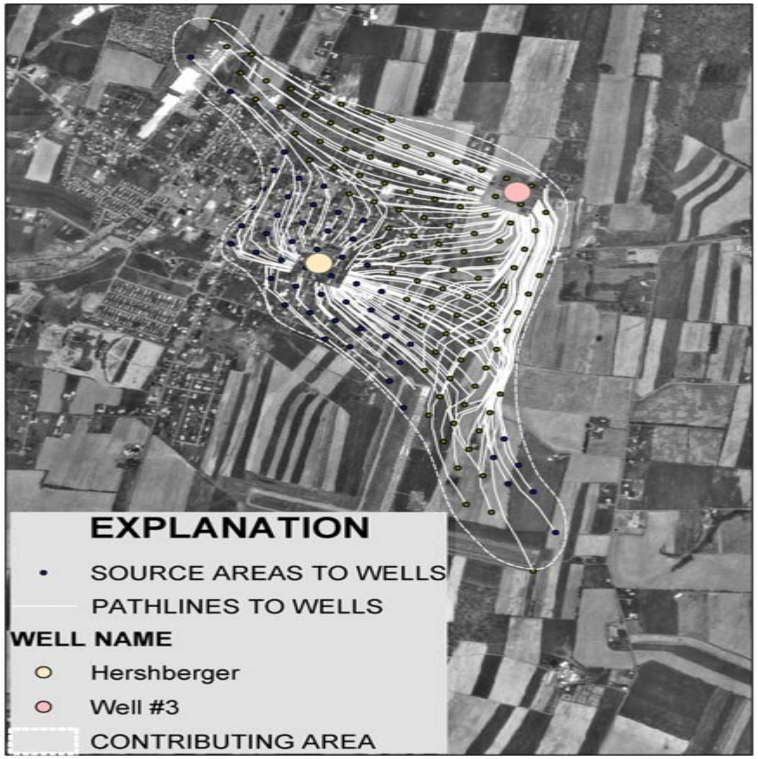
- Understand the surface and groundwater connection in a predominately karst agricultural setting.

Study Scope

- Define contributing areas to public municipal wells
- Differentiate between nitrate concentrations in groundwater
- Determine bacterial sources
- Document baseline quality for long term evaluation of Digester and Composting Effectiveness

Data Collection Process

- Water quality, aquifer levels, fecal samples
- 11 wells and 4 streams
- Simulation of ground water flow through modeling.



Monitoring Parameters

<u>Field data:</u>

flow rate

pH

specific conductance

DO

temperature

<u>Lab analysis:</u>

alkalinity

nutrients

wastewater compounds

nitrogen isotopes

fecal (antibiotic)

Groundwater Conclusions

- Limited data sets make absolute deductions difficult.
- N-isotopes sources inconclusive.
- Clustered isolates from fecal contamination are from cattle manure.
- Well field influence encompasses larger area than expected.

Groundwater Recommendations

- Collection and characterization of water chemistry and bacterial tracking must continue to confirm conclusions.
- Long term evaluation involving community members will result in proactive use of the information.

C.A.R.E's Beginning

- Southern Alleghenies RC&D formed the Ag Today & Tomorrow Committee
- Held symposiums on various technologies
- Organized farm tours
- Completed feasibility study by Black & Vetch on regional approach for digester and composting faclity
- Initiated Ground Water Study

Current Status

- Consultant securing power purchase agreement
- Negotiating land purchase
- Biomass grant
- Coordinating team meeting
- Determining business structure

Future Needs

- Hire staff
- Continue groundwater evaluation
- Submit RFP’s for:

  - digester, generator, solid separator and bedding dryer

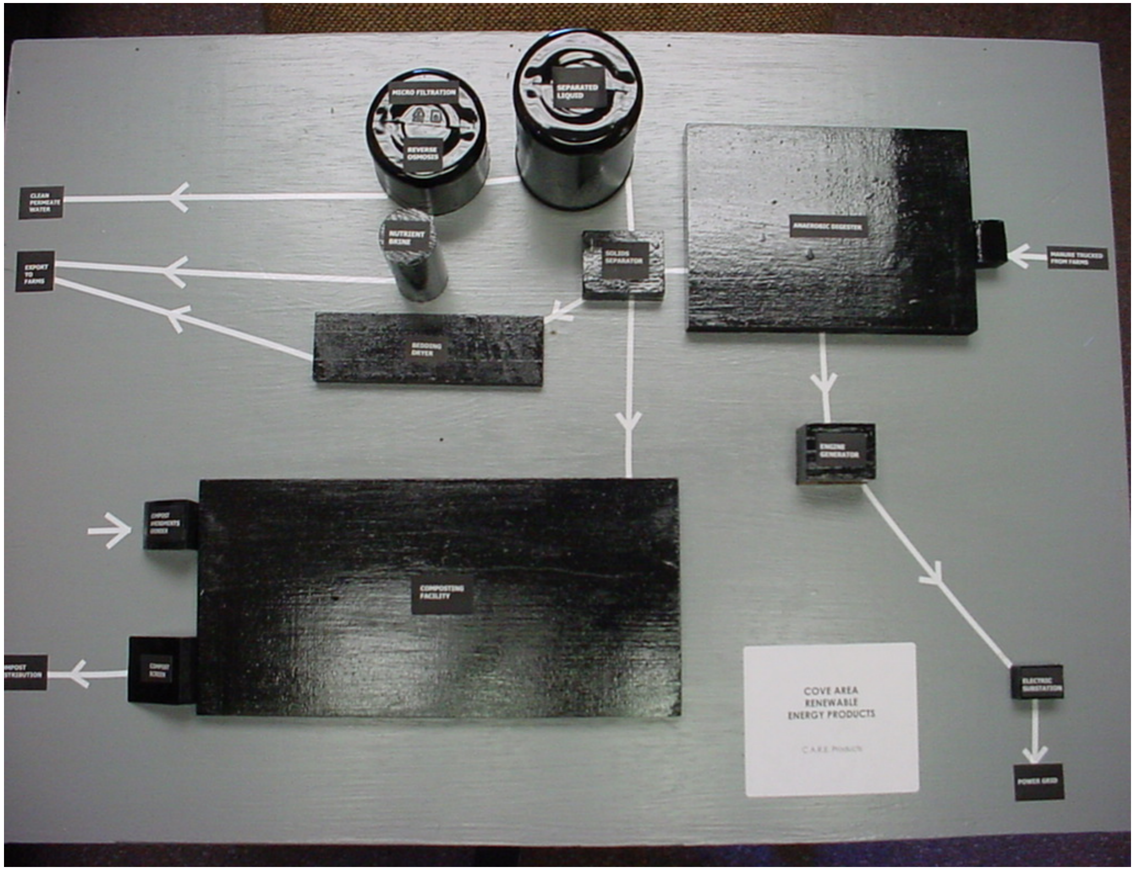
  - vermicompost & vermicompost tea

  - filtration and reverse osmosis

  - aquaculture

  - compost
- Final Design

C.A.R.E. Not To Scale Model



Technology Consideration

- Efficiency
- Practicality
- Economically feasible
- Worker friendly
- Low O&M
- Biologically secure end products
- Pure water as an end product

Technology Knowns

- Plug flow digesters only 60% efficient
- Belt filter press difficult and costly
- Aerobic wind row composting preferred over static composting
- Internal combustion generators not as efficient but practical
- Reverse osmosis produces highest purity product available in a membrane filtration process

Technology Unknowns

- Dryer efficiency must meet bio security concerns for use as bedding
- Feasibility of capturing CO_2 for industrial markets
- Filter use with reverse osmosis
- Vermicomposting integration with other C.A.R.E. products
- P sequestration

Committee Recommendations

- Technology considerations must be tied to final design
- Multiple disciplines needed to integrate the diverse array of technologies

Ag Today & Tomorrow Committee and Partners

- Southern Alleghenies RC&D
- Martinsburg Borough
- Canaan Valley Institute
- Ag Recycle, Inc
- Kulp Farms
- Pleasant View Farms
- NRCS
- Penn State
- Western PA Watershed Program
- Southern Alleghenies Conservancy
- Blair County Solid Waste & Recycling
- Trout Unlimited
- USDA Rural Development Agency
- Blair & Bedford County Conservation Districts
- Blair & Bedford County Commissioners
- North Woodbury Township
- Morrison Cove Industrial Development Authority
- PA DEP
- PA Dept of Ag
- Us Geological Survey
- And many other local supporters (businesses, schools, etc)

{As Prepared for Delivery}

Remarks by Under Secretary for Rural Development Thomas C. Dorr Anaerobic Digester Conference Raleigh, N.C. Tuesday, June 3, 2003 10:30 a.m.

- **Thank you Tom (Christensen) or Ted (Payseur) – (Conference Co-Chairs and Moderators).**

- **I appreciate the opportunity to join in today's discussion on the importance of finding ways to balance environmental stewardship with necessary production of our nation and the world's livestock supply.**

- **I also believe this conference is important because it highlights two exciting and substantial opportunities for Rural America and Rural Economic Development.**

    - **Energy Production, and**

- **Second, to reaffirm what we've known for as long as we've been exploiting natural resources for the betterment of mankind …….. that adding value is truly the business of natural resource utilization.**

- **As a result this is an exciting time in rural America. It is a time when the country and our President are turning to our farmers, ranchers, and rural businesses for <u>their</u> knowledge and resources to help America become more economically strong and energy independent.**

- **As livestock producers continue to utilize new cost-effective technologies and streamlined production modes, they also recognize the need to address critical environmental issues such as the transformation of concentrated animal waste into products that can alleviate these concerns.**

- **Anaerobic digester systems have great potential for success, both as a business venture and as an environmental equalizer.**

- **The use of our natural resource base, which has been so focused on solving the world's nutritional and environmental issues over the past 100 years, is now being positioned to assist in conquering more sophisticated environmental concerns, such as non-point pollution. In addition it is being viewed as a tool in providing energy security for the country.**

- **If adding value is at the heart of resource utilization, it is also a key element of rural economic development. Likewise – economist will always tell you that the greatest opportunity and the most effective way to grow and sustain a business is to focus on its core assets.**

- **By my estimation – focusing on adding value to sunlight and water, that is passed through a dirt medium, and that results in the production of high quality protein, in the form of meat, milk, and poultry products, should surely qualify.**

- **But unless we solve the actual and perceived environmental and nuisance issues presently surrounding livestock production, then our "core asset" in rural America is going to lose significance. Not only will it lose significance, the inability to deal with these issues will create a great economic disparity in the process.**

- **Let me give you a quick example. I'm from Iowa. Roughly, one-fourth of Iowa's GDP (Gross Domestic Product) originates from agriculture. One-half of that contribution comes from livestock production. That means that about one-eighth of Iowa's GDP is based on value-added agriculture – in this case livestock production.**

- **So can we resolve these concerns? Is there the commitment and political will to resolve these issues? This conference is evidence of our commitment.**

- **In fact I believe we are on the cusp of significant new growth opportunities for agriculture and all of rural America. And there is no greater supporter of rural America than President Bush and his administration.**

- **You may recall that the first major policy initiative of the Bush administration was released in May of 2001. It was to develop and give direction to our nation's energy policy – one that highlighted the issue of energy independence and national security. This initiative clearly brought renewable energy to the table.**

- **In my view this focus and emphasis by the Administration set the tone and course for integrating renewable energy into our national security, energy, and agriculture policies.**

Congress Followed Up

- **Then Congress followed up with the 2002 Farm Bill – which the President signed about a year ago.**

- **First, it incorporated significant environmental components which made sense and for which society has indicated a willingness to pay for.**

- **Second, Congress added for the first time an Energy Title to the Bill, Title IX. This is important because it signified a real commitment to Renewable Energy. Bear in mind that it took over 25 years to get ethanol from the development to the commercially successful stage. This legislation, along with the Bush Administration Energy Policy appears to firmly embed renewables into the energy infrastructure and lexicon of this country.**

- **Rural Development directly administers one of these Section of Title IX, Section 9006, and deals indirectly with 9008 and others.**

- **But allow me to reiterate…..the President's commitment and that of Congress sure suggests to me that the citizens of the U.S. are truly committing themselves to improving the energy sufficiency and security of this country.**

- **I would like to focus on Section 9006 of the Energy Title of the Farm Bill… The Renewable Energy Systems and Energy Efficiency Improvements Act. This program was authorized in the 2002 Farm Bill, and $23 million in grant funds were appropriated for fiscal year 2003.**

- **But the development of the NOFA (Notice of Funding Availability) and the currently developing rule for implementing Section 9006 is what is most unique… we used as the model Section 9008 of the Bill, which is known as the Bio-Mass R&D Act. Administered by Mac Gray's shop.**

- **It is unique in that it employed a cross-cutting and collaborative approach to its implementation. It not only involved DOE and USDA joint efforts, but it dictated the use of a Federal Advisory Agency in conjunction with the appointment of a private sector panel of advisors as well.**

- **This effort provided the guidance for determining how to most effectively utilize the funds for research dictated by the act.**

- **This effort also proved that collaboration and interagency efforts worked.**

<u>SECTION 9006</u>

- **Building on the success of 9008 I determined that we would aggressively pursue a collaborative approach to getting this program implemented.**

  - **We conducted joint public hearing to obtain as much input as possible.**

  - **We involved DOE, EPA, ERS, NRCS, and FSA… Bruce Knight was on of the first people that I visited with.**

  - **We urged them to consider two particular issues as they developed the rules…**

    - **Tax Incentives**
    - **Short Distributive Electric Grid Issues**

- **The results are minimum grants of $25,000 for new systems and $10,000 for efficiency improvements and maximum of $500,000 and $250,000 respectively.**

- **No more than 25 percent grant and no more than combined total of 50 percent grant and loan for project.**

- **We have been sensitive to constituent concerns and thus on May 19, 2003 we extended to June 27, 2003 the application-filing deadline.**

- **The reason for pointing this out is that we, not just Rural Development, but all of USDA recognized the importance of the need to resolve the issues surrounding the proven value-added attributes of the livestock industry.**

- **It appears that we not only have technical solutions for the real and perceived nuisances of the livestock industry, but the "nuisances" actually appear to be opportunities.**

Let me go back to the state of Iowa for a minute:

- **The state is #1 in hog production and egg production.**

- **Twenty-five years ago we were #1 in cattle and now we are 7 or 8.**

- **Yet the smell of hog manure that used to be touted as the smell of money, now is disdained. It makes adversaries out of lifelong friends, neighbors, and even family members.**

- **There is no doubt in my mind that Iowan's are much more skeptical of the "mortgage lifter" industry moniker than ever before.**

<u>WON'T CEDE THE INDUSTRY</u>

- **Yet, I am neither ready to cede the industry to international competitors nor those who don't care to understand the value and significance of this industry.**
- **We have solutions. We must deal with this issue and we must deal with it before it is too late and the industry has moved elsewhere in the world.**

- **There is energy in manure. There are valuable nutrients in manure. The evolution of technology has made it a valuable by-product of animal production.**

- **Although Dr. Collins (Keith) will articulate the economic facts… suffice to say that livestock production is a critical component to the health of our nation's economy, as well as to maintaining our competitive ability in global markets.**

- **It is clearly too important to give up when we have the tools to improve and make it more valuable.**

- **The best example of this is a customer of Mark Moser's, co-author of Agstar, near Chico, California. Leo Langerwerf and his wife and family milk 350 cows. They have been in the dairy business a long time. His parents started the farm shortly after they moved to the states from the Netherlands.**

- **The interesting thing is you can tell a working farm/farmer when you drive onto the property. It is generally well-kept, but at the same time functional.**

- **Their digester has been in operation for 20 years and only required shutdown three times -- to overhaul the generator and to empty the digester to look at it. This digester provides all the power and hot water for the dairy operation and the farmhouse – with the exception of peak power demands in July and August. Plus, nutrients that allowed him to produce outstanding forage on limited acreage.**

- **There is no doubt in my mind this technology is commercial and scalable.**

- **If we commit ourselves to this initiative, we will overcome the environmental and nuisance issues associated with waste management.**

- **And how does Rural Development fit into the development of such ventures? Through capital investments.**

- **As rural America's Venture Capitalist, Rural Development provides equity, liquidity, and technical assistance to finance and foster growth in existing and new opportunities for homeownership, business development, and critical community and technology infrastructure. The return on this equity is the economic growth realized through direct assistance and incentivizing private market forces.**

Mission

- **It is with this vision in mind that Rural Development's mission has been designed to deliver programs in a way that will support 1) increasing economic opportunity and 2) improving the quality of life of rural residents.**

- **Rural Development must, as rural America's venture capitalist, utilize the tools and resources at hand to support new economic growth in Rural America.**

- **We seek to accomplish this through the delivery of over 40 programs through three agencies:**

- **Our <u>Rural Housing Service</u> which administers single-family and multi-family housing programs, along with essential community facilities;**

- **Our <u>Rural Business-Cooperative Service</u> that provides grants, loans and loan guarantees to support economic development and job creation; and**

- **Our <u>Rural Utilities Service</u> which support basic community infrastructures such as water, wastewater, electric and telephone, along with technology infrastructure that provides our rural citizens with greater opportunity to enhance their education, to improve local services, increase the competitive edge in the marketplace, and provide an overall higher quality of life.**

Closing

- **When we look at the overall challenges facing our rural communities, foremost, <u>we must recognize that while approaches of the past were right for the time</u>, we must aggressively look to new methods of addressing new challenges that are upon us now.**

- **If we begin to succeed at these initiatives, that of increasing economic opportunities and improved quality of life, many of which are already in play, then opportunities will move into these rural areas.**

- **Thank you.**

How Can Anaerobic Digestion Technology Fit Into a Producer's Environmental Plan?

Environmental Management Solutions, LLC

EMS ™

Earl Dotson

CEO

Who is EMS, LLC ?

- For Profit, Limited Liability Company
- Owned exclusively by the National Pork Producers Council (NPPC)
- Designed to work with all livestock commodity groups

What is the Business of EMS,LLC?

- Services Offered
  - Assessments
    - Environmental—OFAER
      - In cooperation with America's Clean Water Foundation and EPA
    - Animal Welfare--Dairy
  - Audits
    - Environmental
    - Animal Welfare
    - Carbon
      - Working in cooperation with two companies
      - Protocols and Audits developed in cooperation with ARS

What is the Business of EMS, LLC?

- Services Offered
  - Planning
    - Conservation Planning,
    - Comprehensive Nutrient Management Plan (CNMP) Plan
    - Nutrient Management Planning
    - Waste Utilization Plans
  - Environmental Consulting
  - Education and Training
- All of the above are offered to:
  - Pork, Beef, Dairy, Poultry, Crops


ONE EVENT CAN CHANGE AN INDUSTRY

Why is this Program Important to the Livestock Industry?

- Times have changed:
  - Agriculture cannot ignore its environmental challenges
  - Challenges must be addressed with new, significant, programs and technologies
  - Cannot protect the environment by simply passing more regulations
  - If continues, **producers** suffer the consequences

What do we see?

What does the Public see?

Environmental Management Process for the Business

- Environmental Stewardship is an escalating target
- Concerns may be
  - Overwrought
  - Unfair
  - Disproportional to actual scientific risks
- Detractors are not going to suddenly disappear

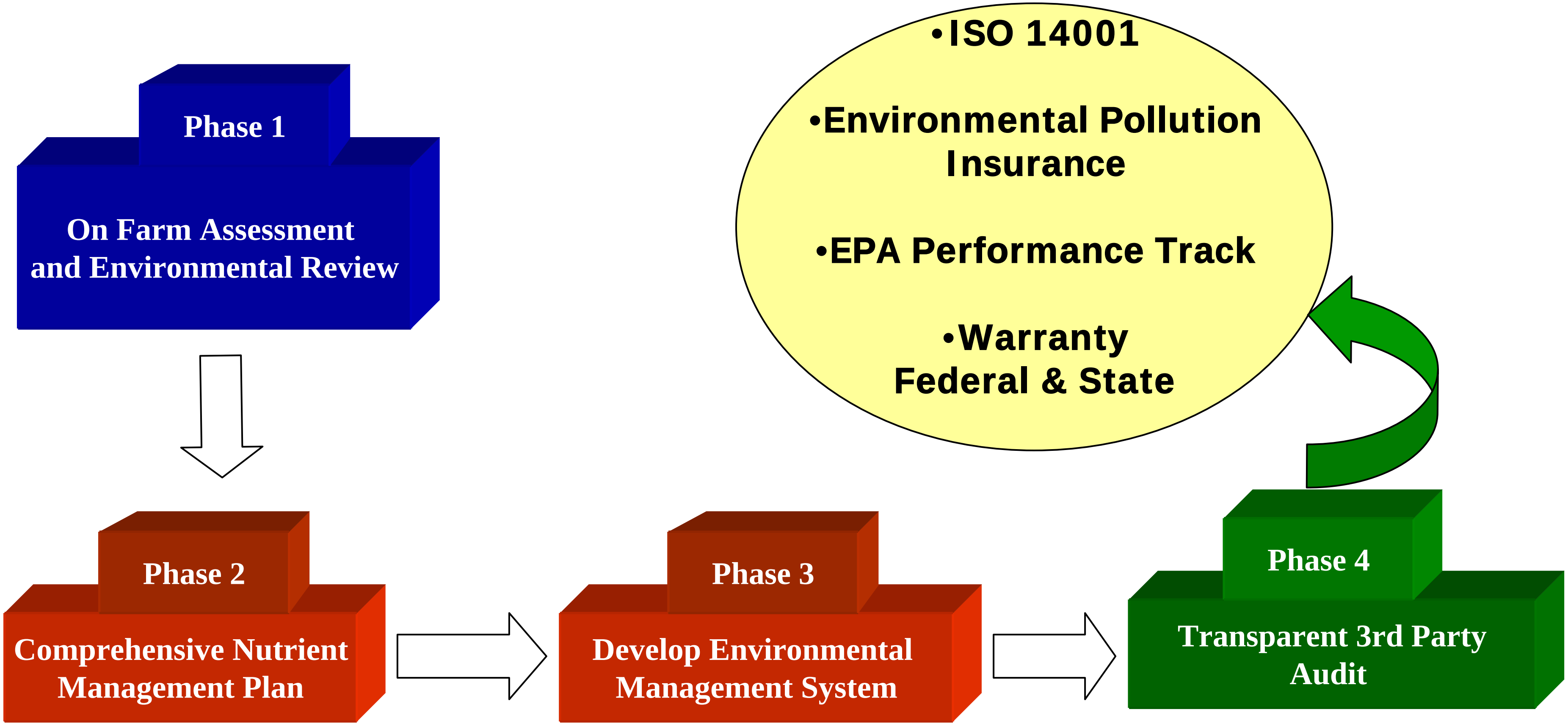
Preferred Environmental Approach

- A **science based**, **incentive driven, voluntary approach** that is **economically feasible**, is the most efficient way to attain our common environmental goals of clean water and clean air.

What is the big Picture?

How Can Anaerobic Digestion Technology Fit Into a Producer's Environmental Plan?

Producer Environmental Plan
Voluntary/Regulatory Approach to Environmental Challenges



Pollutants

- Principal Pollutants in livestock operations
  - Methane Emissions
  - Ammonia
  - Excess Nutrients
  - Biochemical Oxygen Demand (BOD)
- Major Pollution Problems
  - Surface and ground water contamination
  - Surface air pollution
    - Odors
    - Dust
    - Volatile Organics
    - Ammonia

Green House Gases (GHG)

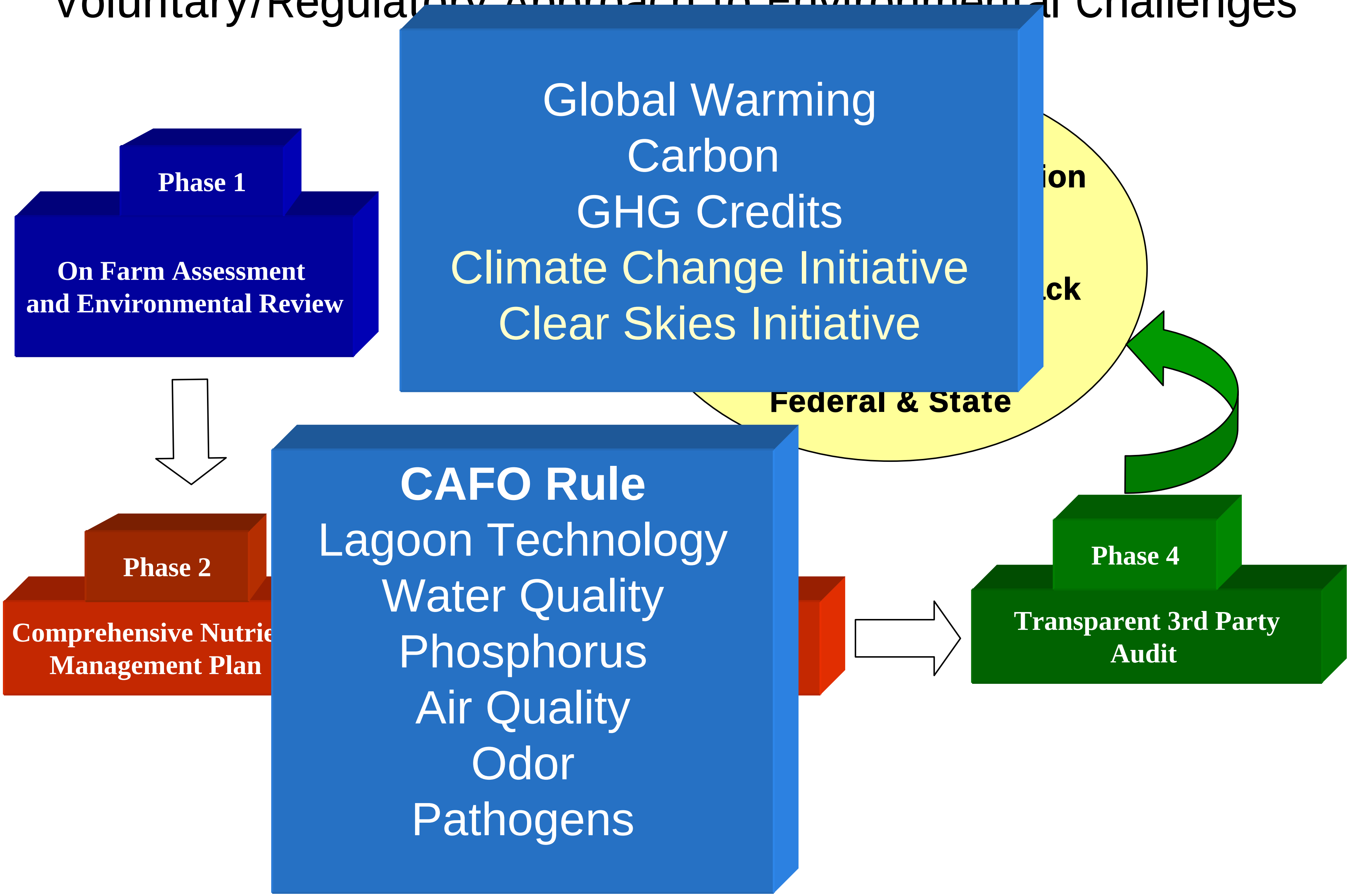
- The United States emits about one-third of the developed world's man-made greenhouse gases

- Nearly 12% of Iowa's GHG is derived from livestock*
  - 87% applicable to hogs in the state

*Ney,R.A., et al., "Final Report: Green House Gas Phase II Carbon Storage Quantification & Methodology Demonstration" Prepared for the IA Dept. of Natural Resources (June 30, 2001)

Producer Environmental Plan

Voluntary/Regulatory Approach to Environmental Challenges



Anaerobic Digestion
What does it bring to the Solution?

- Addresses
  - Water Quality Issues
  - Air Quality Issues
  - Pathogens
  - Sludge
  - Excess Nutrients

Anaerobic Digestion
What does it bring to the Solution?

- Regulatory Considerations
  - Improved Air Quality
  - Lagoons
    - Answer in new operations to Lagoon Technology
    - Retrofit in some existing operations
  - Nutrients
    - Excess Nutrients (Phosphorus)
      - Matched with Liquid/Solid Separation = Transportable Product
    - Product
    - Better suited to land application and addresses nutrient run-off

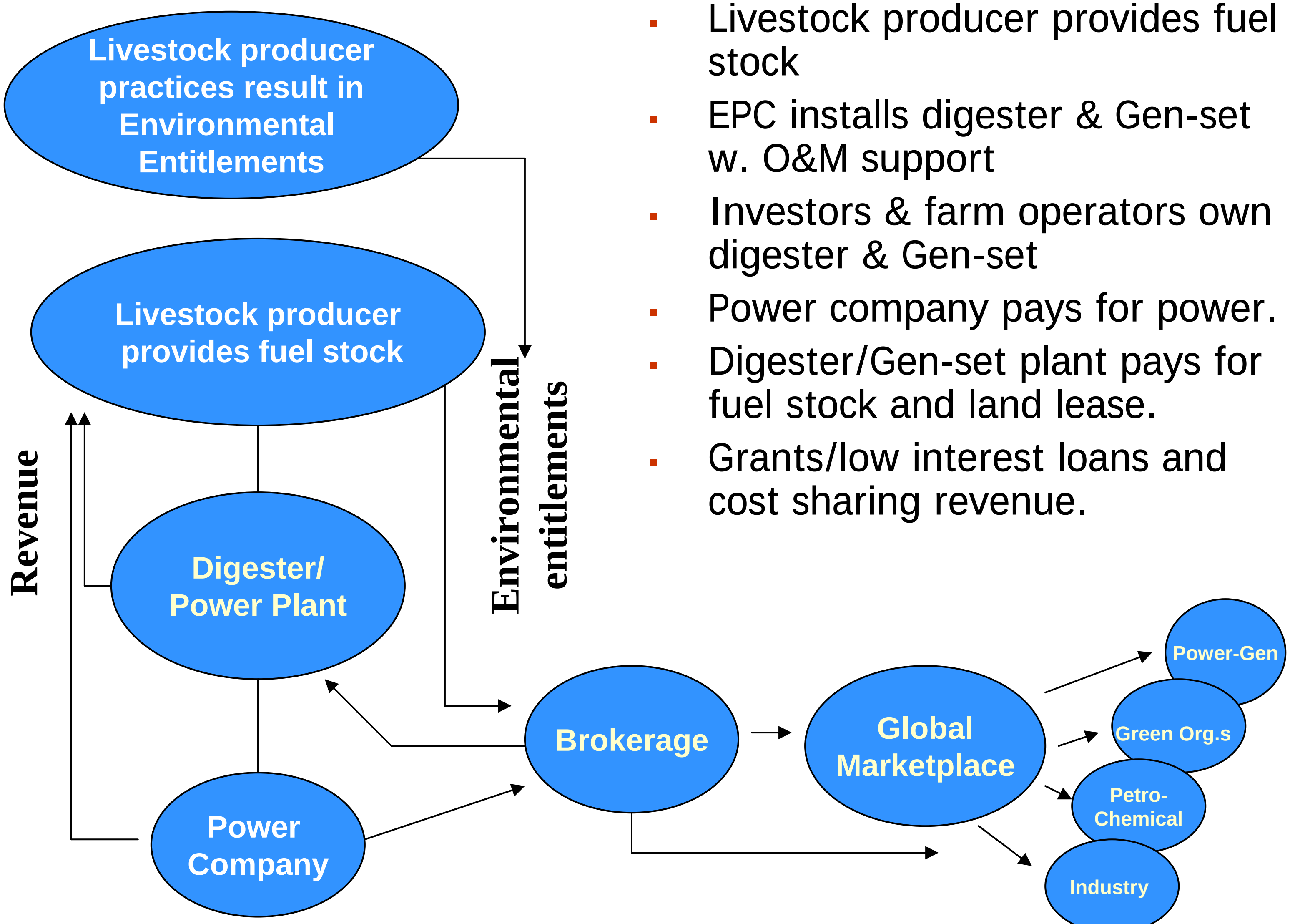
Anaerobic Digestion
What does it bring to the Solution?

- Public Perception
  - Odor Control
  - Pathogen Issue

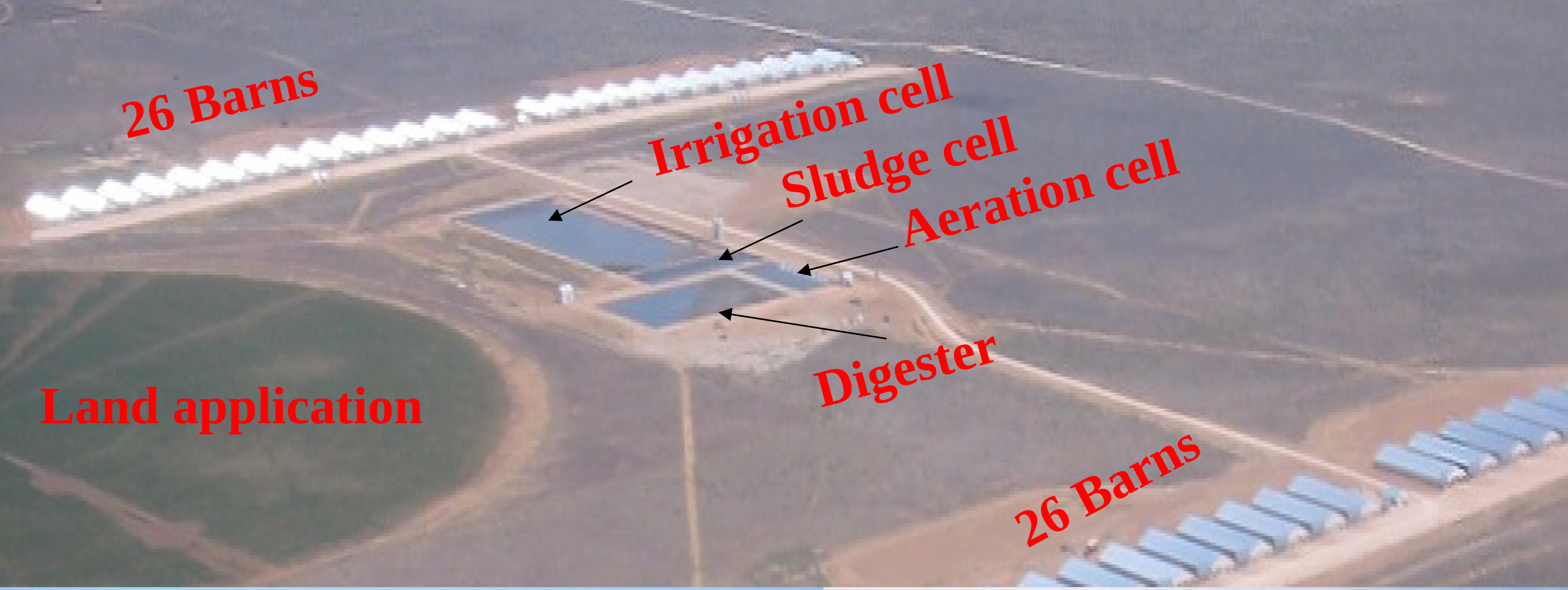
Anaerobic Digestion
What does it bring to the Solution?

- Increased Annual Revenue
  - From Environmental Entitlements
    - Carbon emission reduction credits
      - Carbon Audit
    - Credits for Reduction in GHG
      - SO2, NOX credits
    - Renewable energy credits.
    - Water Quality Credits
  - Sale of Power
- Access to added environmental insurance

Process



- Livestock producer practices receive credits
- Livestock producer provides fuel stock
- EPC installs digester & Gen-set w. O&M support
- Investors & farm operators own digester & Gen-set
- Power company pays for power.
- Digester/Gen-set plant pays for fuel stock and land lease.
- Grants/low interest loans and cost sharing revenue.



108,000 Head Finishing Site

Manure as a Viable Biomass Renewable

- Through improved waste management practices, by the introduction of streamlined digesters, livestock owner-operators may position themselves to offset:
  - Energy costs by way of combined heat and power applications
  - Costs associated with environmental compliance
  - Purchases of external nutrients and byproducts
  - Green house gas emissions while creating an added source of revenue through sale of associated environmental entitlements

Issues to development and adoption of Anaerobic Digestion

Anaerobic Digestion Issues

- Price to producers
- Lessons Learned
  - Past History of Digesters
  - Producer Education
- Management Issue
  - Producer skills and desires

Anaerobic Digestion Issues

- Systems Approach—Implementation Issues
  - Ability to Retro-fit existing producer sites and technology
  - Digesters are part of the solution not the whole solution
    - Not the Single Source answer
- Incentives to producers needed
  - Environmental Entitlements

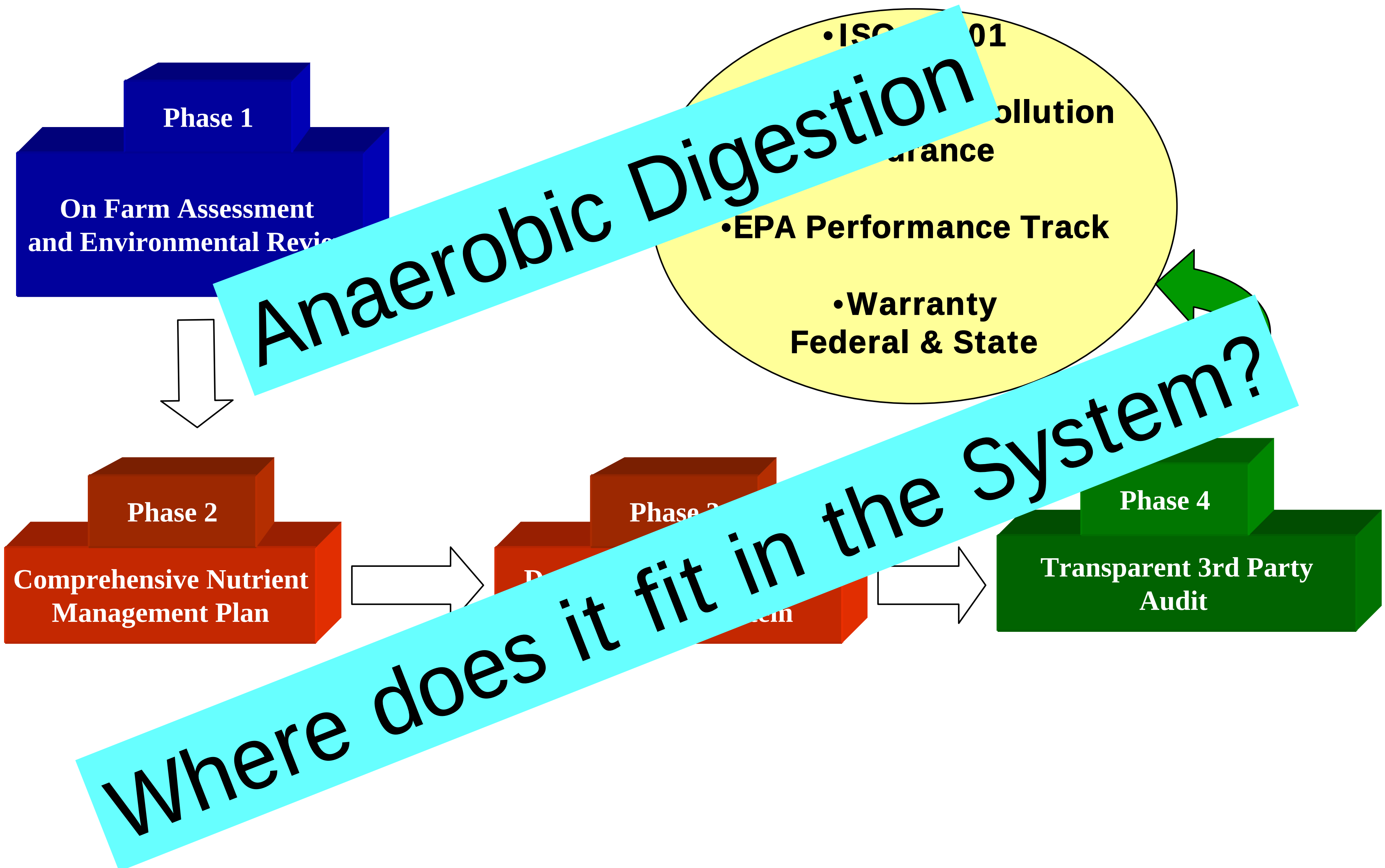
Anaerobic Digestion Issues

- Agency involvement and cooperation
  - Environmental Protection Agency (EPA)
  - United States Department of Agriculture (USDA)
  - Natural Resource Conservation Service (NRCS)
  - Department of Energy (DOE)
- Private Companies
- Livestock and Crop Associations

Summary

- Innovative technologies and approaches are needed
- Anaerobic digestion has the potential to fit seamlessly into <u>some</u> production and environmental systems
  - Economic Benefits
  - Environmental Benefits
- Producers are willing if the right approach is taken

Summary



Phase 1
On Farm Assessment
and Environmental Revi
Phase 2
Comprehensive Nutrient
Management Plan
Phase 3
Phase 4
Transparent 3rd Party
Audit
•ISO 01
ollution
urance
•EPA Performance Track
•Warranty
Federal & State
Anaerobic Digestion
Where does it fit in the System?

CONVERSION OF SWINE MANURE INTO BIO-DIESEL USING ANAEROBIC DIGESTERS

Prince Dugba, Ph.D., P.E.
Smithfield Foods Inc.
277 Faison McGowan Road
Kenansville, NC 28349

ABSTRACT

As consumer demand for high-quality food products at low cost increases along with their low tolerance for environmental pollution, the need to minimize agricultural waste is creating significant constraint on the meat production industry. Currently, the majority of animal producers in the United States flush manure into anaerobic lagoons where it is stored for treatment and irrigation. In an effort to address environmental constraints associated with animal production, Smithfield Foods signed an agreement with the State of North Carolina and agreed to provide $15 million to North Carolina State University to lead a research effort in developing new "environmentally superior" technologies for treating animal waste. In addition, on February 21, 2003, our company announced that we will spend another $20 million dollars to develop a technology that will convert swine waste into biodiesel vehicle fuel.

This paper will present the conception, design, permitting, operation and commissioning of the manure-to-biodiesel production plants. The designs have been completed along with several pilot studies and the final configuration of the system has been submitted to the Department of Environmental and Natural Resources of Utah for review and permitting for construction.

Four mesophilic digesters were designed for biogasification of swine manure from 23 finishing operations totaling 257,000 head at the Skyline complex of the Circle Four Farms in Utah -- a subsidiary of Smithfield Foods. Manure will be flushed from the farms into pumping stations, from where the wastewater will be transferred to a buffer basin with hydraulic retention time of 1.5 days. Gravity thickeners will then be used to concentrate the organic solids fed into the four mesophilic digesters. Thickening will minimize the energy required to maintain the digesters at mesophilic temperature of about 35°C (95°F). Pilot studies from three full-scale digesters at Smithfield Foods show that biogas consisting of about 65-70% methane, 29-34% carbon dioxide and about 1% of trace gasses will be produced at about 60-70% volatile solids conversion rate. The total biogas production is projected to be about 35,000 cubic meters (1.2 million cubic feet) per day.

The biogas will be fed to a biomethanol plant where it will be scrubbed of hydrogen sulfide, and steam reformed into synthesis gas consisting mainly of carbon monoxide and hydrogen. The synthesis gas will then be converted into methanol through a catalytic, thermo-chemical process similar to the Fischer-Tropsch process. About 26,000 L (7,000 gallons) of biomethanol will be produced per day. The biomethanol will be used to produce biodiesel in a process called trans-esterification using biomethanol:oil ratio of 1:6. This will net about 151,000 L (40,000 gallons) of biodiesel per day, and about 20,000 L (5,400 gallons) of glycerine per day. This paper will emphasize design and chemistry.

KEYWORDS: Swine, animal, manure, mesophilic digester, biofuel, methanol, biodiesel

INTRODUCTION

The United States Department of Agriculture (USDA) estimates the national production of animal manure is 250 million dry tons per year. Assuming an average energy value of 14,000 KJ/kg (6,000 BTU/lb) of manure, this is equivalent to about 81 billion liters (21 billion gallons) of gasoline per year. Less than 0.1% of this energy is currently being transformed into useful forms like electricity and biofuels. The current practice is to allow the manure to biodegrade either in anaerobic lagoons or in soils when applied as organic fertilizer. More than 50% of this biodegradation occurs under anaerobic conditions resulting in the production of methane as a by-product. Today, almost all of this methane is wasted and not recovered.

This paper presents the BEST (Biomass Energy Sustainable Technologies) Biofuel System (BEST), which is a full-scale commercial system that transforms manure into biodiesel. Most green energy technologies currently using manure as biomass input seek to produce electricity, which can only be transported through an electrical grid. Biodiesel is a liquid fuel made of methyl esters that can easily be transported. It's fuel characteristics like viscosity, cetane number, and phase changes are similar to regular diesel fuel derived from petroleum. Biodiesel burns significantly cleaner than petroleum-based diesel (US DOE, 2003). The conversion of swine manure to biodiesel using the BEST system is a three-step process:

A. **Biogasification (anaerobic digestion)**: Conversion of manure to biogas
B. **Gas-to-Liquid**: Conversion of biogas to methanol
C. **Transesterification**: Conversion of methanol to biodiesel

Unlike the gas-to-liquid and the transesterification steps, biogasification is a biological process that is controlled by both engineering and biochemical parameters (Dugba and Zhang, 1999). It is therefore the rate-limiting of the three steps. In other words, the overall efficiency of the BEST process is mostly determined by the efficiency of the biogasification process.

Biogasification, also known as anaerobic digestion, of swine manure starts by the extracellular hydrolysis of the long-chain carbonhydrates, proteins and lipids complexes in the manure into shorter chain hydrocarbons. The shorter chain hydrocarbons are further digested by a group of bacteria known as acidifiers into four-, three-, and two-carbon chain acidic compounds known as butyrate, propionate and acetate, respectively. Another group of bacteria known as methanogens convert these volatile organic compounds into biogas consisting mainly of methane and carbon dioxide (Dugba and Zhang, 1999). Hill and Barth (1974) found the stoichiometric chemical formula of swine manure to be $C_6H_{13}NO_5$. The carbon content is the limiting constituent for producing biofuels from manure. About 55% of swine manure is carbon by weight. Therefore, the amount of methanol (and consequently biodiesel) produced from swine manure is dependent on how much of this carbon is transformed into methane during biogasification.

Over the past five years, the environmental technology research group at Smithfield Foods Inc. (SFI) has developed a successful design for the biogasification of swine manure using mesophilic digestion. The design has been adapted and incorporated into the manure-to-biodiesel system presented in this paper. Results from the pilot studies and three full-scale digesters that have been operated by SFI for the past five years show that about 60-70% of the volatile solids content of swine manure can be converted into biogas consisting of 65-70% methane, 29-34% carbon dioxide with about 1% trace gases.

In the second step of converting manure to biodiesel using the BEST process, the biogas is first washed to remove hydrogen sulfide. The clean gas is compressed and taken through two-step thermochemical reactions: (1) steam reformation and (2) conversion of synthesis gas (syngas) to methanol. The BEST process is adapted from a process developed in 1923 by Franz Fischer and Hans Tropsch, also known as the Fischer-Tropsch (FT) process. Unlike the biogasification process, the FT process is non-biological and therefore is a predictable and mature technology. Most of the methanol on the global market today is produced using one of several varieties of the FT process. However, unlike the BEST process the raw material used by most of the commercial methanol producers is methane from natural gas. Because the chemical reactions in this process are reversible, and in order to maximize the forward reaction which favors formation of syngas, methane from natural gas is usually mixed with carbon dioxide (purchased separately) to make up the desirable reactant stoichiometry. The biogas produced in the anaerobic digestion of swine manure is already in the desired stoichiometry (~ 65/35 of CH_4/CO_2), and therefore there is no need to purchase carbon dioxide.

The third and final step in the conversion of manure to biodiesel is transesterification. This is the least complicated of the three-step process for the following reasons: (a) it is not a biological reaction, (b) the reactions take place at relatively low temperature and pressure (<100°C, and at about atmospheric pressure), (c) the technology is mature and can be configured through recycling to achieve 99.99% efficiency. Because of this high efficiency, production of biodiesel is limited mainly by the consumer market.

Transesterification is the reaction of a trigleciride (Fat/oil) with methanol using sodium hydroxide (NaOH) or potassium hydroxyl (KOH) as a catalyst to produce methyl ester (biodiesel). Oils or fat used in the United States in the production of biodiesel today include soybean, waste cooking oil, tallow, and animal fat. Rape seed oil is commonly used in Europe, while the oil of choice in the tropics is palm oil. The oil:methanol ration is about 6:1. Darnoko and Chryan (2000) produced biodiesel from palm oil at 68°C and at atmospheric pressure using KOH as catalyst.

The rest of this paper will present the design features and chemistry of the BEST system used to convert swine manure to biodiesel. The system combines results of five years of research at Smithfield Foods Inc. and other technology partners into a full-scale commercial system that will convert about 40,000 tons of swine manure (257,000-head finishers) into approximately 58 million Liters (15 million gallons) of biodiesel per year.

OBJECTIVES

1. Further improve the environmental quality of animal farms at Smithfield Foods Inc.
2. Develop, design, build and operate a commercially viable biogasification plant.
3. Develop, design, build and operate a commercially viable biogas-to-methanol plant.
4. Develop, design, build and operate a commercially viable biodiesel plant.

DESIGN OVERVIEW OF THE BEST BIOFUEL SYSTEM

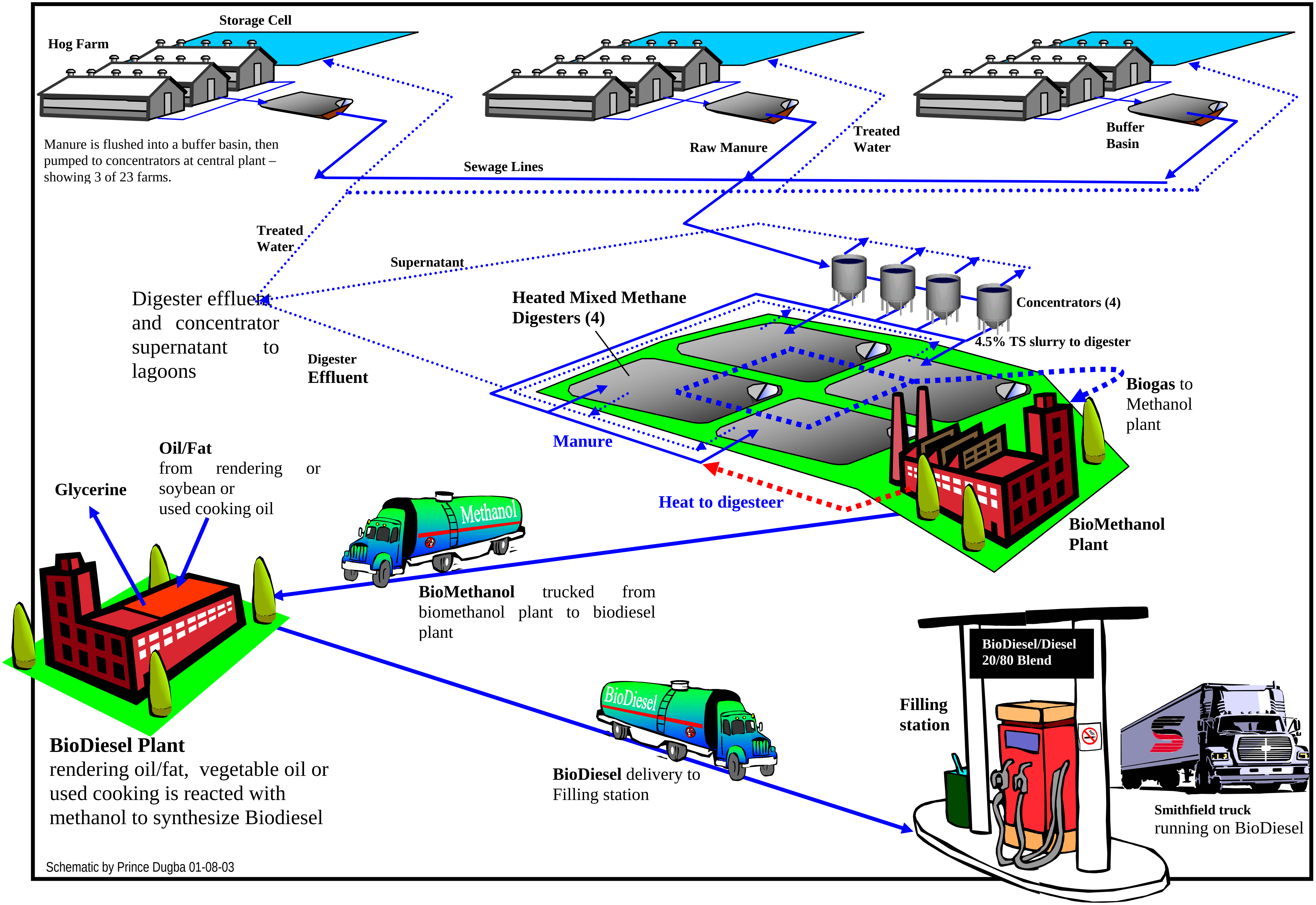
Figure 1 shows the design configuration of he BEST biofuel system. Swine manure from 23 different finishing farms located within 8-Km (5-mile) radius will be flushed and pumped to buffer basins that will equalize wastewater flow to the biogasification system. Figure 1 shows 3 of the 23 finishing farms. The flushed manure is very dilute with TS concentration of 1.5-2.0%, depending on the growth stage of the animal. In order to minimize the energy used to heat and maintain the mesophilic digesters at 35°C (95°F), the dilute wastewater is thickened using conventional thickeners.

Pilot studies at Smithfield Foods show 70-80% of the TS in the flushed manure wastewater can be concentrated in 30% of the daily flow volume using conventional thickeners. Therefore, only 30% of the daily wastewater flushed from the barns will be fed to four mesophilic digesters as shown in Figure 1. All four mesophilic digesters are constructed in-ground and completely enclosed in multiple liners including high density poly ethylene (HDPE) geo-membrane.

Biogas produced from the anaerobic digestion process is collected and fed to the Biomethanol plant. Key design components of the biomethanol plant include (1) a gas scrubbing tower ; (2) pressure vessels packed with proprietary catalysts that serve as thermo-chemical reactors where the steam reformation and biomethanol formation takes place. The chemistry of these reactions are explained below; (3) distillation towers to purify and separate the biomethanol from other products and reactants; and (4) cooling towers to dissipate excess heat.

The biodiesel plant is a lot less sophisticated compared to the Biogasification and Biomethanol plants. Key design components of the biodiesel plant include (1) steel tanks that will serve as batch/continuous reactors where transesterification (chemistry explained below) will take place; (2) distillation towers to separate and purify the biodiesel and glycerine products. The biodiesel produced will meet the ASTM fuel standards and will therefore be transported to a commercial filling station to be sold as a B20 blend. Other design components of the BEST biofuel system are shown in Figure 1.

Figure 1 BEST Biofuel System Design configuration



CHEMISTRY OF MANURE TO BIODIESEL CONVERSION

Conversion of manure to biodiesel is accomplished through a series of chemical reactions that can be divided into three distinct processes: Biogasification, biogas-to-biomethanol, and transesterification. The chemistry of these three processes is as follows:

Biogasification Process -- adapted from Hill and Barth (1974):

The key components of the biogas ($CH_4 + CO_2$ +..) produced during biogasification are underlined in the equations below. The chemical formulae of manure and bacteria used in the equations are $C_6H_{13}NO_5$ and $C_5H_7NO_2$, respectively. Biogasification is a bio-chemical process in which complex carbon (organic) compounds (polysaccharides, proteins, lipids/fat, …) in the manure are broken down by six different bacteria to biogas with C_6-, C_4-, C_3-, C_2-intermediary compounds. Equations 1-7 list the bio-chemical reactions of the process. Note the mass transformation from the complex carbon compounds to the single carbon compounds of methane and carbon dioxide in biogas.

Hydrolysis of manure:

$$C_6H_{13}NO_5 \text{ (manure)} + H_2O + H^+ \rightarrow C_6H_{12}O_6 + NH_4^+ \qquad [1]$$

Acetogenesis:

$$C_6H_{12}O_6 + 0.1115NH_4^+ \rightarrow 0.1115\,C_5H_7NO_2 + 0.744\,CH_3COOH + 0.5\,CH_3CH_2COOH + 0.5CH_3CH_2CH_2COOH + \underline{0.454CO_2} + 0.446H^+ \qquad [2]$$

Propionate Hydrogenesis:

$$CH_3CH_2COOH + 1.786H_2O + 0.0458NH_4^+ \rightarrow 0.0458\,C_5H_7NO_2 + 0.924CH_3COOH + 2.778H_2 + 0.1832H^+ + \underline{0.0924CO_2} \qquad [3]$$

Butyrate Hydrogenesis:

$$CH_3CH_2CH_2COOH + 1.84H_2O + 0.0545NH_4^+ \rightarrow 0.0545\,C_5H_7NO_2 + 1.86CH_3COOH + 1.92H_2 + 0.2180H^+ \qquad [4]$$

Homoacetogenesis:

$$2.073H_2 + CO_2 + 0.0487NH_4^+ \rightarrow 0.0487\,C_5H_7NO_2 + 0.378CH_3COOH + 1.146H_2O + 0.1948H^+ \qquad [5]$$

Hydrogen Methanogenesis:

$$3.813H_2 + CO_2 + 0.022NH_4^+ \rightarrow 0.022\,C_5H_7NO_2 + \underline{0.89CH_4} + \underline{1.956H_2O} + 0.0882H^+ \qquad [6]$$

Acetate Methanogenesis:

$$CH_3COOH + 0.022NH_4^+ \rightarrow 0.022\,C_5H_7NO_2 + \underline{0.945CH_4} + \underline{0.945CO_2} + 0.06H_2O + 0.0882H^+ \qquad [7]$$

Biogas to Biomethanol:

Equations 8 and 9 are the key chemical reactions that takes place in the steam/methane reforming process.

$CH_4 + H_2O \leftrightarrow CO + 3H_2$ ……………………………………………………………….[8]

$CO + H_2O \leftrightarrow CO_2 + H_2$ ……………………………………………………………….[9]

Reaction 8 is endothermic, which means the desirable forward reaction is favored at high temperature and low pressure (~1600°F, ~200 psig). The water gas shift reaction (9) is exothermic. Carbon dioxide shifts the equilibrium towards formation of the desired end product -- synthesis gas (mixture of carbon monoxide and hydrogen), which is also known as syngas. Note that commercial facilities producing methanol from natural gas need to buy carbon dioxide to be used as a reactant to force the equilibrium towards formation of syngas. This purchase is not necessary if biogas is used because the gas already contains carbon dioxide and methane in the desired stoichiometry. Equation 10 shows the formation of methanol (known as biomethanol in this paper because it is produced from an organic feedstock – manure in this case).

$CO + 2H_2 \leftrightarrow CH_3OH$ ………………………………………………………………….[10]

Transesterification

$$\underset{\text{Triglyceride (oil)}}{\begin{array}{c} H_2C\text{-}OR1 \\ | \\ H_2C\text{-}OR2 \\ | \\ H_2C\text{-}OR3 \end{array}} + \underset{\text{Bio-Methanol}}{H_3C\text{-}OH} \xrightarrow[\text{(Catalyst)}]{\text{NaOH}} \underset{\text{methyl ester (Biodiesel)}}{H_3CO_2R1 + H_3CO_2R1 + H_3CO_2R1} + \underset{\text{Glycerine}}{\begin{array}{c} H_2C\text{-}OH \\ | \\ H_2C\text{-}OH \\ | \\ H_2C\text{-}OH \end{array}}$$

…………………….[11]

Equation 11 shows the transesterification reaction. In this example, sodium hydroxide is used as a catalyst. The reaction occurs below 100°C (220°F) and about atmospheric pressure. As shown, the end products are glycerine and methyl esters (biodiesel), which are separated through distillation. R1, R2, and R3 represent alkyl radicals of different oils and fats that make them distinct.

DESIGN PARAMETERS AND DISCUSSIONS

The raw material biomass input into the BEST system will be swine manure from 257,000 finishing hogs producing about 40 tons TS per year. The daily flow rate of the system is 6,500 M^3/d (1.7 MGD). Based on oxygen demand, this flow rate is equivalent to a municipal wastewater plant with a daily flow rate of about 38,000 M^3/d (10 MGD). This is the largest biogasification plant installed on a farm in the United States.

CONCLUSIONS

- The BEST biofuel plant is under construction near Milford in Utah. The results of this project are going to be monitored to determine the economic feasibility and applicability to other applications.

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Abstract

A power point presentation discussing our integrated approach to dairy waste handling both from our dairy farm and other agricultural waste streams including poultry and horse manure wastes. Foster Brothers Farm has been anaerobically digesting its dairy wastes since 1982 and producing electrical energy initially for sale to the grid and subsequently to power the farmstead. In 1992, Vermont Natural Ag Products was incorporated as a subsidiary to Foster Brothers Farm to add further value to the separated solids obtained post digestion. The solids are composted with other agricultural wastes to form a number of soil and soil amendments marketed to wholesale and retail trade in the Northeast under the trademarked labels of MOO DOO® and Nutripeat®. VNAP's feedstock's include dairy and poultry wastes from farms as part of their nutrient management plans. VNAP's mission includes moving excess nutrients from local farms in order to sustain a viable working landscape.

An Integrated Anaerobic Digester, Power Generation, Composting System in Operation for Twenty-One Years

Presented by Robert Foster
Foster Brother Farm and Vermont Natural Ag Products
Middlebury, Vermont

The purpose of this paper is to discuss the use of anaerobic digestion, power generation, and composting on our farm. First, it is appropriate to review a little of the history of the farm. My generation came back to the farm in the early 70's. My brother, Jim, was the first back followed by myself, my cousin,Ted, and several years later, a mutual cousin, George Jr. The farm was owned and managed by my dad and two uncles who had acquired a portion of the farm from my great grandfather. By the time we returned, we were milking in two locations, both in parlors. Over the next several years, we adopted a TMR program, consolidated the dairy into one location with 400 stalls, expanded the herd, and upgraded the parlor, the milk room, as well as, the milking system. We were in a bit of a quandary as to what we might do to deal with our waste stream. As a temporary solution, we put in minimum manure storage and proceeded to look for options.

About this time, the energy crunch of the 70's arrived. Fuel became a precious commodity. We had crops to get in and fuel was very, very short that May and June. One of the first things that we did was to put in two 10,000-gallon tanks for fuel oil and kerosene so that we could blend our own diesel and have a reserve supply.

At the same time, several of our neighbors put in large manure storage structures. However, as most of you are aware that the odors from stored manure seem to increase exponentially with time. We live close to a small college community and have well over forty close neighbors. Odor reduction and/or management were very important to us, as was the need to reduce our dependence on others for energy.

Given these parameters, and the fact that year round spreading did not conserve valuable nutrients, we became intrigued by the system that Richard Waybright had developed at Mason/Dixon Farms. At the time, he was flushing his dairy barn wastes, settling them out and pumping the sludge into an anaerobic digester. The biogas was captured and burnt in an internal combustion engine, which powered a generator, which provided electrical power for his dairy.

We teamed up with a pair of early digester applicators, Bill Hadley and Spencer Bennett of Henniker, NH, to develop our system. The initial concept was finalized to include the following points.

1. Collect our wastes from several points.
2. Transport them to the central facility.
3. Build a central facility that covered the gas collection bag and allowed for the year round loading (both frozen and liquid).
4. Build a mechanical building adjacent to the digester building that housed the generator, heat recovery and separation systems.
5. Digest the manure and milk house waste.
6. Burn the methane gas in a gas-only internal combustion engine to produce electrical power to sell to our local utility acting as a small peaking plant.
7. Separate the solids out of the digested effluent.
8. Reuse the solids as bedding.
9. Transfer the liquids though an underground pipe to an open storage lagoon, which was more centrally located to our farmland where the nutrients could be applied with a conventional water irrigation system to a growing crop.
10. Construct the storage lagoon and lay underground pipe from it to the mechanical building.

Our dairy was not designed to flush. And due to fact that we had open freestall barns, we felt that it was better to transport the manure liquid or frozen to the central site. Also the tight layout of the dairy determined that it was best to locate the digester near the feed center, which allowed the person feeding to handle the manure as well. The utility agreed to pay us $.09 per kilowatt-hour for power, which was more than we were buying it for at the time. In order to sell to the utility, we had to obtain through a hearing process a “certificate of public good” enabling us to become an electrical power generator regulated by the State. This process was quite a bit more complicated than we had anticipated. This was partially due to timing. We became a small power producer under the federal rules of PURPA unfortunately before rules were implemented by the State.

As time moved on, the State determined that our rate of $.09 would decline at 10% a year rather than increase at 10%, as we had been lead to believe. As a consequence, in 1990, we bought and installed a second-generation unit sized for our dairy. It was designed to run 24 hours per day, 7 days a week. An automated transfer switch was installed as well, to allow us to transfer back to the utility if our new unit failed. At the same time we essentially disconnected from the utility as a producer for the grid. At that point, we were receiving less than $.04 per kilowatt-hour for generated power and paying the utility as much as $.26 per kilowatt-hour during peak time use. We installed a very simple gas scrubber using sized marble chips as well as an exhaust heat reclaimer to capture more of the heat generated by the engine.

In March of 1998, we experienced a fire, which leveled the receiving room building and destroyed the south exposure of the roof, as well as, four trusses over the digester. Falling debris also destroyed the bag, which covered the pit and captured the gas. The cause of the fire was human failure to screw back together the pipe to chimney from a wood stove, after the smoke pipe had been cleaned. The wood stove was used to heat the reception area during the winter. Even though the wind was out of the north at about 20 knots and blowing directly toward the mechanical building, the mechanical building escaped the fire. Interestedly, the fire acted as we had anticipated in designing the complex. The fire stayed up in the roof over the bag and did not cause an explosion.

Due to a challenging crop year and short staff, we were not able to complete the rebuild of the digester and receiving building until the winter of 1998. In early 1999, the US Department of Energy awarded the Vermont Department of Public Service in conjunction with the Department of Agriculture a $300,000 appropriation from the FY 2000 federal budget to be used to promote the use of methane recovery technology on Vermont dairy farms. An advisory group was formed to determine the best use of these funds. One of the projects chosen was to modify our digester to use it as a research and demonstration vehicle. This involved redesigning and fabrication of two separate covers; setting up monitoring ports and devices; removing the heat pipes from the north digester; pouring a radiant heat floor in the north digester; developing parallel gas collection systems; and separating and modifying the existing heating system. This created two side-by-side digesters, one using past technology and the other (the north) available to modify for research purposes and comparison. Another project that was funded was to test the feasibility of using live steam injected into the receiving pit to bring the digester up to temperature. This involved modifying the heating system, adding two steam boilers (one methane, one oil fired), and installing a split hot water storage system.

The digester was restarted in September of 2000. Gas production was observed in less than 14 days using the live steam rather than the typical 60 to 90 days observed before. Since that time we have had problems with the bag seals which was initially corrected as of January 24, 2001 but reoccurred this past winter. Exit temperatures from both digesters have been the low 80 degrees F to mid 90 degrees F depending on the heat source.

I would like to share with you some of our experiences of the last 19 years since we first “went on line” if you will. The collection of dairy wastes from several points worked well. It allowed for expansion of the dairy as well as provided an ability to receive wastes from others such a manure, cheese starter, whey, ice cream sludge, and brewery sludge. One needs to be mindful of the characteristics such as % volatile solids, % water, acidity, etc of the waste material being used as a feedstock. Whey for instance is high in volatile solids and an excellent food source for the methane bacteria. We found that within five to six hours of introduction, there was a burst of CO2 released followed by high quality methane production. There was enough CO2 that the engine quit running. Thus, we learned the hard way to meter these materials into the digester slowly over time. This led to the installation of storage tanks to allow for a metered in flow of input material. We also found that with the input of milk house waste and manure from different groups (dry, heifer, and production), a paddle mixer need to be added to the reception pit.

The transport system worked well with the flexibility to use several devices. We currently use a side slinger spreader. This allows us the flexibility to go directly to the field if so desired. The original reception building was design to receive frozen manure. We quickly found that once frozen, manure takes forever to revert back to a liquid. Slush (semi-frozen manure) works okay but frozen material is better stacked in the field.

The separate central digester complex next to the feed area worked well in conjunction with the feeding operation by allowing the outside person to use a routine that flowed from one operation to the next. In retrospect, its location removed the potential fire threat from the dairy, heifer, and feed storage structures. We chose to build an in ground, flexible covered, plug flow digester and built a wood framed structure over it. In order to keep the structure costs down, we built two smaller digesters with a common center wall. The center wood wall acted simply as a divider. This worked but we found that to clean the digester, we had to lower the level of both sides at the same time. If the relative liquid levels were different from one side to the other, the wall fell over. In 1995 we replaced the wall with a reinforced concrete wall essentially making two independent digesters.

With respect to construction materials, we found that steel siding and roofing, even if coated, did not mix well with digester gas. We had holes through the siding within five years. The galvanized steel gusset plates on the trusses rusted away and were replaced by plywood gussets fastened with stainless steel nails. Wood, asphalt, and aluminum seem to be preferable materials. Aluminum is less combustible of course. The steel piping works fine as long as it is submerged. I would recommend schedule 80 rather than 40 steel pipe, as we have noticed that failure occurs in the treaded joints in schedule 40. PVC schedule 40 pipe works well for gas transfer. Copper piping is very susceptible to corrosion in even the smallest amount of biogas.

The separate mechanical building was desirable from the fire prevention perspective but should have been a little further removed (sixty feet rather than twenty five feet) from the digester building. Separation of the buildings also reduces the exposure of equipment to the biogas. Even so, we found that it was desirable to pressurize with outside air the room containing the electrical gear to prevent corrosion of the copper wiring. We also are planning to move the digested effluent separation process and storage to an open shed adjacent to, rather than inside, the mechanical building to reduce the amount of moisture given off as the separated material heats.

Solid separation process proved to be much more difficult than anticipated. The originally installed Ag-Pro inclined screen simply reconstituted the manure and required a very large volume of water to work at all. Several other commercial separators were demonstrated, including slinger and screw press styles. After several years of experimentation, we designed and built our own vertical screw press. It worked reasonably well, however, if it ran dry, the screen experienced severe wear. Eight years ago, we purchased a FAN separator with automatic shut down controls. Since that time, we have made numerous modifications to the unit including redesigning the drive unit. We have found it difficult to impossible to pump digested effluent due to the number of gas bubbles in the slurry, which apparently caused pump to cavitate. Positive displacement pumps, such as a diaphragm pump, seemed to work the best. They also pass extraneous material better.

We have found that the digester collects all sorts of things from neck chains to tools, rocks, sand and minerals. This material can be quite time consuming to remove particularly where there are grids of heat transfer pipes involved. The best solution would be to have removable heat pipes, or better yet, not have them in the pits at all. We hope to address this issue with the work that is now going on at our site. Depending on a number of factors, we feel that a digester and reception pit clean out may be necessary between three and five years. Based on our experience, one should consider some design mechanism that allows for the easy removal of at least the coarser material. One of the projects contemplated for the future investigation is one that addresses this problem.

Contrary to the assumption made in the initial design, milk house wastes consisting of tank and milking equipment wash solutions and treated milk actual increased gas production when added to the input manure. We use the milk house wastes as makeup liquid to produce more uniform slurry. Using the wastewater also captures a waste stream that contains nutrients that would otherwise have to be managed by some other means. We wonder if the milk house wastes might also serve as inoculants as well. We have added provisions for water in both structures subsequent to the initial construction. This drilled well also services the heifer raising facility.

The movement of separated liquids actually worked better than anticipated. The liquids flow by gravity some 3400 feet under a brook to an open storage pond with more than an acre of surface area. The surface of the pond is about twenty-five feet below the holding tank in the mechanical building. We found that a small pump would start a siphon action that moves the material to the pond. We also observed that while the pipe was not laid to grade, liquids flow quite well, as long as it is used on a regular basis. In hind site, we would have installed some manholes to aid in periodic cleaning. We do get a mineral deposit called struvite (I believe) on the interior of the pipe that forms a hard coating. We have experience four blockages from primarily sand in the twenty years of use.

The water irrigation equipment worked well for the separated liquids. We did add a traveling gun and reel to the system to reduce the labor costs. Applying the nutrients to a growing grass or corn crop worked very well and reduced the need for commercial fertilizer. The water component ensured that the nutrients made it into the soil. During several dry years, the moisture was of significant value as well. The nutrients worked well on legume crops for the first year but I think that the rhizomes get lazy and the crop had difficulty wintering over. During several of the dry summers three and four years ago, irrigating the corn crop at tasseling resulted in a healthy crop with several full ears per stalk. This was noticeably different for the corn that wasn't irrigated. The large gun probably volatize some of the nitrogen. Therefore, a drop tube system might work better. The separated digested effluent does have a slightly sweet aroma but nothing like the odor from stored manure. It certainly is not pungent.

As pointed out earlier, we selected a gas-only engine initially. We found that the timing had to be advanced significantly in order to get maximum performance due to the low BTU content of the biogas. Biogas runs between 500 and 550 BTU's per cubic foot. The high concentration of water vapor in the biogas turned out to be a benefit as it naturally scrubbed out stack emissions. The NOX emissions were practically zero when tested years ago. The biggest draw back to a gas-only engine is that it will not run without gas. This means with no gas available that there is no production of power or heat to keep the digester at temperature or heat it during startup. We installed an alternate method of heating the digester, in the form of a small hot water heater. We chose not to scrub the gas initially because of the high capital cost. We changed the oil ever 300 hours using a high TBN oil to remove the sulfur. Subsequently, with the help of a local landfill biogas operator, we developed a scrubber using a used 55 gallon teat dip barrel filled two thirds to the top with sized marble chips from the quarry next door. This has worked very well and was cost effective. Appropriate sizing, composition, and volume of chips needed to scrub a given volume of gas needs further study.

When we moved to the smaller generator unit, we installed an off-the-shelf diesel unit that could be replaced easily. We modified the air intake to meter the biogas into the air stream ahead of the turbo-charger. Sophisticated electronic controls tied the governor to the biogas-metering device. The unit was designed to start on diesel, transfer and pickup load on diesel, and then use up to 85% biogas, if available. Diesel was still needed for engine lubrication. The electronics and metering design has not worked well. Currently, we feed biogas to the engine as available and match load with the original diesel governor. In retrospect, I believe that the electronic coupling was overkill and could have been accomplished by using the turbo boost from the turbo-charger to meter the gas into the engine.

We installed an exhaust heat reclaimer as well. Exhaust temperatures presently run in the 120-degree F range. We still change the oil every 300 to 400 hours. We have worked on the topside of the engine twice but have not worked on the bottom or done a major overhaul until the third week in April of 2002. The engine had some 76,000 hours of operation on it. Three yeas ago, we increased the size of the generator as it had become under-sized for our load and coupled it to the same engine. The smaller unit is not currently wired to connect to the utility and just powers our farmstead. Vermont passed a law allowing net metering, which was recently modified to raise the cap to 150 KW nameplate capacity for the generator. The Vermont legislature enacted a bill to allow group net metering. This bill provided for the usage aggregation of several metering sites within a single farm business which could be offset by power generated onto the grid on a one-for-one kilowatt basis.

We originally planned to use the separated solids for bedding and did so up until seven years ago. The solids worked well as bedding except for warm, humid weather when they became a good growth medium for bacteria. We found that using the separated solids, as a feedstock for composting, was a better use.

In 1992, we incorporated a second family business called Vermont Natural Ag Products (VNAP). VNAP's mission is, one, to market high quality soils and soil amendments to wholesale "mom and pop" retailers, grower, and nurseries; and, two, to provide a system to add value to excess dairy, poultry, and horse manures by removing them from the agricultural sector moving them to the urban sector in the form of compost. Coupled with this is the desire to help sustain a viable working landscape for the community at large.

The feedstock's to our composting business include manure from an egg laying operation, riding stable wastes, sawdust and lumber yard wastes, other dairy farm separated manure, as well as our own digested material. Basically, we work with organic wastes.

We currently compost some 45,000 yards of finished material on a seven-acre site. The site has been improved to funnel surface water and leachate to a collection pond for recycling back into the compost or back on our crops.

VNAP used two primary methods of composting. The first was bucket turned piles using a front-end loader up until January of 2002 when we acquired a SCAT turner. The second was to use static piles, which were turned once in the composting process. The static piles worked well on the more porous mixes.

VNAP's equipment consist a JCB Telehandler, CAT 924G with roll forward bucket, ERIN Star Screenall 200, Western Star tri-axle delivery truck with a 26 foot walking floor body, SCAT 483 Turner, a fluid bed dryer, and a manual bagging line. Two thirds of our product is shipped by outside trucking.

We market our compost throughout the Northeast to growers, retailer, and nurseries. Our trademarked line premium organic is known as our MOO® line of seven products. The bulk growing mixes are known as our NUTRIPEAT® line includes custom blends as well both organic and conventional. We also do a FOSTER BROTHERS line which is high quality but not organic and more price competitive. We also do private label for two medium sized retail chains. Market expansion is limited to a large degree by weight and the resulting transportation costs.

VNAP employs 13 persons full time and provides a way for more of our family members to participate in agriculture. VNAP also provides a way to add value to excess nutrients and recycle them back into the environment in a healthy manner. While we have a lot more work to do, we feel that we have come quite a way in meeting our goal of better using our resources and others to provide a more holistic approach to our part of agriculture and the environment.

In summery, there are several things that one should keep in mind in considering the digestion option.

1. Current research may reduce the past capital and operational costs.
2. A good plan should at least consider the possibility of anaerobic digestion.
3. Each system is unique to the human and physical resources available or that can be applied.
4. Mistakes are much less painful if made on paper and not in practice.
5. The green revolution is mainstream now.
6. Environmental integration and regulation is part of our operational landscape.
7. If one is planning to interface with the utility, a thorough investigation of options and requirements should be done with commitments made in writing.
8. The possibility of green credit may become a reality. Agriculture should become proactive in seeking those credits.
9. Thinking outside the box is healthy, but use of time-tested equipment and materials is appropriate and often necessary.
10. Simplicity is often the best solution.
11. Digesters break down nutrients and making them more readily available to the soil and plant environment but do not make them go away. The nutrients still need to be managed.
12. Anaerobic digesters are alive and need to be treated that way. A digester is not just a piece of machinery.
13. Composting may be a method to add value if there is excess nutrients available.
14. Marketing is an essential component to adding value to compost.

Large Anaerobic Digester Containments Using EPDM Rubber Geomembranes

Ronald K. Frobel, P.E.

ABSTRACT

Rubber based membranes were the original geomembrane used for water containment over 50 years ago and were a spinoff of the development and industrialization of synthetic rubber products during and after World War II. The exceptional characteristics of a fully vulcanized rubber based geomembrane are numerous and include documented long term durability in both covered and exposed applications (arguably the best in the industry), exceptional flexibility, working strain and high conformance /frictional properties to all substrates and adjacent materials. The exceptional physical/mechanical properties as well as large (50 ft X 200 ft) factory manufactured panel sizes to reduce field seaming and installation time make EPDM 45 and 60 mil thick sheet material an ideal choice for animal waste containment applications and large anaerobic lagoon digester liners.

Ethylene-Propylene-Diene-Monomer (EPDM) is a true polyolefin and has been used as a fully vulcanized rubber based geomembrane on a worldwide basis since the early 1970's. The unique characteristics of the fully vulcanized EPDM sheet material which allow it to be installed in fully exposed conditions (no soil cover required) and in virtually any climate have peaked the interest of the agricultural engineering community for use in both water conservation (canal lining systems) and animal waste containment. EPDM is one of the materials approved for use in the NRCS conservation practice on lining systems and has been in use in animal waste containment for over 15 years.

This paper will present the unique characteristics, design considerations and installation methodology for EPDM geomembranes in anaerobic digester lagoon bottom liner applications. In addition, the material considerations and currently available materials for anaerobic cover systems will be presented. These custom designed flexible cover systems provide rainwater collection, eliminate odor and collect biogas while providing long term cost savings over hard surface covers.

INTRODUCTION

Historically, geomembranes have been designed and specified for potable water, liquid containment, gas vapor containment and solid waste containment primarily due to their consistent manufacture and properties of low permeability, large panels, installation ease and excellent chemical resistance. In particular, when investigating geomembrane materials for use on a specific project, the following minimum design criteria should be evaluated:

DESIGN CONSIDERATION	SPECIFIC REQUIREMENT
Uniaxial / Multiaxial Stress and Strain	Reaction to Loading during and after Construction (service life)
Resistance to Installation Stress	Puncture Resistance and Puncture Strain dependent on site conditions
Conformability (Deformability)	Long term deformation without rupture (settlement/subsidence)
Chemical / Environmental Resistance	Minimal change in properties over time in the design environment (containment material or soils)
UV, Ozone, Oxidation Resistance	High resistance aging in exposed applications (minimal change in properties over time)
Maintenance and Repair	Easily repaired after many years of exposure
Installation and Seaming	Large panel or custom panel install and reliable user friendly seaming
Soils Interaction	High interface shear characteristics for soil burial/slope applications

HISTORICAL BACKGROUND

EPDM rubber geomembranes have proven success in numerous applications worldwide and have been used in containment and waterproofing applications since the early 1970's. Over the past 3 decades, research and development programs have successfully improved the membrane itself as well as the user friendly partially vulcanized tape seam system.

EPDM quality and performance record in exposed applications over the past 30 years has proven its ability to remain flexible while resisting degradation due to ultraviolet radiation, ozone and extreme thermal stress.

EPDM geomembrane material is based on a highly stable, inert synthetic rubber compound. In addition to the basic polymer, EPDM also contains a high percentage of carbon black that provides the requisite resistance to UV radiation and Ozone attack.

EPDM geomembranes are available in 45 mil and 60 mil thickness, in reinforced and nonreinforced sheet. They are manufactured in calendered roll widths of 10 ft and factory fabricated into panels that are 50 ft in width by 200 ft in length. The large panel size direct from the manufacturer eliminates secondary prefabrication and the large panel size simplifies installation by reducing the number of field seams required.

For large containment applications, field seaming is accomplished by using a patented prefabricated tape seam process than can be installed by the owner with minimal training. The 6 inch wide tape seam exhibits excellent peel and shear strength values – a critical element in determining long term integrity. In fact, the partially vulcanized tape self vulcanizes over time and becomes stronger with age. Both EPDM and the tape seaming process have a wide window for temperature variation during installation and in fact can be installed in below freezing temperatures.

MANUFACTURING PROCESS

EPDM geomembranes are formulated, manufactured and fabricated in a controlled environment into panels that range in size from 10 ft to 50 ft in width and 200 ft in length. The manufacturing process is a synchronized operation that includes a system for handling and mixing raw materials, a feed system, the calender, take up rolls, panels splicing and final autoclave vulcanization.

The manufacturing process begins with the pre-testing of raw materials that are measured, weighed and mixed together in a predetermined mix ratio in a Banbury mixer, at a specified temperature and duration. The compound is then converted into a slab form on a drop mill suitable for calendering. Each compound batch, which consists of polymer and additives, is then tested prior to the calendering process.

The uncured EPDM compound is calendered into a continuous sheet of uniform thickness. For reinforced EPDM, a polyester scrim is inserted between the plies of membrane and the membrane is then rolled on a core for subsequent fabrication.

PANEL FABRICATION WITH VULCANIZATION

Uncured 10 ft wide rolls of unreinforced EPDM are overlapped and seamed together on an automated platform to form large panels. The large, fused panels are dusted and rolled onto a core. A small amount of release agent is added to the surface of the EPDM to enhance the curing and handling characteristics of the membrane. The uncured membrane is rolled onto a mandrel, placed into an autoclave where it is vulcanized through the application of steam and high pressure. The vulcanization process allows the polymer chains to cross link, thus creating the elastomeric properties and continuous sheet with fully vulcanized seams. Once the vulcanization process is completed, the cured EPDM is removed from the mandrel, cut to size, wound on a core, packaged in shipping wrap that is identified with a color-coded roll tag, and placed in inventory or shipped to the customer.

Continuous statistical process quality control (SPQC) monitoring takes place throughout the EPDM manufacturing process in compliance with ISO 9002 certification. Ongoing process monitoring, sampling and testing per ASTM or other applicable test methods, are undertaken to ensure that the EPDM geomembrane meets published quality specifications and standards.

EPDM SHEET PROPERTIES

Table 1 illustrates the EPDM sheet material properties for a 45 mil thick non-reinforced EPDM. Although comparable to other geomembrane materials, it is important to note that the flexibility (tensile strain) range does not exhibit a yield point but rather provides a working strain up to 500%.

Table 1 - EPDM Mechanical Properties

Property	Test Method	Units	Value
Tensile Strength	ASTM D 882	lb/in	50
Tensile Elongation	ASTM D 882	%	500
Tear Resistance	ASTM D 1004C	lbf	9
Puncture Resistance	ASTM D 4833	lbf	35
Puncture Elongation	ASTM D 4833	%	250
Hydraulic Burst	ASTM D 751A	psi	80
Multiaxial Elongation	ASTM D 5617	%	140

The large scale multiaxial strain behavior of the EPDM material exhibits strain or elongation to break of 140 %. This shows exceptional out-of-plane strain to rupture as would occur under gas uplift loading or in a subsidence / settlement situation. The 6 inch wide tape seam also exhibits large strain to rupture in the large scale multiaxial test of over 100 %. As a comparison, HDPE typically fails at the yield point of approximately 15 %.

FIELD INSTALLATION

The EPDM sheet material is manufactured in standard factory panel sizes up to 10,000 sq ft with fully vulcanized factory seams. Although larger panel sizes can be made, weight limitations in the factory and field limit size of panels that can be handled. Once the panel size is known, the panel is folded (two folds maximum) lengthwise and then rolled on a core. Thus the material comes to the site in roll form. Once on the site, the panels are moved into position by equipment designed for panel / roll placement. Panels are unrolled and unfolded into specific panel locations indicated on a panel layout drawing for the project. Once the specified overlaps are set for adjacent panels, the seams are field fabricated by manufacturers recommended procedures. The flexibility and rubber characteristics allow the material to be placed virtually free of wrinkles in a variety of climates and terrain. This also allows for intimate contact with the subsoils if required.

FIELD SEAM PROCEDURES AND TESTING

The most common field seam procedure for EPDM is the 6 inch wide cover strip tape seam. This patented method uses procedures that can be easily installed by the owner or professional installation crews without special thermal fusion equipment or electric generators. In general, the following procedures apply to the 6 inch wide tape:

- Position adjacent panels to provide a minimum 4 inch wide overlap
- Prepare the overlap area a minimum of 3 inches on each side of the edge by applying a solvent based primer/cleaner
- Apply the 6 inch wide cover strip by removing the release paper and pressing the tape to the seam area
- Apply hand pressure to the seam area by using a teflon roller to provide a fully adhered section
- Test immediately by non destructive air lance test methods

Once the seaming crew becomes familiar with the methods, seaming production typically can approach 10 ft per minute with or without a seaming board. These types of seams can be placed at any site temperature and can even be placed below 32 F without the requirement of preheating the seam area.

Destructive and Non Destructive test (NDT) methods for the tape seam system are similar to other geomembrane seams. Destructive peel and shear testing is accomplished in accordance with ASTM D 4437 using 1 inch wide strip specimens tested at 20 inches per minute strain rate. Typical destructive test results for the tape seams are as follows:

Shear:	35 lb/in and 200% strain
Peel :	14 lb/in

Non destructive testing of 100 % of the seam length is accomplished using the high pressure air lance test method (ASTM D 4437) which uses an exit air jet of 50 psig minimum directed at the edge of the seam overlap through a 3/16 inch diameter nozzle. Seams can be tested immediately after completing the seam area.

EPDM geomembranes are not new to the animal waste containment industry and agricultural applications in general. As lining systems for animal waste and anaerobic digester containments, the following characteristics should be considered when selecting EPDM geomembranes:

- Large factory panels up to 10,000 sq ft
- User friendly seaming methods (owner installation)
- Outstanding load / strain characteristics
- Designed for exposure and long term UV / ozone resistance
- Not affected by temperature extremes
- Lays flat and virtually wrinkle free

- Over 15 years use in animal waste containment
- Not affected by animal waste or biogas

ANAEROBIC DIGESTER FLEXIBLE COVER SYSTEMS

Although biogas waste to energy and anaerobic digesters are relatively new technology in the United States, flexible geomembrane cover systems are not. Depending on the final application and use, several types of covers should be considered for animal waste and digesters.

In general, the following types of geomembranes should be considered for waste covers and all should have a minimum of 40 mils in thickness as per the new NRCS Waste Cover Facility standard of practice 367:

HDPE	High Density Polyethylene
EPDM	Ethylene Propylene Diene Monomer
EIA	Ethylene Interpolymer Alloy
fPP	Flexible Polypropylene
fPP-R	Flexible Polypropylene Reinforced
TPO	Thermoplastic Polyolefin

For odor and general rainwater control only, all of the above materials can be used and in fact manufacturers warranties can be less than 10 years (10 year project life). However, for anaerobic digesters that are specifically designed for capture and use of biogas for energy production care must be exercised in material selection and design must be specific as to tensile strength, strain characteristics under load, attachment methods, prior use, long term maintenance and ease of repair. In this regard, a minimum of 20 years for membrane design life and manufacturer warranty should be required and specific types of materials should be considered based on historical use in floating cover systems and tensioned membrane cover systems other than anaerobic digesters.

The following types of geomembranes should be considered for anaerobic digester designs requiring either a tensioned membrane floating cover with gas collection or a inflatable tensioned cover:

FPP-R	Flexible Polypropylene Reinforced
EIA-R	Ethylene Interpolymer Alloy Reinforced
TPO-R	Thermoplastic Polyolefin Reinforced

The above materials have internal scrim or woven fabric reinforcement to resist the rigors of installation and extreme lifetime stress due to environmental factors such as wind loading, gas pressure, snow loads and stress at perimeter attachments. In addition, these types of materials can be prefabricated into large panels specific to the shape and type of digester unit. All can be (and should be for longevity) colored light or white in color to resist the aging process by reducing surface heat.

SUMMARY

EPDM geomembranes as well as other polymeric materials have been in use as lining systems for waste and liquid containment for decades. This type of material is not new and in fact EPDM has been in use in agricultural animal waste containment for over 15 years. Large anaerobic digestors that are excavated cells are particularly well suited for EPDM geomembranes for reasons stated in this paper and especially when considering the final cost and longevity of an engineered project such as a digester. These materials must be designed to last the life of the facility to result in a maximum benefit to cost ratio. In this regard, the design life and thus geomembrane life in exposed animal waste must be a minimum of 20 years.

Geomembrane materials have also been in use for decades as floating or tensioned cover systems that have been approved by municipalities world wide for drinking water protection. The same methods used for selection, fabrication and attachment to structures or soils can be used in anaerobic digester applications with additional consideration for biogas collection. The anaerobic digester designer must not only rely on external expertise for material selection in flexible membrane liners and covers but he must also consult experts in the field of geosynthetics for proper design and construction methodology to ensure that the finished project will indeed function without failure and with minimal maintenance throughout its design life. As with the lining systems, the digester cover design should also require a minimum of 20 years in exposed conditions and in containment of biogas.

AN ALTERNATIVE AND INNOVATIVE APPROACH TO ANAEROBIC DIGESTION OF DAIRY MANURE

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ABSTRACT

A review of the literature shows that a number of investigators in Asia, Europe, Africa and the Americas performed impressive research to develop technically elegant anaerobic digestion systems for application to dairy manure. Many of these digestion processes were applied in commercial scale in India, Italy, China, Egypt, Germany France and the United States. Unfortunately, most of theses systems are not cost effective. An important lesson derived from the literature review is that in order for a digestion process configuration to be cost effective, it must be a good net energy producer. Revenue from the sale of electric power is a determining factor. This paper presents preliminary findings on the development of a *Plug-Flow Two-Phase Anaerobic Digestion Process* that exhibited high net energy production with feed TS concentration up to 10% TS. About 78% of the digester methane energy is available as surplus for heat and electric power production.

KEYWORDS

Anaerobic digestion, two-phase, dairy manure, plug flow, innovative, renewable energy, nutrients
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INTRODUCTION

Animal manure is a large source of pathogens, putrescible BOD load, and nutrient salts that pollute the air, land, and water environments. In California, animal manure enhanced ground-water salinity to high levels, so much so that well waters in some locations are desalinized by energy-intensive membrane-filtration systems at high cost to the consumers. Surface and ground water contamination by *Cryptosporidium* and other manurial pathogens causes serious public health problems. This is the “bad news” about manure. The “good news” is that the annual production of about 500 million tons (dry basis) of noxious manure in the United States represent about seven *quadrillion* BTUs (Quads or Q) of solar energy. Recovery of this *renewable energy* at 50% efficiency could meet three percent of America’s annual energy demand (about 99 Q in 2002). This manure mass also contains million of tons of nitrogen, phosphorus, and potassium that may be recovered as compost, a highly desirable *bioproduct,* to displace (and conserve) petroleum resources used to manufacture commercial-grade fertilizers.

The energy value of all *organic solid wastes* (OSW) generated in the U. S. in 2002 is about 30 Q. If 33% of this renewable energy is recovered–a task much simpler than landing men on the Moon–then America’s current energy shortfall (30 Q in 2002) may be reduced by 33 %; this is highly desirable to meet the goal of *energy independence* from the Middle East. It is thus necessary to develop a waste-to-energy and *bioproduct-recovery* technology to reduce America's dependence on foreign oil and gas, stop environmental deterioration, create new employment opportunities, promote energy independence for all countries (*via. technology transfer*), foster international goodwill and friendship, develop new business with other nations, and thereby reduce our foreign trade deficits. Such a *waste-to-energy technology* could be applicable to dairy manure and other OSWs.

Role of Anaerobic Digestion

Several waste-processing routes may be envisioned to achieve the aforementioned goals of bioproduct (energy and nutrients) recovery with simultaneous stabilization of raw manure. However, because dairy manure has a high moisture content (~ 85 to 99 %) and because it is *heterogeneous* in terms of physical and chemical composition, biological gasification by *anaerobic digestion* (AD) is perhaps the only practical and economical means of stabilizing this waste material with <u>simultaneous</u> production of renewable energy (methane and mechanical/electric power) and recovery of fertilizing nutrients for agronomic application.

This paper focuses on dairy manure digestion with a brief review of past application of AD in the U. S., Italy, Egypt, China, India, Nepal, and other countries. An innovative approach to dairy-manure management and anaerobic digestion is suggested based on exploratory research.

Characteristics of Dairy Manure

Dairy manure is the end product of *rumen* digestion. Consequently, the *anaerobic biodegradability* of this waste is lower than those of other organic wastes. Fibers excreted from the rumen are difficult to biodegrade in a man-made digester, particularly at ambient temperatures. The total dry solids (TS) content of dairy manure range from less than 1-wt% for flushed manure to about 12-wt% for fresh, scraped manure. The volatile solids (VS) content of dairy manure may be 75% of TS or lower depending on the amount soil and dirt included in the manure. The fiber, lignin, and "hard" carbohydrate substrates of dairy manure are much higher than those of municipal sludge. Since the anaerobic biodegradability of municipal sludge VS is between 60% and 70%, the digestibility of dairy manure is expected to be between 50% and 60%. Manure degradability can be increased by pretreatment which may not be cost effective.

PAST WORK ON DAIRY MANURE DIGESTION

Anaerobic digestion of dairy manure has been practiced all over the world for more than 60 years. Inspired by the Gandhian movement towards self government, Indian agriculturalists developed and used small-scale anaerobic digesters called Gobar (cow dung) gas plants to provide cooking gas and electric power to Indian villagers. These unheated digesters also received human and other wastes to provide waste treatment. The KVIC (Khadi Village Industries Commission) digesters are more common. They were first installed in the 1930s and 1940s. A KVIC digester is a cylindrical concrete or steel tank with a floating cover for gas storage.

The Chinese agriculturists developed the so-called water-pressure, masonry digesters with fixed covers in the 1960s. Digester gas was used mainly for cooking and heating. The Chinese built about seven million small digesters for farmers and villagers.

Indian and Chinese digester designs were used, sometimes with modifications, for small-scale application in many Asian, African, Middle Eastern, and South American countries. These digesters are not heated or mixed.

French engineers developed truly innovative digester designs for animal wastes. Thousands of these digesters were built after World War II. The Ducellier-Isman System consisted of multiple-tank digestion. The manure was first aerated to increase the digester temperature. The warm manure was then anaerobically fermented in insulated gas-mixed digesters. Other French systems included the double-walled Salurba Digesters, Betur Tanks, Baudot-Hardoll Digesters, and Ofta and Samogaz Systems. The Germans were also active in using commercial-scale, manure digestion systems which included the Dermstad Process (heated and mixed plug-flow reactor), Schmidt-Egersgluss or the Bihugas Process (heated concrete above-ground silo), and the Harnisch System (heated horizontal cylinder mixed with wind-powered agitator within a greenhouse enclosure). The French and German commercial-scale digestion systems were uneconomical and abandoned.

There was an upsurge of interest in manure digestion after the oil embargo of the early 1970s. French engineers developed several commercial-scale digestion systems including a short-HRT (0.3 days) anaerobic filter (SGN Process by Bioindustries), and a biogas-mixed CSTR digester promoted by the EMC Group. The Irish developed a two-stage, two-phase anaerobic filter system for dilute manure. The Italians used commercial-scale CSTR and “plug-flow” digesters, and covered lagoons for dairy manure digestion. These “low-priced” digester designs included covered-pit and heated plug-flow reactors. Some plug-flow digesters were placed inside greenhouses for operation at above-ambient temperatures.

An innovative inclined digester was developed and applied in commercial scale by Mr. Pfulg to digest cow manure in Switzerland. This digester was of a plug-flow design with provision for internal inoculation of raw incoming manure.

After the oil embargo American and Canadian engineers were very active in developing and applying full-scale digestion of dairy manure. New plug-flow digestion systems were developed at the University of Illinois, Urbana, IL. A solid-state and a plug-flow two-phase digestion system were developed at the Institute of Gas Technolgy, Chicago and the University of Utah. A number of investigators at the University of Illinois, Urbana, the Clay Center of the USDA, the University of British Columbia, the North Carolina State University experimented with thermophilic digestion of high-solids (7 to 9 % TS) cow manure at short HRTs (5 to 12 days). It is not known if these thermophilic systems produce any surplus energy for sale.

A commercial-scale, thermophilic, manure digestion system was installed and operated by the Hamilton Standard Co., United Technologies, Inc. A 500-TPD cattle-manure CSTR digestion system was built and operated by Calorific Recovery Anaerobic Process (CRAP) at Guymon, OK. Other commercial-scale dairy digestion plants were built and operated by Biogas of Colorado, and Unisyn of Hawaii. These systems were uneconomical and were shut down.

A number of commercial-scale dairy manure digestion systems built by RCM Engineers, CA, Inland Empire Utilities, CA, Synagro, Houston, TX, AnAerobics, New York, and Tindale Farm, WI are operational to the best of this writer's knowledge. Commercial-scale dairy manure digesters exist at Monroe, WA, Bedford, VA, Gettysburg, PA, Henniker, NH, Middlebury, VT, and other locations. During 2002-2003, the California Energy Commission has made about 10 awards for the construction and upgrading of dairy-manure digesters for the purpose of electric power production.

Lessons Learnt

It is clear from the foregoing section that considerable effort was directed to develop various digester designs to gasify dairy manure. Several innovative system designs were developed in the United States, Germany, France, India, China, Switzerland, and other countries. Unfortunately, most of these designs, though technically elegant, were uneconomical.

One lesson that may be learnt from the past experience is that the economic viability of dairy digesters depends on many factors of which innovative fermenter design is only one. It appears that the farmer/investor must have a good revenue stream to afford an acceptable *rate of return* on investment or a short *payback period*, usually less than five years. Sale of surplus electric power or displacing purchased power could be the best income source for a digestion-plant investor. This situation is achieved only if the digestion plant produces energy substantially in excess of what is needed for dairy operation. Thus *net energy production (NEP)* is a must. A system design that maximizes NEP could be a winner.

A healthy revenue stream from sale of electric power combined with income from compost and environmental credits contribute significantly to the economic viability of a dairy-manure digestion plant.

INNOVATIVE DESIGN CONCEPT

Currently, three anaerobic digester designs are used for dairy manure digestion in the United States. These are: unheated lagoon digesters with long HRTs (>80 days), a rectangular tank called "plug-flow" digester, or a "completely mixed" (CSTR) digester. The latter two digester systems could be heated. The lagoon digester is a net energy producer in warm climates, but it has the major disadvantage of large land requirement. No information is available on the net-energy production efficiency of CSTR or PFR (plug-flow reactor) manure digesters. In theory, a plug-flow regime is unattainable. Results of tracer studies are not available to ascertain the deviation from plug-flow behavior. Also, "plug-flow" digesters are not expected to show good performance without organism recycle. Little data are available to evaluate the performance of commercial-scale, plug-flow dairy manure digesters.

NEP can be increased significantly by charging high solids-content (>12% TS) manure to the digester, using a shorter HRT, and enhancing the VS-conversion efficiency. Obtaining high solids-content manure is feasible because 50-90 % of the dairies collect "dry" droppings (> 12% TS) by scraping or vacuuming the alleys. These digesters could produce surplus energy even if the digestion tank is kept at a mild mesophilic (~ 25^o -30^oC) temperatures. Work with municipal sludge and other organic solids has shown that digestion efficiency can be increased by enhancing the efficiency of solids hydrolysis as obtained in a *two-phase anaerobic digestion (TPAD*) process. The CSTR TPAD process is commercial with municipal sludge and high-strength industrial liquid and solid wastes. A plug-flow TPAD Process was deemed appropriate for manure digestion because a PFR does not require the mixing energy input required to operate a CSTR.

METHODOLOGY

A 42-liter multi-channel PFR was operated to test the hypothesis that a plug-flow TPAD process is a net energy producer. Commercial dog food was used to prepare digester feed with TS contents of 3, 4, 6, 8, and 10% (Table 1). The length of the digester was about 175 cm. HRT was set at 13 days. Digester temperature was at 35^oC. Digester effluents were recirculated. Sample ports were located along the feed flow-path to monitor pH, volatile fatty acids (VFA) concentrations, gas production rate (GPR), and biogas methane content.

RESULTS & DISCUSSIONS

As expected from past two-phase digestion work, digester pH dropped below that of the influent feed (pH 7) because hydrolysis and acidification were the predominant reactions within the first 30 cm of the digester. The pH dropped to about 4.4 at this point when a 10%-TS feed was used. Digester pH then increased sharply at first and then gradually to about 7.5 at the effluent port. Two distinct zones of acidification and biomethanation developed within the digester. The observed pH drop was indicative of efficient hydrolysis and VFA production in high concentrations. VFA concentrations of 3000 mg/l, 4800 mg/l, 7000 mg/l, and 10,000 mg/l were observed at feed TS concentrations of 4%, 6%, 8%, and 10%, respectively. The corresponding loading rates were 2.73 kg VS/m^3d, 4.10 kg VS/ m^3d, 5.47 kg VS/ m^3d, and 6.84 kg VS/ m^3d. These loading rates were much higher than the loading-rate range of 0.8 to 2.0 kg VS/ m^3d used for commercial-scale municipal sludge digestion. Gas production rates at these loading rates were high. About 3.4 volumes of biogas were produced per unit digester volume with the 10% TS-content feed. As shown in Table 1, VS reductions were also very high. Methane content of biogas from the methanogenic zone ranged between 75% and 80%. Digester methane yields were high, and ranged between 0. 28 and 0.36 std. m^3/kg VS added.

Net-energy analysis was performed for high and low TS-content feeds. As shown in Table 2, 78% of the digester methane energy is surplus and available for sale with a 10% TS-content feed. The NEP efficiency will be considerably higher with a 12% TS feed, as with fresh dairy manure feed. This table also shows that NEP is negative with a dilute (1% TS) feed. The NEP of plug-flow TPAD is compared with that of an anaerobic filter that can be operated with 1% TS feed. Table 2 shows that the anaerobic filter is better than the plug-flow TPAD for dilute feeds.

CONCLUSIONS

A plug-flow TPAD Process is capable of gasifying high solids-content organic feeds at high loading rates up to 6.84 kg VS/ m^3d with gas production rates up to 3.4 volumes of gas/day-unit digester volume. Distinct zones of acidogenesis and methanogenesis developed within plug-flow reactor. The zone of acidogenic fermentation was confined within the first 30% of the digester length. Digester effluent had a pH of about 7.5. Biogas methane content was higher than 75 mol%. The VS reduction efficiency ranged from 63% to 77%. About 78% of the digester methane energy was surplus and available for sale. Application of the plug-flow TPAD process could be cost effective. Further research is continuing. High methane yields of 0.28 – 0.36 m3/kg VS added was observed.

ACKNOWLEDGEMENTS

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Table 1 -Plug-Flow Two-Phase Operation & erformance

Parameter	Run 1	Run 2	Run 3	4
Feed, %TS	3	**4**	**6**	**8**
Loading, kg/m3-d	2.05	**2.73**	**4.10**	**5.47**
Effluent. pH	**7.46**	**7.32**	**7.39**	**7.43**
GPR, l/l-day	1.17	1.61	2.28	2.77
Methane,%	**59**	**57**	**57**	**58**
Methane Yield, l/g VS added	**0.36**	**0.35**	**0.31**	**0.29**
VS Rrduction.,%	**77**	**78**	**74**	**66**

Table 2 - Net Energy Production from Plug-Flow Two-Phase Anaerobic Digerstion

PROCESS	**CULTURE VOLUME, liters**	**HRT, days**	**FLOW, L/day**	**METHANE PROD. RATE, L/L-d**	**METHANE ENERGY, Btu/day**
PF, 2- PHASE **10% TS** PF, 2- PHASE	**32**	**12**	**2.67**	**2.04**	**2304**

3% TS	**32**	**12**	**2.67**	**0.72**	**814**
PF, 2- PHASE **1% TS**	**32**	**12**	**2.67**	**0.240**	**271**
ANAEROBIC FILTER 1% TS	**2.67**	**1**	**2.67**	**2.88**	**271**

Demonstration of the Induced Blanket Reactor for Anaerobic Treatment of Dairy and Swine Manure

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Abstract

The induced blanket reactor (IBR) is a high rate anaerobic digester featuring a method to retain solids, including slow growing anaerobic bacteria, and it will not plug when treating manure. This paper will report data on a 28 m^3 (6,500 gal) dairy waste IBR facility that has been operating for two years. The paper also discusses a full scale swine waste IBR facility treating manure from 650 animal units (1000 pounds live weight/AU) that is built, but not yet in operation. The swine waste IBR facility uses a Bowman microturbine generator to continuously produce up to 80 kW of electricity from biogas. The microturbine generator is connected to Pacificorp's grid and there is a contract in place to pay the farmer for this renewable power source. The IBR removed at least 70% of chemical oxygen demand or volatile suspended solids with a 6 day liquid detention time.

Sent to Gene DeMichele GDemichele@wef.org on 19 June 2003 & this person replied the same day that he had received it.

Key Words
induced blanket reactor, anaerobic, manure, microturbine, bioenergy demonstration

Background

Anaerobic Digesters

Common types of anaerobic digesters for manure are the plug flow, complete mix, and covered lagoons. All of these systems can anaerobically digest manure and collect biogas. According to a 1998 study sponsored by the U.S. Department of Energy (Lusk, 1998) failure (defined as no longer in service) rates among these types of farm - based digesters which were actually built were staggering: Plug flow failures – 63%, Complete mix failures – 70%, and even covered lagoons had a failure rate of 22%. The failure rates for the plug–flow digester were even higher during the 1980's. There are a variety of reasons why this failure rate is so high and some are unavoidable, but this high failure rate is totally unacceptable, especially on a family farm that is struggling to survive.

Center

In 2000, a team of engineers and scientists at Utah State University started the Center for Profitable Uses of Agricultural Byproducts (CPUAB) with funding initially provided by the state of Utah to help agricultural production and processing industries. Dr. Conly Hansen, a mechanical/agricultural engineer with three decades of experience in agricultural production and processing waste management, is the director of the center.

The CPUAB set out to improve on anaerobic technology previously developed. There were three goals: it had to be reliable; it needed to be a simple design that was easy to operate, and it needed to be affordable. In the process of meeting these goals, it was concluded that reliability, ease of operation, and affordability were all inter-related. If it was not reliable and shut down for any reason the farmer loses money. The simpler to operate, the less chance there was for failure, and the smaller the digester the lower the investment cost. The only way to make a digester smaller was to reduce the hydraulic retention time (HRT) and the only way to reduce HRT was to make an efficient digester.

Anaerobic Induced Blanket Reactor

In order to treat waste at a high rate, anaerobic digesters must have some means of retaining the slow growing anaerobic bacteria. Media can be placed in an anaerobic digester, such as sand in a fluidized bed bioreactor that bacteria attach to. However, the attachment media tend to plug when trying to treat waste containing a high concentration of fibrous solids such as is often found in animal manure. The induced blanket reactor (IBR) is an invention that separates solids from liquids and biogas within a vessel. The separated solids in a mature reactor will contain a large proportion of anaerobic bacteria. In start up, the solids provide attachment media for the bacteria. Separated solids are fed back into the reactor vessel in a variety of ways. If solids concentration in the reactor becomes too great, a portion is removed to avoid plugging. The IBR is a high rate reactor with 6 day hydraulic retention time for animal manure. The complete system consists of above ground corrosion resistant tanks and associated pumps, valves, piping; gas collection system, heat exchange system to keep digester ≥34^{o} C, gas conditioning equipment, electrical generation equipment, and controls. The design concept includes placing the system in a well insulated (≥R 19) building, at least in cold climates. Wastewater can be treated much faster and more efficiently in this anaerobic digester compared to many others. Utah State University has asked that details of the invention not be discussed publicly at this time.

The IBR system can essentially convert all agricultural production and processing by-product of little or no value into electricity. Other products of the process are water suitable for irrigation or flushing, and soil conditioner/fertilizer. The system contains odor during treatment and liquid and solid effluent does not have an offensive odor. It is automated with a programmable logic controller (PLC) and a computer and thus runs with little direct human intervention. The control system can be programmed to call a central office if a key parameter exceeds a defined range. The system satisfies the National Resources Conservation Service (NRCS) standard (NRCS, 2003) for controlled temperature anaerobic digesters under the category "other types of digesters".

An integral part of the IBR system is a modular approach. The advantages of a modular system are that it can be easily built to fit small or large farms or processing plants, the system can be easily expanded, and if part of the system fails, it does not stop the process. Failed tanks can be quickly brought back on line.

Caine Dairy IBR System

In 2001 an IBR system was installed at the Caine dairy, USU's dairy farm in Wellsville, UT. The system at the Caine dairy consisted of 1,000 & 6,500 gal (3800 & 24,600 L) tanks with all associated equipment. The Caine dairy system was not designed for electrical generation. Biogas was used to heat water. The building at the Caine dairy was 20' x 20' x 14' tall (6 m x 6 m x 4.3 m). It was built with a wood frame and insulated with straw bales (Figures 1 & 2). The system was controlled with an Allan Bradley programmable logic controller (Rockwell Automation, Milwaukee, Wisconsin) (Figure 3) connected to a man/machine interface (MMI), which was a 486 personal computer running Microsoft Windows 2000 (Figure 4). Software for the MMI was designed by SAE engineers (Logan, UT). It facilitated making changes in temperature, HRT, and loading rate with a mouse click. The farm milks about 100 Holstein cows. Manure was taken from the milking parlor and also scraped from behind covered free stalls. Animals were bedded on sand that often found its way into pipes leading to the IBR and settled in the feed tank. The manure pump was a two inch (51 mm), two horsepower, Hidrostal™ centrifugal (Wemco, Salt Lake City, UT) that could handle up to about 7.5% solids. The pump moved manure through an in-line grinder (Muffin Mini Monster, Costa Mesa, CA) to the IBR. Effluent from the IBR was stored in a lagoon on the farm. Biogas was collected and burned without preconditioning or pressure boost in a 35,000 Btu/hr, 40 gallon water heater that was a standard home use unit, made to burn natural gas (Envir-Ro-Temp, Johnson City, TN). Most of the time, manure received at the IBR was less than 4% solids (data not shown). In an attempt to increase solids, during the summer of 2002, farmhands dumped calf manure that was handled as a solid with large amounts of straw (Figure 5) into the feed tank.

Figure 1 Caine dairy IBR system building under construction.

Figure 2 Caine dairy IBR with straw bale insulation in place. The feed tank is located next to the building (right) with the lid up. Propane was used for startup and pilot fuel.

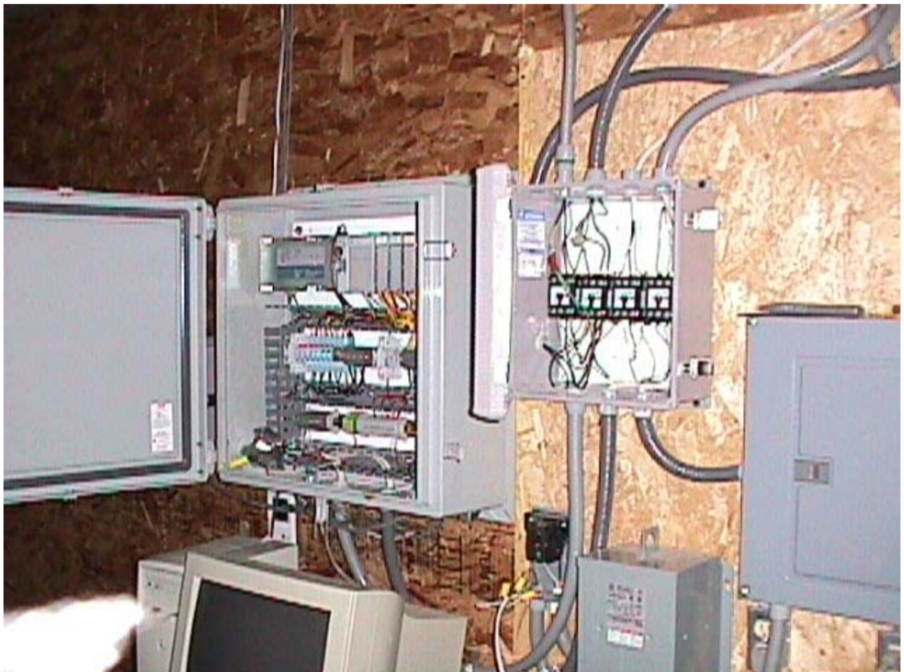

Figure 3 Control system for Caine dairy IBR

Figure 4 Man machine interface at Caine dairy

Figure 5 Manure containing un-chopped straw that caused pumping problems.

Water was added to the calf manure, in an attempt to pump it with a centrifugal pump. Even though moisture content was about 95%, the mixture still fouled the pumps that were being used at the time. Straw in the manure wrapped around shafts of sewage pumps and this caused them to fail. Straw would also plug grinder pumps. These pumps were all relatively small (two horsepower) since we were trying to feed at a constant low rate - down to one gal/min (3.8 L/min). We concluded that we could not use a centrifugal pump for manure containing long stringy material for low flow rates. The Hidrostal™ centrifugal (Wemco, Salt Lake City, UT) pump was able to pump the manure mixture when some straw was removed by selecting a different source of manure. Manure was pumped intermittently using the PLC to control time on and off.

Trial run of dairy farm IBR

After the Caine dairy IBR had been in operation for about a year and starting in the spring of 2002, samples were taken at least three times/wk over a consecutive 160 day period to monitor the influent, effluent and internal contents of the IBR. Analyses were conducted including the following: total (TS), total volatile (TVS), and volatile suspended (VSS) solids concentration; total (TCOD) and soluble (SCOD) chemical oxygen demand, and ammonia concentration. Ammonia concentration was measured using a distillation method. COD was determined using a closed reflux colorimetric method. Solids and all other analyses were done according to standard methods (APHA-AWWA-WEF. 1992). Biogas composition (methane, carbon dioxide, and nitrogen) was monitored less frequently using a GC (Hewlett-Packard, Model 6890) equipped with a split inlet, a thermal conductivity detector, and a 25 m fused silica column (PoraPLOT Q).

The amount of biogas produced was initially estimated based on the ability of the IBR to run the 35,000 BTU water heater. This estimate was later confirmed with an Alicat Scientific Inc. 50-LPM-D (Tucson, AZ) gas flow meter calibrated by the company for use with biogas.

Initially, the IBR was set up, using the PLC to control hydraulic retention time (HRT) at 10 days. This was incrementally reduced over a 160 day period during the summer of 2002 to an HRT of about 4 days during the last 20 days. The plan was to reduce HRT as follows: 10 d HRT for 40 days, 8 d HRT for the next 40 d, 6 d HRT for next 40 d and finally 4 d HRT for the last 40 days. However, due to storm events that diluted the manure and the fact the farmhands were not always dependable in delivering manure scarped from behind the free stalls the HRT and organic loading rate (OLR) was somewhat variable. During the last15 days, the HRT was about 4 days (data not shown) and OLR reached 2.5 Kg COD/m^3/d (Figure 6). The biggest problems were never getting enough solids in the manure and inconsistencies in manure characteristics. At times, the IBR handled manure with > 4% solids, but only for short time spans. The IBR has never plugged during more than two years of operation. On the other hand, a total of five different pumps were tried and sand often plugged pipe lines running to the IBR. Sand that made its way to the IBR was easily removed through a 3 inch (76 mm) port in the bottom of the tank and thence through a flexible hose to move the sand outside the building. Biogas production was about 10 L/min (0.35 ft^3/min) for the longer HRT's. The biogas was about 80% methane with the remainder mostly carbon dioxide. When HRT was reduced to less than six days and solids concentration in the manure was at least 1%, biogas production was at least double or 20 L/min (0.7 ft^3/min). Ten L/min is equivalent to about 0.6 ft^3/ft^3 of digester capacity/day. PH was monitored with a foul resistant probe (ABB Inc., Carson City, NV). PH was not controlled, but never got below about 7.5 (Figure 7). Temperature was monitored with RTD's connected to the PLC. Temperature was maintained close to 90^{o}F (32^{o}C) (Figure 8) in the IBR during the time of the study by recycling manure from the IBR though the 1000 gal (3,800 L) tank, which was double walled and circulating hot water from the water heater through the outer wall of this tank. Recycling was accomplished with a home built pump (originally a stainless steel centrifugal pump for pumping milk) driven by a one horsepower motor.

Figures 9 and 10 show total and insoluble COD in and out of the IBR. The influent TCOD was 4,700 and effluent TCOD was 1,000 for a removal average of about 79%. The Figure also helps to show that removal efficiency was not adversely affected by increasing TCOD to the levels in this study. Organics removal actually improved as the OLR increased (Figure 6). Organic loading rate increased due to changes in the TCOD of the influent and reducing the HRT to four days for the last quarter of the study period. Most likely, optimal OLR and HRT have not yet been reached. Further study will be required to determine what the IBR is capable of doing. Since the IBR concept is new, it is not possible to compare this system with data found in other laboratories, but the literature shows that high rate anaerobic digesters can commonly handle organic loading more than 2 kg COD/m^3.d (Ma, 2002, Speece, 1996). Loading for covered lagoons and complete mix digester are typically lower.

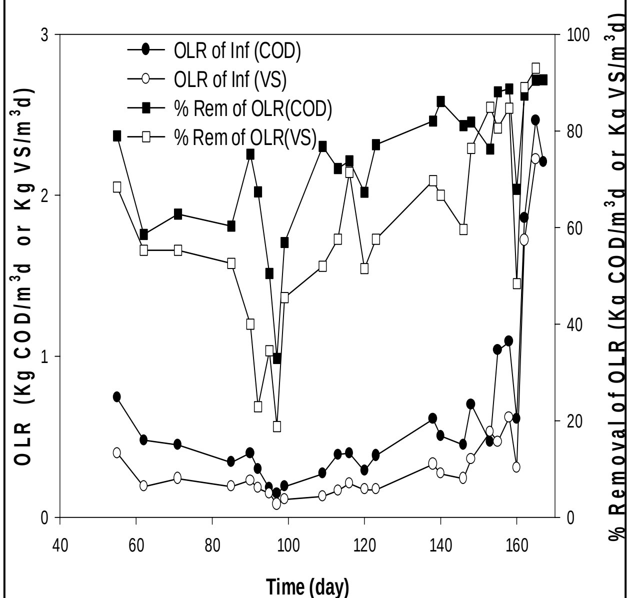

Figure 6 Organic loading and removal rate in Caine dairy IBR.

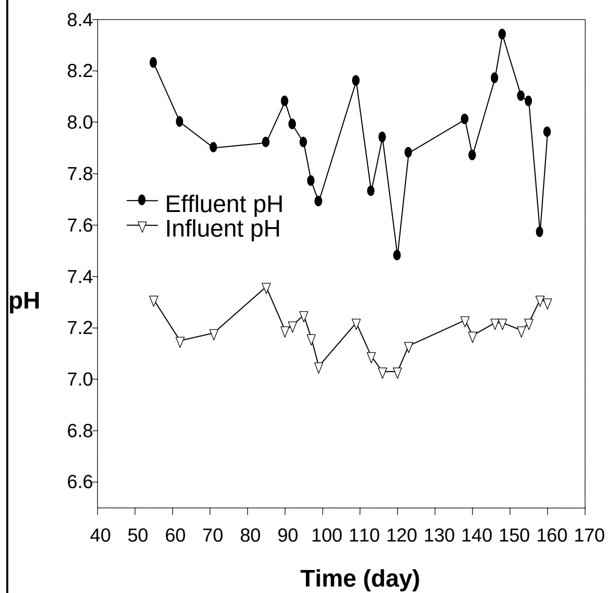

Figure 7 pH in the Caine dairy IBR.

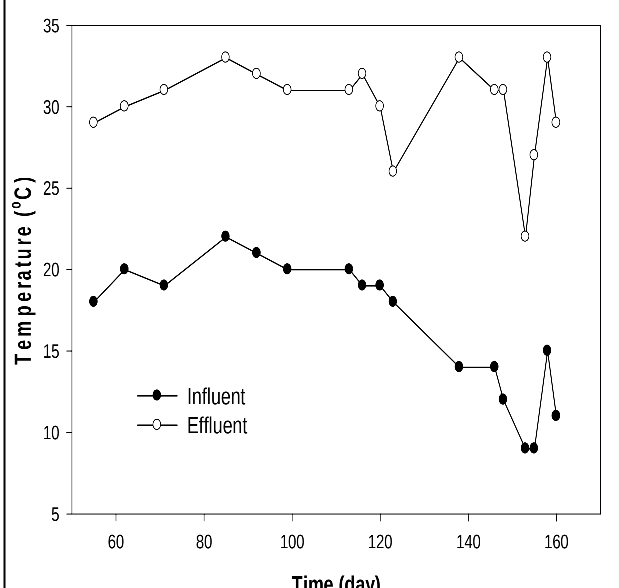

Figure 8 Temperature in Caine dairy IBR.

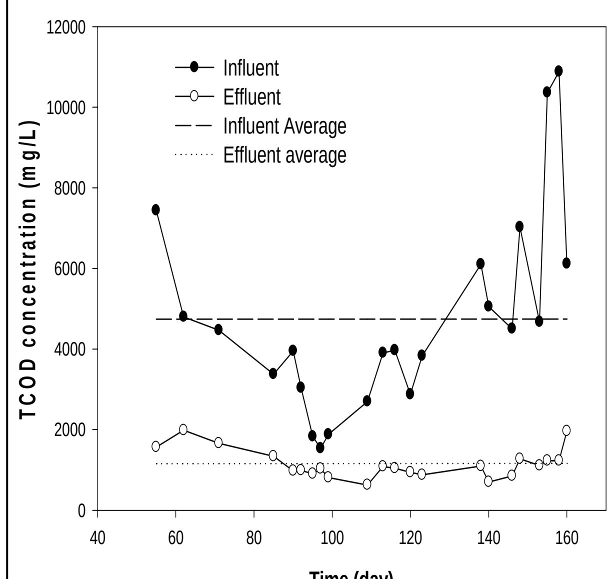

Figure 9 Changes in total chemical oxygen demand in the Caine dairy IBR

Figure 11 shows the removal rate for VSS. The average VSS concentration into the IBR was about 1,200 mg/L (data not shown). As shown in the Figure, the IBR removed about 72% of VSS. The OLR and HRT had little effect on VSS removal efficiency.

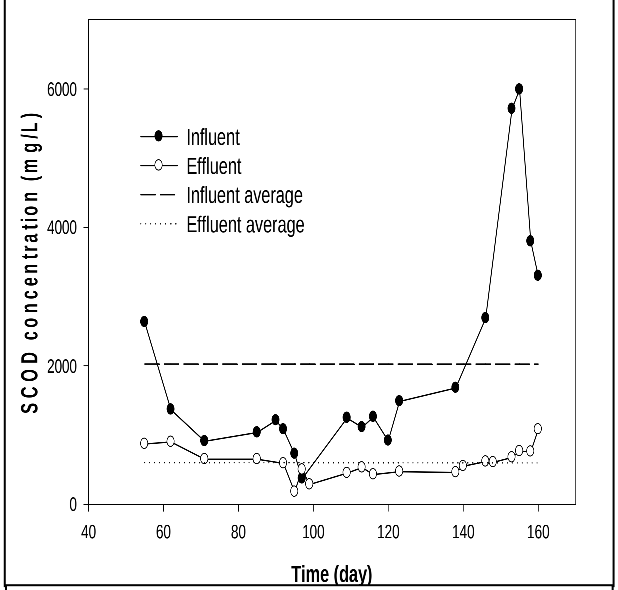

Figure 10 Changes in insoluble chemical oxygen demand in the Caine dairy IBR

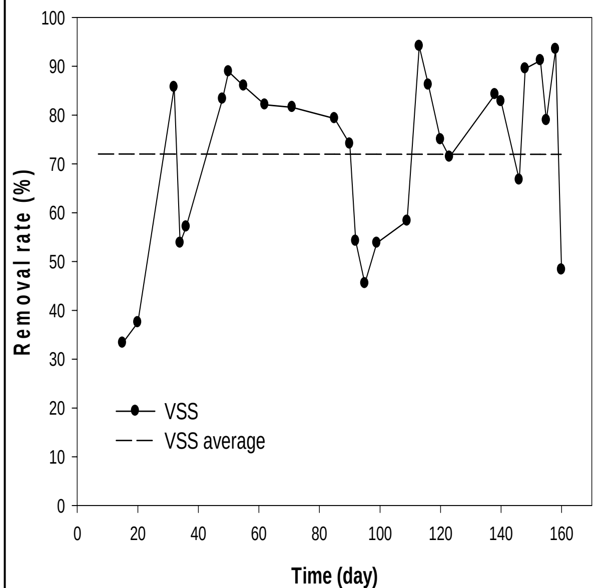

Figure 11 Removal of volatile suspended solids in IBR at Caine dairy.

Hog farm IBR

Having gained experience with the Caine dairy IBR, a larger IBR was planned for a hog farm. This large of facility required that it be built on a cooperators farm. A progressive hog farmer, Todd Ballard, in Benson, UT teamed with the CPUAB to build an IBR system. The Ballard farm was a farrow to finish farm with about 650 animal units (650,000 lbs of live weight). Planning for this IBR facility began in the summer of 2002. Some significant hurdles for approval of the system included licensing, design including structural engineering, and electrical including arrangements with the power company for grid connect. Used stainless steel tanks were purchased by the farmer. Two of the tanks were 12 ft (3.7 m) in diameter 44 ft (13.4 m) high and a third was about 14 ft (4.3 m) in diameter and 38 ft (11.6 m) tall. The final building dimensions were 36 ft x 40 ft x 50 ft tall (11 x 12.2 x 15.2 m). The system was designed with one of the tanks serving as a feed (equalization) tank. Hog manure will be brought to the feed tank usually on a daily basis by hauling from the individual hog building (there were four) in a liquid manure wagon and pumping into the feed tank using a Gorman Rupp (GR)(Mansfield, OH) three in (76.2 mm) ten horsepower (7.4 kW) centrifugal pump. Manure was moved out of the feed tank every 20 minutes using a GR two inch (51 mm) two horsepower (1.5 kW) centrifugal pump. Manure was recirculated with a Bell and Gosset (Morton Grove, IL) two inch (51 mm) one horsepower 0.74 kW) centrifugal in-line pump. Because the system is just coming on line, there is no data available for this paper. Figures 12-15 are pictures of the facility.

Figure 12 Setting tanks for IBR at Ballard farm.

Figure 13 Building housing IBR under construction at Ballard farm.

Figure 14 Completed building housing IBR at Ballard farm.

Figure 15 Microturbine for IBR at Ballard farm.

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Producing Energy and Soil Amendment from Agricultural Wastes

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Abstract

In light of the recent USDA-EPA- Unified National Strategy for Animal Feeding Operations, animal waste is a significant financial liability for agricultural industry. On the other hand, global depletion of fossil fuels and increasing demand for energy is leading into a national and international crisis. Wise use of appropriate technology can accomplish the conversion of agricultural waste into energy, reduce the reliance on fossil fuel, reduce environmental pollution, and add value to agricultural byproducts. A two-phase anaerobic digestion system was used to evaluate the feasibility of producing methane from cow manure and high cellulose agricultural waste . Cotton gin waste and bovine animal manure was combined to utilize the combined advantages of nutrient and cellulase bacteria with the high carbon content of the cotton gin waste. The results showed that 48% of the combined waste can be converted into methane producing 87 m^3 of STP methane gas per ton of combined waste under mesophilic condition. The average methane concentration in the produced gas was 72%. The research also showed that combining manure with cotton gin waste results in 35% higher gas production per unit of digester volume. The nutrient analysis of the digestion residual in Table 1 shows that the biosolids produced by the bi-phasic digestion has 2.4 times as much nitrogen content and 1/2 the sodium found in aerobically composted manure.

Table 2. Residual properties of anaerobically digested manure, combined waste and aerobically composted manure**.**

Parameters	Manure waste	Combined manure+ CGW	aerobically composted manure
Total N, %	2.32	2.56	0.9
Total P, %	0.15	0.43	0.2
Total K, %	0.42	2.2	2.70
Sodium, %	0.24	0.17	0.40

Key words: Energy, Animal Waste, Environment, Anaerobic digestion

Complete Mix Mesophilic Anaerobic Digester in Western NY.

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Abstract

The Matlink Dairy Farm in Clymer, NY is a dairy farm with 675 cows that has been operating an anaerobic digester since December of 2001. This digester system is a completely mixed mesophilic digester that produces electricity with a 130Kw Waukesha generator. The farm also utilizes its biogas to produce heat and electricity for the farm, and to generate income by selling its gas to an onsite food byproduct drying operation. The farm also generates income by accepting tipping fees for food waste from a fish stick processing plant, a grape juice processing plant, and wash water from an ice cream plant. The generator utilizes 76,440 ft^3/day of biogas, or about 113ft^3/cow/day. The added food waste increases gas quantity and quality. It also appears to increase the treatment capabilities of the system.

This paper describes the overall system, its capital costs and annual operating costs, and the overall system benefits and drawbacks.

Project Description

Matlink Dairy Farm is located in Chautauqua County, New York. This farm, planned for 675 milking cows is the single largest dairy operation in the Clymer Valley employing 16 people, and has considerable impact on the local economy. To address a variety of issues including odor, nutrient management, and to increase revenue, Matlink Dairy Farm installed a complete mix anaerobic digester with support from New York State Energy Research and Development Authority (NYSERDA) in late December 2001.

Food industries in the area had been using land spreading, municipal sewage systems and their own treatment systems to dispose of various liquid food wastes. The wastes include spoiled grape juice, ice cream wash water, and used cooking oil and breadcrumbs from the fish stick processing plant. Each of these waste streams are high in biochemical oxygen demand, sporadic in quantity and quality, and too wet to be accepted at the local landfill. This presents a real problem for the food manufacturers in setting up their own disposal system or in utilizing a municipal system.

Matlink Dairy Farm, encouraged by the food companies, turned to anaerobic digestion for solutions to several problems it has faced. Manure generated at Matlink Dairy Farm was stored in a long-term earthen storage and spray-irrigated on the ground in March, April, and November. Summer spreading was avoided to reduce odor complaints. The dairy is located a mile upwind of the Village of Clymer. During times of spray irrigation, the public school has had to keep its windows closed and neighboring businesses have also received comments about the odor. The odor from dairy manure handling and spreading on the farm had seriously affected the local community and the farms image. It is well known that anaerobic digestion is an effective technology to reduce odor from animal waste. Thus, to save its standing in the community, Matlink Dairy Farm initiated this project primarily being motivated by the desire of reducing odor from manure management after it received continuous complaints of excessive odors.

Another driving force is to reduce the potential for nutrients from manure to leach into the groundwater. Manure applied in the fall and early spring is subject to leaching when the ground is saturated. The Town of Clymer discovered its public water supply exceeded the maximum contaminant level of 10 mg/l for nitrate-nitrogen in 1994.

Lastly, the economic benefits of the installation of methane digester will reduce electrical and natural gas purchases at approximately $41,000 per year according to the estimate in EPA AgSTAR program's feasibility study. The farm has 1,250 acres that it uses to grow forage for its cows. This land has a need for the nutrients contained in the manure and food waste.

Supported by NYSERDA, designed by RCM Digesters, Inc., Matlink Dairy Farm started the construction of an anaerobic digester system in the summer of 2000 and finished it by the end of 2001.

Digester System

The digester system on Matlink Dairy Farm is composed of several subsystems (see Figure 1):

- Manure and food waste collection
- Digester for manure digestion and biogas production
- Engine generator set
- Dryer operation
- Separator to separate liquids and solids after the manure is digested
- Liquid storage
- Compost system

The digester installed on this farm is a complete mix digester, which is an insulated rectangular concrete tank installed below grade (76' long x 67' wide x 16' deep). A flexible, impermeable cover on the digester traps the gas at less than two inches of water pressure. The cover hooks to a center beam because the span of the cover material cannot exceed 35ft.

Manure is scraped daily and gravity flows to a manure reception pit. Two 20-Hp manure pumps fixed at two opposite corners of the digester running 2 hours per day turn and mix the manure in the digester. In addition to manure from 675 milk cows, various mixtures of food waste at an average of 3,000 gallons a day is added to the digester. This increases the biogas production and produces a higher methane content biogas that is typically 75% methane. The food waste is delivered sporadically to the food waste reception tank, but pumped into the digester at a controlled rate to minimize upsetting the biological process in the digester. The amount of food waste used each day varies depending on its concentration, and the past feeding rate. Increasing the amount of food waste added daily could be done without upsetting the biological system if it is managed carefully.

Traditionally, treatment systems designed to treat food waste have been expensive aerobic systems. These systems must have a large capacity to meet the instantaneous oxygen demand to keep the food waste aerobic to control odors. The buffering capacity of manure, with its steady production, allows the addition of the food waste without these traditional needs. All the companies involved benefit from this environmentally friendly solution.

Matlink Dairy Farm does have to be permitted by the New York State Department of Environmental Conservation (NYDEC), the state regulatory agency, to handle the food waste. They had to develop a plan, obtain a permit, and operate within the permitted guidelines.

Periodic reports are filed with NYDEC. These reports are not much different than the information required for Confined Animal Feeding Operation (CAFO) compliance.

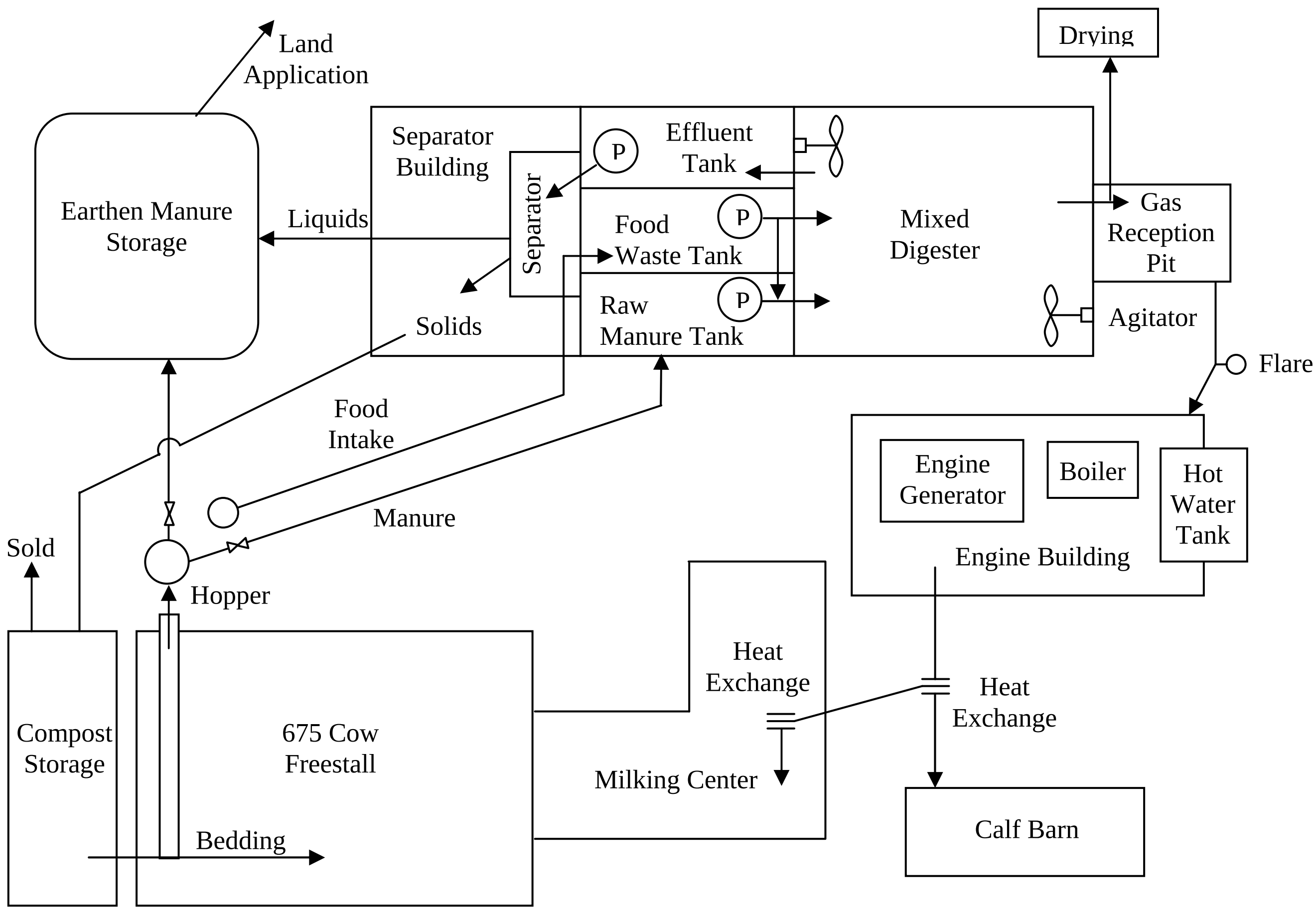

Figure 1. Schematic of Anaerobic Digester System on Matlink Dairy Farm (not to scale).

Combined Heat and Power Generation

The manure from the 675-cows at Matlink Dairy Farms, with the additional food waste as an additive, produces in excess of the 76,440 ft^3/day required by the engine generator, or about 113ft^3/cow/day. This biogas consists of methane (about 75%), carbon dioxide (about 25%), a small amount of sulfide compounds, and other trace gases. The biogas is collected and fed into a Waukesha engine attached to a Marathon generator (130 kW) that uses 22-25 ft^3/kWh. Utility pricing rules limits the power output of the generator to 130kW. The engine will operate 90-95% of the available hours per year. Because of the corrosive hydrogen sulfide in the biogas, engine oil has been changed every 500 hours.

This engine-generator set has an electricity production of roughly 884,000 kWh/year, which meets the electricity needs for the dairy farm and also provides some excess electrical power for sale to the local utility - Niagara Mohawk - at an average value of 2.7 cents/kWh for about $1000/month. Moreover, the heat generated provides hot water to heat the digester and for other on farm uses, which saves about $500/month. New legislation will enable the farm to increase its electrical generation and to utilize net metering, averaging its use of electricity over a year. Demand charges will still be incurred whenever the generation system is down.

Economic Costs and Benefits

The costs and benefits of the system are shown in Table 1. The farm acted as the general contractor using some if it's own labor force to build the digester, engine building, and separator building. The liquid storage already existed at the start of the project. The capital costs are spread over a 20year project life at 5% interest with approximate salvage values.

Table 1: Economic costs and benefits of the digester system.

	Items	Costs/Benefits
Capital Costs	Digester	
	- Digester Construction and Materials	$260,000
	- Mixture Pumps	$77,000
	Subtotal	330,000
	Engine-Generator Set	
	- Engine Generator	$96,317
	- Switching Equipment	$10,000
	- Engine Building	$22,614
	Subtotal	$128,931
	Solids and Liquids Separation	
	- Separator	$46,613
	- Separator Building	$15,076
	Subtotal	$61,689
	Liquid Storage	$45,000
	Others	$56,900
	Total Capital Cost	$622,520
	Total Annual Capital Cost	$61,232
Annual Operating Costs	Maintenance, Insurance, and Repairs	$20,663
	Reporting Food Waste to Regulators	$500
	Water treatment for heat exchange system	$800
	Spreading Costs Tractor tank wagon and irrigation	$93,947
	Total Annual Operating Cost	$115,910
Annual Benefits	Electric Sales off Farm	$50,000
	Tipping fee for handling food wastes	$200,000
	Bedding material replacement, separated partially composted (2 weeks) used as bedding	$15,600
	Compost sales, potential markets still being developed	$6,000
	Hot Water, heat recovered from the engine used in calf barn and milking center	$6,000
	Odor Control, avoided cost of additives and management time to resolve complaints	$5,100
	Nutrient value	$35,700
	Gas sales to drying operation	$100,000
	Total Annual Benefits	$418,485
Annual Income Per Cow for 675 cows ($/cow/year)		$350

The annual operating costs include an estimate of repairs and maintenance as well as the manure spreading cost for the farm. The spreading costs are approximately $140/milking cow/year. The farm has both tanker trucks and irrigation equipment that increases the overall spreading costs compared to other farms.

The annual benefits are also estimated based on anticipated revenues. These amounts will vary and may not all achieve the estimated levels. The benefits include $35,700 for the value of nutrients. Some (but not all) of this value was captured without the digestion system.

A manure treatment and handling system that returns $350/milking cow/year to the farm is remarkable. Meeting environmental goals and achieving a profit is the type of system that all farms should strive for.

Dryer Operation

The complete mix anaerobic digester produces more biogas than the engine generator set can use. Because of the amount of biogas that was wasted Matlink Dairy Farms has started a partnership to produce a rice hull and whey product. The whey and rice hulls are fed into an industrial biogas dryer. The end product from the drying system is 40% moisture and could be used as an animal feed. The partnership provides approximately $100,000/year income for the dairy.

By-Products: Liquids and Solids

After digestion, the treated slurry at 5.5% total solids is pumped to a screw press separator. The separated solids are transferred to a composting area. The separated liquids flow to a 4.5 million gallon earthen manure storage. The separated solids have physical characteristics much like moist peat moss, with a dry matter content of 28%, a pH of 8+, essentially devoid of weed seeds, rich in mineralized nutrients, and the odor of moist earth. The solids are turned two times over a 3-day period in the lower part of the separator building, achieving temperatures of 150^{o}F or more. Approximately 65% of the solids are used on the farm for bedding in the dairy freestall barn; the remaining solids are sold at $5/yard and generate revenue of $500/month. The stored separated liquids are spread on fields by a 4000-gallon tank spreader or distributed through a pipeline system and big gun irrigation system to fertilize the cropland. The treated, odorless manure can be spread during the growing season without disturbing the community. Spreading during the growing season minimizes movement of the nutrients off the field because the fields are dryer. The nutrients are also readily available for crop uptake with out being subject to runoff or leaching losses.

Nutrients

Table 2 lists the average concentrations of 3 sampling events for various constituents in the digester. If you make the assumption that the food waste and dairy manure weight the same as water the daily weights are 25,000 lbs and 113,000 lbs respectively. The concentrations listed in the table indicate that Matlink Dairy Farm is receiving $200,000 / year to treat 9% more phosphorous and 11% more nitrogen. This does not cause any strain on their nutrient management plan.

Table 2: Nutrient Concentrations from 3 sampling events at Matlink Dairy Farm

Location	F. Coli	Volatile Acids	Dissolved COD	COD	NH_3	TKN	Total Phos.	Ortho Phos.	Total Solids	Total Volatile Solids	pH
	CFU/Gram	mg/Kg	mg/L	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	%	%	Std. units
Raw Manure	323,000	2,172	36,715	144,904	1,622	3,828	865	546	11.10	86.23	6.82
Food Waste	< 2	2,843	43,918	575,268	440	2,274	398	192	17.6	97.30	3.72
Digester Effluent	10,667	419	15,210	63,074	1,574	3,361	597	412	5.60	77.97	7.54
Separated Liquids	3,900		18,353	64,700	1,601	3,379	696	404	5.07	76.67	7.69
Separated Solids	1,800		15,910	198,979	1,501	4,796	1,385	723	28.97	91.13	8.72

Conclusions

Since the installation of the anaerobic digester system on Matlink Dairy Farm, the odor from manure handling and spreading has been greatly reduced. The manure nutrients are better controlled and distributed. Manure pathogens such as fecal coliform are also reduced by the treatment system, initial sampling indicates a 1.5 log reduction. The food industries benefit by having their waste processed in a dependable, inexpensive, and environmentally sound manner. The community benefits from the economic activity, the reduced odors, and the lower nutrient loss to the ground water. The farm gains environmentally, economically, and in community acceptance. This process may not be able to be repeated without the cooperation of the community, the utility, the food plants, the regulators, and the design engineers and with the coordination and desire of the farm managers.

Notice

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Historical Perspective On Anaerobic Digester Conservation Practice Standards

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Background

NRCS has been involved with anaerobic digestion technology through the AgStar Program since October of 1993. That was the date an MOU was signed by representatives of EPA, DOE, and USDA to cooperate in development of information about and promotion of the use of anaerobic digesters on operating farms through the AgStar Program. The AgStar Program was initially developed by EPA in response to the Clinton Administration's Global Climate Change Action Plan. The primary purpose of the program was reduction of greenhouse gas emissions, with a secondary purpose of renewable energy production.

One of the activities carried out through AgStar was development of a handbook describing the technology for on-farm use and providing a method including software (Farmware) for feasibility evaluation. As part of that process, three draft digester standards were developed and included in Appendix F of the AgStar Handbook. Those standards were: Covered Anaerobic Lagoon; Complete Mix Digester; and Plug Flow Digester.

Prior to a NRCS reorganization in 1995, national interim standards were developed and issued for evolving technologies. The intent was to issue the three digester standards as national interims. The Covered Anaerobic Lagoon standard was, in fact, issued as a national interim, while work continued on the other two. Following the 1995 NRCS reorganization, the National Standards Subcommittee of the National Field Office Technical Guide (FOTG) Committee made the decision that there would be no national interim practice standards. States, however, could still issue state interim standards. About the time of that decision, work was being done on the Barham Farms AgStar Demonstration Project where a Covered Anaerobic Lagoon was installed. Operational difficulties were encountered with the digester so the national interim standard for that practice was rescinded and the information contained therein was included in Appendix F of the AgStar Handbook as "standard guidance". The information for Complete Mix Digesters and Plug Flow Digesters was also included in that format. State NRCS offices were advised by letter that they could adapt the guidance information as a state interim standard in the event they had the need for installation of an anaerobic digester system. Lee Saele, at that time the NRCS AgStar Engineer headquartered in Raleigh, NC, continued to gather data and work on the completion of national standards for anaerobic digesters.

NRCS Practice Standards Development Process

In order to understand the evolution of the digester standards, a description of the NRCS standards development process is in order. Typically a first draft of a practice standard is done by a team of NRCS employees who are familiar with and have installed the practice through a state interim standard. Once the first draft is complete, it is posted on a NRCS server for a period of 45 days for internal comment by NRCS personnel nationwide. At the end of the 45 day period, all comments received are submitted to the development team leader for consideration. If the comments received would result in substantial changes to the standard, appropriate changes are made and the standard reposted to the NRCS server for a second 45 day comment period. This process may occur up to three times.

Once all comments received through the final internal comment period have been considered and addressed, the standard is posted to the Federal Register for a 30 day comment period. All comments received during that period are reviewed and given serious consideration. Once those comments have been addressed, the final version of the standard is reviewed and approved by the national discipline leader responsible for that practice (each practice standard is assigned to a national discipline leader as outlined in Section IV of the NRCS FOTG) then issued by a National Handbook of Conservation Practice (NHCP) notice. NRCS personnel in each state where the practice will be utilized then adapt it for use in that state.

Current Digester Standards

As previously mentioned, data continued to be gathered for development of national standards. As the development process proceeded and NRCS personnel nationwide provided input, the names of the standards changed several times. Ultimately two digester standards: Anaerobic Digester – Ambient Temperature (365); and Anaerobic Digester – Controlled Temperature (366); and a supporting cover standard: Waste Facility Cover (367) were developed. Criteria for the cover was originally included in the digester standards, but was subsequently developed into a separate standard as a result of comments received from NRCS personnel who suggested use of covers was needed for purposes other than biogas capture.

A significant amount of external input (from EPA, land grant university personnel, private consultants, etc.) was obtained during the development process prior to posting the standards to the Federal Register on April 29, 2003. The comment period closed on Thursday, May 29, 2003. Comments received have, for the most part, been incorporated into the version of the standards that Lee Saele will cover in this session. Standards will be issued by a NHCP notice in the near future and should be available for state adaptation and use no later than July 15, 2003.

The Manure Management Challenge

Remarks by Bruce I. Knight, Chief
Natural Resources Conservation Service, at
"Anaerobic Digester Technology Applications
in Animal Agriculture – A National Summit"
Raleigh, NC, June 3, 2003

Thank you, and good morning.

I'm here today for the same reason most of you are: the traditional ways of handling manure simply aren't enough any more.

I am a second generation livestock operator from South Dakota. I grew up knowing about manure from our cow-calf operations. I remember the days when most of us could just pile up the manure in some convenient spot and spread it on the land when it was convenient.

But, for most of the industry, those days were gone decades ago. Nutrient loads in our nation's waters began to climb. People around the country started to demand cleaner water. Industries weren't doing enough to meet people's expectations, so the Federal government stepped in with clean water regulations.

These regulations, coupled with larger feeding operations, mean that a lot of us have more manure than we can put on the land.

Today, manure management is a challenge. We can't just pile it up and store it the way my Dad did. We have to build and manage a proper facility. And we have to be on the look-out for ways to maximize the value of manure as a source of fertilizer, energy, and other value-added products.

Most of us believe in doing the job right to protect our natural resources. The challenge is to get the job done in the context of maintaining our profitability. For many of us, the water quality problem has been pretty much under control for quite a while now. Success with regard to water quality may have led us to think we had solved the manure management challenge.

But as Bob Dylan wrote 40 years ago – "The times they are a-changin'." The sons -- and the daughters -- of the folks who expected cleaner **water** now expect cleaner **air** as well.

Heavy industry had to start making its contribution to cleaner air long ago. The effects of industrial production were largely urban and obvious to everyone. But voluntary actions in heavy industry did not meet people's expectations, and regulations followed.

Now, attention is moving to agriculture and other diffuse sources. People expect more of agriculture, including livestock and poultry operations, all the time.

Some of these expectations are related to odor. People who live downwind from us want cleaner smelling air and there are more of those people every year as our cities and suburbs grow outward from city centers to meet our farms and ranches. In real estate they say only three things matter: location, location, and location. The same can be said for living downwind of an improperly managed livestock or poultry operation.

Other expectations are related to greenhouse gases and climate change. People want all industries, including agriculture, to do their part to limit greenhouse gas emissions. In some cases, agriculture has not taken action fast enough, and regulation remains a possibility.

Indeed, some regulation is **already here**, for example, EPA's Revised CAFO Rule that addresses water quality.

And, some regulation is **being considered**. Based on a 2003 National Academy of Sciences report, EPA is looking to define feasible regulations on air emissions from animal feeding operations.

These new and potential regulations are ways we can see that the old methods for handling manure aren't enough. That's why it's time to look at additional technologies, such as anaerobic digesters.

And what a great alternative digesters are -- a relatively efficient way to treat manure, while virtually eliminating objectionable odors and the loss of greenhouse gases.

Voluntary Versus Regulatory

You probably noticed that I have described a recurring scenario: people develop expectations, voluntary action does not keep pace, and regulation follows. But that is not the only possible scenario – nor do I think it is the best one.

Regulation is not the best scenario because it can have unintended consequences: compliance raises the cost of production; production moves state-to-state, region-to-region, or country-to-country to avoid these costs; geographic areas with lots of regulation lose economically, the environment loses because production takes place in localities with lower standards.

We have already seen some of these results in the livestock and poultry industries.
I don't like these results, and I'm sure most of you don't, either.

I'm in the livestock business to make money. I stay in the livestock business because I love it. I also love South Dakota. Losing my business to another country or moving my business to another country are not options I want to contemplate.

So, what is the other scenario? People develop an expectation, industry, government, and others develop market-based incentives for voluntary action, America has cleaner water and cleaner air, producers earn a profit, production stays in America, and everybody wins.

In the regulatory scenario, society demands environmental improvements, and the producer bears the costs.

In the voluntary scenario, the market helps the producer recoup his or her costs.

Anaerobic digesters can play a role in either scenario. Either way, digesters help to control odors, reduce greenhouse gas emissions, and provide a rich nutrient source with reduced pathogens.

I hope that today and tomorrow we will see ways in which anaerobic digesters can provide these benefits within the context of an overall comprehensive nutrient management plan, supported by a system of market-based voluntary incentives for reaching our nation's conservation goals.

Making Digesters Viable

Digester technology is not new. Digesters have been around for decades, and several countries in Europe are making extensive use of them. In this country, installation of on-farm digesters is not generally accepted as being economically feasible.

What is relatively new, is the idea that America needs to rely more on digester technology to reach its environmental goals. For this idea to become a reality, we must meet three conditions:

1. Digesters must be inexpensive and reliable enough to make economic sense in more operations.

2. We must have viable markets for the products of digestion.

3. We must have incentives to bring down the cost to producers and to launch the technology.

Incentives

First, let's look at incentives. One thing NRCS does is administer USDA's incentive programs for conservation. As you know, the 2002 farm bill includes an increase of $18.5 billion for conservation, which opens up many more options for many more producers. The farm bill also places more emphasis on livestock and poultry operations, which is good news for all of you.

Our single largest program for conservation on working lands is the Environmental Quality Incentives Program, or EQIP, with $9 billion to invest over ten years. Sixty percent of this investment is designated for livestock and poultry environmental stewardship. You might say we are well **EQUIPPED** to offer incentives.

There are a few instances where we've used EQIP or other programs over the past several years to help producers with part of the costs of digesters, but we've had to use fairly general conservation practice standards to cover this kind of work.

Today, during our lunch break, we will unveil three new conservation practice standards specifically for digesters. These are performance standards that lay out expectations for the performance of the technology but do not prescribe or endorse a particular vendor's product.

One of the standards is for manure facility covers for new lagoons and to retrofit existing lagoons. The second standard is to build new ambient temperature digesters. The third standard is to build new controlled temperature digesters.

These standards were published April 29 in the Federal Register. The comment period ended on May 29. I hope many of you took the opportunity to make your views known. We will incorporate the comments and publish final conservation practice standards as soon as we can. Then they will be available on-line in our electronic Field Office Technical Guide.

These new standards will have two major benefits. They will make it easier for producers to fit anaerobic digesters into their EQIP contracts as part of a comprehensive nutrient management plan. And, they will make it easier for producers to use technical service providers to plan and construct digesters.

As you may know, NRCS will be working much more with technical service providers to deliver conservation assistance to producers. For digesters, this means engineering consultants and consulting firms. We are talking with some of the professional engineering societies about memorandums of understanding that will allow us to certify members of these societies as technical service providers.

We have set aside $20 million this year for the use of technical service providers. With these technical standards in place, digesters will be an ideal practice for technical service providers with this expertise.

We weigh EQIP applications against national, State, and local priorities. The good news for potential digester builders is that both air quality and water quality are national priorities.

States also set priorities, so the priority for digesters may vary from State to State. I hope some of you have been involved with your State Technical Committee to make sure digesters received adequate consideration in setting State priorities. If you don't think your State priorities reflect the resource needs in your State, you should work more closely with the State Technical Committee to make sure your views are known.

Another way to make your views known is to comment on our National Animal Agriculture Conservation Framework. The National Framework is based on State Frameworks developed earlier this year. The national Framework will help livestock and poultry industries meet their regulatory challenges, improve environmental performance, and maintain economically viable operations. We will be publishing the national Framework within a few weeks and soliciting public comments.

State Conservationists also set the cost-share rates within their states. We have a backlog of applications for all our major conservation programs, so it is important that we use cost-share rates properly as incentives, not as entitlements.

To promote equity across States and regions, we are requiring that State Conservationists sign off on cost share lists that include practices with rates of over 50 percent and Regional Conservationists sign off on contracts larger than $100,000. These policies are not intended to prohibit higher cost-share rates or larger contracts. Only to give everyone a chance at participating and encourage fiscal responsibility.

Again, if you think the cost-share rates and contract sizes are not conducive to meeting the needs in your State, you should work closely with the State Technical Committee to make sure your views receive full consideration.

USDA also is supporting activities in the areas of biomass and bioenergy. Farmers and ranchers are eligible for loan guarantees for renewable energy systems, including anaerobic digesters under the Rural Business and Industry Programs administered by Rural Development. Loans can be for farm- or ranch-level systems or to buy stock in cooperatives established to process agricultural commodities.

Also, USDA is funding Biomass Research and Development, including demonstration projects, with $14 million this year through 2007. A request for proposals was published in March, with proposals due the middle of May.

So, we are in pretty good shape for incentives. One of the three conditions for widespread use of digesters is being met. But incentives would go farther if the other two conditions were being met: if digesters cost less and if there was a better market for the products of digestion.

Costs

Now, let’s look at cost issues. Digesters are not cheap, and the technology needed to capture the energy from a digester drives up the cost even more.

EQIP can help meet these costs. Our maximum contract size under EQIP is $450,000, but we cannot offer many contracts that large and still meet the needs of enough producers. The sale or use of value-added products from digestion also can help producers cover the costs of installing digesters.

But helping meet the costs is not enough. We also need to bring down the total cost of digesters, both large and small, to make this technology affordable for more and more producers. The cost and efficiency of digesters reminds me of the ethanol industry 20 years ago.

Bringing down the cost involves technology, production, experience, and installation variables, which are things entrepreneurs, universities, and corporations can help with. We are relying on you. I know that the formula that made ethanol cost competitive can do the same for digesters.

Markets

In terms of markets, there is much to be done. The fact is, there are fewer than 300 digesters now being used in agriculture in this country to produce usable energy – as opposed to burning off gases. If there were better markets, that number could be in the tens of thousands.

The collected biogas from anaerobic digesters is typically 60-70 percent methane, which is a valuable energy resource. The challenge is to build a market for this methane.

We are not far enough along in being able to market the effluent from digesters. Effluent from the digester process is a valuable source of nitrogen that can improve our agricultural productivity. It also is low in pathogens.

To maximize this market, we need to do two things.

The first is feed management -- particularly in the beef and dairy industries -- to produce a product that is better balanced in nutrients. For example, many farms that fertilize with today's manure are maxing out on phosphorus, limiting the amount of manure they can apply. Feed management will produce effluent that is more useful on-farm.

The second is to improve the economics of manure management in holistic ways that take into account all costs, including production, storage, and transportation of the marketable products of digestion, be they methane or effluent.

Developments in all these areas will help make it profitable to manage manure.

Producers need to work closely with their local utility regulators to make them aware of barriers to creating markets for electricity generated using products of digestion. Working together with utility companies themselves also can build markets. One example is the plan in Oregon to build centrally located generators, with the utility company brokering the hauling and disposal of solids.

Today, we have a new era of cooperation between EPA, USDA, and others to create a Federal regulatory environment that takes into account both environmental needs and the economic realities of agricultural production. The new CAFO rule is an example of this cooperation.

Producers and producer organizations need to work at the State level to help create this same kind of cooperation.

Conclusion

This summit is going to be exciting.

I am sure we will hear a lot about what the various presenters are doing to help anaerobic digester technology take its place in the conservation arena, including

- Developments in digester technology that will bring down both the cost of digesters and the cost of associated technologies to capture and use the products of digestion.

- Development of markets for these products of digestion, through development of private sector partnerships,
-
- Creation of a flexible, business friendly regulatory environment and closer cooperation between government and the private sector.

- And, finally, appropriate use of incentives, direct and indirect, to help producers recoup some of the costs of producing clean air and clean water.

Success in these areas is not just desirable, it is essential. Essential to creating the kind of voluntary, market-based approach to air and water quality that we need.

We have 250 million dry tons of manure a year out there to use properly, and a public that is increasingly intolerant of degraded air and water quality. If we producers and others don't put our heads together and manage manure through the voluntary approach, then we will have to live with the possibility of greater regulatory influence. And that is a future I think we would all like to avoid.

Thank you.

Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs (2003)

A Summary presented by Richard Kohn

(From the National Academy Press http://books.nap.edu)

Public concerns about the environmental effects and, to a lesser extend, the possible health effects of air emissions from animal feeding operations have grown with the increasing size and geographic concentration of these operations. This intensification has been driven by the economies of domestic and export markets for meat, poultry, milk, and eggs. Public concerns have also grown as the population, both exurbanites and expanding urban centers, have moved into what had been largely rural farming areas. Objectionable odors from AFOs are a significant concern not only to the new residents in these areas, but also to many long-time residents.

Prompted by legislation, especially the Clean Air Act (CAA), as well as by public concerns, the U.S. Environmental Protection Agency (EPA) has been considering what information is needed to define and support feasible regulation of air emissions from AFOs. At the same time, the U.S. Department of Agriculture (USDA) has been using its authority to aid farmers in mitigating the effects of air emissions with modified agricultural practices. Acting jointly, these two agencies scientific information needed to address these issues. A 16-person *ad hoc* committee was appointed, the Committee on Air Emissions from Animal Feeding Operations, which has been guided by a Statement of Task that was agreed upon by the National Academies and the sponsoring agencies (Appendix A).

The statement of Task directed the committee to:

- review and evaluate the scientific basis for estimating the emissions to the atmosphere of various specified substance from confined livestock and poultry operations;
- review the characteristics of the agricultural animal industries, methods for measuring and estimating air emissions, and potential best management practices for mitigating emissions;
- evaluate confined animal feeding production systems in terms of biologic systems and;
- identify critical short and long-term research needs and recommend methodology and modeling approaches for estimating and measuring air emissions and potential mitigation technologies.

FINDINGS AND RECOMMENDATIONS

FINDING 1. Much confusion exists about the use of the term “animal unit” because EPA and USDA define animal unit differently.

RECOMMENDATION: Both EPA and USDA should agree to define animal unit in terms of animal live weight rather than as arbitrary definition of animal unit.

FINDING 2. Air emissions from animal feeding operations are of varying concerns at different spatial scales.

RECOMMENDATION: These differing effects, concentrations, and spatial distributions lead to a logical plan of action for establishing research priorities to provide detailed scientific information on the contributions of AFO emissions to potential effects and the subsequent implementation of control measures. USDA and EPA should first focus their efforts on the measurement and control of those emissions of major concern.

FINDING 3. Measurement protocols, control strategies, and management technologies must be emission and scale specific.

RECOMMENDATIONS:

- For air emissions important on a global or national scale (i.e., ammonia and the greenhouse gases methane and nitrous oxide), the aim is to control emissions per unit of production (kilograms of food produced) rather than emissions per farm. Where the environmental and health benefits outweigh the costs of mitigation it is important to decrease aggregate emissions. In some geographic regions, aggregate emission goals may limit the number of animal produced in those regions.
- For air emissions important on a local scale (hydrogen sulfide, particulate matter [PM], and odor), the aim is to control ambient concentrations at the farm boundary and/or nearest occupied dwelling. Standards applicable to the farm boundary and/or nearest occupied dwelling must be developed.
- Monitoring should be conducted to measure concentrations of air pollutants of possible health concerns at times when they are likely to be highest and in places where the densities of animals and humans, and typical meteorological conditions, are likely to result in the highest degree of human exposure.

FINDING 4. There is a general paucity of credible scientific information on the effects of mitigation technologies on concentrations, rates, and fates of air emissions from AFOs. However, the implementation of technically and economically feasible management practices (e.g., manure incorporation into soil) designed to decrease emissions should not be delayed.

RECOMMENDATION: Best management practices (BMPs) aimed at mitigating AFO air emissions should continue to be improved and applied as new information is developed on the character, amount, and dispersion of those air emissions, and on their health and environmental effects. A systems analysis should include impacts of a BMP on other parts of the entire system.

FINDING 5. Standardized methodologies for odor measurement have not been adopted in the United States.

RECOMMENDATIONS:

- Standardized methodology should be developed in the United States for objective measurement technologies of odors to correspond to subjective human response.
- A Standardized unit of measurement of odor concentration should be adopted in the United States.

FINDING 6. The complexities of various kinds of air emissions and the temporal and special scales of their distribution make direct measurement at the Individual farm level Impractical other than in a research setting. Research into the application of advanced three-dimensional modeling technologies accounting for transport over complex terrain under thermodynamically stable and unstable planetary boundary layer (PSL) conditions offers good possibilities for improving emissions estimates from AFOs.

RECOMMENDATION: EPA should develop and carry out one or more intensive field campaigns in evaluate the extent to which ambient atmospheric concentrations of the various species of interest are consistent with estimated emissions and to understand how transport and chemical dynamics shape the local and regional distribution of those species.

FINDING 7. Scientifically sound and practical protocols for measuring air concentrations, emission rates, and fates are needed for the various elements (nitrogen, carbon, sulfur), compounds (e.g. ammonia and particulate matter).

RECOMMENDATIONS:

- Reliable and accurate calibration standards should be developed, particularly for ammonia.
- Standardized sampling and compositional analysis technologies should be provided for PM, odor, and their individual components.
- The accuracy and precision of analytical technologies for ammonia and odor should be determined, including intercomparisons as controlled (i.e., synthetic) and ambient air.

FINDING 8. Estimating air emissions from AFOs by multiplying the number of animal units by existing emissions factors is not appropriate from most substances.

RECOMMENDATION: The science for estimating air emissions from individual AFOs should be strengthened to provide a broadly recognized and acceptable basis for regulations and management programs aimed at mitigating the effects of air emissions.

FINDING 9. Use of process-based modeling will help provide scientifically sound estimates of air emissions from AFOs for use in regulatory and management programs.

RECOMMENDATIONS:

- EPA and USDA should use process-based mathematical models with mass balance constraints for nitrogen-containing compounds, methane, and hydrogen sulfide to identify, estimate, and guide management changes that decrease emissions for regulatory and management programs.
- EPA and USDA should investigate the potential use of a process-based model to estimate mass emissions of odorous compounds and potential management strategies to decrease their impacts.
- EPA and USDA should commit resources and adopt current or adopt new programs to fill identified gaps in research to improve mathematical process-based models to increase the accuracy and simplicity of measuring and predicting emissions from AFOs.

FINDING 10. A systems approach, which integrates animal and crop production systems both on and off (imported feeds and exported manure) the AFO, is necessary to evaluate air emissions from the total animal production systems.

RECOMMENDATIONS: Regulatory and management programs to decrease air emissions should be integrated with other environmental (e.g. water quality) and economic consideration to optimize public benefits.

FINDING 11. Nitrogen emissions from AFOs and total animal production systems are substantial and can be quantified and documented on an annual basis. Measurements and estimates of individual nitrogen species components (i.e., molecular nitrogen) should be made in the context of total nitrogen losses.

RECOMMENDATION: Control strategies aimed at decreasing emissions of reactive nitrogen compounds from total animal production systems should be designed and implemented now. Those strategies can include both performance standards based on individual farm calculations of nitrogen balance and technology standards to decrease total system emissions of reactive nitrogen compounds by quantifiable amounts.

FINDING 12. USDA and EPA have not devoted the necessary financial or technological resources to estimate air emissions from AFOs and develop mitigation technologies. The scientific knowledge needed to guide regulatory and management actions requires close cooperation between the major federal agencies (EPA and USDA), the states, industry and environmental interests, and the research community, including universities.

RECOMMENDATIONS:

- EPA and USDA should cooperate in forming a continuing research coordinating council (1) to develop a national research agenda on issues related to air emissions from AFOs in the context of animal production systems and (2) to provide oversight on the implementation of this agenda. This council should include representatives of EPA and USDA, the research community, and other relevant interests. It should have authority to advise on research priorities and funding.
- Exchanges of personnel among the relevant agencies should be promoted to encourage efficient use of personnel, broadened understanding of the issues, USDA and EPA should initiate and conduct a coordinated research program designed to produce a scientifically sound basis for measuring and estimating air emissions from AFOs on local, regional, and national scales.
- For the long term, USDA, EPA, and other relevant organizations should conduct coordinated research to determine which emissions (to water and air) from animal production systems are most harmful to the environmental and human health, and to develop technologies that decrease their releases into the environment. The overall research programs should include research to optimize inputs to AFOs, optimize recycling of materials, and significantly decrease releases to the environment.

FINDINGS 13. Settling priorities for both short-term and long-term research on estimating air-emissions rates, concentrations, and dispersion requires weighing the potential severity of adverse impacts, the extent of current scientific knowledge about them, the potential for advancing scientific knowledge, and the potential for developing successful mitigation and control strategies.

RECOMMENDATIONS:

- Short-term research priorities should improve estimates of emissions from individual AFOs including the effects of different control technologies.
- Priority research for emissions important on a local scale should be conducted on odor, PM and hydrogen sulfide.
- Priority research for emissions important on regional, national, and global scales should be conducted on ammonia, N_2O, and methane.
- Long-term research priorities should improve understanding of animal production systems and lead to developmental of new control technologies.

SUMMARY

These findings and recommendations, taken together, point to two major changes in direction for improving the basic information needed for dealing with the adverse effects of air emissions from AFOs. One is to replace the current emission factor approach for estimating and tracking the rates and fates of air emissions using a process-based modeling approach with mass balance constraints. The second is to initiate a substantial long-term research program on the overall system of producing food from animal feeding operations with the goal of eliminating the release of undesirable air and other emissions into the environment.

Facing the need for defensible information on air emissions from AFOs, in a timely manner, is a major challenge for EPA and USDA. Neither has yet addressed the need for this information in defining high-priority research programs. Each has pursued its regulatory and farm management programs under the assumption that the best currently available information can be used to implement in program goals.

The scope and complexity of the information needed by these agencies, as well as the potential environmental impacts of air emissions from AFOs, require a concentrated, focused, and well-funded research effort. Such an effort is described in this report.

Abstract for Paper:

Inland Empire's Regional Plant #5 Anaerobic Digester for Dairy Waste: Comparative Performance and Concepts for Improvement

Glen Lindgren – CH2M HILL, John Gundlach - Inland Empire Utilities Agency, Fred Soroushian, William Kitto – CH2M HILL

The anaerobic digester installed at Inland Empire's Regional Treatment Plant #5 (RP-5) is one of the largest plug-flow design anaerobic digesters for dairy waste in the world, and the only one in the U.S. that operates as a centralized facility, taking in manure slurry from several local dairies in the Chino Valley area. The digester installation was designed by Synagro Technologies Inc. This facility started up in 2002, and has learned a number of operational lessons as production has stabilized. In early 2003, the unit was steadily producing 120,000 – 180,000 cubic feet per day (cfd) of biogas with manure input varying between 30% and 90% of maximum. It runs in a mesophilic temperature range around 90 – 95 degrees Fahrenheit.

The paper examines the performance of the RP-5 digester along several technical and financial parameters, and compares it against similar tabulated and graphed data for other digester systems of similar design. Plug-flow and complete-mix units (on-farm units) in the U.S. are considered, as well as large, centralized complete-mix digester operations in Denmark, where the regional digester concept for agricultural waste has been pioneered and applied successfully. Lessons learned from various comparable case studies, and their application to the conditions at RP-5 are described.

The paper further considers several concepts for upgrading the RP-5 facility, to leave it as a plug flow digester, to modify it to a mixed digester, and to add a mixed, thermophilic phase to make a combination thermophilic-mesophilic design. Technical merits, environmental benefits, and system life-cycle costs, revenues, and savings are analyzed. A financial analysis is presented with recommendations for the best alternative course of action.

ANAEROBIC DIGESTERS AT DAIRIES IN COLD CLIMATES

Richard Mattocks, Principal, Environomics[1]
Mark Moser, Principal, RCM Digesters, Inc.

ABSTRACT

Farmer motivation for building and operating an anaerobic digester includes electricity production, heat production, manure treatment cost savings, nutrient conversion, odor and pathogen control, and byproduct recovery. There is concern for the reliability of these systems in cold climates. Keys to success in cold climates are reviewed. Properly designed units can recover excess heat from engine generators for building, floor and space heat. Commercial scale heated dairy plug flow digesters operating in NY, WI, MN and IL are presented. The only commercial scale mixed dairy and industrial waste digester operating in the US is described. The mixed waste digester is producing 250,000 ft3 of gas a day, which is 400% of the cow manure biogas potential. All systems meet Natural Resources Conservation Service draft standards. System installation and operation are described. A summary table to allow comparisons of costs and benefits is presented. Biogas recovery and use in boilers or engine-generators is discussed for each farm. Anaerobic digesters operate successfully in cold climates and are economically viable for dairy farms.

KEYWORDS

Dairy, cow, manure, residuals management, biogas, methane, odor, anaerobic digestion, digester, plug flow digester, complete mix digester, nutrient management, pathogens, weedseeds, Environomics, RCM Digesters, Inc.

INTRODUCTION

Anaerobic digestion is more extensively used outside of the US where treatment of animal waste has been a concern for a longer time. An anaerobic digester is a vessel designed to retain decomposing manure for a sufficient time at the designed operating temperature to allow the growth of methanogenic bacteria in a “steady-state”. The bacteria grow without oxygen, decompose the waste, and produce methane as a useable fuel byproduct.

Low ambient temperatures impact manure digestion systems and have the potential for impeding performance. Cold weather system designs will ameliorate the impact of ambient temperature. Several digesters have been operated in US cold climates utilizing these design features. In reviewing operating cold climate digesters, system performance is found to be minimally effected when adequate design precautions are taken.

AgSTAR is a voluntary program sponsored by the US Environmental Protection Agency (EPA), the US Department of Agriculture - Natural Resources Conservation Service (NRCS) and the US

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Department of Energy (DOE), to encourage methane capture as a part of manure management. Since 1996, AgSTAR provided technical support to 14 AgSTAR Partner farms that were developing anaerobic digester systems. Several of the digesters reported here were constructed with AgSTAR assistance. All of the 14 AgSTAR digesters were designed by RCM Digesters.

BENEFITS OF DIGESTION SYSTEMS

Farmer's are motivated to build and operate anaerobic digesters due to their inherent benefits including electricity production, heat production, manure treatment cost savings, nutrient conversion, odor and pathogen control, and byproduct recovery. Traditionally, animal production facilities have used their manure digestion facilities as a means to produce electricity, offsetting electric bills, and selling surplus power to their utility. Methane rich biogas from the digesters may also be used to fire boilers, produce hot water for space heating or to meet process heat requirements. Properly designed units can recover excess heat from engine generators for building, floor and space heating

In recent years, digesters have been installed to reduce the odor associated with manure. Naturally occurring organisms in the digester, use the organic material in manure as a substrate for growth. Odor reduction is often in the 90% to 95% range with a properly designed and operated manure methane digester.

A digester is the only treatment system that will pay for itself. An anaerobic digestion system achieves odor reduction as does an aerobic/oxidation system. However, an anaerobic digestion system also produces energy from the treatment process (by generating methane usable as a fuel) whereas aerobic systems consume electrical energy.

Suspended solids may be recovered from raw untreated manure for use as animal bedding or as an ingredient in a soil mix. Usually, additional treatment by chemicals or composting is required to make the raw fiber acceptable for these uses. Suspended solids recovered from anaerobically digested manure have been successfully used for animal bedding with little additional processing. Also when left to compost, the digested solids heat much faster than is customary with raw recovered fiber.

During the digestion process, manure nutrients are "premineralized" in the controlled environment of the digester. Typically, nutrients in raw or incompletely treated manure are made available to soil borne organisms with growth and metabolic rates dependent on ambient temperature. These same nutrients are premineralized in the digester, making them more readily available for plant uptake.

Pathogenic organisms are greatly reduced in a digester. The reduction is observed to be in excess of 99% for fecal indicator organisms. Weedseeds are also observed to be greatly reduced, though the decimation rate is not known. There is also a significant reduction in the number of flies in waste management facilities handling digested manure.

Manure viscosity goes down during the digestion process. Therefore, less power is required to pump or push digested manure through pipelines and irrigation systems.

DIGESTION SYSTEM COMPONENTS

Manure digestion systems consist of 5 subsystems:

1. Mix tank,
2. Digester,
3. Effluent tank,
4. Solids separation,
5. Energy conversion.

Manure is removed from barns and holding areas, frequently with rubber tire “skid steer” tractors with scrapers/buckets, or by mechanical scrapers on chain, cables or metal straps. Manure is placed in a holding tank where it is mixed prior to introduction into the digester. Typically the holding tank has a capacity for 2 or more days. After mixing, the manure is pumped into the digestion vessel, usually sized for about a 20 day manure retention time. The digester is heated, permitting year around bacterial action on organic material in the manure. Manure from a barn cleaned mechanically is typically treated in a “plug flow” digester. Manure collected by “flushing” with water and diluted to 3-8% total solids is treated in a “complete mix” digester. Treated manure is collected in an effluent storage tank, frequently sized for a minimum of 2 days of storage. This effluent is pumped to solids separation equipment, frequently a screw press or a screen separator. Solids are collected and stored or used, liquid is placed in a longer term storage facility. Gas from the digester is pressurized and introduced to a boiler or an engine with an attached generator.

KEYS TO SUCCESSFUL COLD WEATHER OPERATIONS

The digestion system is sensitive to cold temperature and must be designed accordingly. In reviewing successful cold climate digesters, there are found to be certain keys to their successful and reliable operation.

1. <u>Manure Collection</u>
   Frozen manure is managed as a solid not as a liquid and may not be loaded into the digester. Any bypassed manure will neither contribute to energy production nor will it be treated. Fewer digester benefits will be realized in barns which are not constructed or managed to reduce the incidence of freezing.

2. <u>Thermal System Design</u>
   Heating is required to support the metabolic requirements of the anaerobic organisms. This heat may be supplied either by burning commercially available fuel, or biogas. In either case efficient combustion and heat recovery is desirable. Boiler and cogenerator design for maximum heat recovery will assure adequate quantities of heat to support the biological process in the digester.

3. <u>Digester Design</u>
   Digester design considers two basic heat requirements: bringing of incoming fresh manure to digester temperature, and replacement of heat lost through the digester walls, floor and roof. Important considerations are insulation of the digestion vessel and adequate sizing of the digester heating system.

4. Exposed Pipes
   Liquid will freeze in layers as it passes through pipes that have their wall exposed to winter ambient temperatures. Appropriate measures are to insulate pipes or enclose them in insulated structures.

COLD WEATHER DIGESTER INSTALLATIONS

Five commercial scale plug flow digesters and one commercial scale complete mix digester were built on farms in the northern cold climate regions of the United States. All are heated with hot water brought to temperature by burning biogas. A description of each follows as well as a summary table. Biogas recovery and use in boilers or engine-generators is also discussed for each farm:

New York	Minnesota
Matlink, Clymer	Haubenschild Dairy, Princeton
AA Dairy, Candor	
DDI Dairy, Homer	
Wisconsin	**Illinois**
Stencil Farms, Denmark	New Horizons, Elmsford

CLIMATE

Average temperatures (in degrees Fahrenheit) for six RCM cold weather digesters are noted. Of particular interest are the extremely cold January and February averages.

Winter Ambient Temperature for Six Cold Climate Digesters

Month	Matlink	AA	DDI	Haubenschild	Stencil	New Horizons
October	51.0	50.2	48.8	47.0	49.1	55.1
November	40.2	39.6	38.2	30.3	35.1	41.1
December	28.2	27.8	26.1	15.3	22.2	28.7
January	23.0	22.6	21.2	8.6	16.4	23.7
February	24.3	23.8	23.2	14.9	20.0	28.4
March	32.9	32.3	32.0	26.8	29.8	39.0
Winter Average	33.3	32.7	31.6	23.8	28.8	36.0
Annual Average	47.2	46.7	45.6	41.8	44.2	51.6

COMPLETE MIX DIGESTERS

Complete mix digesters are used to treat waste with 3 to 10% total solids and adequate volatile solids to produce enough biogas methane to maintain digester temperature

Matlink Dairy- 700 Head Dairy and Food Waste, Clymer, NY
The only commercial scale mixed dairy and industrial waste digester operating in the US is at

Matlink Dairy. The mixed waste digester is producing 250,000 ft3 of gas a day. This is 400% greater than what could be produced by dairy manure alone.

Matlink Dairy, Clymer NY

Matlink Dairy has 700 cows housed in 1 freestall barn. The system was designed for manure from the equivalent of 900 cows. Manure is collected continually with cable scrapers to a drop gutter. As much as 12,000 gallons of wastes from a food processor has been received daily including: breaded fish cooker sludge, juice and dairy pipe cleanout, and out of specification foods. Multiple years of seasonal odor episodes from the manure storage pond were not acceptable to downwind neighbors. Consequently, the farm chose RCM Digesters, Inc. to design an innovative, low cost, heated, mixed, concrete digester. The approximately 80' x 70' x 16' deep digester holds roughly 20 days of material.

The digester produces enough methane to fuel a 130 kW Waukesha engine generator set and a food waste dryer. A flare burns the unused biogas. Electricity generated offsets farm electrical requirements, with the utility purchasing the surplus. Cogen hot water maintains digester temperature, heats the calf barn and supplies heat to the barn space and floor heating. Stabilized digester effluent flows to the storage pond. The pond no longer emits odorous gases. The digester is able to accommodate the variation in manure and food waste loading rate.

The primary benefits to the owners are odor reduction of stored and field applied manure. A secondary benefit is the substantial reduction in electricity and natural gas purchases. There have been no odor complaints since the digester was installed and compliance investigations by state regulators have stopped. The digester started up in about 30 days switching to biogas from natural gas in November 2001. Within 5 hours of the placement of the digester top, biogas was being flared. The engine has been in operation about 95% of the time since startup.

PLUG FLOW DIGESTERS

Plug flow digesters are used to treat scraped manure (in the 11% to 13% total solids range) from dairies. Since 1997, several 1,000 cow digesters and larger have been built. Five have operated through a winter in areas of the US with extremely cold winters.

AA Dairy, Candor, New York - 1000 cow digester

AA Dairy Farm built and started up their 550 cow anaerobic digestion facility, complete with a boiler fired

AA Dairy, Candor, NY

system in October 1996. The digester is sized for future expansion. AgSTAR provided technical assistance in all phases of the project.

The digester has operated without problems and the engine has had occasional outages for repair. In total the generator is operating over 90% of the time. The system is currently operating at a capacity of 70 kW, as well as producing hot water and about $60/day of digested fiber. Odor has been controlled permitting the dairy to now spray irrigate treated manure, substantially reducing the cost of manure application.

Haubenschild Dairy, Princeton, Minnesota - 1000 cow digester

Haubenschild Dairy Farm started their digestion system September 1999 while populated with only 480 of their current 1,000 cows system. Biogas is being used to fuel a naturally aspirated Caterpillar 3406 engine, producing about 130 kW of power about 98% of the time since startup. Heat recovered from the cogen is supplied to maintain temperature in the digester, parlor, employee areas and the walk area of the newest barn. The dairy has chosen to wait to install a separator to recover solids for resale.


Haubenschild Dairy, Princeton, MN

The local utility, Eastern Electric, has been a promoter of and asset to the project. The project has been well received and promoted within the state, receiving numerous environmental awards.

Odor has been controlled and manure handling is much easier for the owner. The owner is of the opinion that there is a significant increase in nutrient value from the manure as a result of digestion.

Dairy Development International - Homer, NY 1000 cow digester

Dairy Development International (DDI) started up their 1000 cow digester in October 1999. Digested manure is passed through a screw press separator. DDI chose to introduce digester biogas directly into a boiler specifically designed for biogas. All dairy hot water needs are met by the biogas fired boiler. All barn floors are heated as are all office and employee areas. Digester heat also is supplied from the boiler. The plan is for DDI to install four Capstone turbines to produce electricity with biogas. Power produced in excess of the farm's needs will be sold to the utility.

The system was installed to reduce the


Dairy Development International, Homer, NY

odors associated with manure storage and land application. Few complaints have been received in spite of the dairy having been recently constructed in a neighborhood disinclined to its presence.

Stencil Farms – Denmark, WI - 1200 cow digester
Stencil Farm started their digestion system December 2001 while populated with only 1000 of their current 1,200 cows. Biogas has been used to fuel a naturally aspirated Caterpillar 3406 engine, producing about 130 kW of power about 95% of the time since startup. Heat recovered from the cogen is supplied to maintain temperature in the digester and employee areas. The dairy has a separator to recover solids for bedding.

Stencil Farms, Denmark, WI

The utility, Wisconsin Power has been an asset to the project

Stencil Farms installed the digester to improve the bedding quality of the recovered fiber. They had been bedding for more than 5 years with fiber recovered from raw manure. Since bedding with digested fiber, milk somatic cell and plate count values have been dramatically reduced, increasing milk bonuses for milk quality. Manure odor has been controlled and manure handling is much easier for the owner.

New Horizons Dairy – Elmwood, IL - 2400 cow digester
New Horizons started their digestion system in October 2002 while populated with only 1200 of the eventual 2400 cow capacity. Illinois' Attorney General pursued legal action against New Horizons under their previous name of Inwood Dairy, for odor and other related manure issues. The dairy was fined and ordered to redesign the facility. No further action has been taken since installation of the digester.

New Horizons, Elmwood IL

Thirty nine days after the digester was filled, the top was placed. The next day the flare was lit with full gas pressure. Five days later the engines were started on biogas. Biogas has been used to fuel two naturally aspirated Caterpillar 3406 engines, producing about 200 kW of power approximately 95% of the time since startup. Heat recovered from cogeneration is supplied to maintain temperature in the digester. The dairy has installed separators to recover solids for sale.

COST BENEFIT

Construction costs and benefits associated with six cold climate digesters are reported in the following table.

Costs and Benefits of Six Cold Climate Digesters

System	Start Date	Capital Cost	Electric Savings/sales $/Year	Hot Water Savings $/Year	Fiber Value $/Year
Haubenschild	1999	$335,000	$80,000	$20,000	No recovery
Stencil	2001	$450,000	$40,000	$15,000	$40,000
New Horizons	2002	$875,000	$100,000	$19,000	$60,000
AA Dairy	1997	$311,500	$40,000	-	$10,000
DDI	2001	$325,000	none	$30,000	$15,000
Matlink	2001	$625,000	$80,000	$15,000	$30,000

CONCLUSION

Six manure digestion systems have been installed in the cold climate regions of the US. Several have over three years of operating time. One system, AA Dairy in the Finger Lakes Region of Northern New York State, has been in operation since 1997. Manure has been treated in these systems almost continually from the beginning of their operation. Biogas has been used to fuel boilers and cogeneration systems. Electric purchases have been reduced, electric sales made, and fuel purchases for heating reduced. The success of these operations illustrates that anaerobic digesters can operate successfully in cold climates and are economically viable for dairy farms.

ACKNOWLEDGEMENTS

The EPA AgSTAR program initiated a program in the early 1990’s to construct full scale commercial manure digestion systems around the US. AgSTAR provided RCM Digester professional assistance to three of the installations reported here, AA Dairy, Haubenschild Farm and Matlink Dairy. Without the foresight of the AgSTAR program, there would not be the many digestion systems around the US for perspective digester owners to visit.

PARTNERING ARRANGEMENTS IN VERIFICATION PROGRAMS FOR INNOVATIVE TREATMENT TECHNOLOGIES

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The Greenhouse Gas (GHG) Technology Center, one of twelve centers operating under the U.S. EPA's Environmental Technology Verification (ETV) program, provides performance verification testing for innovative technologies in various greenhouse gas technology focus areas that include animal waste management and animal agriculture. The Center and its partner verification organization – Southern Research Institute – provide this information to GHG technology vendors, buyers, utilities, agencies, and others that have a need for the performance and emissions data. The Center develops test protocols, conducts field tests, collects and analyzes data, and reports findings. Performance evaluations are conducted according to a rigorous verification plan and established protocols for quality assurance to assure objective and systematic evaluation of innovative GHG technologies. The ETV program was created to accelerate the entrance of new technologies into the marketplace. This program can also provide economic assistance to companies seeking to verify their technology and have the results made public.

The GHG Center is currently in various testing phases of three projects seeking renewable energy from animal wastes. A 5,000-head swine farm in Lamar, CO, uses anaerobic digesters and an engine generator to produce electricity from methane-rich biogas created from the animal waste. A microturbine with heat recovery has also been installed. Performance and emissions data are being sought for the microturbine and engine. An additional test at this site will evaluate the use of biological reactants to accelerate biogas production from the anaerobic digesters and, subsequently, increase electricity generation at the farm. A third test will be conducted at a 700-head dairy farm in Homer, NY. Performance and emissions data will be sought for four microturbines fired with bio-fuel from the anaerobic digestion of manure. The test protocols and parameters will be discussed along with future work on these projects.

The GHG Center is seeking to expand testing activities in the animal waste industry. New and innovative technologies needing a third-party testing program, funding assistance from the EPA for testing, and a means for publishing the data (and putting it on the EPA's web site) would benefit from this program. A Stakeholder group consisting of industry experts, trade organizations, technology vendors and buyers, environmental technology finance groups, and government research organizations is being developed to help the Center develop strategic plans, establish credible technology evaluation strategies, review verification results, distribute results widely, and address regulatory issues.

KEYWORDS

innovative, verification, treatment technologies, greenhouse gas, economic, environmental, energy, power, emissions, testing, biomass, funding, Environmental Technology Verification (ETV) Program, stakeholder, EPA

1.0 BACKGROUND

The U.S. Environmental Protection Agency's Office of Research and Development (EPA-ORD) operates the Environmental Technology Verification (ETV) program to facilitate the deployment of innovative technologies through performance verification and information dissemination. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and innovative environmental technologies. Congress funds ETV in response to the belief that there are many viable environmental technologies that are not being used for the lack of credible third-party performance data. Technology buyers, financiers, and permitters in the United States and abroad can use the performance data developed under this program to make informed decisions regarding environmental technology purchase and use.

The Greenhouse Gas (GHG) Technology Center began operations in 1997 under a cooperative agreement with the U.S. EPA. The GHG Center is one of six verification Centers operating under the ETV program, and is the only Center focusing on technologies that produce, reduce, or monitor GHG emissions. The GHG Center locates promising GHG mitigation and monitoring technologies, subjects them to independent third-party performance testing, and distributes performance results to the public free of charge. Southern Research Institute (SRI), located in Research Triangle Park, NC, is the EPA's partner verification organization that manages the GHG Center. The GHG Center's verification process consists of developing verification protocols, conducting field tests, collecting and interpreting field and other data, obtaining independent peer-review input, and reporting findings.

The GHG Center is guided by volunteer groups of stakeholders. These stakeholders offer advice on specific technologies most appropriate for testing, help disseminate results, and review Test Plans and Technology Verification Reports ("Report"). The GHG Center's Executive Stakeholder Group consists of national and international experts in the areas of climate science and environmental policy, technology, and regulation. It also includes industry trade organizations, environmental technology finance groups, governmental organizations, and other interested groups. The GHG Center's activities are also guided by industry-specific stakeholders who provide guidance on the verification testing strategy related to their area of expertise and peer-review key documents prepared by the GHG Center.

The primary mission of the GHG Center is to verify the performance of commercial-ready technologies that can be used domestically and internationally to reduce or monitor GHG emissions. The identification of GHG mitigation technology options was one of the first steps taken in this program. A ranked list of technology priorities was subsequently developed for the GHG Center to pursue. It was quickly recognized that the use of GHG technology typically requires a market - not environmental laws or regulations - to stimulate growth and use of the technology. Four technology areas or industries were selected in 1998 for initial focus: (1) biomass combustion (small-scale), (2) landfills, (3) the oil and gas industry, and (4) electricity end-use technologies. The GHG Center has expanded its program to include a wider range of technology types such as animal and human waste technologies, distributed generation (DG) technologies, combined heat and power (CHP) technologies, transportation technologies, and others.

Testing costs are shared between the GHG Center and the vendor. The GHG Center currently requires verification participants pay 50 percent of the estimated cost of verification planning, testing, and reporting.

U.S. policy regarding climate change mitigation continues to avoid regulatory instruments, but interest in mitigating GHG emissions is expanding due to new voluntary mitigation initiatives and technology development programs sponsored by federal and state governments. These actions, coupled with an increase in mitigation activity abroad and a developing sentiment that GHG mitigation is inevitable in the U.S., are expanding opportunities for technology verification at the GHG Center. These increased opportunities can be seen in the level of activity and cost sharing recently experienced by the GHG Center. The GHG Center will complete more verifications in 2003 than in any previous year since it began in 1997.

2.0 TECHNICAL APPROACH

2.1 ETV Fundamental Tasks

There are six fundamental tasks associated with the ETV program:

- prioritizing technology areas,
- soliciting and selecting technology candidates for testing,
- developing verification test and quality assurance plans,
- conducting field testing,
- conducting data analysis and reporting, and
- management and administration.

2.1.1 Prioritizing Technology Areas

The U.S. continues to move toward more aggressive actions to address climate change. Although this is beginning to impact the implementation of technologies that mitigate GHG's, market forces will continue to play a significant role in the development and implementation of commercial GHG mitigation and monitoring technologies. The primary criteria for prioritizing technology areas for verification testing will include their market potential, environmental performance, and the interest that exists through other federal and state technology programs that may want to partner with the Center. Stakeholder guidance will always play a key role in prioritizing technology areas. Technologies may not be excluded because of poor market potentials if they also offer significant environmental, health, or other benefits.

Technology area prioritization will be an ongoing process because of the volatility and rapidly changing nature of the GHG issue. The GHG Center continuously monitors and reviews the evolving nature of GHG technology priorities by:

- routinely reviewing publications and attending conferences that focus on technology areas the Center is involved in;
- reviewing national and international policy and emissions trading publications;
- attending highly specific technology-focused meetings and conferences;

- continuing and expanding the Center's Stakeholder interactions;
- expanding engagements with SRI's network of constituents in the emissions policy and technology areas (e.g., National Governor's Association, New England Governor's Association, state offices in New York, Colorado, Connecticut, and California, trade groups); and
- seeking out and engaging new groups active in other high-profile areas.

2.1.2 Soliciting and Selecting Technology Candidates for Testing

The approach that will be used to solicit and select new candidate technologies for verification is outlined below.

Vendors of mitigation technologies for potential verification testing can be identified by using: (1) contacts contained within the GHG Center's stakeholder and partner organizations; (2) announcements published in Federal Business Opportunities; (3) announcements at trade meetings and/or in journals; (4) announcements in the GHG Center's newsletter; (5) direct phone solicitation; (6) formal GHG Center stakeholder meetings; and (7) press releases. Stakeholder meetings are planned to help develop this process.

Interested vendors will be given information on the ETV Program as well as guidance and instructions on how to submit an Application for Testing. Factors that may be considered when assessing the suitability of an applicant for verification testing include: commercial status, technical soundness, breadth of technology's applicability, completeness of the Application for Testing, market potential, GHG reduction potential, cost of the technology, cost of technology testing, availability, potential for significant adverse or positive secondary environmental impacts, and the ability of a vendor to provide cost-sharing. The initial screening process is intended to eliminate vendors with casual or other interests to avoid wasting resources.

2.1.3 Developing Test and Quality Assurance Plans

A Test Plan is prepared to be a highly prescriptive blueprint for testing, quality assurance, data analysis, and documentation. It is the focus of intense scrutiny by all parties involved in the process including the EPA, vendors, buyers, ETV partnering organizations, stakeholder group members, and organizations that support testing standardization. Test Plans are a critical step in the verification process. It is essential that the effort required not be understated and that the cost to develop Test Plans continues to decrease as test methods are developed and reused by the GHG Center.

Test Plan development begins with the specification of concise verification parameters and identification of Data Quality Objectives (DQOs) for those parameters. Specific testing strategies are then formulated and consideration of relationships between emissions and operating parameters is made. Measured or monitored variables (depending on the process) may include process measurements such as feed or production rates, material composition, pressures, power output levels and quality, temperatures, fuel input, ambient conditions, costs, and others. Since it is generally necessary to characterize process operations or emissions over a range of operating conditions, Test Plans also specify the appropriate range of process operation. Test Plans also contain detailed methods for reducing data and reporting final results, field-data log forms, specific instructions for conducting quality assurance measurements and executing audits, and other materials.

A site visit will usually be taken as the Test Plan nears completion. The visit will evaluate preliminary testing plans, identify physical and technical constraints, and coordinate future testing activities. It is important to gather as much site-specific information as possible during the pre-test surveys. This information includes:

- visual inspection of the process and auxiliary components of the facility, review of on-site records,
- interviews with site personnel regarding process and control system operating practices and conditions,
- preliminary measurements, and
- the collection (sometimes) of various material samples and photographs.

2.1.4 Conduct Field Testing

Field testing is preceded by a series of pre-test activities including:

- setup of test equipment;
- performing appropriate calibration checks and prescribed QA activities; and, in some cases
- taking preliminary measurements to ensure that the individual sampling systems are operating within acceptable data quality limits.

It is usually appropriate to check the process operation while sampling equipment is being readied and to ensure process and control equipment operation match the test conditions outlined in the Test Plan. Technical Systems Audits (TSAs), Performance Evaluation Audits (PEAs), or calibration checks of specific process monitoring devices can be performed at this point.

One individual from the GHG Center will be designated as Test Coordinator and will be empowered to make decisions as the test progresses. This will always be a SRI employee, whether SRI is conducting the test or simply monitoring a subcontractor during the test. Communication lines and responsibilities of all verification test participants (SRI, vendor and host-site personnel, EPA or third-party observers, or third-party test organizations) will be monitored and maintained as prescribed in the Test Plan. The GHG Center will carefully monitor process-operating conditions during testing. The use of instrumental methods or on-site analyses require that real-time results be used as an indicator of problems in case on-site corrective actions are needed. Tests can be repeated or expanded to accommodate the difficulties encountered and to allow the goals of the Test Plan to be accomplished. The Test Coordinator is responsible for ensuring data quality objectives are met and that corrective actions are taken based on findings of internal and external audits. The Test Coordinator carefully documents any events that occur during testing that may affect later interpretations of the results. This is generally conducted with log forms contained in the Test Plan. The Test Coordinator will normally maintain a logbook to record occurrences not anticipated in the log forms.

The GHG Center is guided by its Quality Management Plan (QMP) which has been approved by the EPA. One of the most significant changes to the plan is that on-site audits of data quality must now be conducted at each field test.

2.1.5 Data Analysis and Reporting

Analysis and interpretation of data requires a variety of skills. These include:
- strong scientific skills;
- experience in assessing data trends;
- a tenacious investigation of data anomalies;
- an open mind to the causes of those anomalies;
- access to independent engineers and scientists with hands-on knowledge of the technology being verified;
- good judgment skills; and
- an ability to conduct investigative research that effectively balances the need for further investigation against available program resources.

Data analysis may begin prior to the completion of testing partly to speed development of the Verification Report but, more importantly, to ensure adequate technology performance and QA data have been collected. Data analysis usually occurs in the field before testing is complete, allowing corrective action to be taken before leaving the field. SRI will always conduct some level of in-field data analysis.

Data analysis may include a wide range of different types of activities carried out at different levels. The level and type of analysis conducted are generally influenced by the technology evaluated, the goals of the test, and the availability of information and data. The types of analysis conducted can include, but are not necessarily limited to:

- identification and examination of performance limitations or anomalies;
- correlation of performance and process variables;
- comparison of performance results with expected values or baseline technologies;
- development of mass and energy balances;
- evaluation of secondary environmental impacts;
- interpretation of emission test results and development of emission factors;
- comparison of emissions and other performance characteristics under different process operating conditions;
- confirmation of the performance and applicability of test methods and equipment;
- performance of re-calibrations under field conditions;
- estimation of capital and operating costs;
- statistical evaluations; and
- assessment of energy efficiency.

Data is compiled in a Verification Report when the analysis is complete. The Verification Report will include:

- key data collected and values calculated;
- process, field, and analytical data;

- calculations and assumptions used to reduce the data;
- descriptions of the process and verified technology operations; and
- summaries and discussions of the reduced data.

Detailed statistical analyses are frequently conducted of data scatter, uncertainty, error propagation, and confidence intervals. The data management approach outlined in the Test Plan is always monitored to ensure completeness of the raw data, to direct the data flow through reduction and evaluation, to ensure accuracy in data manipulation and calculations, and to provide traceability.

Verification Reports carefully document test conditions, results, and QA/QC findings. Draft Verification Reports will be submitted to the host site, vendors, and other direct participants for an accuracy review. Following this review, SRI will subject the Verification Report to external peer-review by up to 3 qualified reviewers and an EPA QA review by the ETV QA Team. The final Verification Statement, Verification Report, and Test Plan are placed on the GHG Center and ETV Web sites in a format that allows their download and use by any interested party. SRI also highlights verification results in journal articles, conference presentations, press releases, the GHG Center's newsletter, and elsewhere as part of an ongoing outreach effort.

3.0 ANIMAL WASTE PROJECTS

EPA estimates U.S. methane emissions from livestock manure management at 17.0 million tons carbon equivalent, which accounts for 10 percent of total 1997 methane emissions (EPA 1999a). The majority of methane emissions come from large hog and dairy farms that manage manure as a liquid. EPA expects U.S. methane emissions from livestock manure to grow by over 25 percent from 2000 to 2020. Cost-effective technologies such as anaerobic digesters are available that can reduce this emission growth by recovering methane and using it as an energy source. The recovered methane from decomposed manure can fuel power generators to produce electricity, heat, and hot water. Digesters also reduce foul odor and can reduce the risk of ground- and surface-water pollution.

Biogas production from livestock manure management facilities has developed into a fuel alternative for distributed generation (DG) technologies. Distributed generation refers to equipment, typically ranging from 5 to 1,000 kilowatts (kW), that provide electric power at a site closer to customers than central station generation. DG technologies provide customers one or more of the following main services: standby generation (i.e., emergency backup power), peak shaving generation (during high demand periods), baseload generation (constant generation), or cogeneration (combined heat and power generation).

3.1 Pork Farm CHP System

The GHG Center and the Colorado Governors Office of Energy Management and Conservation (OEMC) have collaborated and shared the cost of verifying two DG technologies that operate on biogas recovered from swine waste. This verification program will evaluate the performance of a microturbine combined heat and power (CHP) system offered by Capstone Turbine Corporation and an internal combustion (IC) engine CHP system offered by Martin Machinery, Inc. Both units are currently in operation at an anaerobic digestion facility managed by Colorado Pork, LLC, near Lamar, Colorado.

Colorado Pork began the sow farrow-to-wean operation in 1999. The facility employs a complete mix anaerobic digester to reduce odor and meet water quality regulations mandated by the Colorado Department of Public Health and Environment. The anaerobic digester promotes bacterial decomposition of volatile solids in animal wastes. The resulting effluent stream consists of mostly water which is allowed to evaporate from a secondary lagoon. Waste from 5,000 sows is collected in shallow pits below the slatted floors of the hog barns. These pits are connected via sewer lines to an in-ground concrete holding tank (50,000-gallon capacity). The pits are drained each morning on a rotating basis to flush 12,500 gallons of waste to the holding tank. The holding tank is equipped with one 17-horsepower (HP) chopper pump that breaks up large pieces of waste. The pits are emptied each morning around 5:00 a.m. after 12,500 gallons of waste is pumped from the holding tank into the digester (requires approximately 20 minutes). The digester is a 70' x 80' x 14' deep in-ground concrete tank with a capacity of 500,000 gallons. The digester is equipped with two propeller-type mixers on each end. The mixers normally operate for 30 minutes daily in the evening to rejuvenate gas produced that would otherwise decline between feedings. Hot water is circulated through the digester using a matrix of 3-inch black steel pipe (total length of about 0.5 mile) to maintain the digester temperature at 105 °F. Small adjustments to the water flow rate are required periodically and are conducted manually by the site operator. The retention time in the digester is about 40 days.

This is the only swine farm in Colorado that is producing electrical power from animal waste. The electricity is used by Colorado Pork to offset electricity purchases from the local electric cooperative. Some of the recovered heat is used to control digester temperature, which optimizes and enhances biogas production. The GHG Center will evaluate the performance of the microturbine and the IC engine CHP systems as they run off the same biogas stream at Colorado Pork. Field tests will be executed over a 2-to-3 week period to independently verify the electricity generation rate, thermal energy recovery rate, energy efficiency, environmental emissions, electrical power quality, and emission reductions associated with CHP electricity generation.

The process diagram of the Colorado Pork waste-to-energy process is shown in Figure 3-1.

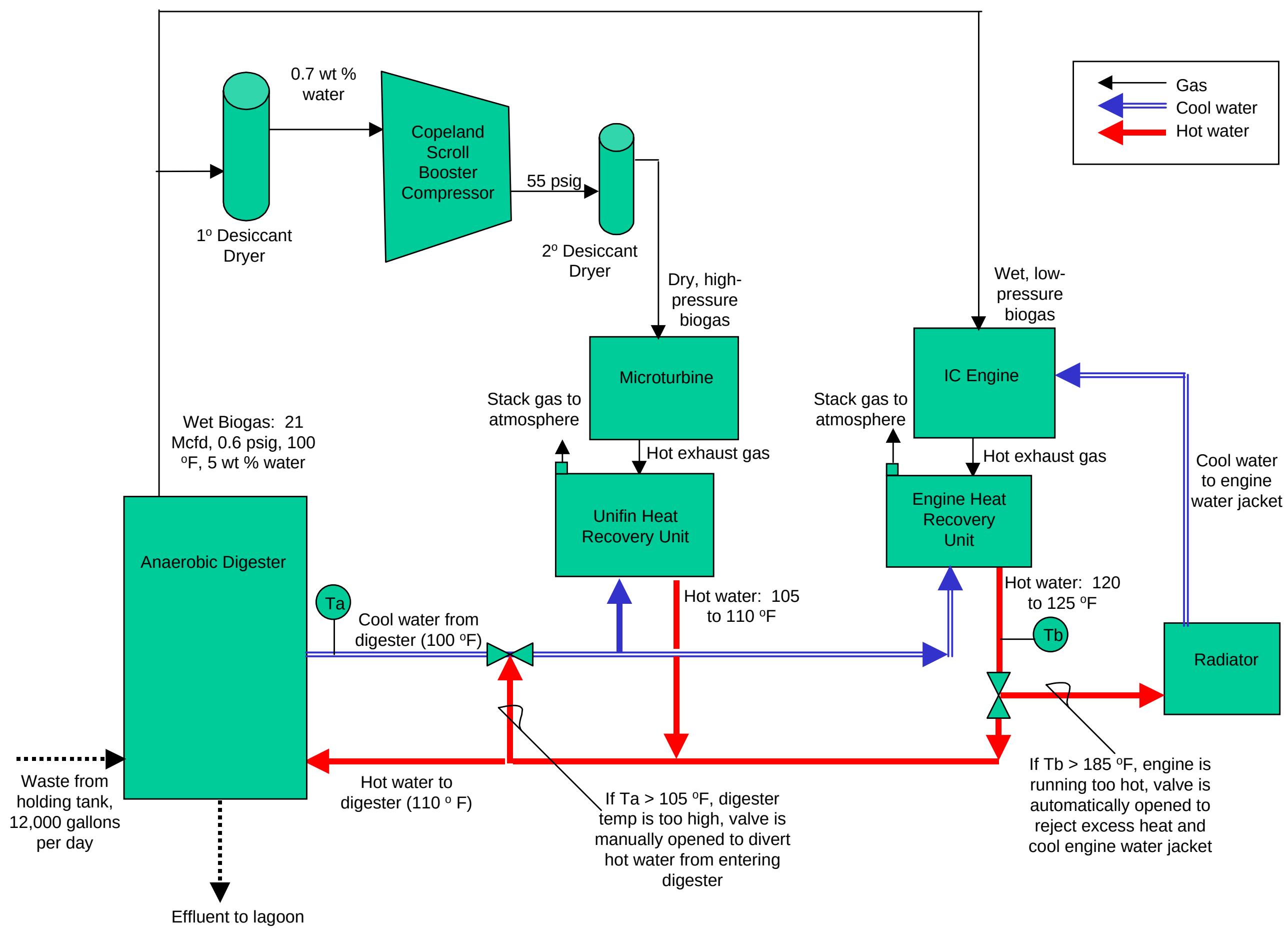

Figure 3-1. Colorado Pork Waste-to-Energy Process Diagram

Biogas production rates at the test site limit engine operation to approximately 65 kW, or about 65 percent capacity. Electricity generated at this load is fully consumed by equipment used at the facility. Power demand exceeds the available capacity of the engine/generator set during normal farm operations so additional power is drawn from the grid. The local utility does not currently permit power to be exported to the grid. The facility has a backup emergency generator to provide additional power in the event of a grid power failure. No digester gas conditioning or compression is needed to operate the engine under these conditions. Digester gas is directed to the engine and fired at the pressure created in the digester. The biogas produced from the decomposed waste is collected under a high-density polyethylene (HDPE) cover at a pressure of 17 to 18 inches water column. A manifold collects the biogas and routes it to the engine/turbine building. A pressure-relief valve senses pressure buildup when neither the engine or turbine are operating and diverts the biogas to a flare. Approximately 646,000 cubic feet of gas per month (cfm) or an average daily production of 21,253 cfd is produced.

3.1.1 Performance Verification Parameters

The verification test is scheduled to take place during June 2003. The primary objective of the test is to verify each CHP system's power and heat production performance, electrical power quality, and emissions performance. The approach selected for testing is intended to evaluate the performance of the CHP systems only - not the specific operational or management strategy of the test facility.

Each system will be examined individually to characterize emissions and power/heat production performance at power outlet levels where users of the technology are likely to operate. Controlled performance testing will be conducted at four electrical loads summarized in Table 3-1.

Three test runs - each lasting about 0.5 hour for the microturbine and one hour for the IC engine - will be executed at the four electrical loads. The microturbine and IC engine CHP systems will be allowed to stabilize at each load for 15 to 30 minutes before starting the test runs. Simultaneous monitoring for power output, heat recovery rate, fuel consumption, ambient meteorological conditions, exhaust stack emission rate, and pollutant concentrations in the exhaust stack will be performed during each test. Average electrical power output, heat recovery rate, energy conversion efficiency (electrical, thermal, and net), and exhaust stack concentration and emission rates will be reported for each load factor. Emission results for the following pollutants will be reported: CO_2, CH_4, NOX, CO, sulfur dioxide (SO_2), total hydrocarbons (THCs), ammonia (NH_3), total particulate matter (TPM), and total reduced sulfur (TRS).

Completion of the controlled load testing will be followed by efficiency and emissions performance evaluations at normal site operating conditions. The site plans to operate the microturbine under normal conditions at maximum electrical power output (30 kW nominal) while the IC engine supplies the remaining electricity (35 kW nominal). The heat demand is significantly lower at normal site conditions as the site currently uses the heat for maintaining digester temperature. The hot-water supply temperature at normal site operating conditions will be set at the levels determined by the site operator to provide sufficient heat to the digester (i.e., 110^{o}F for the microturbine and 125^{o}F for the IC engine). Three test runs - each lasting about 0.5 hour for the microturbine and one hour for the IC engine - will be executed at these settings. The results will indicate each system's electrical, thermal, and combined efficiency and air emission rates at normal site operating conditions. Completion of the efficiency and emissions performance evaluations will be followed by additional verification data collected for a period of one week while each system is operating at normal site conditions.

Table 3-1. Verification Test Matrix

Efficiency and Emissions Performance Evaluations

Controlled Load Testing – Microturbine CHP System

Test Condition (Percent of Rated Power Output)	Power Setting (kW)	Heat Exchanger Supply Temp. (°F)	No of Replicate Test Runs Executed	Duration of Each Test Run		
				Power, Heat, and Efficiency Determination	CO, NO_X, SO_2, THC, TRS, CO_2, and CH_4 Emissions	NH3 and TPM Emissions
100	30	125	3	30 mins	30 mins	120 mins
75	22	125	3	30 mins	30 mins	not tested
60	18	125	3	30 mins	30 mins	not tested
50	15	125	3	30 mins	30 mins	not tested

Controlled Load Testing – IC Engine CHP System

Test Condition (Percent of Rated Power Output)	Power Setting (kW)	Heat Exchanger Supply Temp. (°F)	No of Replicate Test Runs Executed	Duration of Each Test Run		
				Power, Heat, and Efficiency Determination	CO, NO_X, SO_2, THC, TRS, CO_2, and CH_4 Emissions	NH3 and TPM Emissions
100	100[a]	135	3	60 mins	60 mins	120 mins
75	75[a]	135	3	60 mins	60 mins	not tested
60	60	135	3	60 mins	60 mins	not tested
50	50	135	3	60 mins	60 mins	not tested

Testing at Normal Site Operating Conditions

	Power Setting (kW)	Heat Exchanger Supply Temp. (°F)	No of Replicate Test Runs Executed	Duration of Each Test Run		
				Power, Heat, and Efficiency Determination	CO, NO_X, SO_2, THC, TRS, CO_2, and CH_4 Emissions	NH3 and TPM Emissions
Microturbine	30	110	3	30 mins	30 mins	not tested
IC Engine	35 to 65	125	3	60mins	60 mins	not tested

Power Quality and Emission Reduction Evaluations

Extended Testing at Normal Site Operating Conditions

	Power Setting (kW)	Heat Exchanger Supply Temp. (°F)	Duration of Testing		
			Power Quality Determination	Total Energy Generated (electrical, thermal)	Emission Reductions from Electricity Offset
Microturbine	30	110	1 week	1 week	1 week
IC Engine	35 to 65	125			

[a] If sufficient biogas is not available to achieve this power output, load testing will be conducted at the highest achievable load (approx. 65 kW), the lowest achievable load (approx. 32 kW), and two loads

Both systems will be operated 24 hours per day and will use all the biogas produced at the site. Continuous monitoring of electrical power generated, heat recovered, fuel consumed, ambient meteorological conditions, and power quality will be performed. The results of this extended monitoring will be used to report total energy generated (electrical and thermal) and average power quality data. The parameters to be verified are listed in Table 3-2 below and brief descriptions of each parameter follows in the subsequent paragraphs.

Table 3-2. Verification Parameters

Power and Heat Production Performance
Electrical power output at selected loads, (kW)
Heat recovery rate at selected loads, Btu/hr, (kW)
Electrical efficiency at selected loads, (%)
Thermal energy efficiency at selected loads, (%)
Combined heat and power production efficiency at selected loads, (%)
Total electrical energy generated, (kWh)
Total thermal energy recovered, (Btu)
Electrical Power Quality Performance
Electrical frequency, (Hz)
Voltage output, (VAC)
Power factor, (%)
Voltage total harmonic distortion (THD), (%)
Current THD, (%)
Air Pollutant Emission Performance
CO, NOX, THCs, NH_3, TPM, TRS, CO_2, and CH_4 concentrations at selected loads, ppmv, (%)
CO, NOX, THCs, NH_3, TPM, TRS, CO_2, and CH_4 emission rates at selected loads, (lb/hr), (lb/Btu), (lb/kWh)
Emission Reductions
Estimated NOX emission reductions, lb NOX, (%)

3.1.1.1 Power and Heat Production Performance

The GHG Center will install an electrical meter to measure the cumulative power generated by the microturbines. Fuel input will be measured using flow meters installed in the gas flow streams. Gas sampling and energy content analysis of the blended gas will be performed to determine the LHV of the fuel supplied to the microturbines. Fuel energy-to-electricity conversion efficiency will be determined by dividing the average electrical power output by the heat input for each load condition. Heat recovery rates will be verified simultaneously with power output measurements by metering the flow rate, hot (supply) and cold (return) water temperatures. Thermal energy conversion efficiency at each load will be determined by dividing the average heat recovered by the heat input. CHP production efficiency will be reported as the sum of electrical and thermal efficiencies at each operating load. The sum of one-minute average power output measurements and heat recovery rate measurements, collected over a one-week extended testing period, will represent total electrical energy generated and thermal energy recovered. Ambient temperature, relative humidity (RH), and barometric pressure will be measured throughout the verification period to support determination of electrical conversion efficiency.

3.1.1.2 Power Quality Performance

The monitoring and determination of power quality performance is required to insure compatibility with the electrical grid and to demonstrate that the electricity will not interfere with or harm microelectronics and other sensitive electronic equipment within the facility. Power quality data is used to report exceptions which describe the number and magnitude of incidents that fail to meet or exceed a power quality standard chosen. The Institute of Electrical and Electronics Engineers' Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems (IEEE 1993) contains standards for power quality measurements that will be followed. Power quality parameters will be determined over the one week of normal operation test conditions. The same wattmeter used to measure electric power output will be used to measure the power quality parameters listed earlier.

3.1.1.3 Air Pollutant Emission Performance

The measurement of the emissions performance of the microturbine and IC engine are critical to any assessment of the environmental impact of the technology. Emissions testing for all pollutants, with the exception of NH_3 and TPM, will be conducted simultaneously with the efficiency determinations. Emission tests at each load will be repeated three times. This triplicate measurement design is based on U.S. EPA New Source Performance Standards (NSPS) guidelines for measuring emissions from stationary gas turbines (EPA, 1999). Concentration and emission rate measurements for CO, NOX, THCs, NH_3, TPM, TRS, CO_2, and CH_4 will be conducted in the microturbine and IC engine exhaust stacks at the selected operating loads. Exhaust stack emission testing procedures will be adapted to verify the verification parameters listed earlier. Concentration measurements will be reported in units of parts per million volume, dry basis (ppmvd) and corrected for 15 percent O_2 at the microturbine. Emission rates will be reported in units of mass/hour, mass/heat input, and mass/power output for both units. Sample locations are shown in Figure 3-2.

3.1.1.4 Emission Reductions

Emission reductions for CO_2 and NOX will be estimated by subtracting emissions from the on-site CHP system from emissions associated with a baseline electrical power generation technology. It will be assumed that the on-site CHP electrical power will reduce the need for the same amount of electricity from the local grid after adjusting grid power needs upward to account for transmission line losses. The subtraction of the estimated emissions from the on-site units from the estimated emissions associated with the mix of power stations serving the local grid will yield an estimate of the CO_2 and NOX emission reductions over the testing period.

Life-cycle emission reduction calculations are performed for some projects, but not for this project. This type of effort would address emission savings from anaerobically digesting waste that would normally be disposed of in an open lagoon, sequestering carbon in the soil amendment, using waste heat that would normally be produced by on-site boilers, and consideration of CO_2 rejected during the wet biogas treatment process. A full life-cycle emission estimation procedure would require a national assessment of “baseline” waste management techniques and heat production systems.

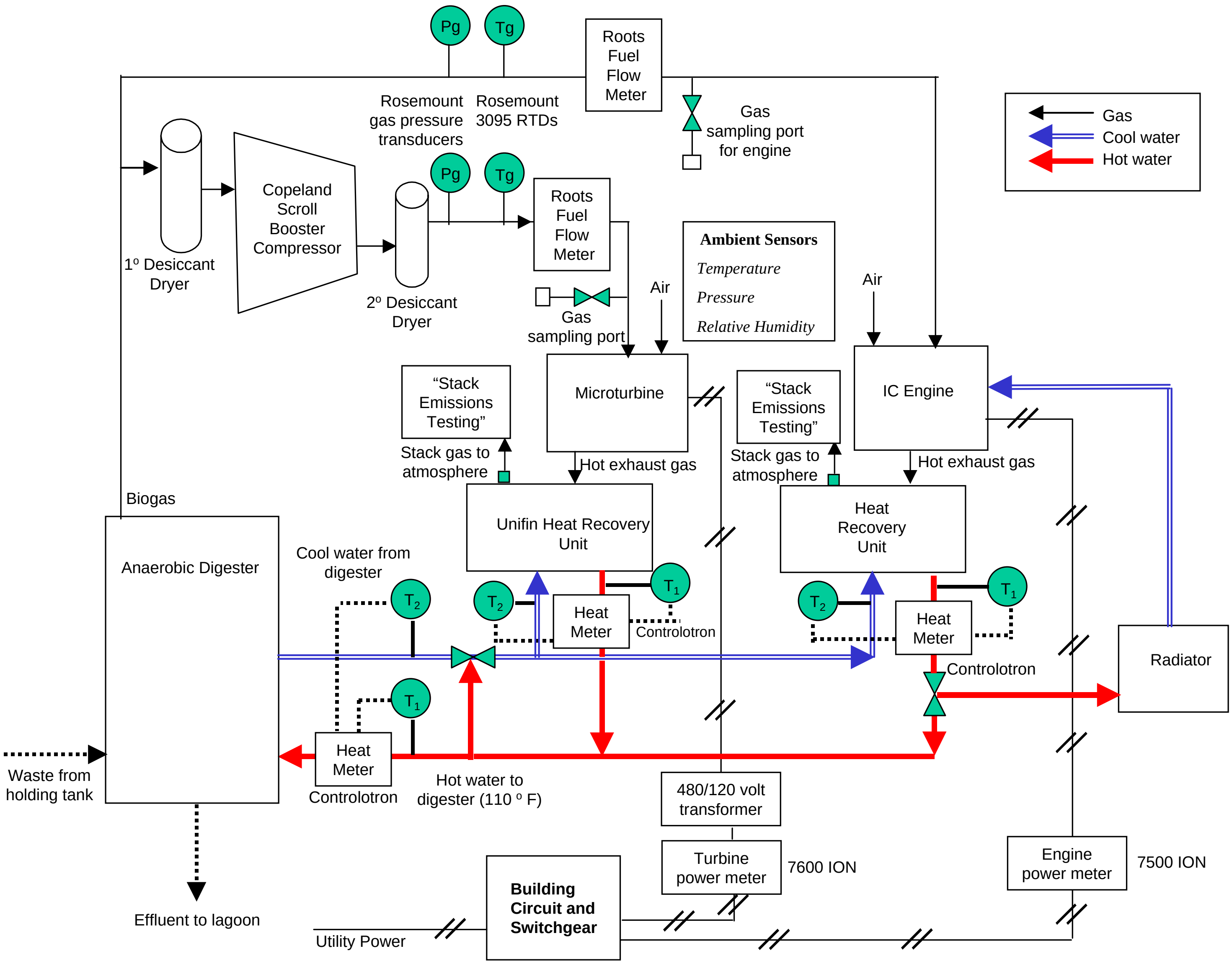

Figure 3-2. Sampling Measurement System Schematic at Colorado Pork.

3.1.1.5 Stack Emission Rate Determination

Exhaust stack emissions testing will be conducted on both CHP systems to determine emission rates for criteria and other pollutants (CO, NOX, NH_3, SO_2, THCs, and TRS), greenhouse gases (CH_4 and CO_2), and TPM. The stack emission measurements will be conducted simultaneously with electrical power output measurements during load tests on each of the CHP systems. Following NSPS guidelines for evaluation of emissions from stationary gas turbines, exhaust stack emissions testing will be conducted at four loads within the normal operating range of the microturbine and IC engine CHP systems. Test points will include 50, 75, 90, and 100 percent of the normal full-load capacity (30 kW) for the microturbine. For the engine, 100 percent of rated capacity is not achievable as a result of digester gas production rates. Therefore, the four test points will include the maximum achievable load (approximately 65 kW), the lowest achievable load (approximately 32 kW), and two additional points between this range. Note that emissions testing for NH_3, TPM, and TRS will be conducted only at the highest load factor tested on each unit. The emissions testing will be conducted simultaneously with the efficiency evaluations. Full-load testing on both CHP systems includes emission rate determinations for TPM and NH_3. These tests will require approximately 120 minutes to complete because their concentrations are expected to be very low and longer test duration will increase the method sensitivity. All three full-load test replicates for efficiency and gaseous pollutant (each 30 minutes in duration) will be conducted during the first TPM/NH_3 test run during the microturbine CHP testing. The remaining two TPM/NH_3 full-load test runs will then be conducted at full load before changing load. The same procedure will be followed for the IC engine testing (i.e., finish TPM and NH_3 testing after the efficiency testing is completed). Operators will maintain process operations to be consistent with the maximum permissible limits throughout the testing. The testing contractor will provide all equipment, sampling media, and labor needed to complete the testing and will operate under the supervision of the GHG Center Field Team Leader. U.S. EPA Federal Reference Methods from Title 40 CFR 60, Appendix A will be the guide for emissions testing procedures. These Methods include procedures for selecting measurement system performance specifications and test procedures, quality control procedures, and emission calculations.

3.2 Pork Farm Digester Additive System

The GHG Center has also agreed to partner with the Colorado Governor’s OEMC to evaluate the performance of an animal waste digester additive. The “Lagoon Bio-Regen” digester additive - offered by Microganics, LLC of Dallas, TX - is designed to accelerate the production of biogas in the anaerobic digester and remove contaminants such as ammonia and sulfur species from the biogas. This effect could ultimately increase the production of renewable energy on the farm and reduce emissions of criteria air pollutants from the microturbine.

The general approach for evaluating the effectiveness of the Lagoon Bio-Regen is to compare digester and microturbine performance parameters before and after the additive is introduced. The Capstone 30 Microturbine testing program will represent the baseline power and emissions performance data. The full-load power and emissions performance testing will be repeated on the Capstone 30 after the digester is inoculated with Lagoon Bio-Regen and has stabilized. Several other gas production performance parameters will also be evaluated as outlined here.

3.2.1 Performance Verification Parameters:

The verification test is scheduled to take place during summer 2003. The verification parameters to be addressed are:

- Changes in power and heat production performance;
- Change in electrical power output at full load;
- Change in heat recovery rate at full load;
- Change in electrical efficiency at full load;
- Change in thermal energy efficiency at full load;
- Change in combined heat and power production efficiency at full load;
- Changes in air pollutant emissions;
- Change in CO, NO_X, THC, NH_3, TPM, TRS, CO_2, and CH_4 emission concentrations at full load;
- Change in CO, NO_X, THC, NH_3, TPM, TRS, CO_2, and CH_4 emission rates at full load;
- Change in digester biogas production rate; and
- Change in biogas quality, including methane, H_2S, TRS, NH_3, and mercaptan contents and biogas lower heating value

Testing will be completed in two stages – (1) baseline testing to determine the specified parameters under normal farm operating conditions without any digester additives and (2) additive testing to evaluate the same specified parameters after addition of Lagoon Bio-Regen and stabilization of the digester.

3.2.2 Farm and Digester Operational Parameters

Process variables and conditions that affecting digester performance are a concern in evaluating the performance of the Lagoon Bio-Regen additive. These parameters include manure solids content, operating temperature, manure input rate, and digester retention time. Comparisons between results for tests occurring at two different times - and under possibly different conditions - must be normalized for appropriate comparison to ensure that changes in gas quantity and quality are not incorrectly attributed to the Microganics product.

Several process variables will be monitored during testing to allow normalization of testing results and direct comparisons between the baseline and additive tests. These variable include:

- Barn and waste holding tank temperatures (^oC);
- Digester gas temperature (^oC);
- Waste product properties (digester feed) - total solids (TS), volatile solids (VS), total organic carbon (TOC), chemical oxygen demand (COD), pH, ammonia, total Kjeldahl nitrogen (TKN), nitrate, nitrite, phosphorus, orthophosphate, alkalinity, density;
- Digester effluent properties - total solids (TS), volatile solids (VS), total organic carbon (TOC), chemical oxygen demand (COD), pH, ammonia, total Kjeldahl nitrogen (TKN), nitrate, nitrite, phosphorus, orthophosphate, alkalinity, density;
- Hog population and makeup (sows/day, % sows/day, average total hog weight in lb/day);
- Digester waste feed rate (gal/day); and

- Digester effluent flow rate (gal/day).

These measurements will be used to normalize results of the performance tests to farm, waste, and ambient conditions for comparison. For example, microturbine power output will be reported in units of kilowatts (kW) and then normalized to process conditions including hog population, digester retention time, and waste volatile solids (VS) content. Power output during the baseline and additive testing can then be reported as kW/hog-day-VS for comparison. This normalization approach will also be used for heat recovery rate, electrical and thermal efficiency, and emissions performance. The following procedures will be used to monitor the process variables.

3.2.2.1 Temperature Monitoring

Temperatures in two of the five barns (randomly selected), the waste holding tank, and the digester (gas phase) will be monitored during the verification test period. Temperatures at each location will be monitored using temperature dataloggers equipped with an internal thermistor-type temperature sensor. Temperatures will be recorded hourly for the entire period between and including the baseline test and the additive test. Temperature measurements will be used simply to indicate that conditions in both the barns and digester during the baseline and additive tests are comparable.

3.2.2.2 Waste Feed Rate

Approximately 12,500 gallons of waste is pumped from the waste holding tank to the digester each morning using a 17-HP electric pump. Pump operations will be monitored to calculate the amount of waste fed and feed rate (time to feed). A voltmeter will be used to record the duration of pump operation each day. These data will be used in conjunction with the pump's rated flow rate to calculate daily waste feed amount and rate. The pump's flow rate will be verified by measuring the change in holding tank level, holding tank surface area measurements, and time required to complete the batch feed on at least three days.

3.2.2.3 Waste (Digester Feed) and Effluent Properties

Samples of digester feed and effluent will be collected during the baseline testing and again during the additive testing. The samples will be collected by compositing grab samples from the waste holding tank prior to pumping the waste to the digester.

3.2.2.4 Continuous Monitoring

Inoculation of the digester with the Lagoon Bio-Regen additive will begin soon after completion of the baseline testing. A stabilization period of 2-4 months will be needed prior to conducting the additive testing. Digester gas output, digester temperature, ambient temperature, and hog population will be monitored and logged during the time between the baseline and additive tests. Data will be used to evaluate digester function and farm stability to ensure that the baseline and additive tests are completed under similar conditions and that the additive test is not scheduled during a time when significant changes are occurring at the farm (i.e. large increases or decreases in hog population, temperature, digester function). Additive testing will be completed following a period of a minimum of two weeks during which average daily hog population changes by no more than 5%, digester temperature is within 5% of the baseline test average daily temperature and ambient temperature is within 10% of the baseline test average daily temperature.

3.2.2.5 Digester Gas Production Rate

A flowmeter will be used to measure gas flow from the digester. This meter is located near the biogas outlet of the digester but prior to gas lines leading to the biogas flare, microturbine, or internal combustion engine. The analog signal will be connected to a datalogger to log biogas output flow rate continuously throughout the verification period. Flow rate will be monitored every 60 seconds; hourly average flow rates (scfh) will be calculated and logged by the datalogger.

3.2.2.6 Ammonia Content of Biogas

The current sampling protocol specifies collection of digester gas samples from the feed gas line to the generators on a regular basis during testing. However, ammonia analyses cannot be completed from collected gas samples because ammonia reaction with other constituents will result in inaccurate analyses. Therefore, real time ammonia sampling will be completed for the biogas. A gas sample will be analyzed by inserting the probe into the access port located in the fuel line prior to the flow meters. Sampling will be done daily prior to and after completion of emission tests so as not to disrupt the flow of gas into the generators due to the opening of the access port.

3.3 Dairy Farm CHP System

States such as New York, Colorado, and California are exploring technology solutions to address manure waste management, odor, and water discharge problems. Anaerobic digesters, coupled with DG technologies, are considered a viable option. The GHG Center and the New York State Energy Research and Development Authority (NYSERDA) have agreed to collaborate and share the cost of verifying several new DG technologies throughout the State of New York. One such technology consists of a series of microturbines that operate on biogas recovered from a dairy farm anaerobic digestion process in Homer, NY. This verification will evaluate the performance of four 30 kW microturbines coupled with a single heat-recovery system offered by Capstone Turbine Corporation (Capstone). The cost to conduct this verification is being funded jointly by EPA's ETV program and NYSERDA.

The Capstone combined heat and power (CHP) system is currently being installed at a 850-cow dairy farm operated by Dairy Development International (DDI). It is part of a joint project between NYSERDA, Dairy Development International, LLC (DDI), and the New York State Gas and Electric Corporation (NYSEG). The CHP system will be operating on a mixture of biogas and natural gas and will be interconnected to the electric utility grid. The site does not anticipate exporting power for sale since most of the electricity generated will be consumed on-site. Heat will be recovered according to the thermal demand of the site (i.e., heat digester, heat barn floors), and any unused heat will be discarded from the CHP system exhaust stack. The overall energy conversion efficiency is estimated to range between 50 and 75 percent, which is high enough to significantly reduce greenhouse gas (GHG) emissions and provide end users with a renewable source of energy.

The manure from the free-stall barns and the wastewater from the milk house are collected in a 17,000-gallon concrete collection pit where the solids content is monitored to ensure a maximum concentration of 12 percent. Manure is then pumped through a 6-inch polyvinyl chloride (PVC) line to the anaerobic digester (plug flow). Anaerobic digestion reduces the volume of manure by 4 to 6 percent. The retention time of manure digested at 100 ^{o}F is 21 days and results in a stable effluent with reduced odor. A Separator receives the solid and liquid effluent streams. The digested solids will be sold for landscaping and nursery purposes. The liquids are drained by gravity into a 391,600 cubic feet (ft^3) glass-lined aboveground steel structure (Slurrystore®). This liquid manure can (under proper conditions) be added to cropland as a soil amendment to provide nutrients to growing crops and reduce the need for chemical fertilizers.

The biogas exits the digester and is collected in a manifold system which is routed to the turbine building for on-site power and heat generation. A pressure-relief valve senses pressure buildup when the turbines are not operating, and diverts the biogas to a flare. The primary gas constituent present in the biogas is CH_4 (60 to 70 percent), followed by carbon dioxide (CO_2, 30 to 40 percent). The biogas also contains ammonia (NH_3), hydrogen sulfide (H_2S), mercaptans, and other noxious gases.

3.3.1 Performance Verification Parameters

CHP systems operating on anaerobic digestion gas are a relatively new application of DG technologies; the availability of performance data in such applications is limited and in great demand. Performance parameters of greatest interest include electrical power output and quality, thermal-to-electrical energy conversion efficiency, thermal energy recovery efficiency, exhaust emissions of conventional air pollutants and GHGs, GHG emission reductions, operational availability, maintenance requirements, and economic performance.

The primary objective of the test is to verify the CHP system's power and heat production performance, electrical power quality, and emissions performance. The microturbine CHP system will be evaluated at power outlet levels where users of the technology are likely to operate. Performance testing will be conducted at four electrical loads: 100, 90, 75, and 50 percent of rated power output (30 kW each or 120 kW total, nominal). Simultaneous monitoring for power output, heat recovery rate, fuel consumption, ambient meteorological conditions, exhaust stack emission rate, and pollutant concentrations in the exhaust stack will be performed during each test load. Average electrical power output, heat recovery rate, energy conversion efficiency (electrical, thermal, and net), and exhaust stack concentration and emission rates will be reported for each load factor. Emission results for the following pollutants will also be reported for each load condition: CO_2, CH_4, NO_X, CO, sulfur dioxide (SO_2), THC, NH_3, total particulate matter (TPM), and total reduced sulfur (TRS). Annual emission reductions for CO_2 and NO_X will be estimated by using the full-load emission rates and annual electricity offsets from the power grid.

Verification testing will be extended for a period of one week to evaluate electrical power quality performance. The microturbines will operate 24 hours per day at maximum electrical power output (120 kW total). Power quality parameters such as electrical frequency, voltage output, and power factor will be monitored in one-minute intervals. Continuous logging of power output, fuel input, heat recovery rates, and ambient meteorological conditions will be performed to examine daily trends in power and heat production.

The parameters to be verified are listed in Table 3-3 below:

Table 3-3. Verification Parameters

Power and Heat Production Performance
Electrical power output at selected loads, (kW)
Heat recovery rate at selected loads, Btu/hr, (kW)
Electrical efficiency at selected loads, (%)
Thermal energy efficiency at selected loads, (%)
Combined heat and power production efficiency at selected loads, (%)
Electrical Power Quality Performance
Electrical frequency, (Hz)
Power factor, (%)
Voltage total harmonic distortion (THD), (%)
Current THD, (%)
Air Pollutant Emission Performance
CO, NO_X, THCs, NH_3, TPM, TRS, CO_2, and CH_4 concentrations at selected loads, ppmv, (%)
CO, NO_X, THCs, NH_3, TPM, TRS, CO_2, and CH_4 emission rates at selected loads, lb/hr, lb/Btu, lb/kWh
Emission Reductions
Estimated annual NO_X emission reductions, (lb NO_X/yr)
Estimated annual GHG emission reductions, (lb CO_2/yr)

3.3.1.1 Power and Heat Production Performance

Power production performance represents a key operating characteristic that is of great interest to purchasers, operators, and users of these systems. The GHG Center will install an electrical meter to measure the cumulative power generated by the microturbines. Fuel input will be measured using flow meters installed in the natural gas and blended gas flow streams. Gas sampling and energy content analysis of the blended gas will be performed to determine the LHV of the fuel supplied to the microturbines. Fuel energy-to-electricity conversion efficiency will be determined by dividing the average electrical power output by the heat input for each load condition.

Heat recovery rates will be verified simultaneously with power output measurements by metering the flow rate, hot (supply) and cold (return) water temperatures. Thermal energy conversion efficiency at each load will be determined by dividing the average heat recovered by the heat input. CHP production efficiency, or net system efficiency, will be reported as the sum of electrical and thermal efficiencies at each operating load.

Ambient temperature, relative humidity (RH), and barometric pressure will be measured throughout the verification period to support determination of electrical conversion efficiency.

The monitoring and determination of power quality performance is required to insure compatibility with the electrical grid, and to demonstrate that the electricity will not interfere with or harm microelectronics and other sensitive electronic equipment within the facility. Power quality data is used to report exceptions, which describe the number and magnitude of incidents that fail to meet or exceed a power quality standard chosen.

3.3.1.2 Air Pollutant Emission Performance

Emissions testing for CO, NO_X, THCs, TRS, CO_2, and CH_4 will be conducted simultaneously with the efficiency determinations at the four load conditions. Three test runs, each lasting about 30 minutes in duration, will be replicated at each load condition. Emissions testing for NH_3 and TPM will require 120 minutes per test run to complete due to their low concentrations in the exhaust stack.

3.3.1.3 Emission Reductions

Annual emission reductions for CO_2 and NO_X will be estimated by subtracting emissions from the on-site CHP system from emissions associated with a baseline electrical power generation technology. It will be assumed that the on-site CHP electrical power will reduce the need for the same amount of electricity from the local grid, after adjusting grid power needs upward to account for transmission line losses. The subtraction of the annual estimated emissions from the on-site units from the annual estimated emissions associated with the mix of power stations serving the local grid will yield an estimate of the annual CO_2 and NO_X emission reduction. Annual estimates of emissions from each on-site unit will be determined based on measured emission rates at full load, projections of annual biogas flows, and on-site electrical energy demand provided by DDI.

4.0 FUTURE WORK AND COLLABORATION

4.1 Promotional and Stakeholder Activities.

Strong promotion acts to increase the number of vendors participating and users benefiting from ETV verification. SRI maintains the GHG Center’s profile by delivering conference presentations, preparing and publishing trade journal articles, publishing and distributing several issues of the GHG Center's newsletter (distribution 1,700), issuing press releases about significant events and verifications, and participating in partnerships and collaborations within the technology and policy communities. The GHG Center also hosts stakeholder meetings. These meetings may be held collaboratively with EPA, DOE, state government, or other organizations to increase participation and decrease costs.

4.2 Development of New Partnerships

SRI will continue to seek partnerships with organizations that have a need for high-quality performance data or other products developed under the ETV Program. SRI and the GHG Center are particularly interested in developing working relationships with vendors and participants in the animal waste industries. Subjects range from new equipment to additives as described in Section 3.2 above. Our experience and program benefits will provide excellent opportunities for participants interested in third-party verification programs. This ETV offers a mechanism for verifying equipment that may otherwise encounter various obstacles to testing and funding.

The GHG Center is also seeking stakeholders with experience in the animal waste industries. The stakeholders can help guide the program towards future trends and the equipment that supports them.

Anaerobic Lagoon with a Permeable Cover for Reduction of Odor and Ammonia Volatilization

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Abstract
Anaerobic lagoons and liquid manure storages are widely used for the treatment and storage of livestock and poultry manure. Although relatively inexpensive to construct, these devices have been widely criticized based upon their odor and ammonia release. A floating, permeable, composite cover manufactured from recycled polyethylene chips topped with a geotextile layer containing zeolite particles was first evaluated under both laboratory and field conditions. Under laboratory conditions, the cover was found essentially to eliminate odor release and to reduce ammonia emissions by over 80 percent with time.

When installed on a 0.9 ha swine manure lagoon in Eastern North Carolina, the cover survived severe storms and allowed even intense rainfall to pass through without causing cover inundation. Under these field conditions, the cover was found to reduce ammonia emissions approximately 80 percent. Odor emissions were consistently very low. Microbiological examination of the cover after four months of use showed an active population of aerobic bacteria and protozoa; analysis showed that nitrifying, sulfide oxidizing and methanotrophic bacteria were likely trophic components of the microbial populations observed. The cover quickly became covered with an algae population within two weeks of installation. This and other vegetative growth had no discernable impact on the performance of the cover.

Keywords:
Lagoons, odor, swine, waste management, ammonia volatilization, lagoon covers,

INTRODUCTION
Earthen manure storage basins, under-floor liquid manure pits and anaerobic lagoons continue to be used by a great majority of swine producers in the United States. Their popularity is based upon their relatively low construction cost to provide a complete system when employed in conjunction with land application and their operational flexibility. Because a large portion of the manure nitrogen is volatilized to the atmosphere, less land area is required for effluent disposal in those areas where manure application rates are based on nitrogen loading. There has been widespread objection to the use of anaerobic lagoons for swine manure based on the impact of odor release. More recently, ammonia emissions from anaerobic manure storages have become of increasing concern due to their contribution to deteriorating air quality (Chadwick et al., 2000 and Robarge et al., 2000). In addition, methane emission, including that from uncovered anaerobic manure storages, is receiving increased attention due to its potency as a contributor to global warming as a greenhouse gas (U.S. Dept. of Energy, 1997).

One way to control the escape of odors and other gaseous emissions from anaerobic manure storages is the installation of covers. Both permeable and impermeable covers have been used. An air-supported pneumatic structure made of a vinyl-coated fabric supported by a low-pressure blower was described by Hussey et al. (2000). Other impermeable covers that have attempted to capture biogas for beneficial uses or for odor treatment have also been described. There is a long tradition in which permeable covers have been recognized as having odor control benefit. Among the earliest recognitions of the odor-control benefit of a permeable cover was the observation that dairy manure lagoons with a thick floating scum tended to have less odor than lagoons with an open-water surface. Patni and Jui (1993) evaluated several alternatives for the control of odor emissions and reported that none were effective except for the addition of peat moss, which formed an intact scum layer on top of a manure storage tank.

A fabricated, floating, permeable cover designed to reduce odor and ammonia volatilization was described by Miner and Pan (1995). Their experiments utilized a variety of open- and closed-cell polyurethane foams with and without natural zeolite added as an ammonia absorbant. Their studies indicated that so long as the open-cell material could be supported above the free-water surface, ammonia and odor reductions in excess of 60 percent could be achieved. The presence of zeolite in the aerobic portion of the cover improved ammonia removal. Since the open-cell polyurethane material was not sufficiently buoyant to be self supporting, it tended to become flooded by liquid manure, and all effectiveness was lost. The closed-cell foam was impermeable, hence ineffective from a biological perspective in odor removal. Miner and Suh (1997) reported on a series of laboratory scale investigations in which polyurethane foam manufactured to have variable ratios of open and closed cells was used to cover liquid swine manure. These investigations confirmed effective ammonia and odor removal when the liquid surface was covered by a permeable layer of material suitable for the support of an aerobic bacterial population to catabolize the ammonia and other reduced gases associated with odor release.

Similarly, there are numerous livestock confinement facilities which store liquid manure in deep pits beneath slotted floors. Ventilation air is drawn from the buildings immediately above the liquid manure surface. Although this design provides healthy conditions in the animal quarters, the intensity of the odor in discharged air is sufficiently high to cause complaints from downwind neighbors.

Laboratory study: The laboratory study was conducted at the Oregon State University Water Quality Laboratory in Gilmore Hall. Boards of recycled polyethylene foam described below were used. All tests were conducted by filling vertical-sided, 30 cm diameter, 40 cm tall, food-grade plastic pails approximately half full of pig manure from the OSU Swine Research Farm. The manure slurry was approximately 5 percent solids in each of the pails. Five separate alternatives were tested. Each alternative was tested in duplicate, 10 pails were utilized. The alternatives evaluated are defined in Table 1.

Table 1. Definition of the alternative liquid manure covers evaluated during the laboratory study in the summer of 1999.

Identification	Description
Control	Liquid manure, no cover. The manure slurry was the same in all pails
Cover	A single layer of the foam board was floated on the slurry surface.
Half thickness cover	The foam board was cut with a knife to approximately half thickness.
Cover plus geotextile	A single layer of the foam board plus a layer of the geotextile.
Cover plus zeolite	A single layer of the foam board topped with zeolite particles

The performance of the four covers was evaluated by measuring the ammonia concentration in the headspace over the covers. This was done by passing a measured volume of air through a dilute acid trap, and measuring the absorbed ammonia using Nesslers reagent to form the typical yellow color that can be read on a spectrophotometer. Four separate measurements were made one week apart beginning one week after the covers were placed on the manure. Results in Table 2 are expressed in percent reduction in the ammonia concentration.

Table 2. Results of the laboratory trials expressed as percent reduction in ammonia concentration in the headspace compared to the control.

Identification	Week 1	Week 2	Week 3	Week 4	Average
Cover	51	71	79	79	70
Half Cover	44	59	60	58	55
Cover plus geotextile	59	78	83	89	77
Cover plus zeolite	72	81	89	88	82

Informal odor observations (frequent sniffing by students and lead author) confirmed odor reductions consistent with the ammonia concentration reductions. The data in Table 2, also make the points (1) The covers tended to become more effective with time, this is consistent with the expectation that an aerobic bacterial population within the cover is essential for ammonia oxidation. (2) The thicker covers achieved a greater ammonia reduction than the thin ones. (3) The addition of a geotextile or a zeolite layer increased the ammonia reduction . This was particularly apparent during the first two weeks of cover use

Field demonstration and evaluation

Location and description of the field site: In order to evaluate the effectiveness of the floating cover, a farm was selected in Onslow County, North Carolina, that had a well-established anaerobic lagoon serving a growing-finishing swine herd. The farm, owned by George Gillette, was designed by the Onslow County Soil and Water Conservation Commission to serve a conventional, mechanically ventilated building with a total capacity of 1,224 feeder to finish pigs. The lagoon as designed is 4 m deep with 3:1 side slopes. The intent was to provide 2.6 m of permanent storage, 1 m of temporary storage and 0.3 m of free board. Expected nitrogen production from the facility was calculated to require either 8 ha of Bermuda hay or 15 ha of corn based on a nitrogen balance The lagoon has a surface area of approximately 0.9 ha.

Description of the lagoon cover: The floating cover consisted of two parts: a permeable foam board and a proprietary biocover. The foam board is made of post-industrial recycled, closed-cell polyethylene foam. It is highly air and water permeable. The technical data for the foam board are summarized in Table 3. The biocover adds a gas absorption and selective cation exchange capacity. It too is highly gas and water permeable and increases the structural strength of the overall cover for severe weather protection (heavy rain and strong wind). The biocover is also highly UV resistant.

Table 3. Technical data: Permeable foam board.

Characteristic	Value
Material	Recycled post industrial, cross-link, closed cell polyethylene foam cut into chips nominally 1 cm dimension then heat bonded
Dimensions	35 mm thick, 1 m by 2.2 m
Density	30 to 60 kg/m^3
Weight	3 kg/m^2
Water permeability	Horizontal : >0.036 m/s Vertical: >0.032 m/s
Gas permeability	2 l/s at 2 cm pressure drop
Chemical resistance	Resistant to most chemicals
Life expectancy	10 to 20 years

Installation procedure: The materials were shipped to the site prior to the installation and unloaded by the owner of the farm. The six-man installation crew arrived on site and selected an area near the lagoon as the initial assembly area.

The assembly procedure consisted of placing the 35 mm foam panels on the ground, joining them together by heat bonding the adjacent panels to each other. After an area of foam more than 8 m wide across the end was completed, the geocomposite was unrolled over the foam. The geocomposite was bonded to the foam panels with an adhesive. Granular zeolite was then placed on the geocomposite at a uniform rate.

The completed cover section was then pulled onto the lagoon. This process was continued until the cover reached the center of the lagoon. The assembly area was then moved to the opposite end of the lagoon, and the remainder of the cover was assembled and pulled across the lagoon from this end. The two sections of the cover were then joined together with adhesive and the entire perimeter of the cover was secured in an anchor trench around the lagoon.

SAMPLING AND ANALYTICAL PROCEDURES

Water sampling :.

Liquid samples were collected from the Gillette Farm lagoons during the time preceding and immediately following the installation of the cover. Samples of the lagoon cover were collected for microscopic examination and analysis for nitrifying bacteria approximately three, four and six months after installation. In the first sampling only the upper layer was sampled. In subsequent samplings, a complete cover sample was collected, which included both the geocomposite and the supporting layer of polyethylene foam board. In each of the first two samplings, a section of cover approximately 6 cm square was collected, immediately placed in a small volume of phosphate buffer solution for microscopic examination. Temperature loggers were placed to measure the surface temperature of the lagoon cover and at the 15 cm water depth at two locations on the covered lagoon from Sept. 28 through Oct. 4, 2000. Fifteen cm water depth temperatures were also measured at the same time and at two locations in a similarly sized but uncovered nearby lagoons.

Ammonia flux rate measurement:

The approach used to measure the ammonia emission rate from the lagoon both before and after installation of the cover combined path-integrated concentration data acquired with an open-path Fourier transform infrared (OP-FTIR) instrument along with a recently proposed and evaluated computed tomography (CT) technique (Hashmonay and Yost 1999, Hashmonay et al. 1998, and Hashmonay et al. 2001). Measurements were made when the wind was from the ESE in order to eliminate the confinement pig building as an odor source. Wind speed and direction data were collected and averaged over the same time. The concentration values are calculated for every 2x2-m-square elementary unit in a vertical domain, then integrated incorporating wind speed data at each height to compute the flux. Concentration values are converted from parts per million by volume to micrograms per cubic meter using molecular weight ratios and ambient temperatures. Using wind speed enables the calculation of the fluxes in grams per second.

RESULTS AND INTERPRETATION

Lagoon content analyses*:*

The results of lagoon liquid sampling are presented in Table 4. These results coupled with the ammonia emission data show that the cover is reducing ammonia volatilization Although, the lagoon samples were collected from a variety of locations the constituents analyzed did not vary between sampling locations. This indicates that even with a cover in place, there is sufficient mixing within the lagoon to cause essentially uniform concentrations of the soluble constituents.

Table 4. Concentrations, mg/l, of various soluble constituents in the lagoon immediately before and after cover installation on August 9, 2000.

Date, ‘00	Kjeldahl N	Ammonia N	Total P	COD
July 21, before cover installation	668	510	180	3316
Aug. 4, after cover installation	607	465	101	1470
Aug. 25, after cover installation	669	513	116	1204

Bacteriological examination: The Sept. 28 sampling of the surface cover revealed a population of healthy filamentous large green algae, some blue-green bacteria, diatoms, motile bacteria, nematodes and ciliated protozoa. This indicates that sufficient moisture and nutrients were available within and on the cover surface to support an environment suitable for such active microbial metabolism. It is also noteworthy that green algae are unable to fix atmospheric nitrogen, thus nitrogen in the form of ammonia and other nutrients including phosphorus and trace minerals contained in the lagoon liquid and/or escaping gases are likely transported into the cover matrix. An end product of green algae metabolism is oxygen, and the extent of growth observed no doubt contributes to a cover surface environment suitable for active aerobic metabolism. Qualitative bacterial observations indicated that potential methane and sulfide oxidizing bacteria may have been present in the observed microbial population. Methane and hydrogen sulfide are both gases associated with anaerobic treatment of swine manure. As such, the presence of these bacteria in this environment is not surprising.

The Nov. 19 samples showed significantly increased numbers of bacteria and protozoa as compared to the September samples. Qualitative observations indicated the presence of many different bacteria, including potential sulfur oxidizing bacteria and a few nitrifying bacteria. Enrichment culture analysis provided reasonable evidence for the presence of both ammonia and nitrite-oxidizing bacteria. It is logical to anticipate the presence of nitrifying bacteria in the aerobic environment of the biological cover.

Direct microscopic examination and analysis of the Jan. 11, 2001 samples showed that microbial activity continued to increase. As previously observed, the microbial population was diverse and contained algae, bacteria and protozoa. Protozoa, however, were not observed in significant numbers, and this may have been the result of cooler conditions. Sulfide, and ammonia oxidizing bacteria were still present.

Collectively, these data show that under the environmental conditions provided by this swine waste treatment lagoon, the permeable cover matrix established an active and environmentally beneficial microbiological population. Microbes contained in the population are capable of catabolizing environmental nutrients and gases associated with liquid swine manure, including ammonia, hydrogen sulfide and perhaps methane. Conclusions regarding transport mechanisms of nutrients from the lagoon environment into the cover matrix, the extent (rate) of catabolism of these nutrients, long-term biological performance, and fate of metabolic by-products within the cover matrix cannot be drawn from this study.

Odor evaluations:. The odor panel data show that on the two August sampling dates, odor and irritation concentrations were very low in emissions from the lagoon as well as in the lagoon liquid.

Temperature: Temperature was measured on the cover surface and in the lagoon liquid for the period Sept. 28-Oct. 4, 2000. The most immediate message from these data is that the dark-colored cover is an effective absorber of solar energy as well as an effective radiator during the night. Secondly, the cover is an effective insulator in that the water temperature at the 15 cm depth in the covered lagoon was constant at 24 C while the water at the 15 cm depth in the uncovered lagoon varied by up to 6 C between daily high and low temperatures.

Ammonia concentrations in air over the lagoon before and after installation of the cover: Ammonia concentrations in the air 30 cm above the lagoon surface were measured during two periods. The first period, July 8-14, 2000, was before the installation of the cover. The second period, Aug. 5-21, was after installation of the cover. As would be expected, there was considerable scatter in these data due to differing wind conditions and temperatures at the time of sampling; however, the data do confirm the approximately 80 percent reduction in ammonia emission rate measured in the laboratory studies.

Ammonia flux from the lagoon before and after installation of the cover: Average results over two hours of data collection for ammonia emission fluxes for July 11, 2000 (before lagoon cover installation), Aug. 16 (one week after lagoon cover installation) and Oct. 24 (three months after lagoon cover installed) indicated that the ammonia emissions dropped from 900 to 216 to 25 g/hour. The ammonia flux data are in agreement with both the laboratory study and the conventional ammonia in air concentration data in demonstrating a reduction in the ammonia emission rate in excess of 80 percent.

OBSERVATIONS:

1. The cover resulted in the ammonia evolution rate being reduced by over 80 percent with time compared to the same lagoon prior to cover installation and under more controlled laboratory conditions where a similar uncovered surface was available for comparison.

2. The surface of the cover reached a daytime temperature in excess of 49 C, but this heat was not transferred to the water surface due to the insulating properties of the cover material. The cover reduced the diurnal temperature fluctuations of the water surface to less than 1 C. The cover reduced the rate at which the lagoon surface cooled in the autumn compared to a similar uncovered surface.

3. Under laboratory conditions in which intensely odorous manure slurry was being used as the odor source, the cover resulted in a nearly complete blockage of odor emission. Under field conditions, the odor measured by the trained panel was of very low intensity just as was the odor of the liquid beneath the cover. Thus, the field sampling added little to document the effectiveness of the cover as a mode of odor control.

4. The lagoon cover became colonized with a diverse microbiological population, including dispersed aerobic bacteria and free-swimming ciliated protozoa. These conditions are those that would be expected in a floating cover that was rich in nutrients as well as highly aerobic due to the relatively high porosity and low organic loading rate.

5. The material from beneath the cover is likely to be more odorous than that from a similar uncovered lagoon and will require further treatment if it to be reused for flushing the building without contributing to elevated odors within the building.

6. Lagoon liquid nitrogen concentration has increased, conserving nitrogen for utilization alternatives.

7. A hurricane and heavy rains have not affected the cover integrity since installation in August 2000.

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A Dozen Successful Swine Waste Digesters

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ABSTRACT

Swine waste can be successfully stabilized in farm scale anaerobic digesters. Four examples each of ambient temperature covered lagoon digesters, heated mixed tank digesters and heated mixed lagoons are included. All systems meet Natural Resources Conservation Service draft standards. Gas use in boilers, engine generators and flares is discussed. Summary tables are presented to allow comparisons of costs, savings and gas use between the projects. Biogas recovery and use in boilers or engine generators is discussed. A detailed case study of a single cell heated covered lagoon for odor control from 120,000 pigs is presented. The system cost $1,200,000. The system started up readily and is producing an average 530,000 ft^3 of biogas per day. The system benefits and methane reductions are described.

Keywords: Hogs, swine, pigs, biogas, methane, odor, anaerobic digestion, digester, covered lagoon, complete mix digester, nutrient management, pathogens

Introduction

Anaerobic digestion is more extensively used outside of the US where treatment of animal waste has been a concern for a longer time. An anaerobic digester is a vessel designed to retain decomposing manure for sufficient time at the designed operating temperature to allow the growth of methanogenic bacteria in a "steady-state". Methanogenic bacteria produce methane as a metabolic biproduct. Electricity and heat production from methane combustion are direct benefits of anaerobic digestion. The effluent of a digester has an earthy smell with some ammonia present. The first dairy digester systems in the US were installed principally to produce energy during the energy crisis. The first pig manure digester systems in the US were installed principally to control manure odors. Today, farmer motivation for building and operating anaerobic digesters has expanded from direct energy benefits to include key non-energy benefits such as: odor control, improved manure handling, mineralization of organic nitrogen, weed seed destruction, pathogen reduction and byproduct production such as digested dairy solids.

Ambient Temperature Covered Lagoon Digesters

Ambient temperature covered lagoon digesters are most successful in warmer climates south of the Mason-Dixon line. A properly sized lagoon receives dilute manure with less than 2% total solids. The manure is either flush or pull plug collected and decomposes in the lagoon resulting in year round biogas production. Gas production varies seasonally and is useable for electricity production or is flared for odor control.

Barham Hog Farm, Zebulon, NC - 4000 sow farrow to wean

Barham Hog Farm has 5 buildings with pit recharge. The farm was built with a single cell treatment and storage lagoon. The project installed a separate covered lagoon prior to the existing lagoon. AgSTAR provided design, installation and troubleshooting support and worked with NRCS to design the lagoon. Lagoon construction began in July 1996. The lagoon cover, 400,000 Btu boiler and a 120 kW generator were installed in December 1996. Biogas use for heating water began in January 1997. Lagoon cover manufacturing problems limited biogas recovery and the production of electricity, however the boiler has operated almost continuously, providing hot water for pig mats under farrowed pigs. The owner was refunded his money and has purchased a new 40 mil HDPE cover. The 18 month average for biogas recovery is 632 m3/d (22,300 ft3/d) of biogas. Much of the year the generator is operated 12 hr/d at up to 90 kW during the daytime and during nighttime 12 hours, a boiler is operated to produce hot water for keeping baby pigs warm . Odor is virtually non-existent. Cheng (1999) found that 30% of the total Kjeldahl nitrogen (TKN), 75% of the P and 20% of the K was retained in the covered cell. Cheng (1999) found pathogen reduction to be 2 to 3 orders of magnitude.

The farm has been limited to offsetting about $18,000 per year in electricity and about $12,000 per year in propane purchases. The local utility is not in favor of farm cogeneration. However, odor control benefit is very important to the owner because large subdivisions are being built within one mile of the farm. Also, the improved biological stabilization and nutrient mineralization in the digester resulted in the effluent from the storage lagoon containing 60% less nutrients than before. Consequently, the farm manure treatment and nutrient application complies with the 1997 manure management regulations without additional investment.

Martin Family Farm, South Boston, VA - 600 sow farrow to feeder pig

Martin Family Farm covered the first cell of a two cell lagoon receiving flushed manure in 1993 and began engine-generator operations in spring 1994 with a matching grant from the Southeast Regional Biomass Energy Program (SERBEP). The first cover slowly sank and collected less gas each year. In 1997, Engineered Textile Products of Mobile, AL and Seamens Corporation contributed a demonstration XR-5 modular cover system to replace the original failed cover design. Martin Farms installed the new cover and replaced the corroded lagoon heat loop with radiators. Methane recovery has been continuous throughout the project, though gas use has not been. The farm has produced up to 397 m3/d (14,000 ft3/d) of biogas and 600 kWh/d during the summer. Winter gas production drops off to less than 170 m3 (6,000 ft3/d) and use has been problematic. The farm has planned and purchased a hot water boiler for pig mats under farrowed pigs. A boiler will more closely match the farm labor skill and availability. Odor is virtually non-existent, the effluent is stable and nutrient content of the second lagoon has been reduced substantially.

The major benefit to the farm has been odor control and elimination of objections by neighbors. The farm has produced several thousand dollars worth of electricity. A secondary benefit from the two cell approach has been nutrient reduction in the second lagoon and ease of effluent management in sprinklers on fields that are closer to the neighbors than the farm is.

Corneche, Chile - 102,000 finish hogs and La Ramirana, Chile – 20,000 Sows + 40,000 wean – finish.

Both of these facilities chose to install an anaerobic digester system in order to reduce the odor emanating from their waste storage lagoons. Their manure collection systems are pull plug and flush systems. The lagoons are earthen basins and were fully covered with HDPE liner with the edges buried around the lagoon banks. The Corneche installation was producing biogas by July 2002 and no problems were experienced during start up. The La Ramirana digester will be under going start up in late 2003. The primary benefit to both farms is the reduction of odor. Both farms will be flaring the biogas for odor control. No electricity will be generated with the biogas.

Farm	Start	Pigs	Type	Cost	Savings	Gas use *
Martin	1993	600	sows	$120,000	odor	E, F
		2,000	grower			
Barham	1996	4,000	sows	$289,500	$ 29,000	E, H, F
Corneche	2002	102,000	finisher	$700,000	odor	F
La Ramirana	2003	20,000	sows	$800,000	odor	no
		40,000	wean-fin			
* - E = electricity, H = hot water, F = flare						

Tank Complete Mix Digesters

Tank Complete mix digesters are used to treat waste with 3 to 10% total solids. This concentration contains adequate volatile solids to produce enough biogas (60% methane, 40% carbon dioxide) to maintain digester temperature. These units are usually heated with hot water from an engine to 100 degrees and mixed to maintain a high level of bacterial activity. The hydraulic retention time is greater than 12 days. Complete mix digesters produce a steady gas output that can be used for cogeneration or in a boiler.

These units can represent a cost savings over using an ambient temperature lagoon designed to Natural Resources Conservation Service (NRCS) or American Society of Agricultural Engineers (ASAE) standards to perform the same level of treatment for odor control. Ambient temperature lagoons would be 10-20 times larger than these digesters to perform the same function.

Colorado Pork, Lamar, Colorado and Bell Farms, Thayer, IA - 5,000-sows farrow-to-wean each

The farms are very similar in size and operation. Colorado Pork has about 600 more pigs growing as replacement gilts. However, the farm buildings and equipment are different. Both facilities were built in 1997-8 on sites that had been range or pasture. Environmental concerns of neighbors and state authorities prompted both owners to weigh waste management alternatives. Both chose complete mix digesters with separate storage to: 1. biologically stabilize manure, eliminate odor and optimize methane recovery for electricity production. 2. reduce their investment in waste management and 3. avoid problems with regulators by installing an environmentally beneficial system.

Periodically, plugs are pulled and manure is drained to a concrete collection tank and then pumped to the 2,100-2,200 m3 concrete tank digesters. The digesters are heated, mixed and covered by two biogas inflated plastic gas collection domes. Effluent at Colorado Pork flows into a nearby basin to be evaporated, while Bell Farms effluent is stored in 2 concrete tanks for annual application to cropland. Biogas fuels one Caterpillar 3306 engine attached to an 80 kW generator at each farm. All electricity produced is used on the farms. Heat, recovered as hot water from the engine and exhaust, is used to maintain the appropriate temperature in the digester. Biogas is automatically flared when not being used by the engine (for example during maintenance). The farms produce up to 60% of their own electricity needs. The farms are not expected to have surplus electricity to sell to the utility and do not have sales metering. The farms chose not to sell electricity rather than submit to uneconomical requirements and controls of the utility company. Future plans include using excess heat in the farrowing barns.

The Colorado Pork digester heating began August 6, 1999 using natural gas to fuel the generator. System operations on biogas began late September 1999. The digester has been problem-free. The engine has had typical startup mechanical problems, however, the unit has been operating continuously. In the first 5 months, the generator operated over 90% of the time, burning 48,160 m3 (1,700,000 ft3) of biogas and producing 140,000 kWh at an average load of 50 kW. The system output increased to 67 kW after 2 bad sensors were found and fixed. From early 2002 to Fall 2002 the farm was closed while sow stock was changed. The farm and the digester returned to operation in late 2002.

The Bell Farms digester was filled and heated over a 90-day period and started biogas production in August 1999, after delays due to additional construction on the digester tank. Full biogas yield was reached in September 1999. The digester has been virtually trouble free. The generator has operated 77% of the time during the first 6 months yielding 64,250 m3 (2,268,000 ft3) of biogas with an electricity output average of 67 kW. Typical startup issues of bad sensors cropped up. The engine was rebuilt under warranty after a breakdown due to loss of coolant. The system had a manure spill reach a ditch through a drain added by contractors. The local utility and the larger transmission and distribution utility were inconsistent on requirements for interting the farm to the utility grid. The methane recovery system at both Colorado Pork and Bell Farms has diminished farm costs of production by reducing the quantity of electricity purchased, while greatly improving site odors from manure storages which were objectionable to all who experienced them and contributing to the farm’s environmentally sound manure management strategy. At Bell Farms, the digester is annually producing about $46,600 worth of electricity at $0.09/kWh. The annual value of electricity produced at Colorado Pork is estimated to be $34,800 based on $0.07/kWh.

DJ Acres, 7 Valleys Pennsylvania, 15,000 farrow to finish

The anaerobic digestion facility at DJ Acres as with many of these facilities was designed to reduce the odor coming from their waste storage ponds. The digester was started-up in 1986. Start up had been slow due to low winter temperatures. The manure at the farm was scraped producing a slushy mixture that lended itself to treatment in a complete mix digester. The digester consisted of one concrete tank that were heated and mixed and covered with inflatable tops. The biogas was used to produce heat and electricity. The heat was recovered from the engine by doing jacket and exhaust heat recovery. The generator produced 90% of the heat required by the farms. The electricity generated was used onsite with the surplus sold to the local utility. The hog farm was closed nine years later in 1995 resulting in the end of the digester operation as well.

Gypsy Hill Farm, Lancaster PA – 4000 Pigs and Whey.

The Gypsy Hill complete mix digester was originally designed by a company called Energy Cycle in 1983. The system has been in operation since that time producing biogas and 120 kW of electricity. The system was redesigned and rebuilt, increasing its capacity, by RCM Digesters in 2000. All the electricity produced is sold to the utility. The heat recovered from the engine is used to heat the digester, and any additional heat is used to meet the farms thermal needs. Excess biogas is flared for odor control.

Manure collection at the farm is accomplished by mechanical scrapers. The manure is then sent to a collection tank before mixing with cheese whey and introduction into the digester. Effluent from the digester is stored in a metal tank and an earthen basin prior to field application.

Tohoku Farm, Aomori, Japan – 30,000 Pigs farrow to finish and
Kazuno Farm, Hachinohe, Japan – 21,000 Pigs farrow to finish

These two facilities are similar in size and operation. Both chose to install anaerobic digestion equipment primarily for odor reduction. Manure collection at the facilities employs mechanical scrapers. The manure flows to a mixing tank before it is sent to the digester. At both sites the digester consists of 2 separate concrete tanks each covered by an inflatable cover. In Tohoku the effluent from the digester flows to an HDPE lined basin prior to land application. At Kazuno, effluent is further treated by extended aeration to meet local requirements. The primary benefit experienced at both farms is waste treatment and electricity generation. The electricity generated is used on farm in both cases to power aeration treatment. Neither site has experienced any start-up or operational problems since beginning operation in October 1989 at Kazuno and January 1989 at Tohoku.

Farm	Start	Pigs	Type	Cost	Savings	Gas use
DJ Acres	1986	17,000	farrow to	$ 250,000	$72,000	E, H, F
			finish			
Gypsy Hill	1983	4,000	finish	$ 289,500	$ 29,000	E, H, F
		12,000 g	whey			
Tohoku	1989	21,000	farrow to	unknown	unknown	E, H, F
			finish			
Kazuno	1989	30,000	farrow to	unknown	unkknown	E, H, F
			finish			
Swine USA	1999	5,000	sow	$ 525,000	$ 36,000	E, F
Colorado Pork	1999	5,000	sow	$ 374,000	$ 44,800	E, F
* - E = electricity, H = hot water, F = flare						

Heated Mixed Covered Lagoon

Heated mixed covered lagoon digesters are used to treat waste with 3-6% total solids with adequate volatile solids to produce enough biogas (60% methane, 40% carbon dioxide) to maintain digester temperature. These units are heated to maintain a high rate of bacterial growth. Mechanical mixing or stirring is used to improve the contact between substrate and microorganisms thereby promoting decomposition of the substrate.

A heated digester should represent a cost savings over using an ambient temperature lagoon designed to Natural Resources Conservation Service (NRCS) or American Society of Agricultural Engineers (ASAE) standards to perform the same level of treatment for odor control. Heated mixed covered lagoons are 1/3 the volume or less of ambient temperature lagoons to perform the same function. The design and operation goal of the subject digester is consistent biological stabilization of waste and odor control rather than optimization of biogas production and use while stabilizing the waste.

Apex Pork - 8,600 Head Pig Finishing Facility, Rio, IL

Apex Pork has 8,600 hogs in 9 buildings with pull plug manure collection. Three years of seasonal odor episodes from the manure storage pond were not acceptable to downwind neighbors. The farm chose Resource Conservation Management, Inc. to design an innovative, low cost, heated, mixed covered earthen lagoon digester. A bank-buried insulated floating cover is installed on the 36.3 x 48.5 x 5 meter (120 x 160 x 16.5 ft) lagoon which can hold roughly 20 days worth of manure. The digester produces enough methane to fuel a boiler to heat the digester and flares unused methane. Stabilized digester effluent flows to the storage pond. The pond no longer emits odorous gases. The primary benefits to the owners are odor reduction of stored and field applied manure. There have been no odor complaints since the digester was installed. Compliance investigations by state regulators has stopped. The digester is able to accommodate the variation in manure loading rate that results from all-in-all-out operation.

The digester started up in about 30 days switching to biogas from propane in June 1998. By mid summer, 1998 the system was producing 1,020 m3 (36,000 ft3) of biogas per day. The unit was running well when a microburst damaged the gas collection cover and nearby buildings in August 1998. The partial cover was replaced with a bank attached floating cover over the whole lagoon in October 1998. Concurrently the farm was emptied of pigs to allow building renovations and a change of pig production technique. The farm, originally a continuous flow facility, converted to all-in-all-out operations. Digester heating began in December 28, 1998. The boiler system was switched to biogas January 24, 1999 and has run full time with little or no maintenance since. The digester gained temperature during the coldest times of the year. The digester has been through 3 grow-out cycles without problems. The system is simple to operate and the owner only spends about 10 minutes daily to check the system. Several lessons of this project were: 1. A bank-buried complete lagoon cover, though a more expensive first cost, is less expensive to maintain than a floating edge partial cover. 2. Inexpensive cover materials such as 20 mil HDPE coated fabric can present problems in extreme weather. 3. Pig operations can change rapidly and radically and present a completely different waste stream.

Peralillo, Chile – 120,000 Finish Hogs, La Estrella, Chile – 137,000 Finish Hogs and Pocillias, Chile – 238,000 Finish Hogs.
La Estrella and Pocillias were built in 2002 and have been started as of January and February of 2003. Peralillo has been in operation since January 2001. All three facilities have a mixture of pull plug and flush manure collection. The collected manure flows to heated mixed lagoons where it is treated and the effluent sent to an earthen basin for storage and use. The primary benefits at all three sites has been odor reduction and waste treatment. The biogas generated is used to fire boilers at all the sites and the hot water generated meets the thermal needs of the digesters. Peralillo did not experience any start up problems. La Estrella and Pocillias both experienced some plumbing problems at the outset as a result of low winter temperatures.

Farm	Start	Pigs	Type	Cost	Savings	Gas use *
Apex	1993	8,600	finisher	$ 174,000	odor	H, F
Peralillo	2001	120,000	finisher	est $1,100,000	odor	H, F
La Estrella	2003	137,000	finisher	est $1,200,000	odor	H, F
Pocillias	2003	238,000	finisher	est $1,500,000	odor	H, F
* - E = electricity, H = hot water, F = flare						

Biogas recovery and use in engine generators or boilers

Biogas can be used for electricity production in an engine generator set, hot water production in a boiler, or flared for odor control. A Caterpillar 3306 engine (shown below) has been used continuously to generate 45 kW of power for the last 21 years.

The biogas boiler in Pocillias Chile produces 20 Mbtus of thermal energy used to generate hot water for use in the hog farm.

One of the primary benefits of anaerobic digestion is odor control. If the biogas is not being used to generate electricity or hot water then it will be flared to control the odor.

Detailed case study of a single cell heated covered lagoon

Perallillo, Chile - 120,000 Head Pig Finishing Facility, South America

Background
The farm has 120,000 hog capacity in 120 buildings. The site is operated as an all-in-all-out grow-finish facility. Approximately 90 buildings were built with flushed manure systems and 30 were constructed with pull plug manure collection. All wastes were originally drained to a storage facility which was the dammed upper portion of a small watershed drainage. The storage facility has almost 88 acres of surface area but is predominantly shallow, less than 10 feet average depth. Quite a bit of shallow sloped land was included in the storage. The facility was sized for about 6 months of volumetric storage. Odor from the manure storage pond was not acceptable to the owners, workers, neighbors, or government officials. In addition, seasonal pumping of manure exposed large areas of perimeter beaches that served as breeding grounds for copious quantities of flies.

The owners committed to resolution of the problem, conducting a world-wide solicitation for designers with demonstrated cost effective technology. The farm owner chose Resource Conservation Management, Inc. to design an innovative, low cost, heated, mixed covered earthen lagoon digester based on similar success of the approach that was demonstrated at Apex Pork in Rio, IL on an 8,900 head finisher facility.

Manure Collection and Transfer
All flush buildings are flushed daily with fresh water. The flush manure flows to collection tanks. Collection tanks are pumped daily to the digester. Pull plug buildings are pulled on a rotating schedule where 2 to 3 buildings are drained to a transfer tank on a daily basis and then pumped to the digester. The daily flow to the digester varies between 900 m3 and 1800 m3.

Digester
A bank-buried insulated floating cover is installed on the 105 x 105 x 9 meter (346 x 346 x 29.7 ft) lagoon which can hold roughly 20 days worth of manure (32,000 m3 approximately 8,000,000 gallons).

Digester Heating
The digester is operated at 35 degrees C and can vary up to 4 degrees C. Digester is heated with an external exchanger.

Digester Mixing
The digester is mechanically mixed. Pump mixing is continuous.

Gas Production
The digester produces enough methane to fuel a boiler to heat the digester and flares unused methane. Gas production has varied between10,200 m3 to 15,500 m3 (360,000 to 550,000 ft3/d) since the digester startup. After 2 hydraulic retention times with the

farm fully populated, the digester output averaged 530,000 ft3/d over a 2 month period. Gas production fluctuations are expected due to fluctuations in farm pig population.

Digester Effluent
Stabilized digester effluent flows to the storage pond.

Digester Operations
The digester was started up over a 4 month period in ending in November 2000. Flare operation began in late December with flaring of 150,000 ft3 of biogas. By late January 2001 the system was producing 5,600 m3 (200,000 ft3) of biogas per day. The unit was running well when the pig population was brought up to farm capacity.

The digester maintained temperature during the coldest times of the year. The digester has been through 3 grow-out cycles without problems. The system is simple to operate and a single operator is charged with operating the system. The main work is checking the system operations readings.

Construction Costs
The costs for construction are shown in the appended table. Most equipment was imported and these costs are included in the cost estimate. In-country construction costs are remarkably similar to US construction costs as virtually all construction materials and equipment are imported, thereby offsetting labor cost savings. The capital cost is approximately $10.06/pig of capacity. The system life should be 15 years. Assuming no interest charges and 2.5 turns per year the cost per pig produced would be $0.27.

Operation Costs
Operations are routine at this time. Approximately 1.5 men are working at the digester, though their main work is pumping manure from buildings to the digester and from the digester to storage. Assuming this facility has 2.5 turns per year, the cost per pig shipped is approximately $0.25.

Results
After 2.5 years of operation the digester is healthy and operating well. It is maintaining its heat level and the storage no longer emits malodorous gases. The primary benefits to the owners are odor reduction of stored and field applied manure. There have been no odor complaints since 4 months after the digester was started up. Compliance observations by regulators continue, but the government participated in an open house 6 months after startup to demonstrate their support of the odor control solution. The digester is able to accommodate the variation in manure loading rate that results from all-in-all-out operation. The attached figures present operational information including influent flow, biogas flow and CO2 variations.

Lessons Learned
Several lessons of this project were: 1) Low cost, in-ground, heated, mixed, floating cover digesters can meet farm environmental needs; 2) Large single tank, anaerobic

reactors are possible on farms; 3) Finishing farms with flush manure collection have the options of heated anaerobic digesters.

Future Options
The owner would like to generate electricity for his operations. There is the possibility to install about 1.5 megawatts of electric capacity. Equipment costs and benefits have been developed. Equipment specifications have been developed. Negotiations with the power company have begun.

The success of the project in meeting its environmental goals led the owner to begin another project to retrofit other farms with RCM design anaerobic digesters.

A Low-Cost Digester to Control Odors at a 120,000 Head Hog Farm

Paper Number 012298 Session 128 Poster #142

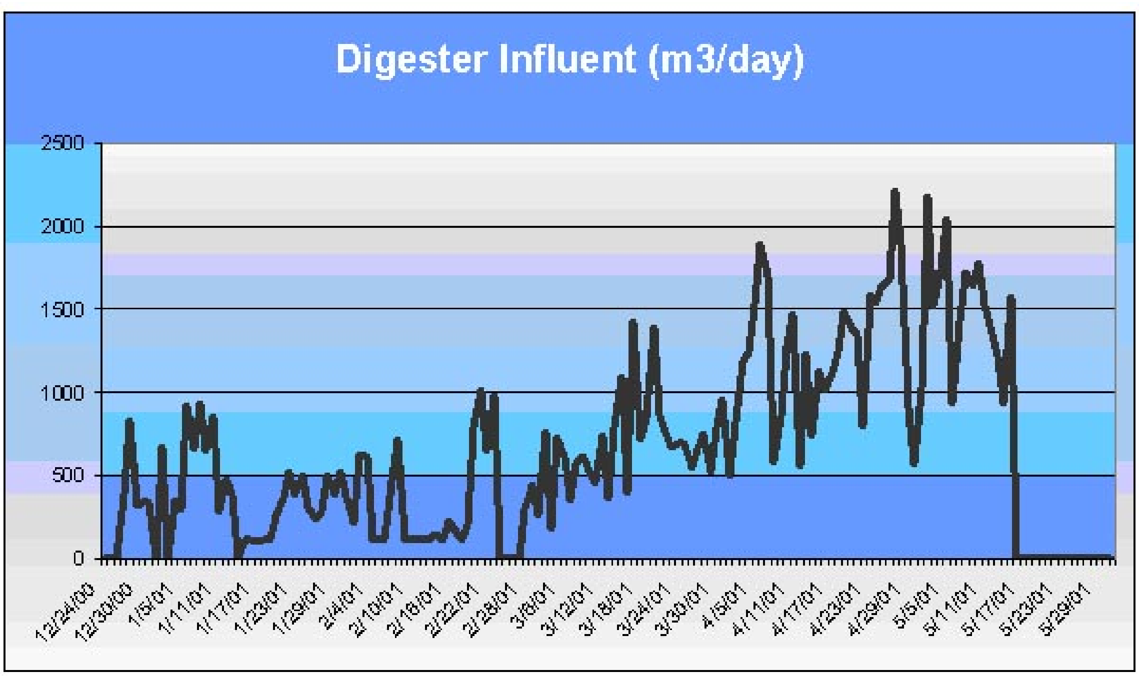
Construction Costs

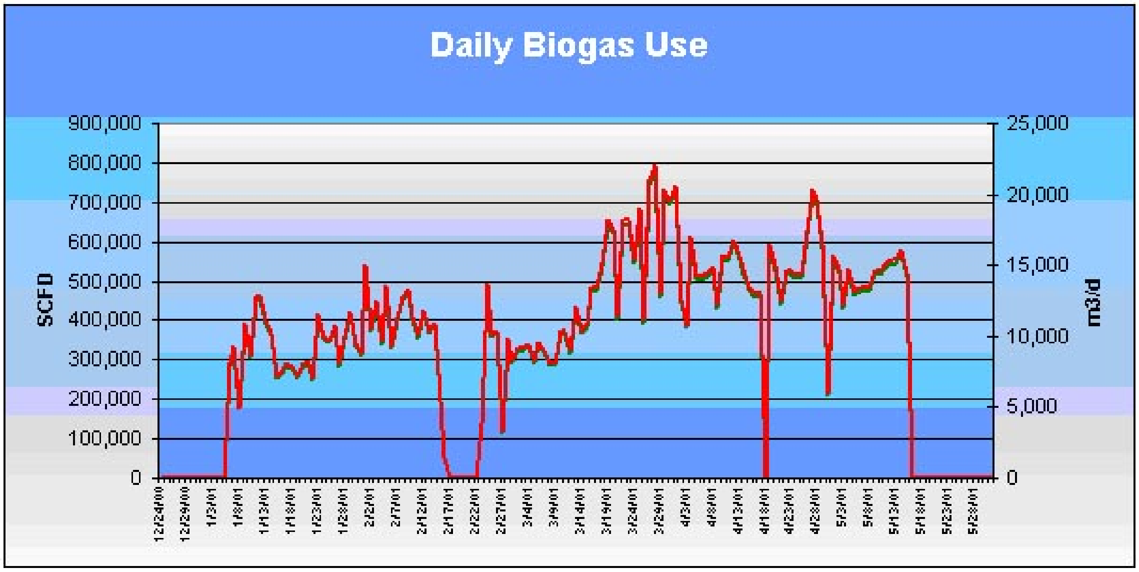
Earthwork, soil testing	$ 94,000
Influent piping	$ 37,000
Digester liner, cover, stirrer, heat exchanger, gas collection	$ 470,000
Effluent pump station	$ 67,000
Energy building	$ 72,000
Gas handling - meter, pump, flare, controls, piping and wiring	$ 144,000
Boiler with shipping and duties	$ 175,000
Engineering	$ 142,000
Startup	$ 7,000
Total Cost	$ 1,208,000

Approximate U.S. Capital Cost - $10.06/head capacity for reliable odor control

Estimated U.S. Operating Costs - $ 0.25/head sold (1.5 employees plus repairs)

Mark A. Moser, RCM Digesters, Inc.
P.O. Box 4716, Berkeley, CA 94704 **Phone (510) 658-4466** **Fax (510) 658-2729** **rcmdigesters.com**

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700,000
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500,000
400,000
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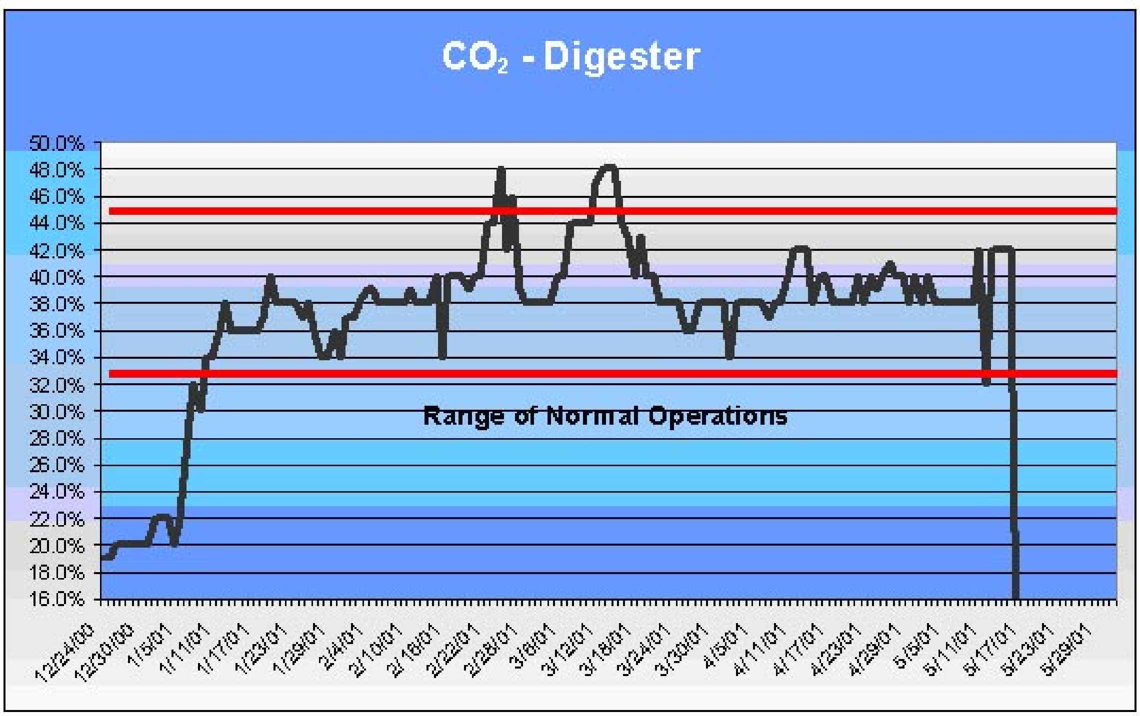
CO2 - Digester
50.0%
48.0%
46.0%
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Range of Normal Operations
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Fertilizer Value and Weed Seed Destruction Potential of Digested Manure

Presented at:
Anaerobic Digester Technology Applications in Animal Agriculture: A National Summit, June 2-4, 2003, Raleigh, North Carolina

Authors[1]: Deborah Allan, Department of Soil, Water and Climate, University of Minnesota (dallan@soils.umn.edu); Elizabeth Katovich, Department of Agronomy and Plant Genetics, University of Minnesota (katov002@umn.edu); and Carl Nelson, The Minnesota Project (cnelson@mnproject.org)

ABSTRACT

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. The project is composed of three components, focusing on dairy AD systems. The first, augmented with field trial research, compares soil quality and yield response for commercial fertilizer, stored digested manure, and un-digested manure. The second considers the destruction of weed seeds, a widely-claimed, but little studied, benefit of AD. The project tests viability of weed seeds suspended in an anaerobic digester. The final portion of the project considers the economic performance of AD systems, which will be considered in another paper.

Results to date indicate the following key preliminary conclusions: (1) stored, digested manure can result in crop yields equivalent to undigested manure or fertilizer when applied at similar nitrogen rates, while simultaneously allowing the capture of bioenergy; and (2) the digestion process does not appear to significantly destroy weed seed viability, although germination times may be impacted.

BACKGROUND

The need to more fully understand questions posed by anaerobic digesters was spurred in Minnesota by the installation of an anaerobic digester system at Haubenschild Farms, an 800-cow dairy farm an hour north of Minneapolis/St. Paul. In 1999, the farm installed a heated plug flow digester with a 130-kilowatt engine/generator to utilize the biogas. The

[1] Other participants in this project include: Michael Schmitt, Department of Department of Soil Water and Climate, University of Minnesota; C. Roger Becker, Department of Agronomy and Plant Genetics, University of Minnesota; William Lazarus, Department of Applied Economics, University of Minnesota; and Margaretha Rudstrom, West Central Research and Outreach Center, University of Minnesota.

successful operation of this facility (the generator has been running over 98% of the time since start-up) has resulted in much interest from policy-makers as to the applicability of digesters to other animal feedlot operations in the state. Also, there were claims by the digester industry of the superiority of digested manure, with only anecdotal evidence to support them, and there was a desire to more fully investigate these claims.

In 2000, The Minnesota Project, a non-profit environmental and rural development group, was the recipient of a 4-year U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) grant to look into several questions related to the environmental performance and financial feasibility of anaerobic digesters at dairy farms, as compared to alternative dairy systems. Specifically, the project had three objectives:

1. Compare effects of three nutrient sources - commercial fertilizer, undigested manure and digested manure - on soil quality, crop growth and nutrient uptake;
2. Determine weed seed survival as affected by manure handling; and
3. Conduct an economic evaluation of alternative manure management systems on dairy profitability.

Results from the third objective will be covered in separate paper.

The Minnesota Project contracted with several partners from the University of Minnesota to conduct much of this work. The results presented below are only preliminary (year 3 of a 4-year project), so they should be interpreted as such. Full results will be available at the end of 2004. More information on the Haubenschild Farm and this grant is available at **www.mnproject.org**.

DIGESTED MANURE INTERACTIONS WITH SOIL AND CROPS

A number of studies have shown that manure increases yields over fertilizer applications. This advantage may arise from a number of causes, ranging from slow release nutrient availability to increased soil biological activity to enhanced soil physical properties. Regardless of the specific causal agent, the organic fraction of the manure is associated with this beneficial crop response. Anaerobically digesting manure has little effect on manure's nutrient composition, although some studies have shown that, on a total solids basis, digester effluent has more total nitrogen (N) and a greater percentage of ammonium than undigested manure.[2] Overall, there is a lack of scientific research on the impact of anaerobically digested manure on crop production and soil properties. The objective of this project is to compare and contrast effects of anaerobically digested and undigested manure sources on: a) soil biological and chemical properties; and b) crop yields.

Materials and Methods

Three fields with distinct cropping histories on Dennis Haubenschild's farm were selected as experimental sites. In 2001 when the study began, the Bruce field had been in CRP for the previous two years and had no history of manure application in the past 30

[2] Dahlberg, S.P., J.A Lindley, and J.F. Giles. 1988. Effect of anaerobic digestion on nutrient availability from dairy manure. Transactions of the ASAE 31:1211-1216.

years. The Lilac field had been in alfalfa for the last two years and had a history of manure application in the rotation, and the Appel field had been in corn for the last two years and had a history of manure application. The treatment comparisons at the three sites were fresh raw manure and stored digested manure from the Haubenschild farm, and conventional fertilizer applied as urea.

At each of the three sites with different cropping histories, 18 plots (20' x 200') were established. The 18 plots represent three replications of each of three treatments: stored digested manure, fresh raw manure, and conventional fertilizer. There are two subtreatments, which represent an annual application of manure or fertilizer (Annual) or applications made in Year 1 and Year 3 (Biennial). The biennial application is intended to highlight the differences in residual or carryover nitrogen from the two manure sources and conventional fertilizer. In 2002, a second year of this experiment was conducted on the three fields previously evaluated in 2001.

At the Haubenschild farm, manure is typically applied at a rate of 6,000 gallons per acre. In order to maximize yield differences between the treatments we applied nitrogen at less than optimum rates, but at identical rates for stored digested and fresh raw manure. In spring 2001, using Dennis's manure analysis of 40 lbs total N per 1000 gals of manure (results were the same for both digested and raw manure), and assuming 55% availability in the first year, we applied 3,000 gallons per acre, or approximately 66 lbs available N. Urea fertilizer was applied at 75 lb N/acre. In 2002, application rates were again 3000 gals/A manure for the two manure treatments and 100 lb N as urea fertilizer. Manure samples were taken at the time of application in the spring of 2001 and 2002 (see Table 1). In both years starter fertilizer was applied according to Dennis's usual practice (190 lbs/A of 9-9-31-6.)

Soil samples were collected in 2001 at three dates (4/23/01, 7/3/01 and 8/23/01). Soil was sampled twice per plot at nine row and interrow positions between rows 3 and 5. The first sampling was to a depth of two feet (split into 0-1' and 1-2' sample depths) and was analyzed for soil nitrate. At the second and third sampling times, samples were taken with a soil probe to a depth of one foot, and split into 0-6"and 6-12" sample depths. The samples for each plot at the two different depths were composited into one sample per plot at each depth. Samples were delivered to the lab in coolers and air-dried or refrigerated for subsequent analysis. In 2002, samples were again collected at three dates (5/1/02, 7/18/02, and 8/27/02). Grain yield and silage samples were taken at crop harvest in September of both years.

Soil Analysis

Laboratory analysis of soil samples from July and August of 2001 included available nitrogen (potassium chloride (KCl) extractable ammonium and nitrate), potentially mineralizable nitrogen, total carbon and total nitrogen. In 2002, additional analyses included microbial biomass C and N, and particulate organic carbon and nitrogen (results not yet available). To prepare soils for analysis, the soil was sieved to 4mm, then half was air-dried and the rest stored at 4^{o}C. The air-dried soil was sieved to 2mm after drying. A Leco instrument (Leco Corporation, St. Joseph, MI) was used to determine total percent nitrogen and carbon using 250 mg of air-dried soil. Available N was measured by extracting 30 g of air dried soil with 150 ml KCl, and analyzing on a Lachat (Lachat Instruments, Milwaukee, WI).

Soil microbial biomass carbon and nitrogen was determined for refrigerated soil by moistening it to 60% water-filled pore space. Two sets of duplicate samples were placed in desiccators; one set was fumigated with chloroform and the other served as controls. After two days of fumigation treatment, the beakers of moistened soil were incubated for 10 days at 25^o C in canning jars along with NaOH traps to collect CO_2. The trapped C was then analyzed on a Dohrmann C analyzer (Tekmar-Dohrmann, Cincinnati, OH). Carbon dioxide evolved from the controls during the incubation was subtracted from the fumigated samples and the result was multiplied by a correction factor to obtain a value for microbial biomass carbon. Biomass nitrogen was extracted with 30 mls of KCl for 3.5g of soil. After being shaken for 30 min and centrifuged at 4000 rpm for 10 min, 15ml of KCl was pipetted into scintillation vials and frozen, to be analyzed later on the Lachat.

Potentially mineralizable nitrogen (PMN) was determined by using 30g of air-dried soil and adding 8.5mls of water to maintain 60% water filled pore space in a canning jar. A 5ml vial of water was placed in the jar to keep the soil moist. Jars were incubated for 28 days at 25 degrees C. After 28 days the soil was extracted with 150 mls KCl to determine available N.

Results

Manure analysis

Manure samples were collected from the raw and stored digested manure at time of application to the plots in spring 2001 and 2002, as shown below.

Table 1. Manure analysis for samples collected in Spring, 2001 and 2002.

	Dry matter	**Nitrogen**	**P2O5**	**K2O**
	%	**--------------lbs/1000 gals----------------**		
	Spring 2001			
Raw	8.9	32.9	12.5	32.3
Stored digested	5.5	30.4	10.5	29.5
	Spring 2002			
Raw	7.6	30.2	11.9	39.6
Stored digested	5.7	31.2	9.3	35.5

Total nutrients were similar (on a liquid basis) at the two spring samplings, which suggests that similar amounts of nitrogen were applied to the plots from the raw and stored digested manure sources (about 100 lbs/A of total nitrogen each year).

Manure samples were also collected in October, 2002 from the raw manure mix pit, the fresh digested manure immediately after digestion, and the stored digested manure in the lagoon (at time of mixing and field application). The stored digested samples had lower levels of total and available (ammonium and nitrate) nitrogen than the raw manure or fresh digestate when compared on a wet basis (per 1000 gallons), but amounts were higher on a dry weight basis (Table 2). These differences are partly due to losses of solids during digestion (10% to 7.3% dry weight), and subsequent dilution in the lagoon (7.3 to 4.4% dry weight).

Table 2. Manure analysis for samples collected in October, 2003.

	Dry wt	**Total N**	**InorgN**	**Total N**	**InorgN**
	%	**-----lbs/1000 gal------**		**---% (dry wt basis)--**	
Raw	10.0	33.2	15.7	4.0	1.9
Fresh digested	7.3	32.7	20.2	5.4	3.3
Stored digested	4.4	22.3	13.3	6.1	3.6

Grain yields

Results for grain yield are shown in Fig. 1 (2001) and Fig. 2 (2002). Yields did not differ for any of the three soil treatments, although yields did differ among the three field sites due to variations in previous management history and soil properties. Yields were lower than typical yields obtained on the farm (see "typical" bar in Fig. 2) since N availability was limited by design. By avoiding a situation of luxury nutrient supply, we hoped to maximize the differences in effects of the three nutrient sources.

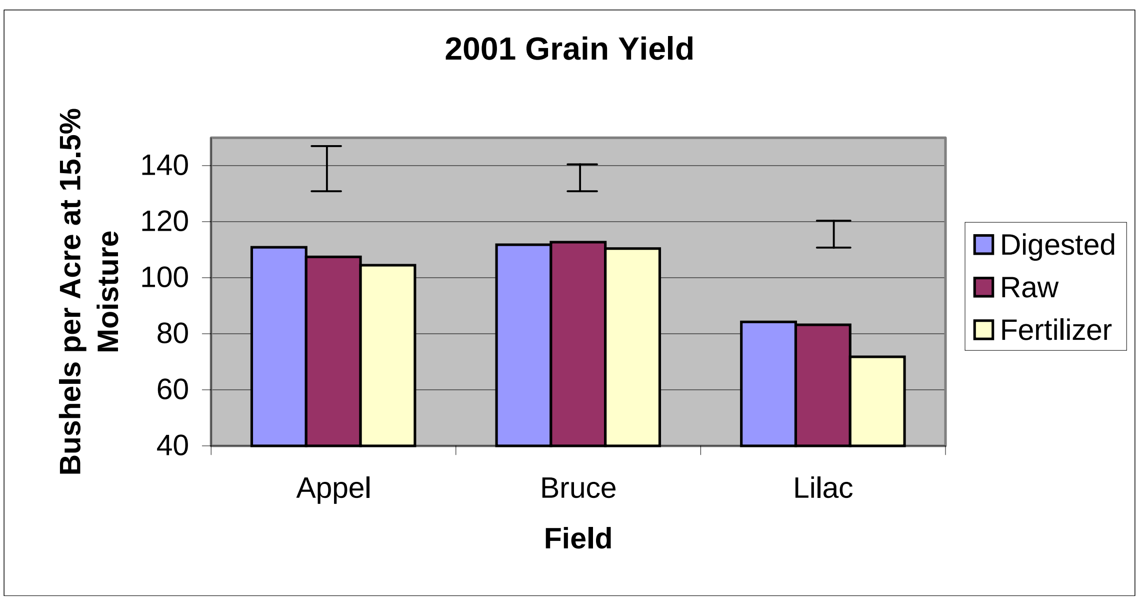


Figure 1. Grain yield for the three field sites on the Haubenschild farm in 2001. Averages of the annual and biennial applications are presented. Error bars represent LSD values for p=0.05. There were no significant differences among yields for any of the three treatments.

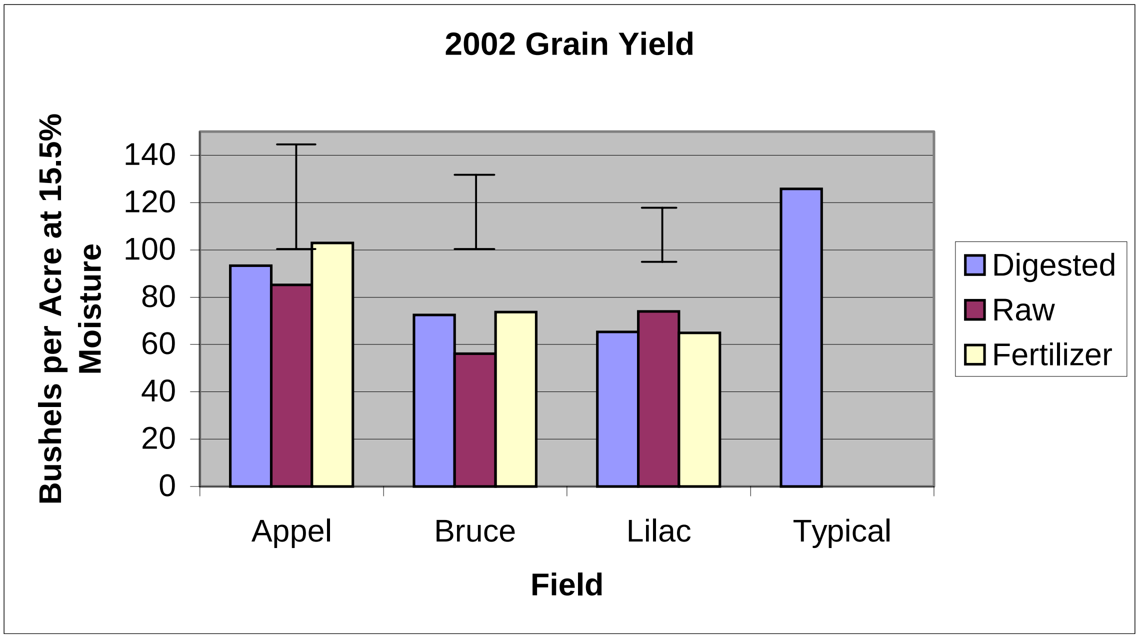


Figure 2. Grain yield for the three field sites on the Haubenschild farm in 2002. Averages of the annual and biennial applications are presented. The bar labeled "typical" shows the yields obtained outside the experimental plots. Error bars represent LSD values for p=0.05. There were no significant differences among yields for any of the three treatments.

Soil nitrogen

Amounts of available nitrogen (KCl-extractable ammonium and nitrate) measured in air-dried soil samples and released after a 28 day incubation at optimal moisture and temperature (PMN) also were not different for the three treatments (Figs. 3 and 4).

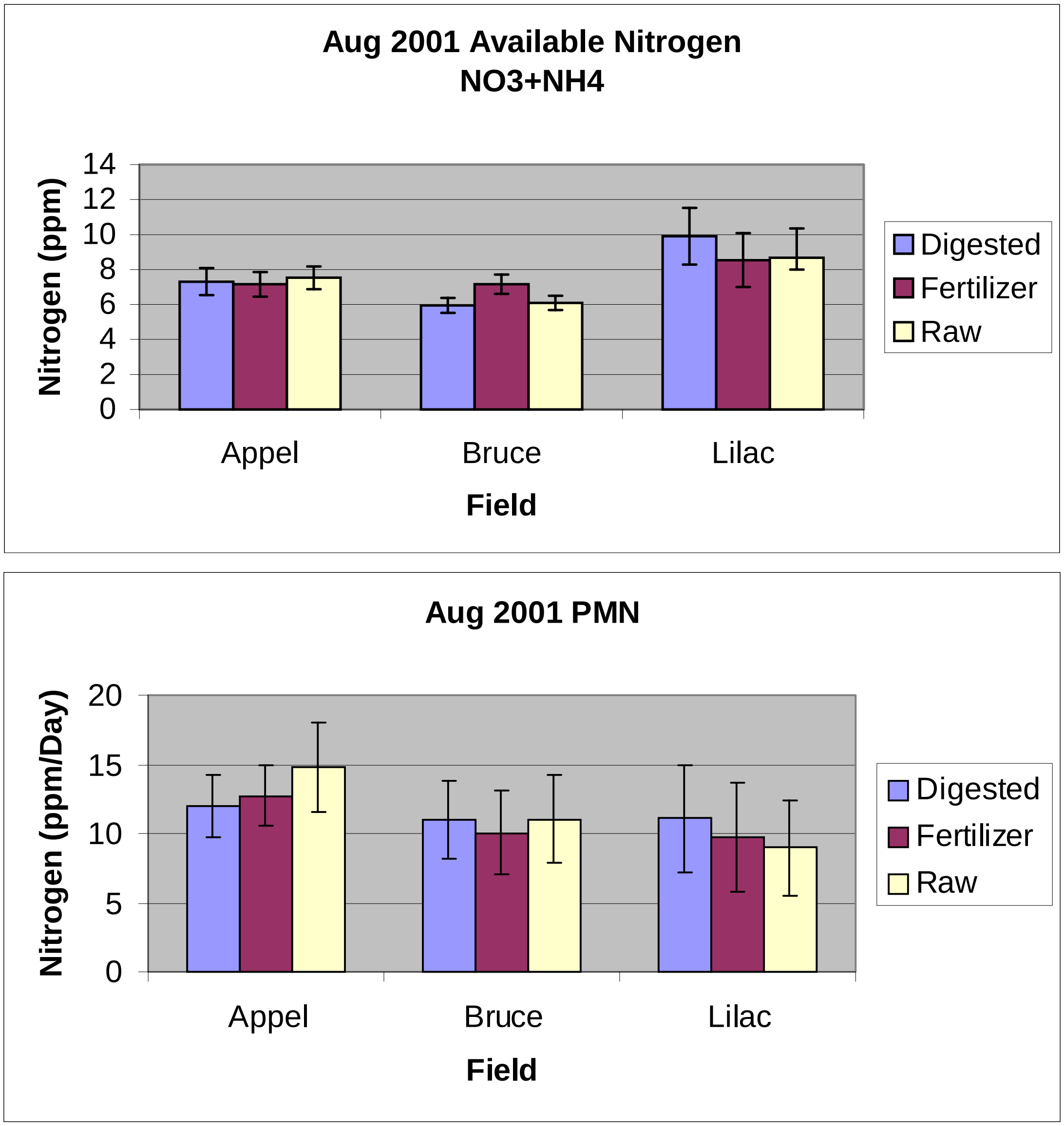
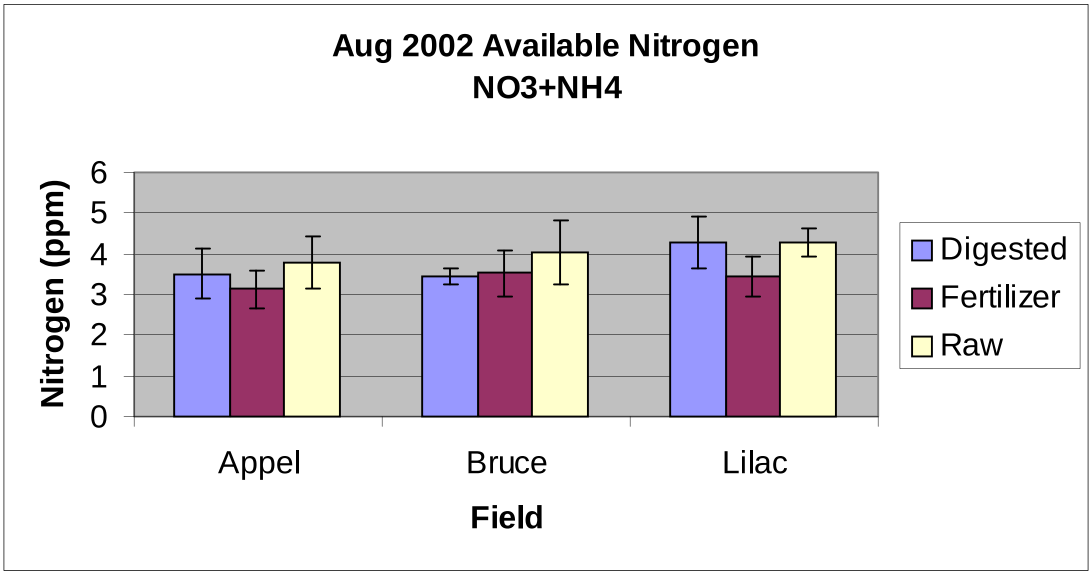


Figure 3. Amounts of available nitrogen (KCl-extractable ammonium and nitrate) and potentially mineralizable nitrogen (extracted after 28 days incubation) are averaged over 0-6" and 6-12" depths for the August, 2001 sampling time. Error bars represent the standard deviation for the mean of 6 replicate samples.



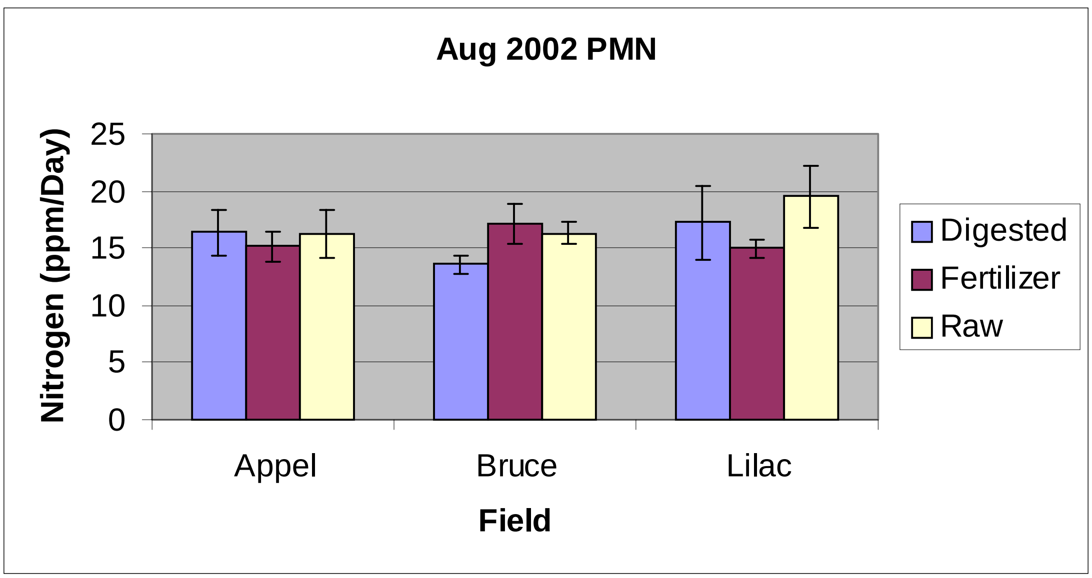


Figure 4. Amounts of available nitrogen (KCl-extractable ammonium and nitrate) and potentially mineralizable nitrogen (extracted after 28 days incubation) are averaged over 0-6" and 6-12" depths for the annual fertilize or manure application at the August, 2002 sampling time. Error bars represent the standard deviation for the mean of 3 (Bruce and Lilac fields) or 6 (Appel field) replicate samples.

Microbial biomass

As an indicator of differences in biological activity, we measured microbial biomass carbon. Digested manure had equivalent microbial biomass to fertilizer and raw manure treatments except in the Bruce field, where the raw manure treatment had a higher biomass (Figure 5).

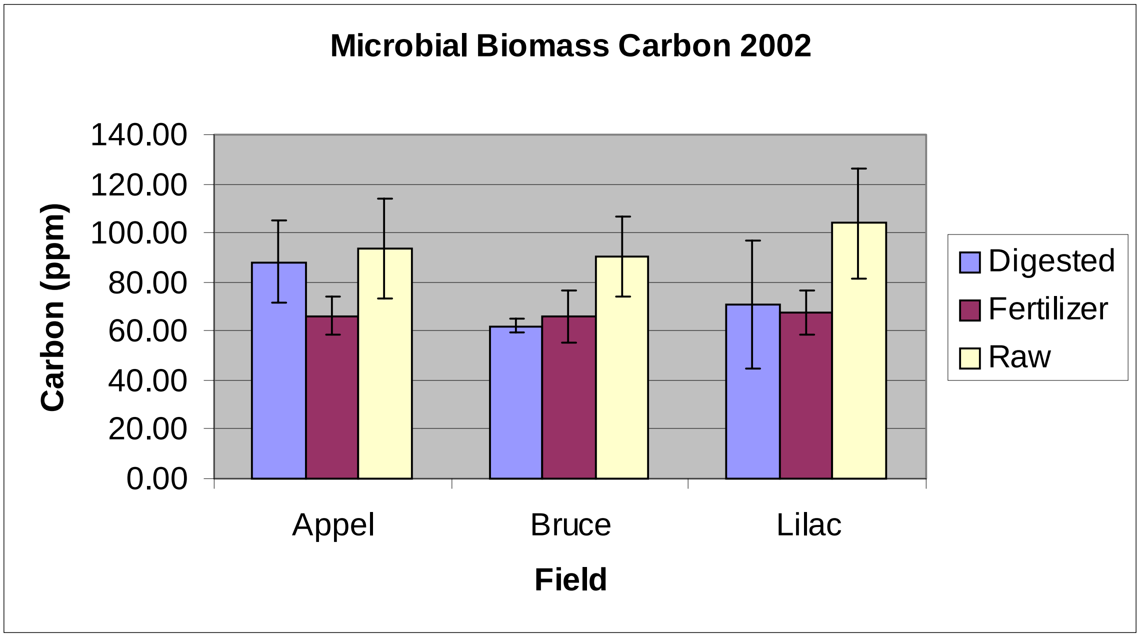


Figure 5. Microbial biomass carbon (ug C/ g soil) for the annual fertilizer or manure application at the three field sites in August, 2002. Error bars represent the standard deviation for the mean of 3 (Bruce and Lilac fields) or 6 (Appel field) replicate samples.

Summary

Results from two growing seasons have shown that use of stored, digested manure can result in crop yields equivalent to undigested manure or fertilizer when applied at similar nitrogen rates, while simultaneously allowing the capture of bioenergy. Neither were there significant differences in the amounts of available nitrogen or microbial biomass measured in soil samples from field plots treated with these three amendments. Further testing is being carried out to see whether nitrogen supplied by mineralization is different for these amendments when they are incubated with the same, homogeneous soil under ideal conditions in the laboratory.

WEED SEED SURVIVAL AS AFFECTED BY MANURE HANDLING

Introduction

The potential for weed seed introduction to cropland through the application of manure is a question faced by many farmers. One potential benefit of anaerobic manure digestion includes a reduction in weed seed germination and viability. In a field study, this project will determine the effect of anaerobic digestion on germination of weed seeds common to this system. Because of the uncertainties of weed seeds origin and health, and to work within the limited funding available, weed seeds were obtained form a known source and were characterized for potential germination and viability to establish a baseline prior to inclusion in the study. To track this "needle in a haystack" weed seed lot, the seed needed to be contained and retrievable and so were placed in nylon mesh bags. For the two manure storage treatments, mesh bags were placed in either the anaerobic digester or in raw, undigested manure prior to its entering the digester. Seed bags were in manure treatments for 20 days (length of time for one batch of manure to pass through the digester though weed seeds may pass through at different rates depending on size, solution/suspension density, etc.). Seeds were placed in the end of the anaerobic digester where the manure exits prior to entering the storage lagoon, as this position was the only available internal access from which to introduce the seeds and ensure they could be retrieved again. Though not ideal, we feel this approach most closely reflects anaerobic digester conditions, considering limitations of internal access to the digester and the need to track a seed lot know origin and viability in lieu of using a simulated digester.

Materials and Methods

Six weed species were chosen in part to reflect species typically found in manure in the region and to include representatives of weed seed groups. Species include grass and broadleaf species, large and small seeded species, true seeds and achenes (smartweeds), and species with known impermeable, protective seed coats (velvetleaf). Weed Species included in this experiment are as follows:

1. velvetleaf (*Abutilon theophrasti*)
2. common lambsquarters (*Chenopodium album)*
3. redroot pigweed (*Amaranthus retroflexus*)
4. wild proso millet (*Panicum miliaceum*)
5. giant foxtail (*Setaria faberi*)
6. ladysthumb smartweed (*Polygonum persicaria*)

Weed seeds were collected from the Rosemount Experiment Station during the Fall of 2001. Seeds were cleaned and stored at room temperature until used in experiments. Seed germination was tested by placing seed in a petri dish between moistened filter paper at 24 C for 14 days in the light. Seeds with emerged radicals were counted as germinated (Buhler et al. 1999). Viability of 400 of seed from each species was determined by placing seed in a petri dish between moistened filter paper for a minimum of 48 hours in a germinator at 24 C, then treated with a 1% (w/v) solution of tetrazolium. Seeds were considered viable if the embryo stained red.

For each treatment, all six species of weed seeds were combined into one mesh bag. One hundred seed per species was added to each bag. Each treatment was replicated six times. Since most, (but not all) of the weed seed in the system will pass through a cow, we subjected seed to an *in vitro* rumen fermentation procedure (Marten and Barnes, 1980) which has been proven to simulate conditions of a cow′s digestive system. In this procedure, weed seeds were soaked in rumen fluid for 48 hours in an Ankom Daisy fermentor oven. Next, the weeds were immersed in a pepsin and hydrochloric acid solution for 24 hours to simulate passage through the stomach.

The experiment had the following three treatments:

1. anaerobic digested manure, +/- weed seeds
2. conventional lagoon stored manure, +/- weed seeds
3. inorganic fertilizer control, +/- weed seeds

Wooden frames, 15 x 18 inches, were placed in an area previously in sod. The sod was removed and the soil worked to a depth of approximately 3 inches. A soil sample was taken and analyzed. Wooden frames were placed 2 inches into the soil. In late November, 2001, weed seeds were removed from the digester or conventional manure storage, placed in the appropriate wooden frame and incorporated into the soil. Digested or non-digested manure was added to the wooden frames at a rate of 6000 gal/A, a rate used by Dennis Haubenschild in fields where corn will be planted the following year.

In mid-April of 2002, ammonium nitrate (34-0-0) at a rate of 529 lb/A was added to each plot requiring inorganic fertilizer. The number of germinating weed seeds was recorded on a monthly basis and weeds were hand pulled from the plot. In April of 2003, soil within each frame will be mixed to a depth of two inches and germinating seedlings will again be counted and removed. Each treatment was replicated six times and the experiment is being repeated. Results from the experiment were analyzed as a randomized complete block design and means were separated with a Least Significant Difference test at the 0.05 level of significance.

Results and Discussion

Viability of weed seed used in the experiment ranged from 99% for velvetleaf to 81.5% for wild proso millet (Table 1). No giant foxtail or wild proso millet seeds germinated in plots from any treatment during spring or summer of 2001. This is most likely due to treatment of the weed seed in rumen fluid and simulated stomach acid. There were no differences in number of broadleaf seeds germinating between conventional lagoon and anaerobic digestion manure treatments, with one exception. Velvetleaf seeds had higher rates of germination after the anaerobic manure treatment (Table 2). However, it must be noted that of 100 seeds of each weed species added to every plot, only smartweed seeds had a high rate of germination. The remaining weed seeds may still be dormant and may germinate next summer. Counting and removing all weed seedlings in each plot next summer will give us additional information about the effect of each manure treatment on weed seed germination. It must also be noted that there were many smartweed seeds present in the soil in addition to those added for this experiment, which will be accounted for through the use of control treatments without weed seed added. These results are preliminary as the study will be repeated in time and space.

Table 1. Percent germination and viability of weed seed used in anaerobic digestion experiment, prior to rumen digestion. Fall, 2001.

Species	Germination*	Viability*
	(%)	(%)
pigweed	2.3	91.8
common lambsquarters	11.3	88.3
wild proso millet	0	81.5
Ladysthumb smartweed	0	94.5
velvetleaf	0	99.3
giant foxtail	0.8	88.3

*Mean of 4 lots of 100 seeds for each species.

Table 2. Numbers of weed seed germinating in the spring and summer after 20 days of fall storage in different manure storage systems. Haubenschild Farms. 2002.

Manure system	With weed seed added[1]				Without weed seed added			
	Weed species[2]				Weed species			
	CLQ	**PW**	**VL**	**SW**	**CLQ**	**PW**	**VL**	**SW**
Anaerobic Digestion	21	4	12	47	10	6	1	69
Lagoon Storage	5	6	7	37	2	2	0	44
Inorganic Fertilizer	11	5	9	110	11	16	0	71
LSD (0.05)	NS	NS	3	47	NS	NS	3	47

[1] No giant foxtail and wild proso millet seed germinated in plots.
[2]CLQ = common lambsquaters
PW = pigweed spp.
VL = velvetleaf
SW = smartweed spp.

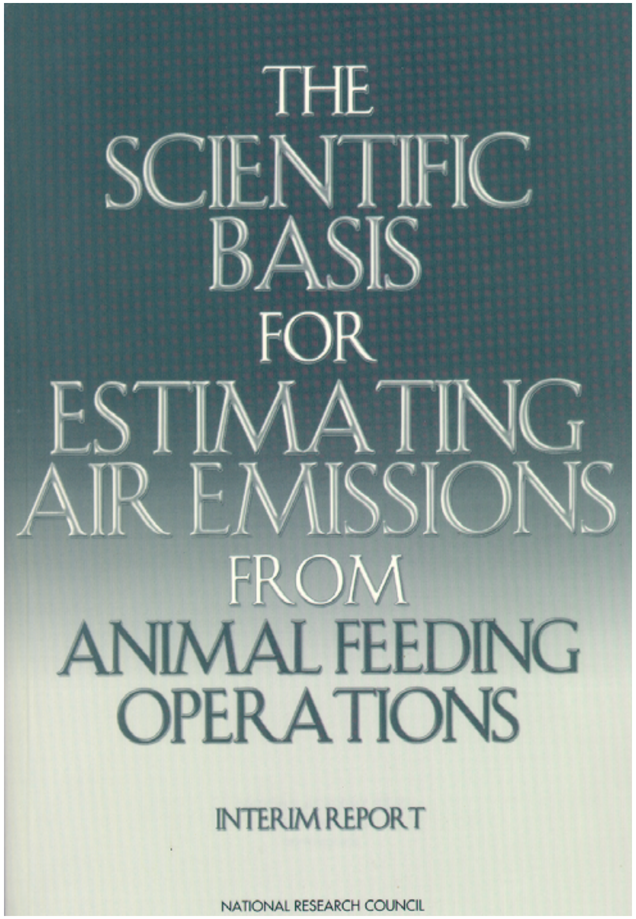
Comparative Environmental Benefits of Anaerobic Digestion of Animal Wastes

Kurt Roos
AgSTAR Program
U.S. Environmental Protection Agency

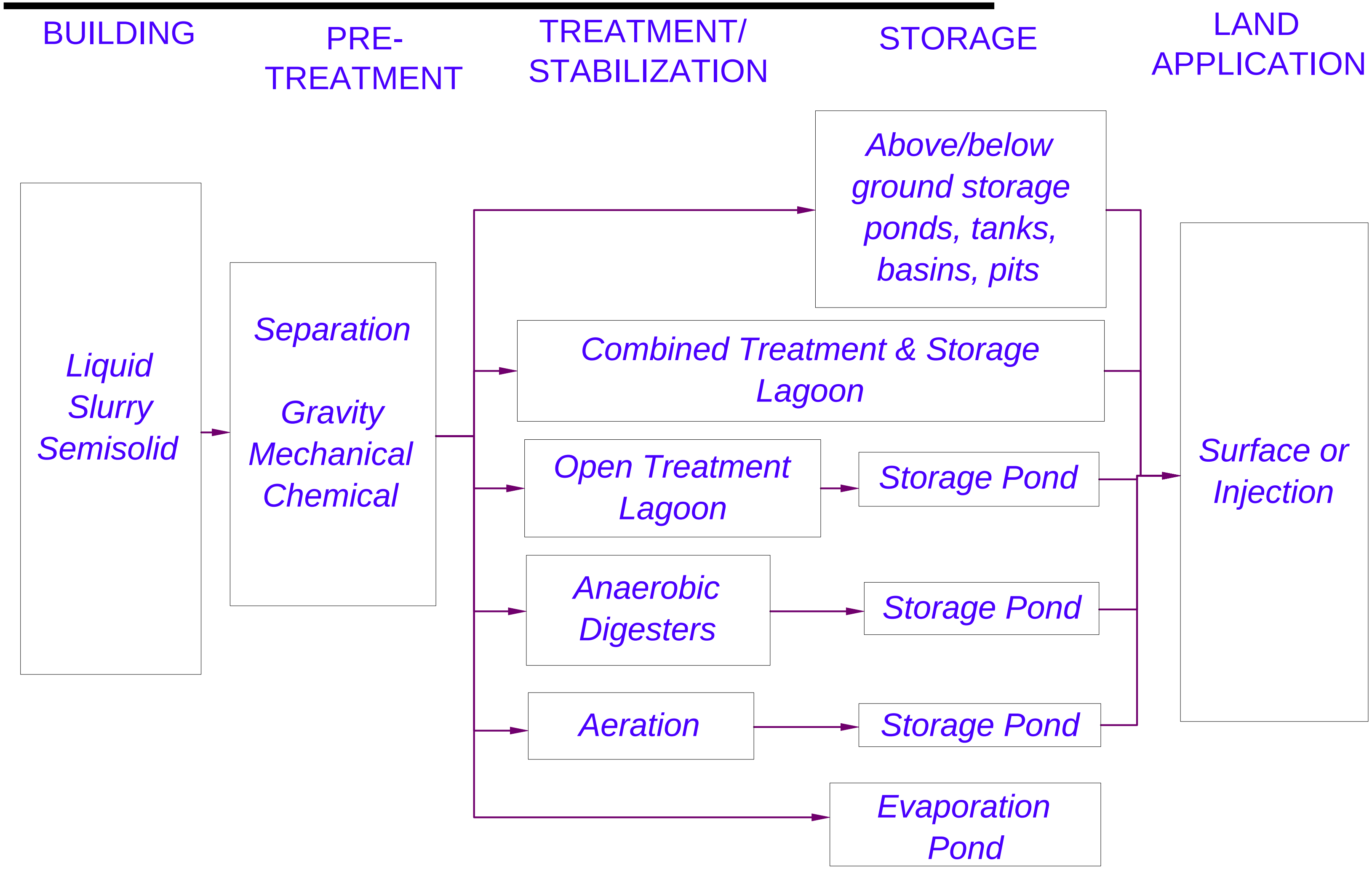
Environmental Concerns

Air Quality
Ammonia
Hydrogen Sulfide
Volatile Organic Compounds (VOC's)
Methane
Nitrous Oxide
Particulate Matter (PM_{10} & $PM_{2.5}$)

Water Quality
Nitrogen
Phosphorus
Metals
Organics (BOD)
Pathogens
Salts



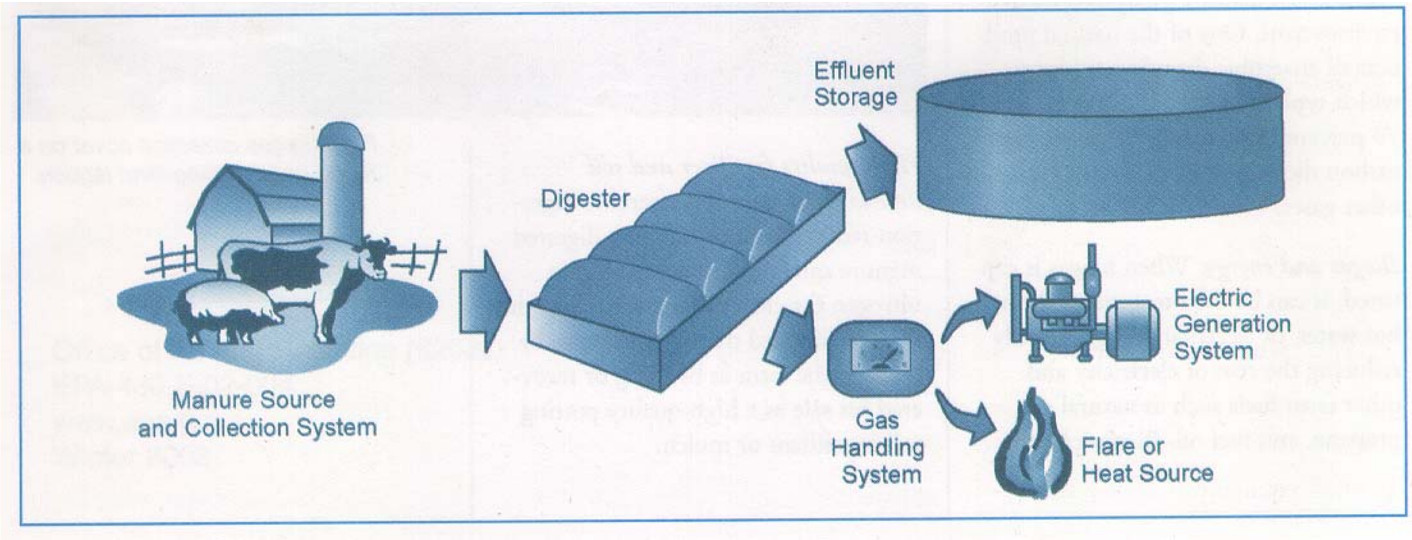
Process Trains Determine Performance



What are Anaerobic Digesters?

Biological treatment/stabilization systems applicable to liquid, slurry, and semi-solid waste that collect and combust off-gases.

Digesters separate manure treatment from storage functions which can result in lower initial installation costs for new or expanding farms



Four General Digester Types

Covered Lagoon - Ambient temp.

Attached Media - Ambient temp.

Mix Tank and Lagoon - Mesophilic

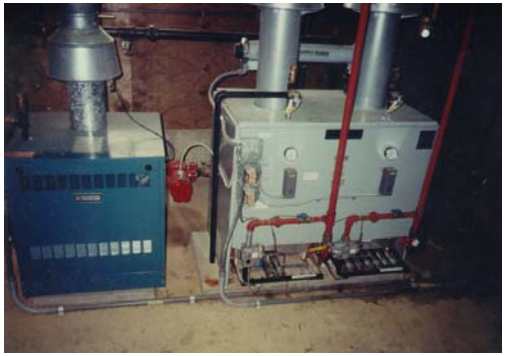
Plug Flow (Dairy Only) - Mesophilic

Gas Use Options

Cogeneration Electrical Production

Odor/Emission Control Flare

Boilers

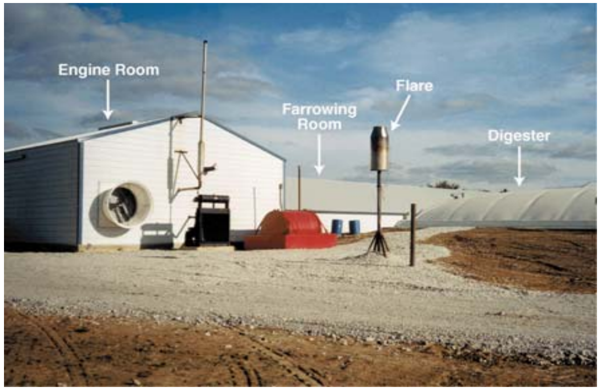


Hot Water Storage

Hot Water Use

Operational Approaches

- On-Farm or Farm Scale: System is owned and operated by farm owner/manager
  - Currently the predominant project type in the U.S.
- Regional or Centralized Digesters: Off farm management and operation with a third party
  - Ideally located at a large energy (electric or heat) consuming source or interconnection point (feed mills or utility substation)



Environmental Retrofit

Retrofit Plan

Before

After

Why Anaerobic Digesters?

1) Offer Air Quality benefits
   - -Control odors from storage and field application
   - -Reduces Greenhouse gases (methane)
   - -Controls other emissions (H_2S, ammonia)

2) Offer Water Quality benefits
   - -Stabilize manure organics (BOD)
   - -Significantly reduce pathogens
   - -Provide nutrient management predictability and flexibility

3) Offer return on Investment....Energy Revenues

Mass Balance Evaluation Method

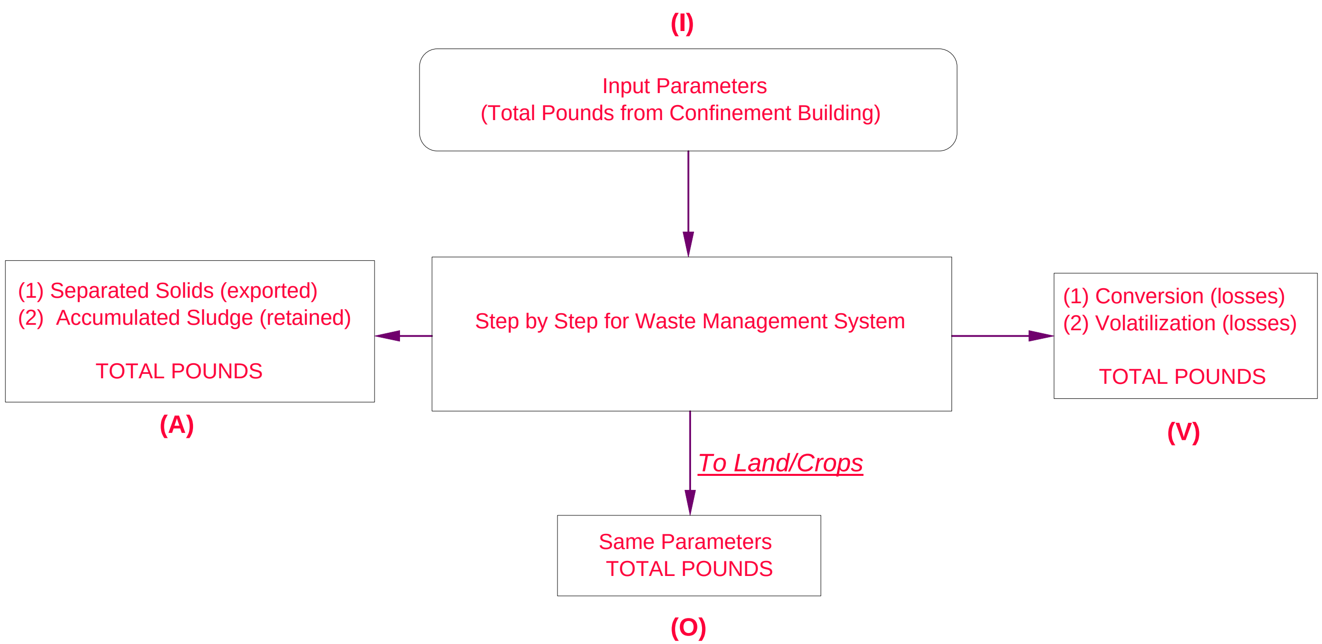
EVALUATION REQUIREMENTS

Digester operating at:
(1) steady state (3-5 HRT's and constant gas production), and
(2) >90% design load

Evaluation include Sampling Protocol and QA/QC plan, Statistical methods, extreme values, and hydraulic closure over a 1 year period

MEASURED PARAMETERS

(1) Total Solids
(2) Volatile Solids
(3) Fixed Solids
(4) Chemical/Biological Oxygen Demand
(5) Nitrogen (TKN, ammonia N)
(6) Phosphorous (Total p, ortho P)
(7) Metals
(8) Fecal Coliforms
(9) Pathogens



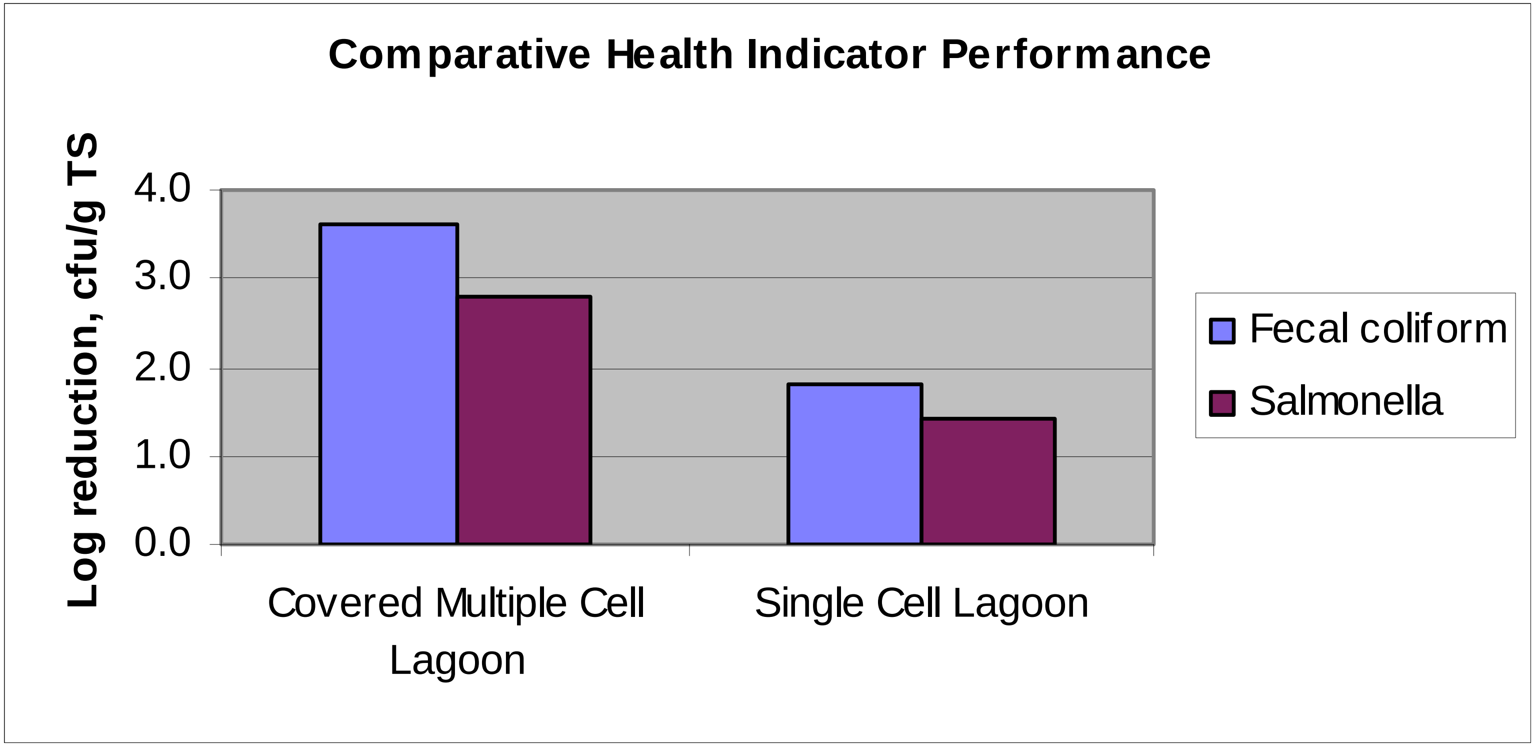
I = A + O + V (mass balance)

Environmental Case Study

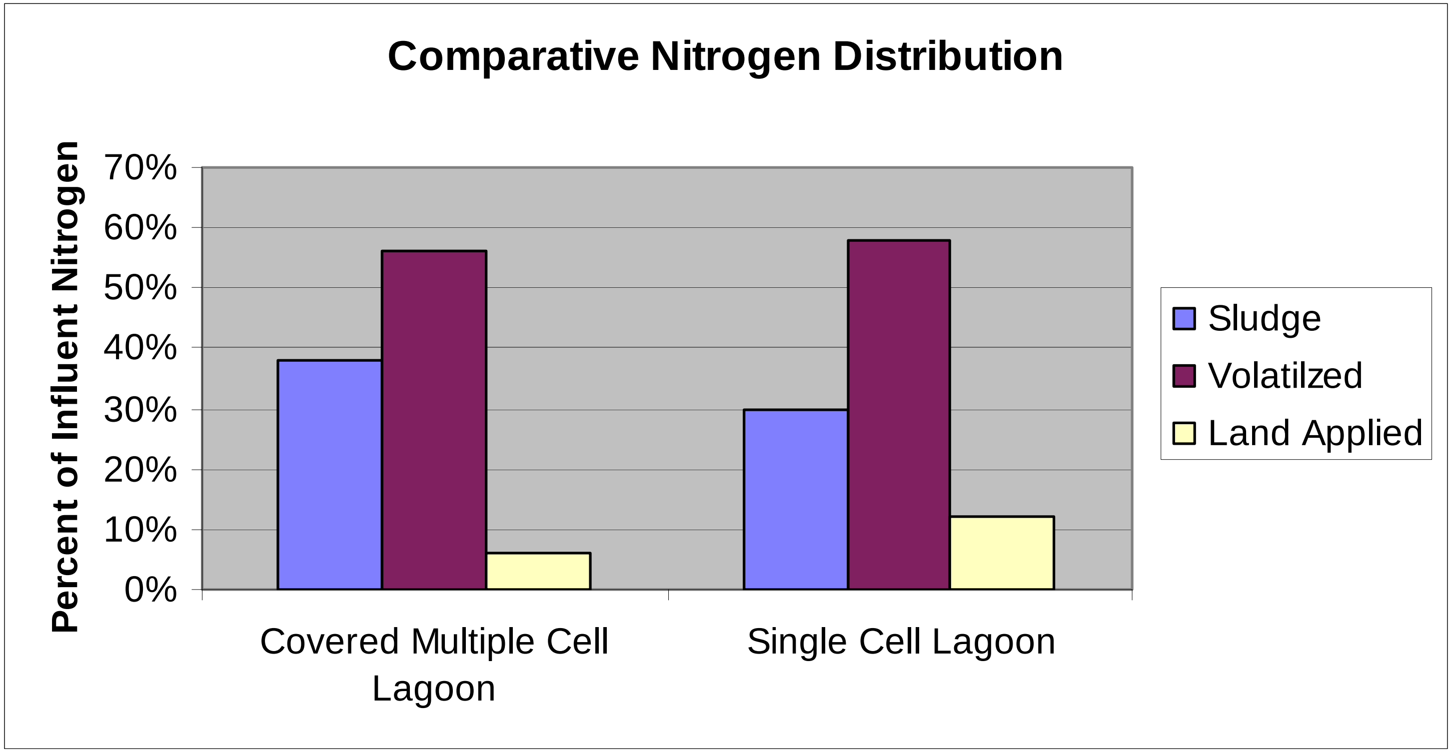
- Process train characterized by mass balance characterization method
  - Single cell lagoon
  - Multiple cell covered lagoon (Barham Farm)

- Evaluation Conducted over a 1 year period
  - Systems at steady state and design load
  - Composite sampling 2x month
  - Flow metered

Pathogen Performance

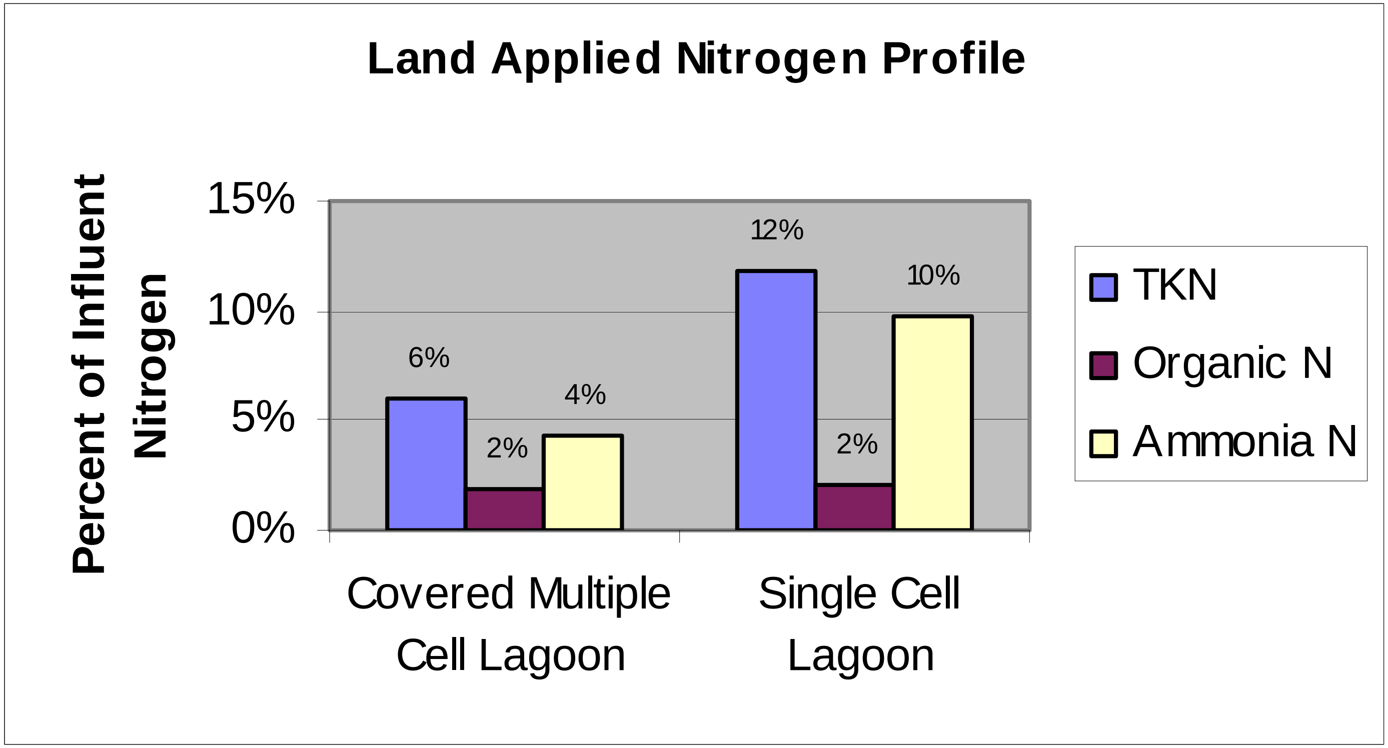


Nitrogen Performance



- Comparative reductions of Phosphorus (Total & Ortho) were @97% for each system

Nitrogen Performance (cont)



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Land Application Performance

Comparison of relative land requirements for nitrogen and phosphorus application

Application rate basis	Multiple Cell Covered Lagoon	Single Cell Lagoon
Nitrogen	X	2.7x
Phosphorus	X	0.9x

Organics Stabilization and Odor Control

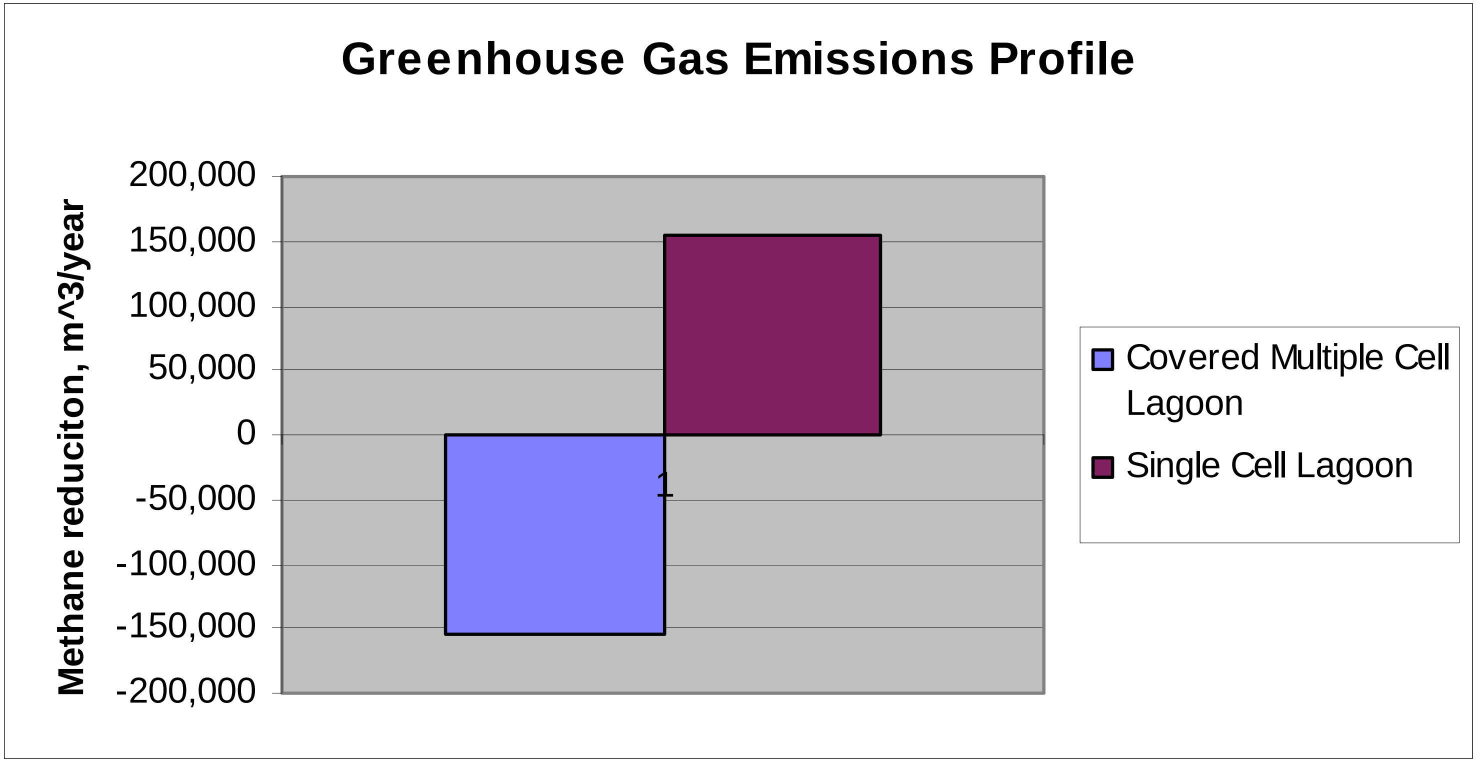
Parameter	Net Loads	Covered Lagoon Reduction		Storage Pond Reduction	
	kg/day	kg/day	%	Kg/day	%
Total Volatile Solids	1,194	1,139	95%	44	8%
COD	2,813	2.729	97%	79	3%
BOD	422	409	97%	12	3%

Source: A Comparison of the Performance of Three Swine Waste Stabilization Systems, draft EPA, 2002

Odor Concentration (odor units/m^3 air) following spreading of pig slurries on grass land				
Days in Storage	Farm A		Farm B	
	Undigested	Digested (% Reduction)	Undigested	Digested (% Reduction)
5	611	142 (77%)	1,101	223 (80%)
20	219	18 (92%)	177	38 (79%)

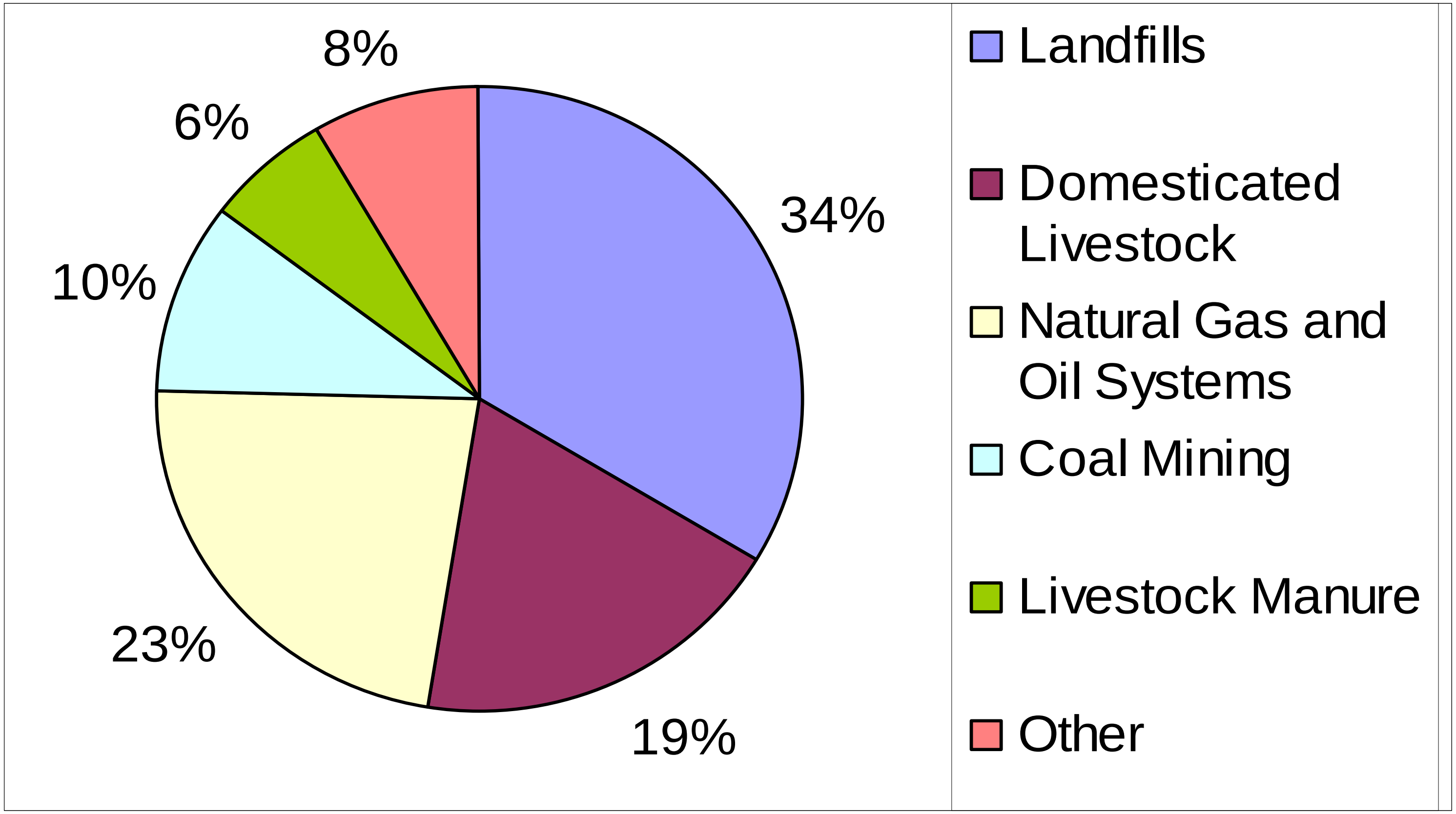
Source: B.F. Pain, T.H. Misselbrook, and C.R. Clarkson; Odor and Ammonia Emissions Following the Spreading of Anaerobically Digested Pig Slurry on Grassland; Biol. Wastes 34: 259-267; 1990

Greenhouse Gas Performance



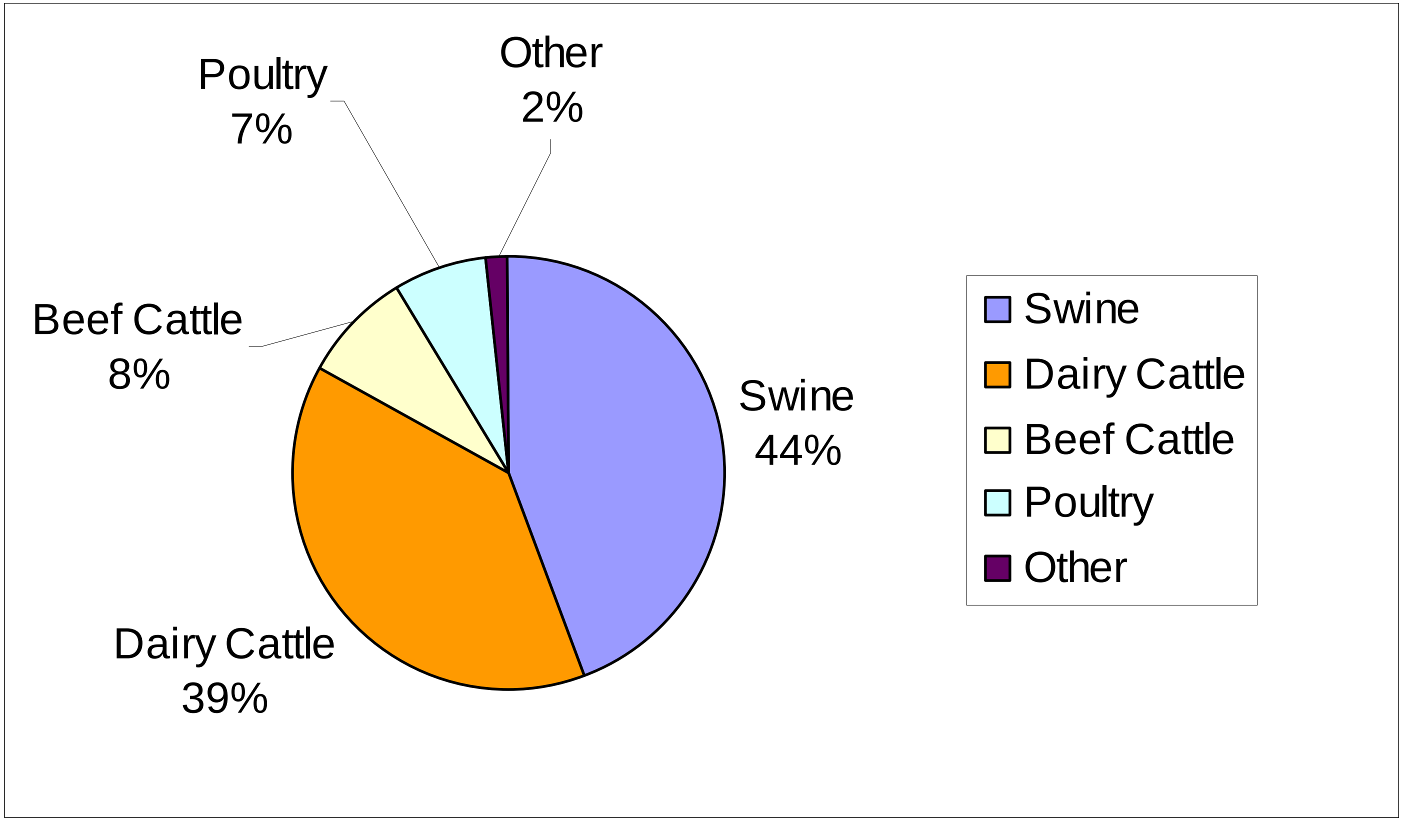
Greenhouse Gases

U.S. Anthropogenic Methane (2001)

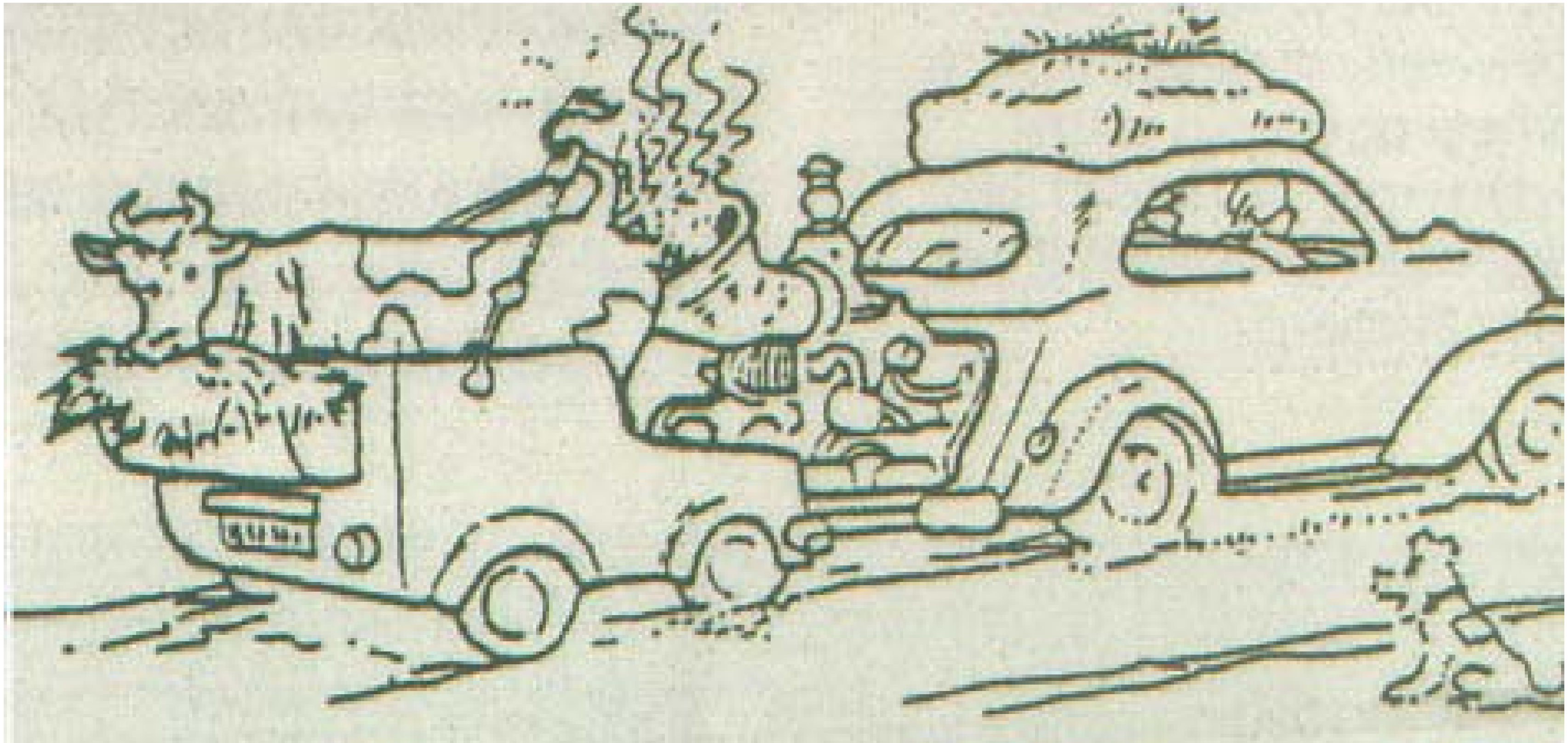


Greenhouse Gases

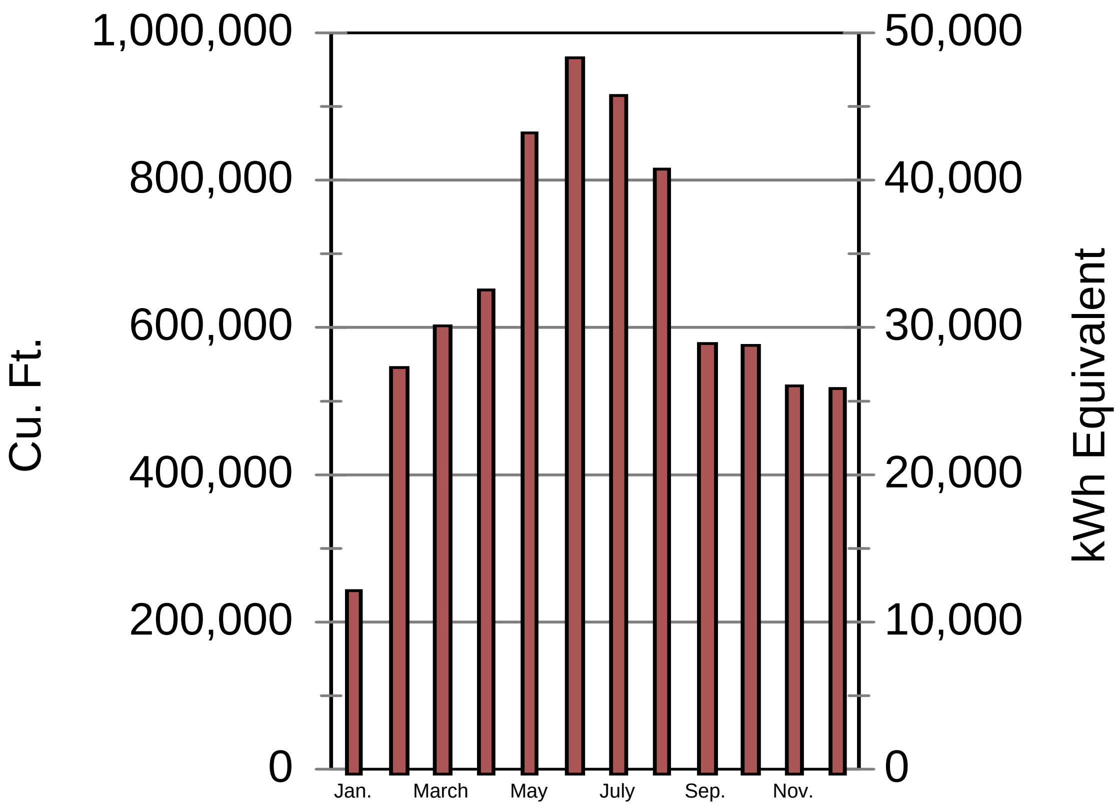
U.S. Livestock Manure Emission Profile (2001)



And...Digesters Provide Energy



Energy and Gas Production



Digesters are Cost Effective when Environment Considered

Environmental Effectiveness of Manure Management Options

Options	Odor Control	Greenhouse Gas Reduction	Water Quality Protection	Cost Range†† (per 1,000 lbs/ live weight)
Covered lagoon digesters with open storage ponds	E	H	G	$150-400
Heated digesters (i.e., complete mix and plug flow) with open storage tanks	E	H	G	$200-400
Aerated lagoons with open storage ponds†	G-E	H	F-G	$200-450
Separate treatment lagoons and storage ponds (2-cell systems)	F-G	L	G	$200-400
Combined treatment lagoons and storage ponds	P-G	L	F-G	$200-400
Storage ponds and tanks	P-F	M-H	P-F	$50-500

Key: P=poor, F=fair, G=good, E=excellent, L=low, M=medium, H=high

†Aerated lagoon energy requirements add an additional $35-50 per 1,000 lbs/year.

††Cost ranges do not include annual operation and maintenance (O&M) costs.

EPA
USDA
DOE

AgSTAR

ENERGY AND POLLUTION PREVENTION

U.S. Experience with Anaerobic Digestion of Animal Wastes

Kurt F. Roos
AgSTAR Program
U.S. Environmental Protection Agency

Presentation Overview

- What are anaerobic digesters?
- What has the U.S. Experience been?
  - First Generation
  - Second Generation
- Demonstrated A.D. Technologies
- Demonstrated Gas Uses
- Today’s Trends
- Recommendations

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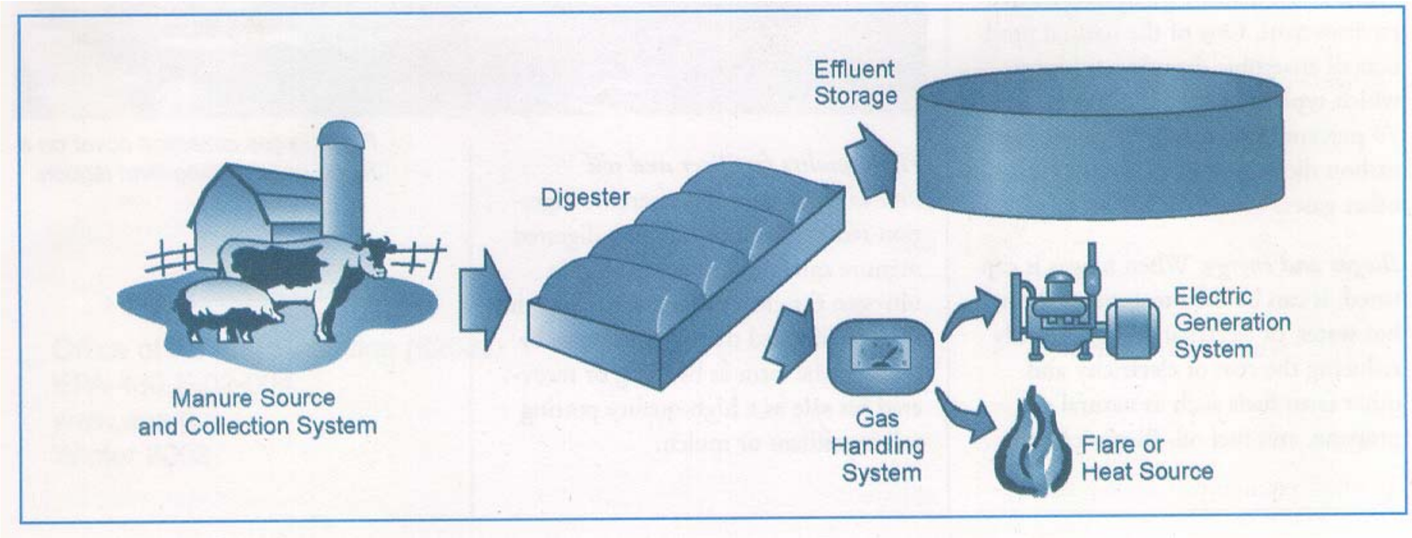

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- On-Farm or Farm Scale: System is owned and operated by farm owner/manager
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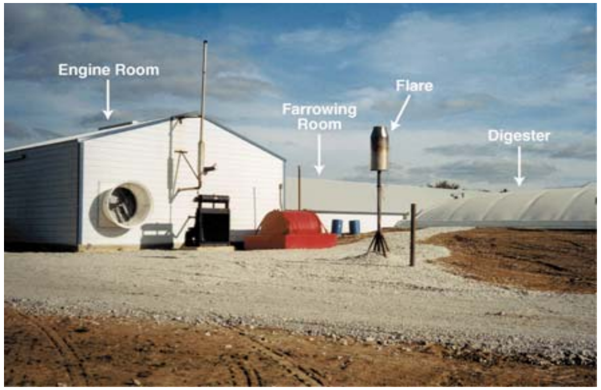
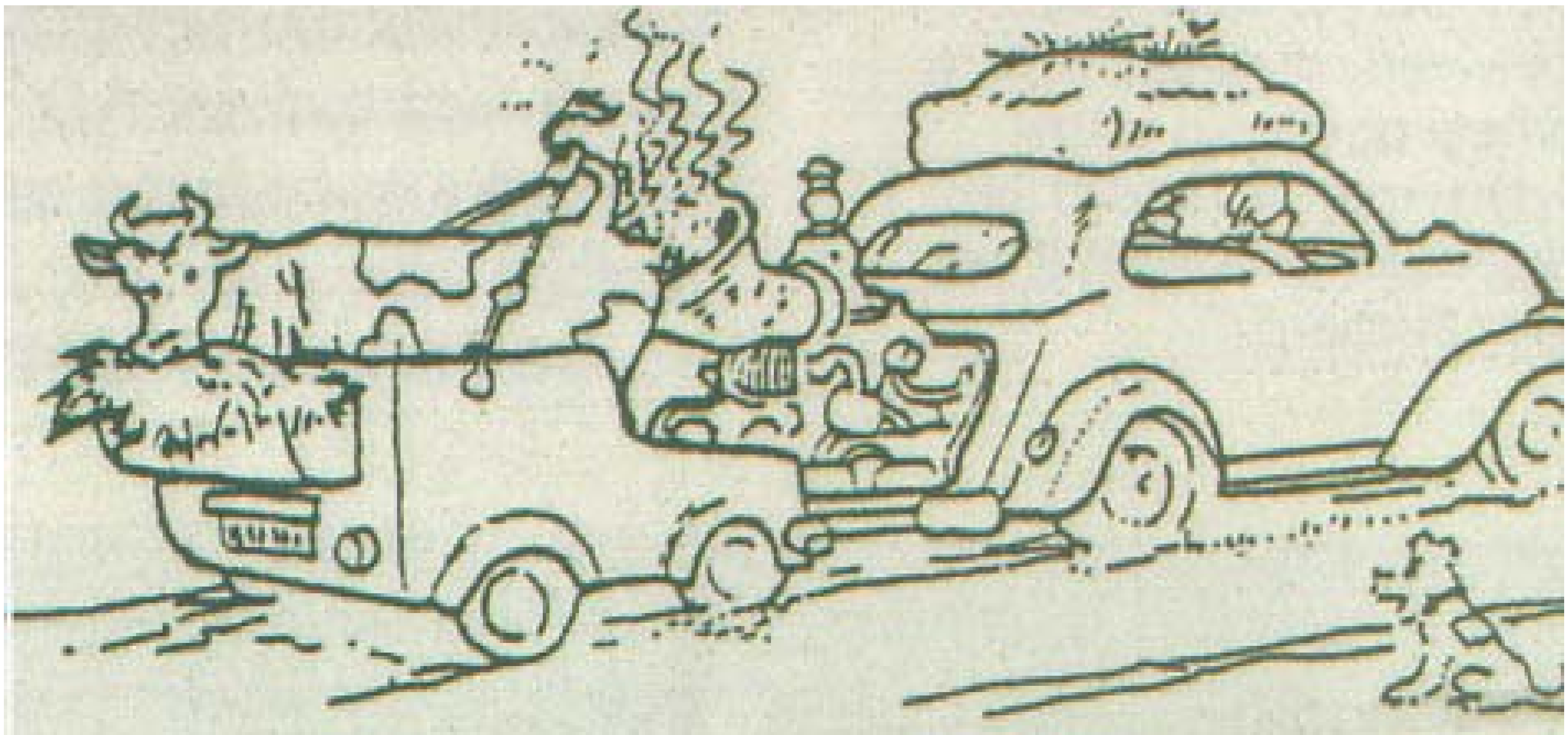


The U.S. Digestion Experience



Is it time yet Bessie?

First Generation: 1970-1990

- Mid 1970's rising oil prices triggered interest in farm scale digestion for energy production
- 140 systems installed
  - 69 as university research
    - None in operation today
  - 71 at commercial swine, dairy, and layer farms
    - >60% failure rate

	Complete Mix	Plug Flow	Covered Lagoon	TOTAL
Operating	9	9	7	25
Not operating	13	30	3	46
TOTAL	22	39	10	71

Source: DOE, 1995 "Methane Recovery from Animal Manures: A Current Opportunities Casebook", 1995

Examples of Failures

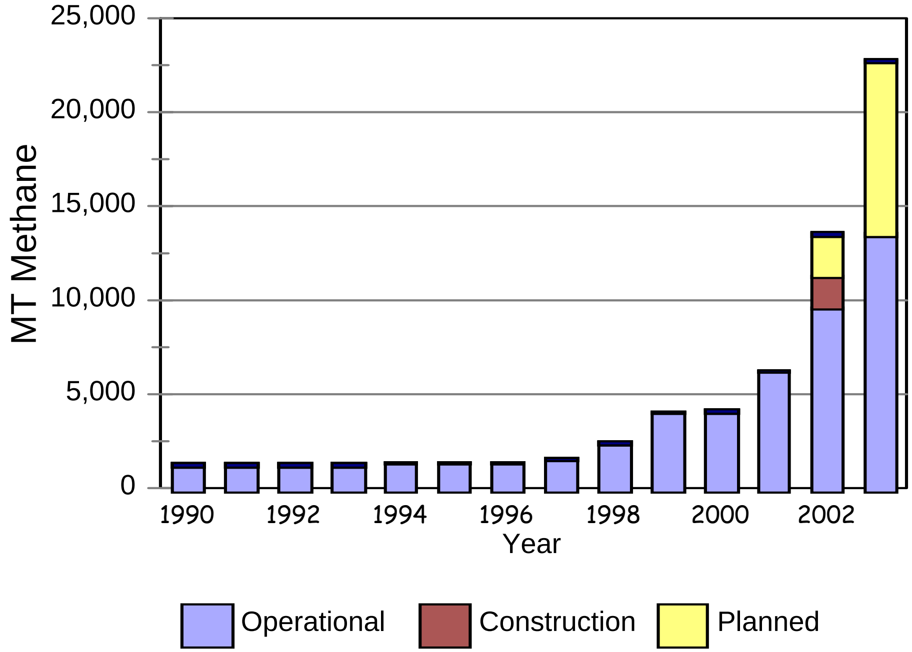
Reasons for High Failure Rates

- Scaled up experimental systems
- Inappropriate equipment installed:
  - over sizing, under sizing, reliability
- Complex digestion processes transferred from other industries.
  - Farm did not upgrade labor skills, receive adequate training and technical support.
  - Systems became to expensive to maintain and repair because of complexity or poor design.
- “Cookie cutter” design approaches
  - 19 failures occurred by one vendor

Second Generation: 1990-2000

- 1993 AgSTAR Program launched
  - Program strategy based on “First Generation Experiences”
  - Identifies livestock waste market and commercially ready technologies
  - Establishes set of 3 U.S. Digester Interim standards w/ USDA
  - Develops set of project development tools
    - *Handbook, FarmWare, Industry Provider List*
  - AgSTAR *Charter Farm* program launched 1997:
    - Farm scale digesters reach critical mass
    - Primary catalyst in stimulating farm demand for digestion systems in late 1990’s
- National effort results in many “spin-off” State Anaerobic Digestion Programs by 2000

Current Status



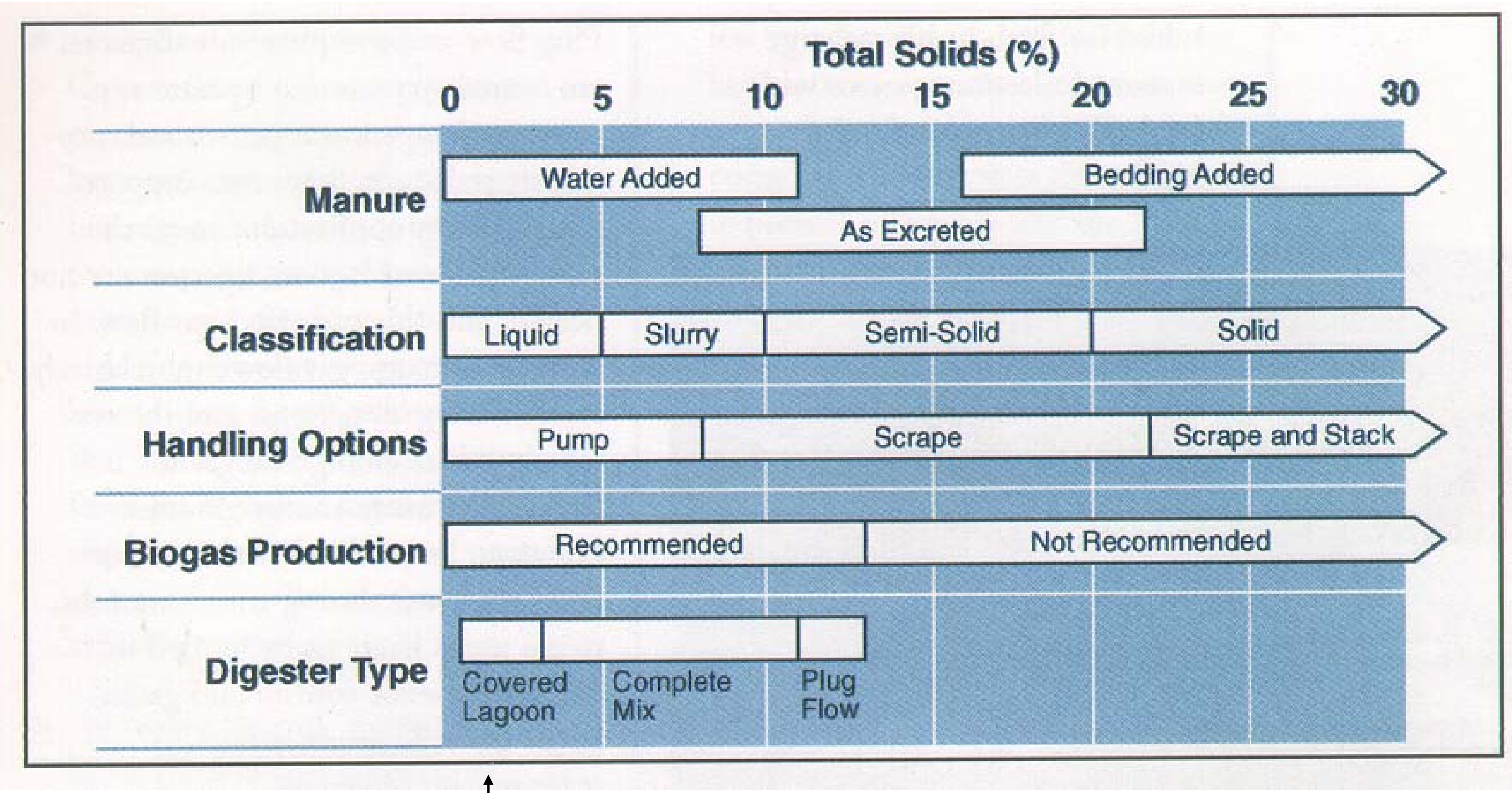
<u>In 2003</u>

All projects @30 million kWh equivalent

@80 projects; 45 operating or in construction and 35 planned

Represent about 2% of dairy industry and <1% of pork industry.

What have we learned and what has been commercially demonstrated?



Attached Film

Unheated Digesters

Covered In-ground Digester

Bank-to-Bank Cover

Modular Cover

Attached Media

Heated (Mesophilic) Digesters

<u>Mixed Digesters</u>

<u>Plug Flow Digesters</u>

Used for Dairy only w/ Separation

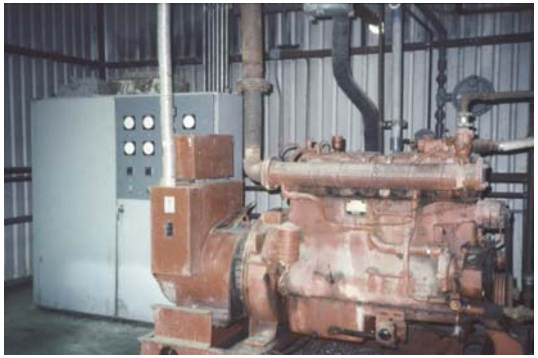
Gas Use: *Electric*

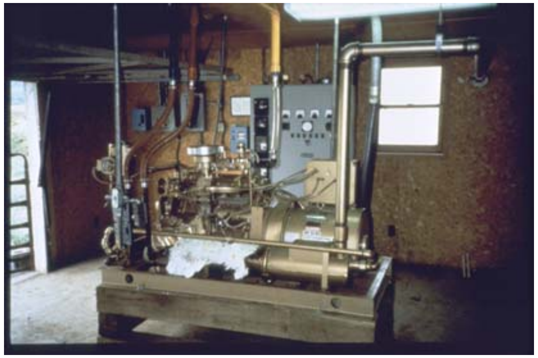
Recip. Engines 40-150kW

Engine Controller

Net Metering

More Engines





Gas Use: *Electrical Generation*

Recip. Engines 40-150kW

C
O
M
P
O
N
E
N
T
S

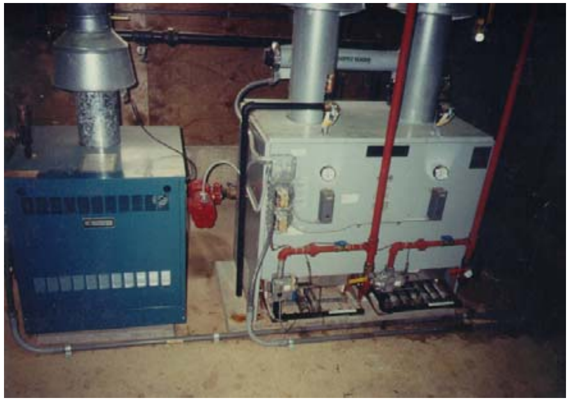
Gas Handling

Engine Controller

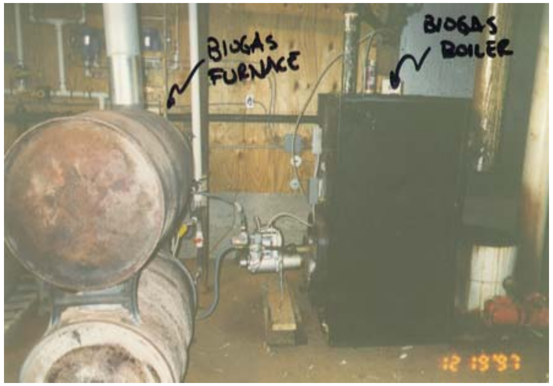
Electric Metering

Gas Use: *Heat*

Boilers



Forced Air

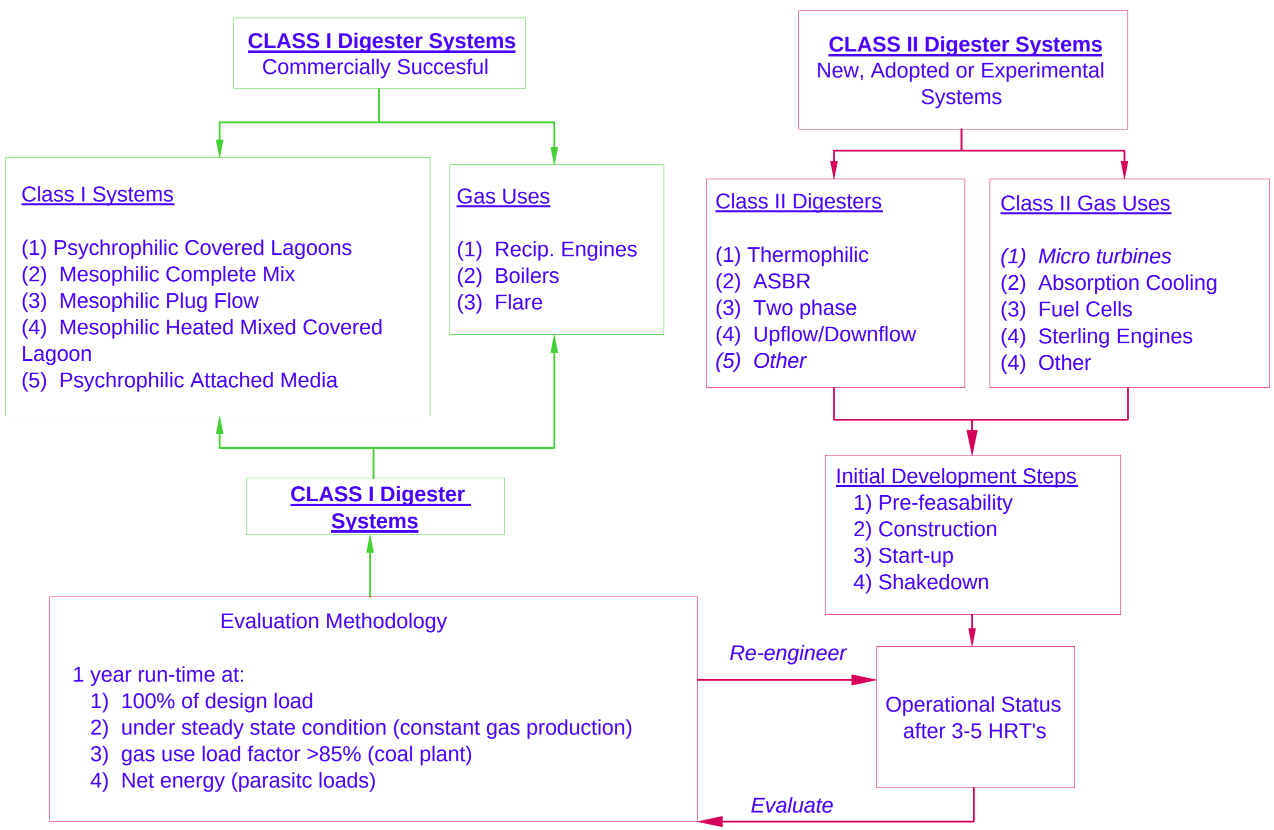


Hot Water Storage

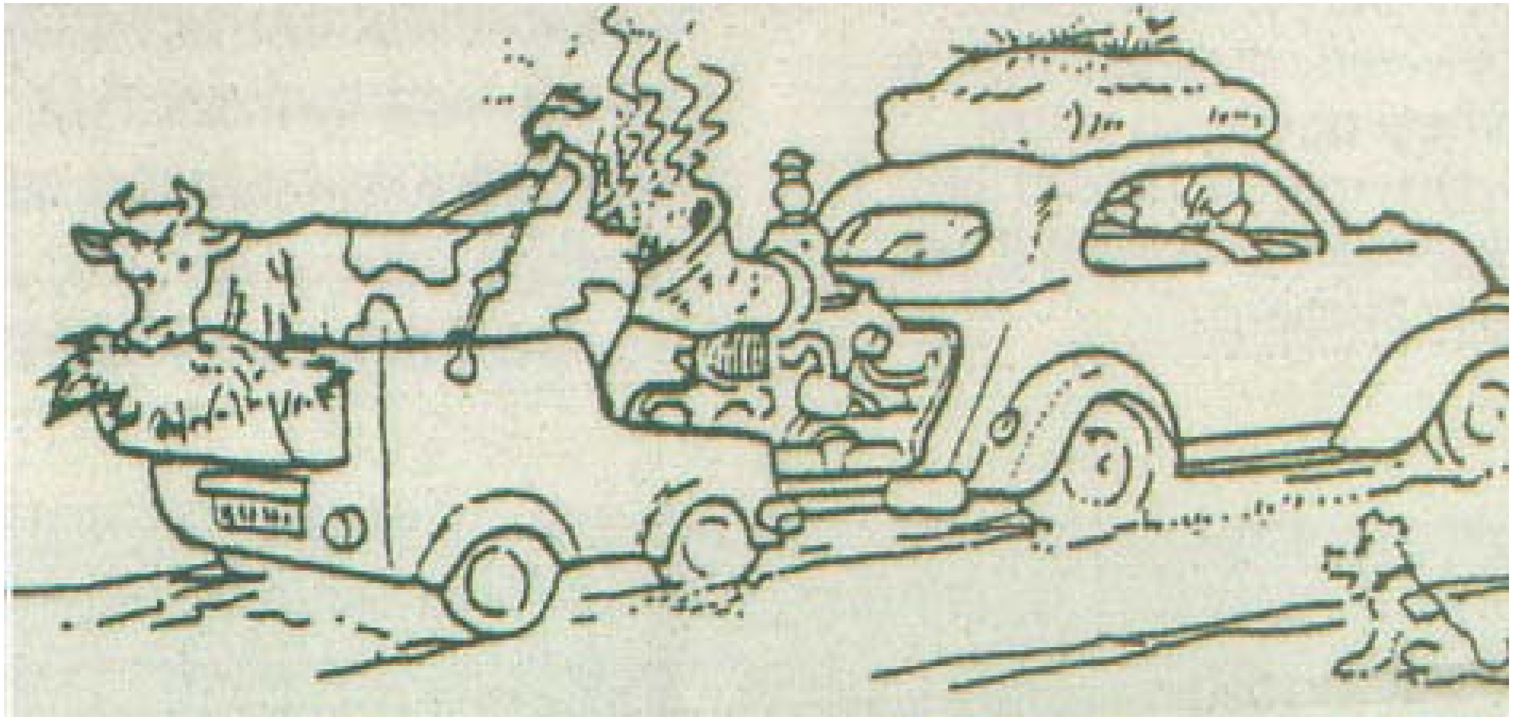
Hot Water Use

Emerging Issues: Performance

- Cost effective operational performance is critical to expand demand and avoid risk/failure perception in Livestock Market



And that's all for now...



See the AgSTAR Website at www.EPA.GOV/AGSTAR

Thank You

Ammonia Deposition and Air – Water Interface Issues

The Anaerobic Digester Summit
June 3rd and 4th, 2003

Joe Rudek
jrudek@environmentaldefense.org

environmental defense
finding the ways that work

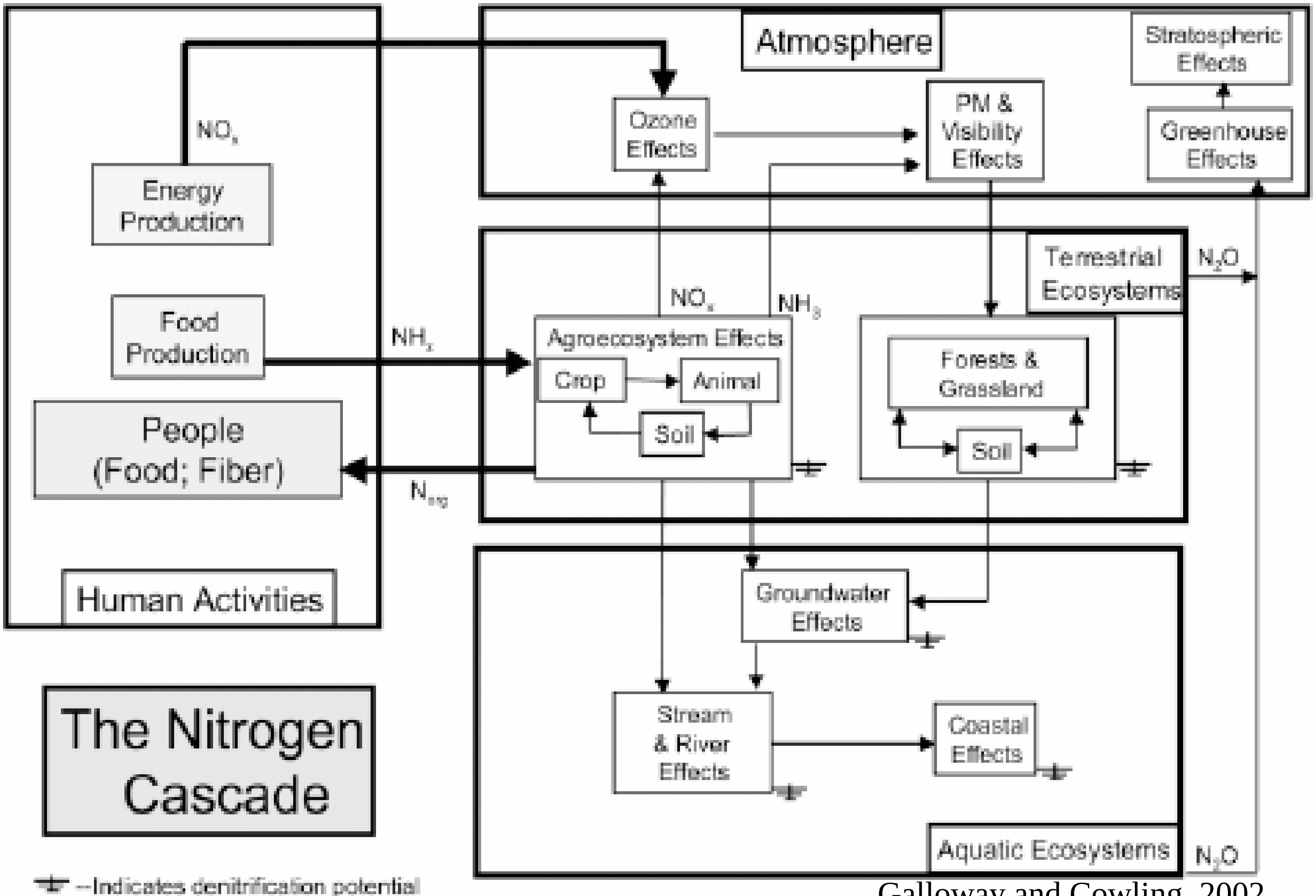
Overview

- The Nitrogen Problem
- Nitrogen Loss from AFOs
- Anaerobic Digesters as an Alternative Treatment Component

Anthropogenic Perturbations of the Biogeochemical N cycle

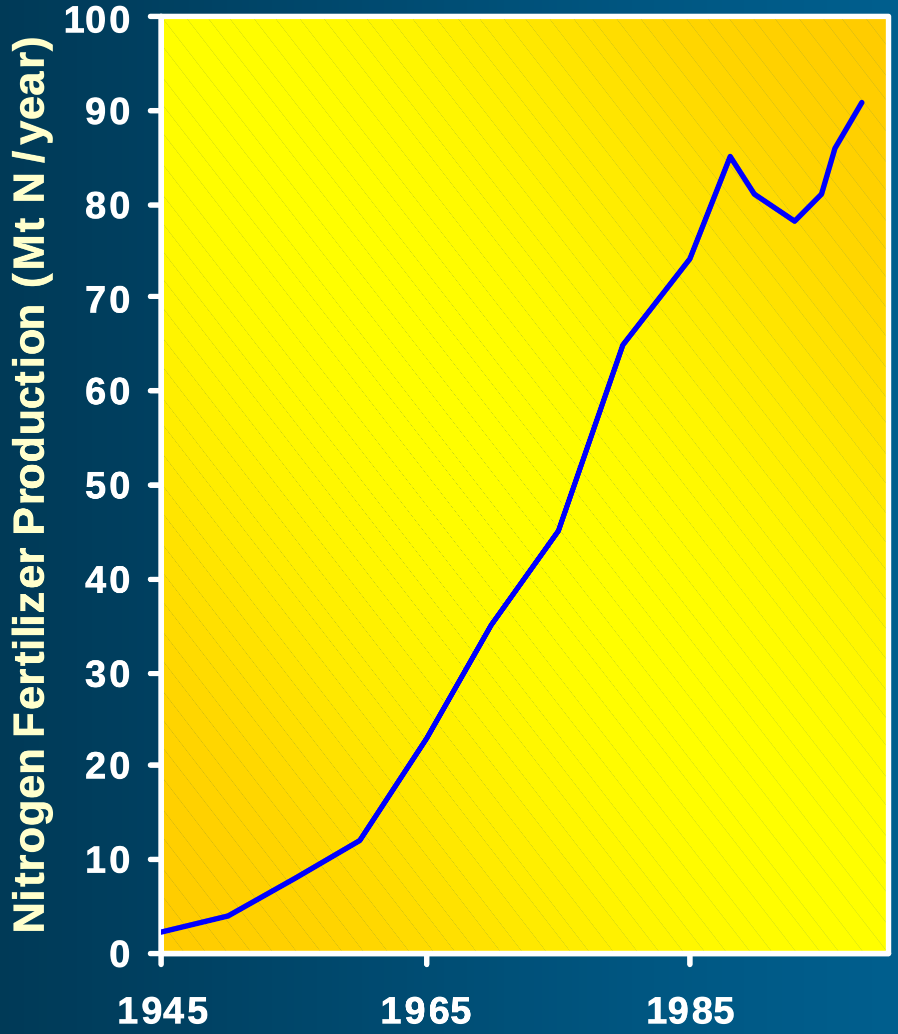
- **> 2X the pre-industrial supply rate.**
- **Percent Anthropogenic Contribution to Total Emissions:**
  - **NHx 70%,**
  - **NOx 80%,**
  - **N20 40%**

The Nitrogen Cascade

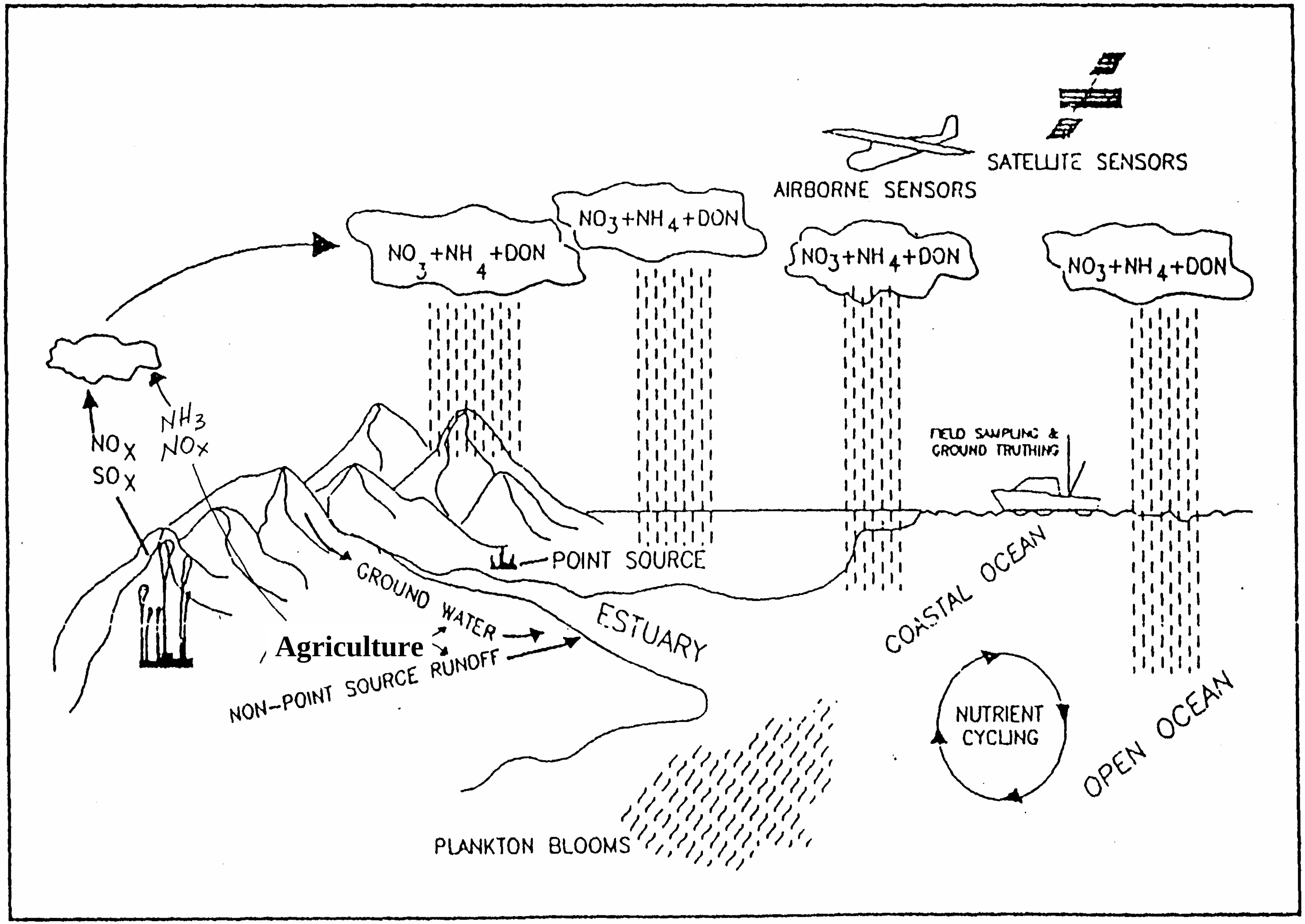


Galloway and Cowling, 2002

Global Production of Ammonia-based Nitrogen Fertilizers



Source: Smil, 2001


SATELLITE SENSORS
AIRBORNE SENSORS
NO_3+NH_4+DON
NO_3+NH_4+DON
NO_3+NH_4+DON
NO_3+NH_4+DON
NO_X
SO_X
NH_3
NO_X
FIELD SAMPLING & GROUND TRUTHING
POINT SOURCE
GROUND WATER
ESTUARY
COASTAL OCEAN
Agriculture
NON-POINT SOURCE RUNOFF
NUTRIENT CYCLING
OPEN OCEAN
PLANKTON BLOOMS

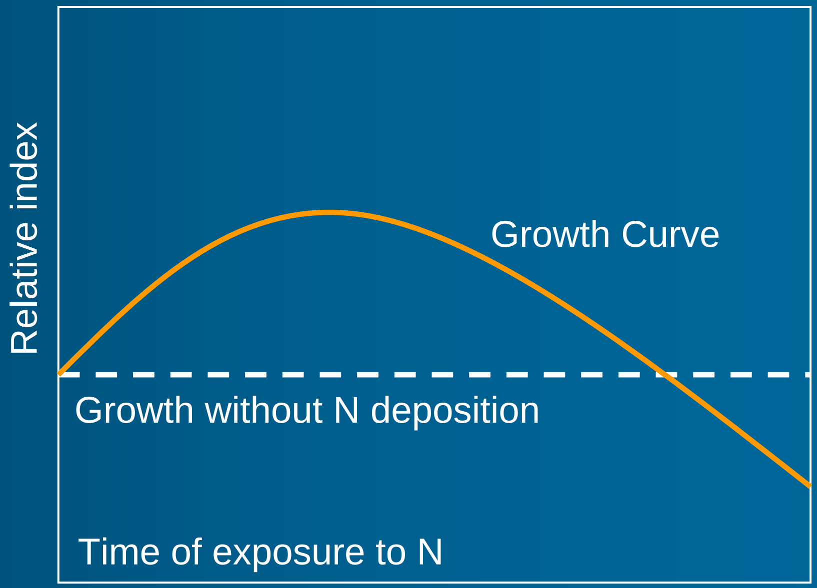
Effects of Nitrogen Loading

increased production → changes in metabolism → accumulation → decreased vitality →

- Aquatic and Terrestrial Ecosystem Impacts

(from deposition)

- Ecosystem production (critical load)
- Diversity loss
- Coastal eutrophication



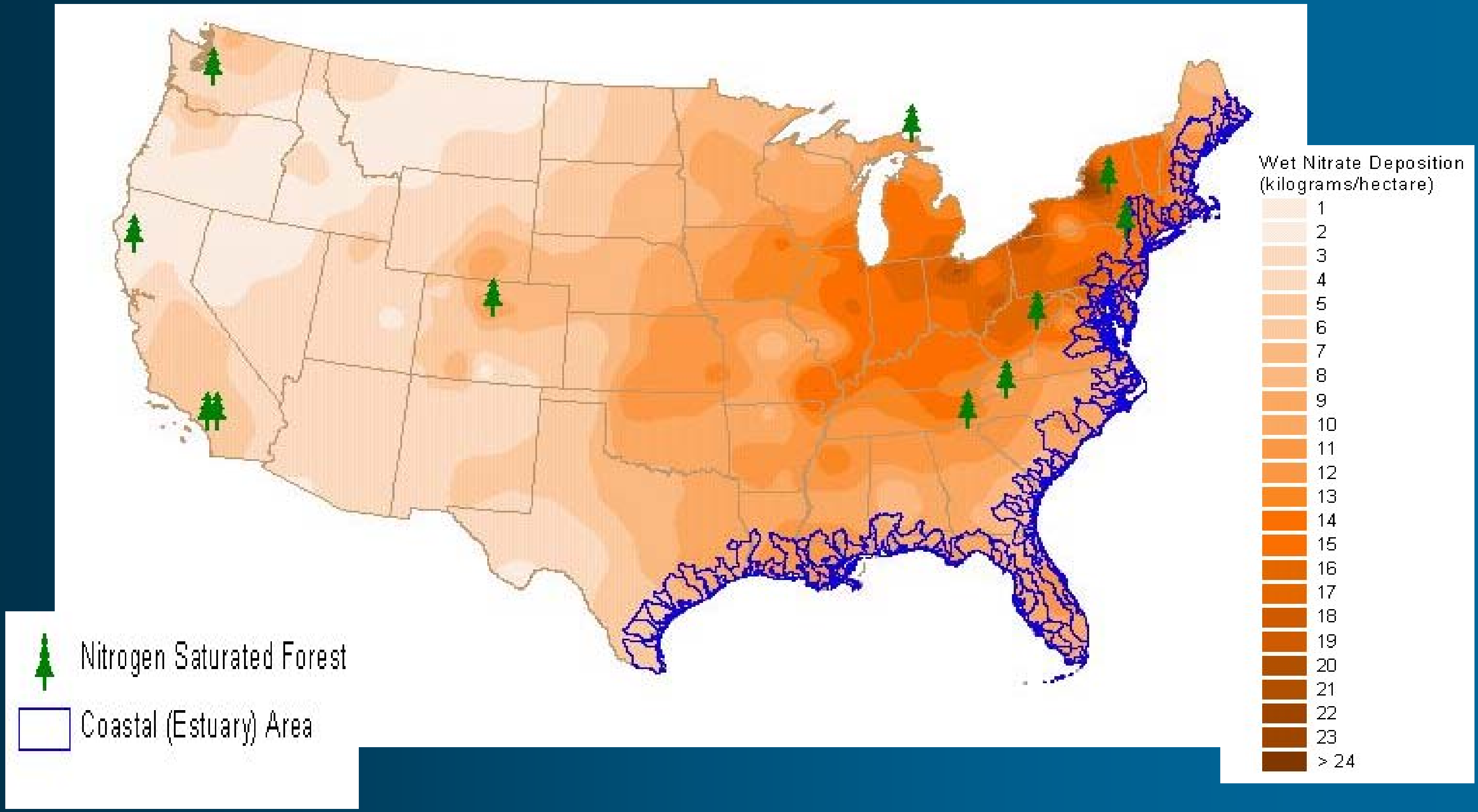
Hypothetical growth curve
(redrawn from Gundersen, 1992)

adapted from McCullouch

Nitrogen Loading = Algal Blooms =Oxygen Depletion

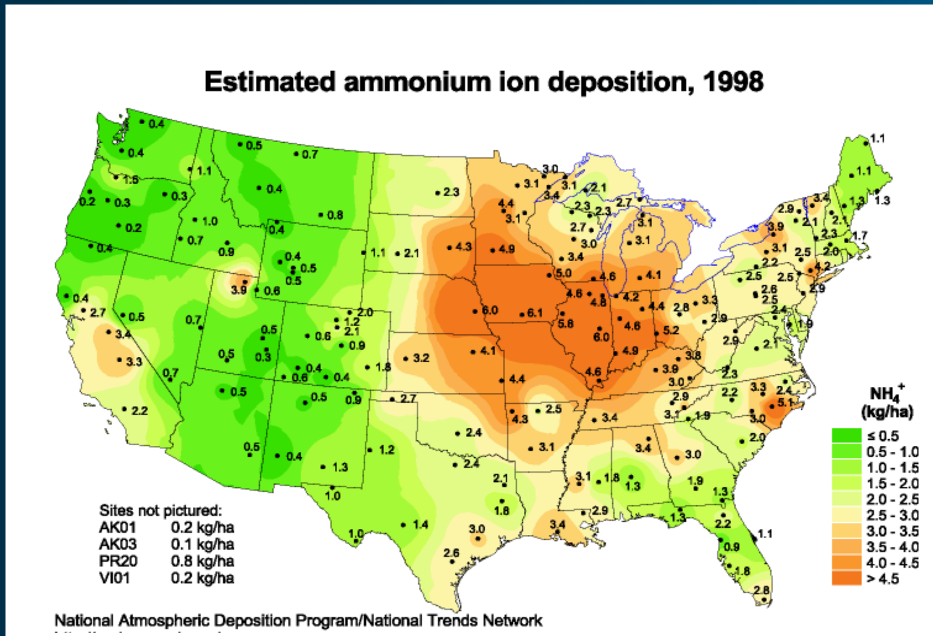
Oxygen Depletion = Fish Kills

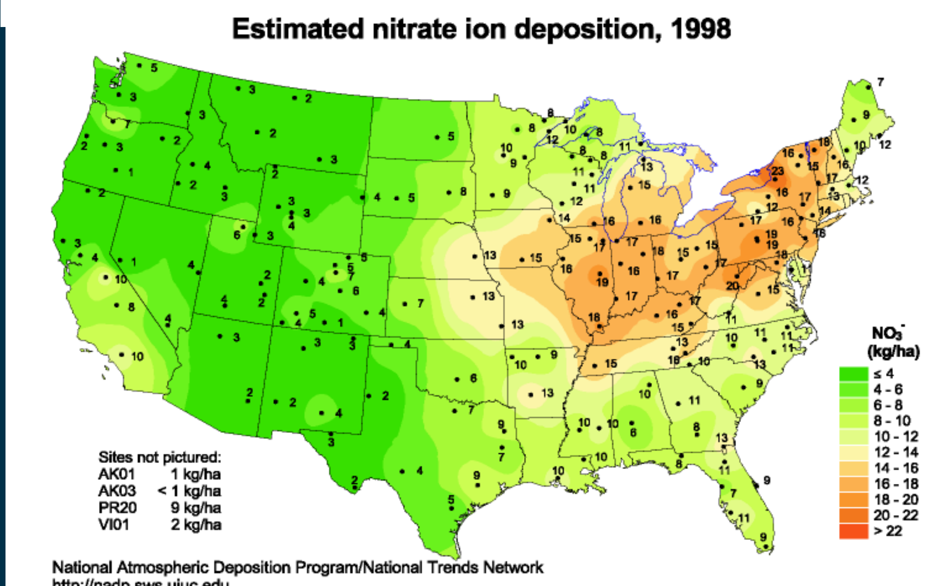
Wet Nitrate Deposition to Sensitive Resources



Deposition data from CASTNet and NADP measurements, 1997-1999

Slide prepared by Rona Birnbaum, US EPA



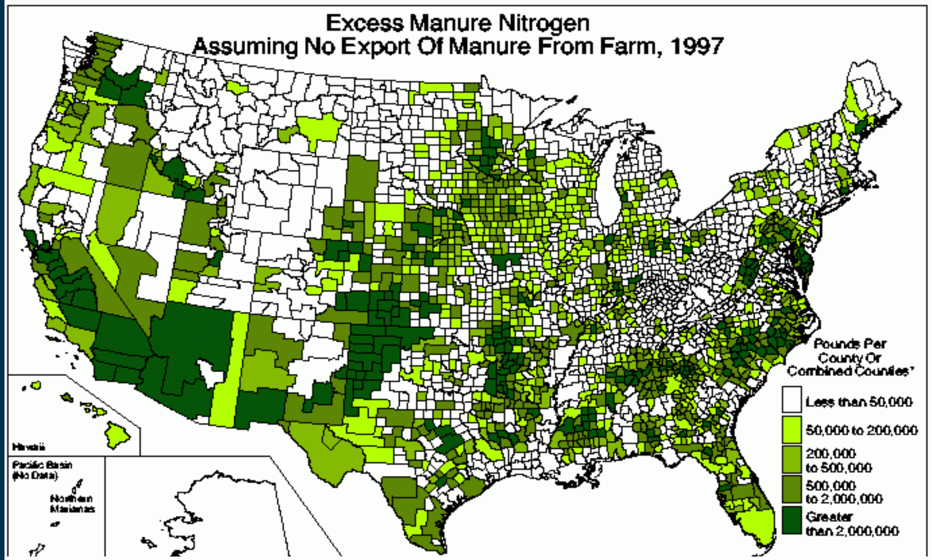


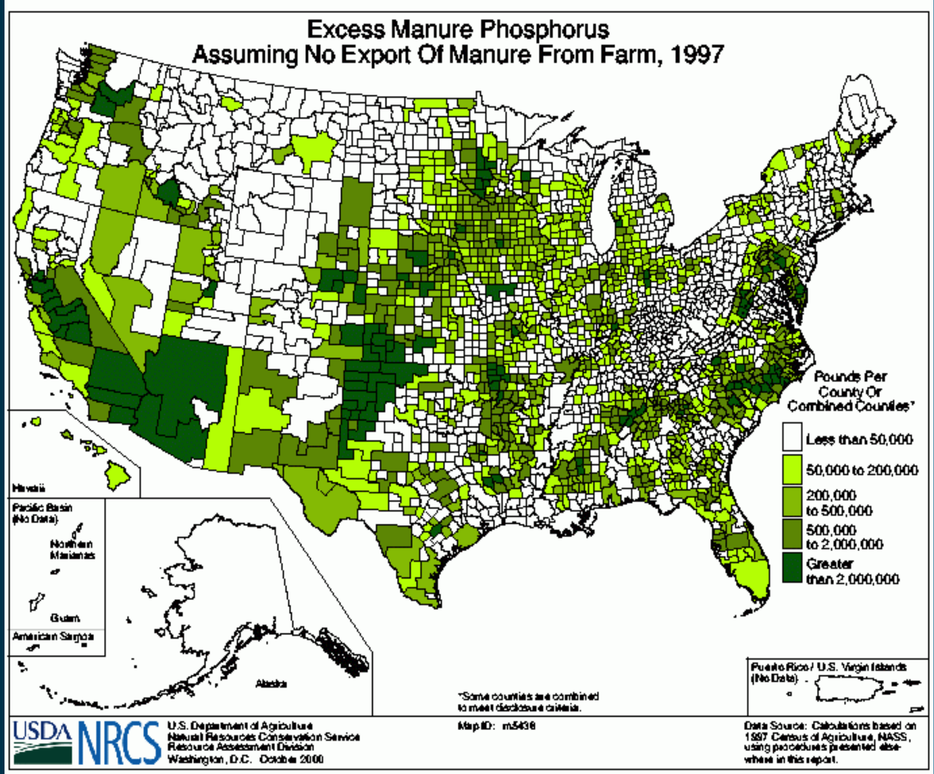
http://nadp.sws.uiuc.edu/

- Atmospheric nitrogen deposition rates approach or exceed critical limits in a number of areas in the US.
- Harmful algal blooms are on the increase globally.

Global Inventory of NOx and NH_3

Source or Sink	**NO_X (Tg N yr^{-1})**	**NH_3 (Tg N yr^{-1})**
Fossil fuel combustion	19.9	2
Biomass burning	12.0	5
Sea surface	< 1.0	13
Domestic animal waste	–	32 (20-35)
Human excrement	–	4
Lightning	8	–
NH_3 oxidation by OH	1	–
Stratospheric input	0.5	–
Soil emissions	8 (4-16)	19 (12-22)
Total Sources	**48**	**75**





Available manure nutrient exceeds crop system needs

Nutrient	# of Counties
N	266
P	485

Assimilative capacity of ILO cropland ~ 40% of manure N

Ammonia Losses

Forage / Feed N

↓

Production Houses → Urine/feces → NH_3 Volatilization

↓

Waste Storage and Treatment Systems → NH_3 Volatilization

↓

Land Application (i.e., spraying) → NH_3 Volatilization

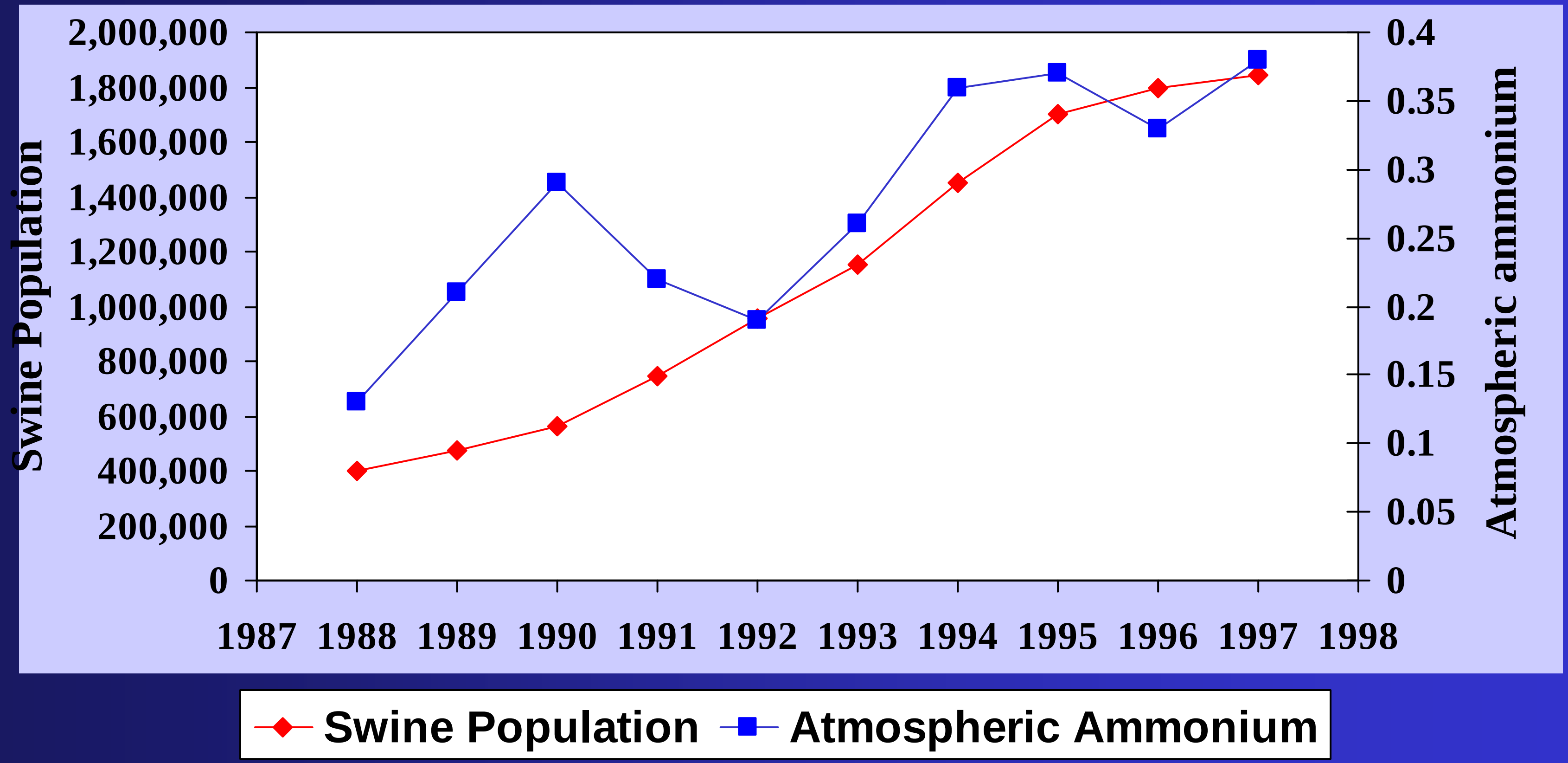
↓

Biogenic Emissions from Soil and Crops → NH_3 Volatilization

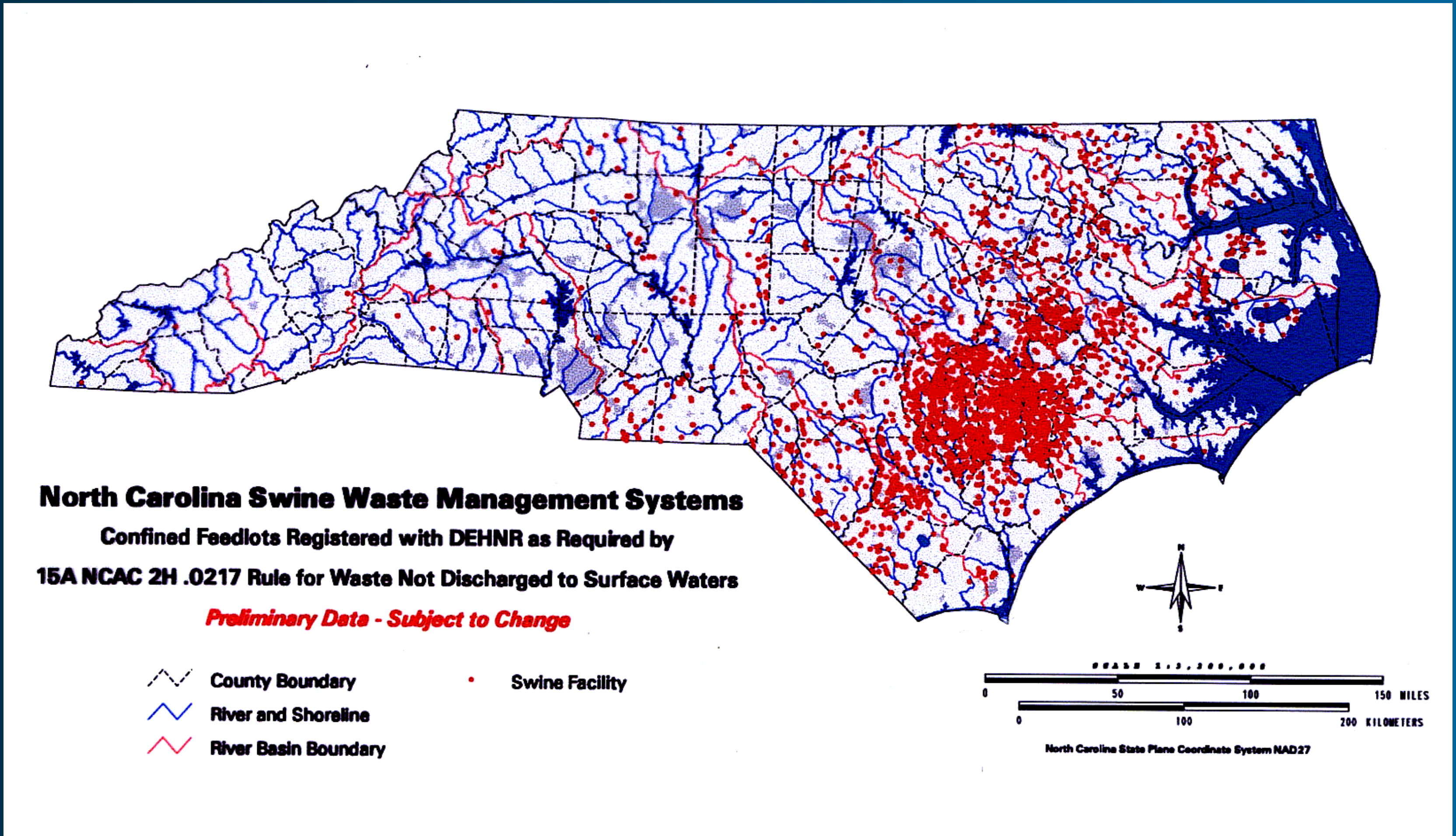
Aneja et al., 2001

Concurrent Increases in Swine Population and Atmospheric Ammonium in Sampson County, N.C., 1988-1997.

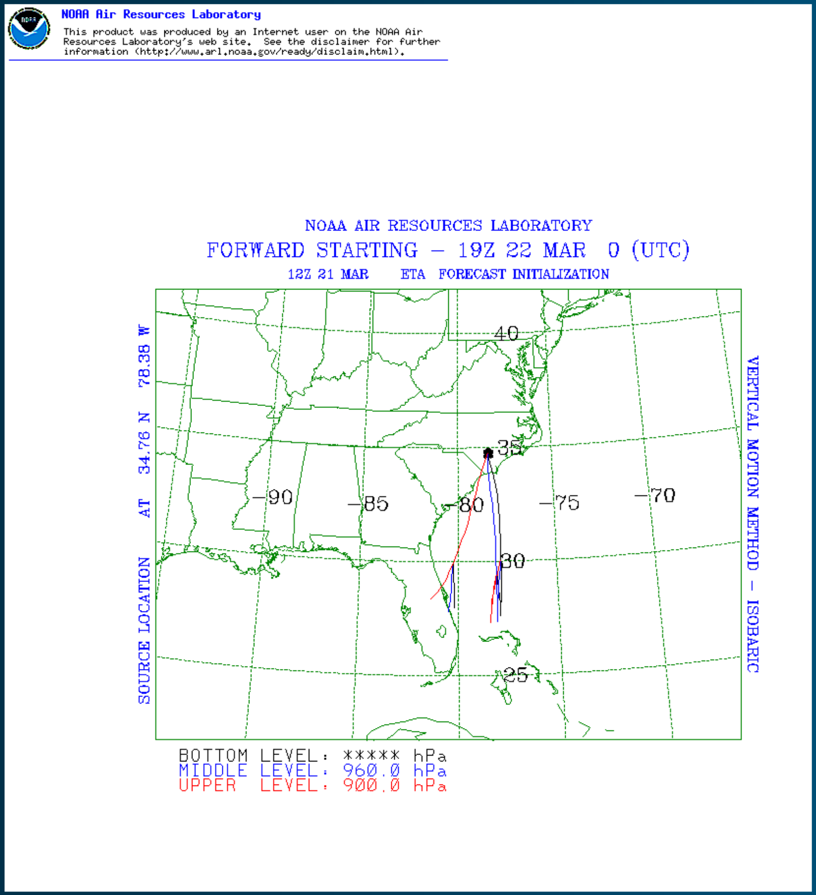
Correlation between airborne NH^4 and hog population: r=0.85, p=0.002



Swine Farm Distribution in North Carolina



Transport of Ammonia Emissions

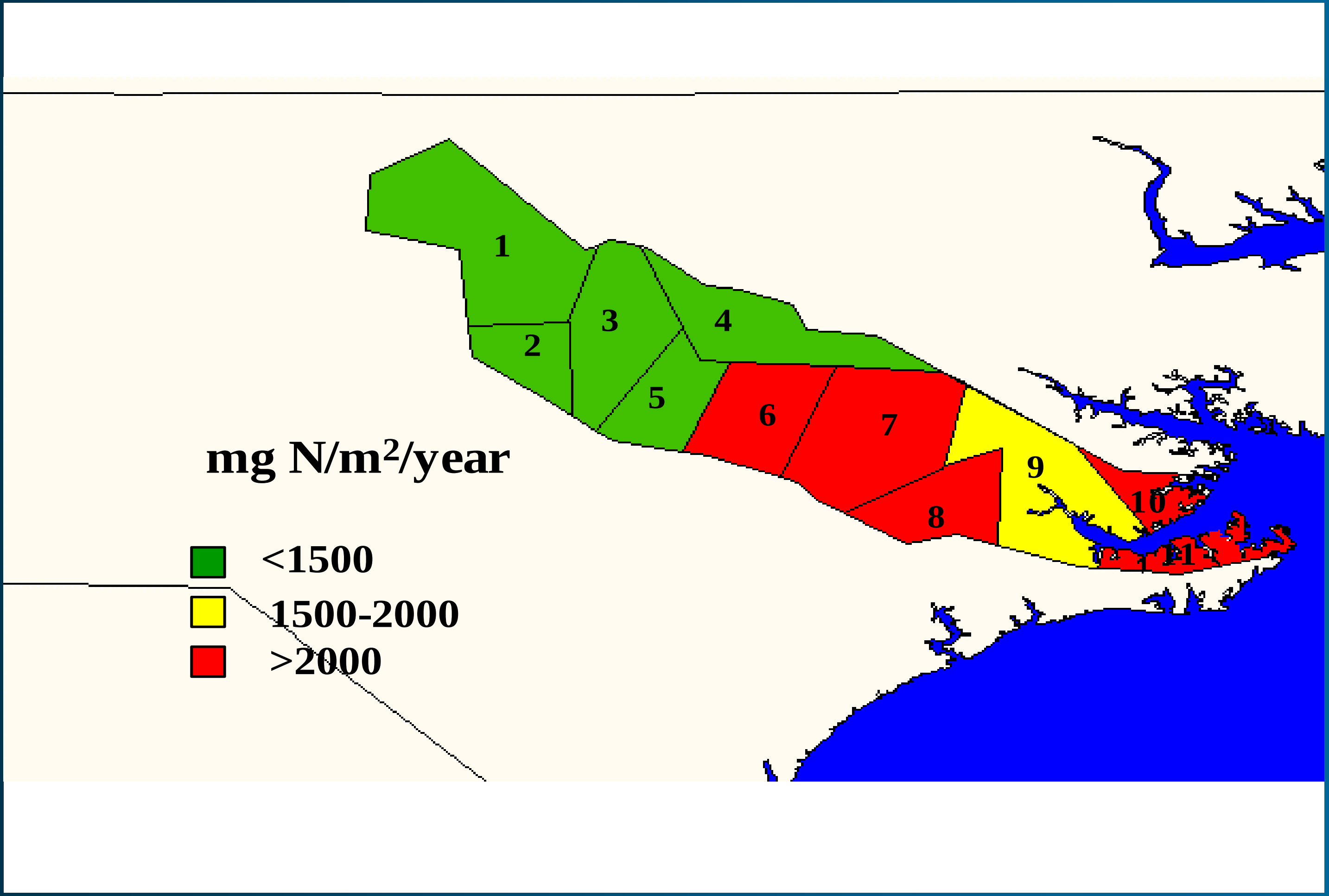


Air masses moving over areas of high density hog operations carried rain with elevated ammonia concentrations at least 50 miles downwind.

Walker, J.T., Aneja, V.P., Dickey, D.A. 2000.

adapted from R McCollough

Atmospheric Nitrogen Deposition in the Neuse River Basin: 1996-1999



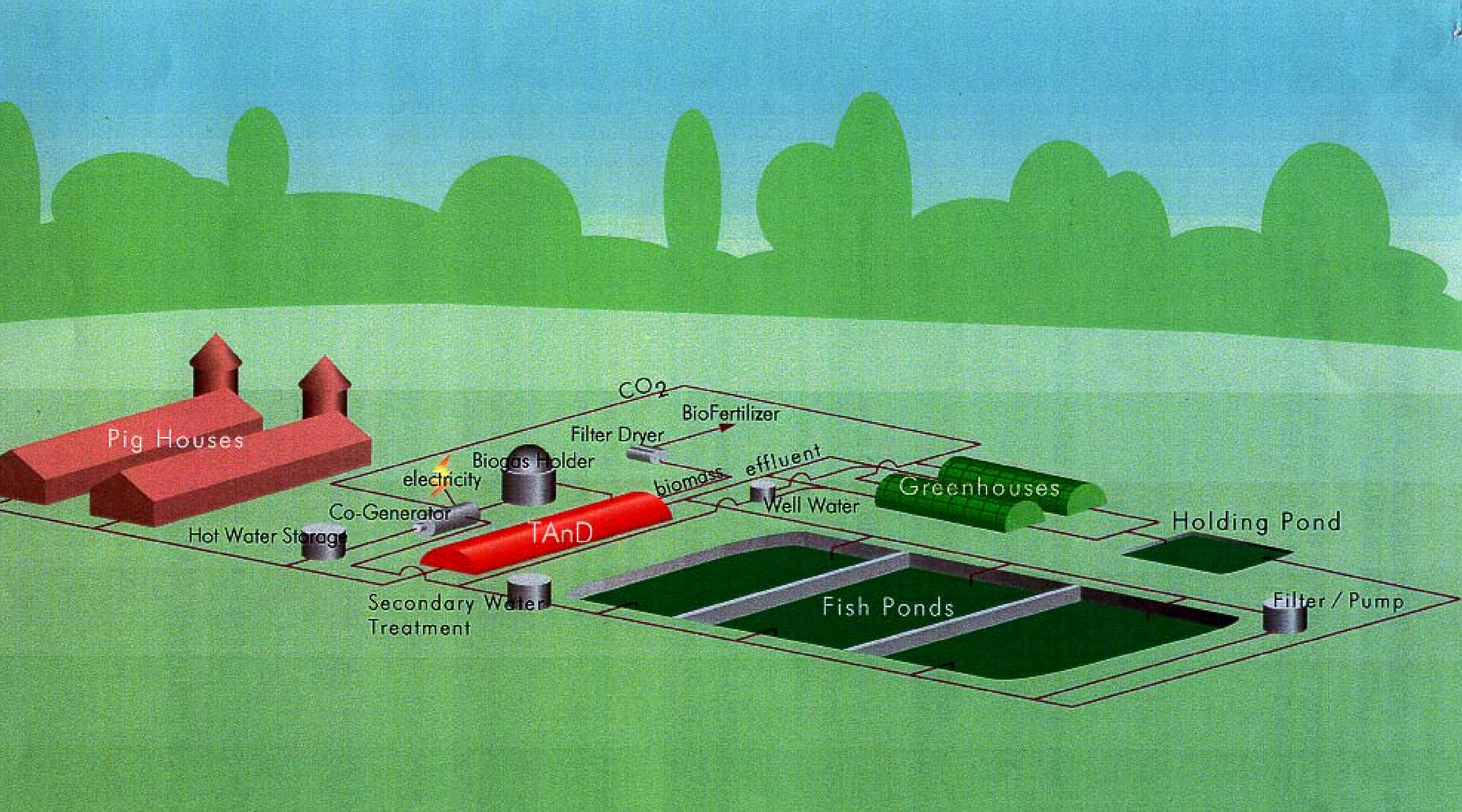
Paerl and Whitall, 2000

Role of Digesters as a Component in Animal Waste Treatment

- Process carbon and capture Green House Gases.
- Mineralize manure organics without loss to atmosphere.

Therefore:

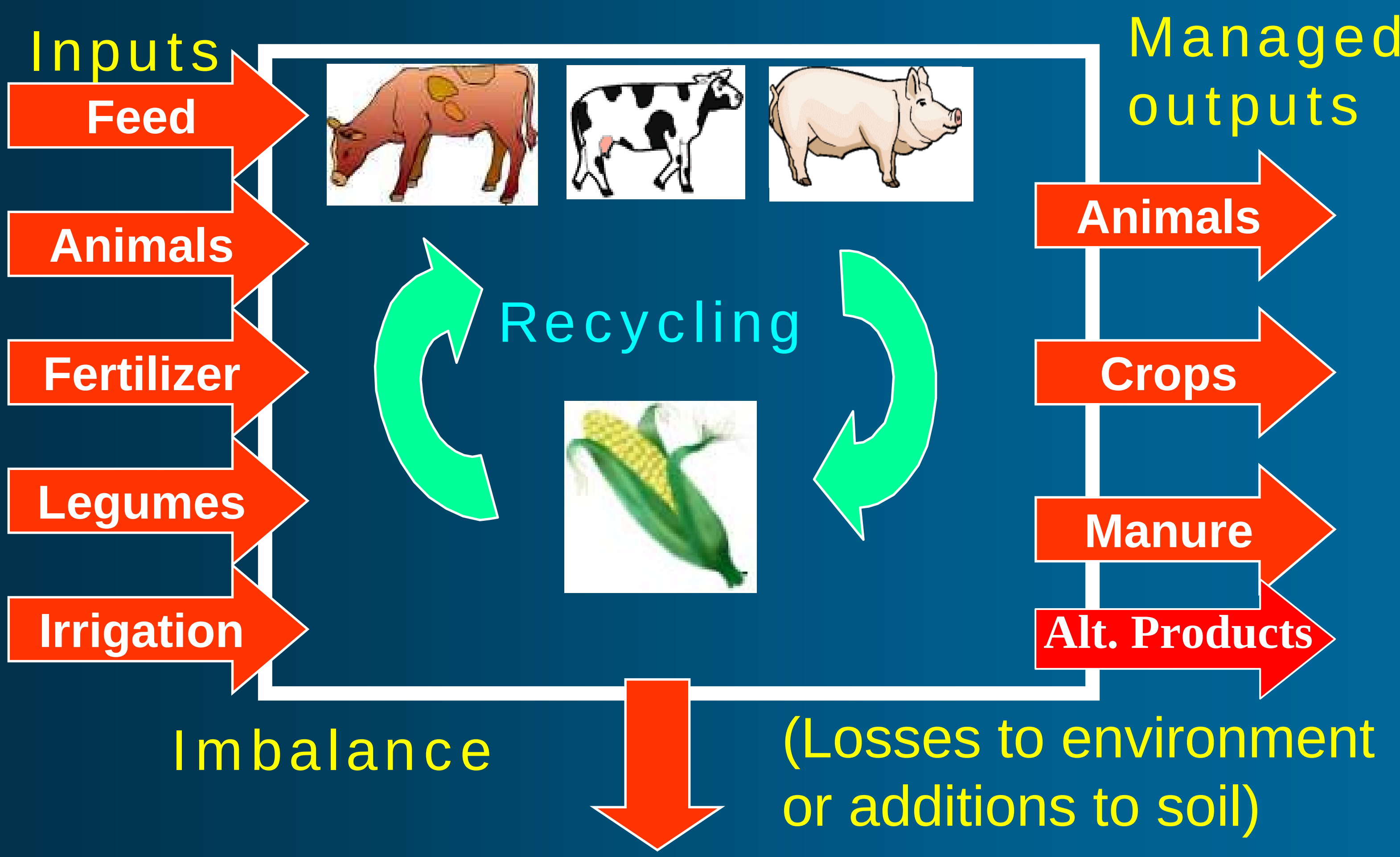
- Digestate must be properly handled to control loss of NH_3 to atm.
- More N = More land UNLESS manure nutrient resources are captured in an alternate value added product.



An Integrated Farming System

urce: Shih, 1999.

Whole Farm Nutrient Mass Balance



NCSU APWMC / National Center Comments on Proposed EPA CAFO Rules 2001

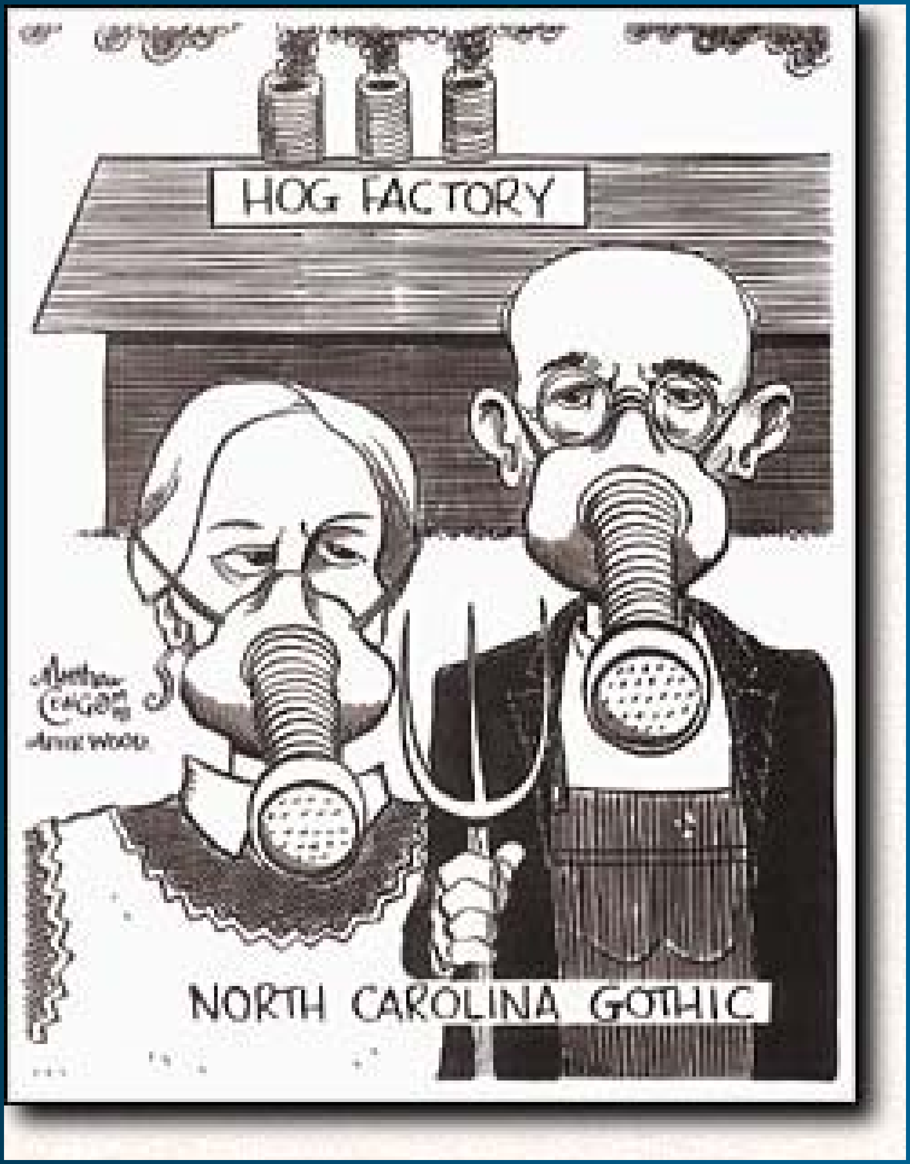
Potential Value-Added End Products

- **Conc. Fertilizer/ Feedstock/ Chemicals**
- **Alt. Livestock feed- e.g. duckweed, bamboo**
- **Aquaculture/pet food**
- **Fiber/ Structural products- e.g. trees, bamboo**
- **Algal products- pigments, chemicals**
- **Nursery stock and cut flowers**
- **(Methane, Ethanol, Biodiesel)**

NITROUS OXIDE EMISSIONS

- If manure denitrification treatment becomes common - could increase N_2O emissions.
- N_2O has high GHG potential. (GWP = 310)
- Denitrification treatment processes could have a higher percentage of N_2O loss than natural systems.

Odor is a Major Issue



Odor

... **it is possible for odorous emissions from animal operations, wastewater treatment, and recycling of biosolids to have an impact on physical health.**

Schiffman et al 2000

Conclusions

- Atmospheric emission and deposition of N is a major problem.
- Livestock production contributes about half of NH_3 emissions.
- Digesters are one component of a complete manure treatment system.
- Accomplish necessary treatment (mineralization) in a closed environment thus avoiding loss of NH_3.
- Digestate must be properly handled to avoid loss of NH_3.
- Value added manure products likely needed to capture nutrients.

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

ANAEROBIC DIGESTER – AMBIENT TEMPERATURE

(No.)

CODE 365

DEFINITION

An unheated waste treatment impoundment.

PURPOSE

To biologically treat waste as a component of a waste management system to:

- produce biogas and capture for energy
- improve air quality
- reduce greenhouse gas emissions

CONDITIONS WHERE PRACTICE APPLIES

This practice applies where:

- Biogas production and capture are components of a planned animal waste management system. Suitable geographic areas for energy recovery are shown on Figure 1.
- Existing waste impoundment(s) can be modified to the requirements of this standard or for new construction.
- The digester is in conjunction with a separate waste storage facility or where the digester and storage are congruent.
- Manure can be collected fresh and delivered to the digester with a total solids (TS) concentration in the influent waste of less than 2%.
- The operator has the interest and training to monitor and maintain processes or contracts with a consultant to provide these services.

CRITERIA

CRITERIA APPLICABLE TO ALL PURPOSES:

Laws and regulations. Waste treatment facilities must be planned, designed, and constructed to meet all federal, state and local regulations.

Manure Characteristics. This practice is applicable to manure that is collected fresh, generally less than 7 days old. Manure shall be essentially free of soil, sand, stones or fibrous bedding material (including clumps of straw) or processed to remove such material.

Ruminant manure's shall be treated with solid separation prior to entry into the digester.

Rainfall Runoff. Rainfall runoff shall be diverted away from the digester.

Anaerobic Digester. The digester shall meet the General Criteria for All Lagoons contained in Practice Standard 359, Waste Treatment Lagoon, as appropriate, and the following additional requirements:

1. Minimum Treatment (Design Operating) Volume. The design operating volume shall be based either on the daily volatile solids (VS) loading rate per 1,000 ft^3, or the minimum hydraulic retention time (HRT) adequate for methane production, whichever is greater. The maximum daily VS loading rate shall be selected from the values listed on the map in Figure 2. The minimum HRT shall be selected from values listed on the map in Figure 3.

2. Required Total Volume. The required total volume of the digester shall be equal to the Minimum Treatment Volume except where waste storage is included in the design, then the volume shall meet the additional criteria for Design Storage Volume in Practice Standard 313, Waste Storage Facility, as appropriate.

   The digester storage volume does not need to account for rainfall except for partially covered digesters.

3. A minimum of 2.0 feet of freeboard above the digester design water surface shall be provided except when rainfall is included in determining the operating volume, only 1 foot of freeboard is required.

4. Length to Width Ratio. The ratio of length to width of the digester is limited to 4:1 or less.

5. Operating Depth. The operating depth of the digester shall be 12 feet or greater over 50 percent or more of the bottom area.

6. Interior Slopes. The interior slopes shall be as steep as permitted by soil properties and construction techniques.

7. Waste Inlet and Outlet. The inlet and outlet devices shall be located as far apart as practical to minimize “short circuiting”.

8. The inlet shall discharge a minimum of 12 inches below the digester water surface.

9. Outlet. The digester shall be equipped with an outflow device that will maintain the digester water surface at its operating level. Except where the digester is designed to include storage, the outlet shall release directly to the waste storage facility without release of trapped gas.

10. Digester Cover. The digester cover, materials, anchorage and all appurtenances such as weights and floats shall be designed to capture and convey biogas to the gas collection system. The digester cover and materials shall meet the requirements of Practice Standard 367, Waste Facility Cover.

Separate Waste Storage Facility. Separate waste storage facilities shall meet the requirements of Practice Standard 313, Waste Storage Facility. No storage credit shall be attributed to the digester in meeting the minimum storage requirements in Practice Standard 313 except for sludge volume reduction based on expected total solids (TS) removed or destroyed.

Gas Collection, Transfer and Control System. The biogas collection, transfer, and control system shall be designed to convey captured gas from under the digester cover to gas utilization equipment or device (flare, boiler, engine, etc.).

Gas Collection and Transfer

1) Perforated pipe and other components under the digester cover shall be designed to exclude floating debris and waste residue and shall have a service life consistent with the expected cover life, but not less than 10 years.

2) Pipe and components under the cover shall be securely anchored to prevent displacement from normal cover forces.

3) The collection and transfer pipe shall be designed for wet biogas. In colder climates, the pipe shall be protected as necessary to prevent frost buildup. In no case shall the pipe size be less than 3 inch diameter.

4) Pipe used for transfer of gas can be buried or installed above ground and must include provisions for drainage of condensate, pressure and vacuum relief, and flame traps.

Gas Control

1) Gas control equipment and components shall be conveniently located and sheltered from the elements. A minimum distance of 30 feet (10 m) shall separate the control facility from the digester.

2) Gas control equipment and components shall have a service life of not less than two years and shall be readily accessible for replacement or repair.

3) The size of equipment and connecting pipe shall be based on head loss, cost of energy, cost of components and manufacturers recommendations.

4) Where electrical service is required at the control facility, the installation and all electrical wire, fixtures and equipment shall meet the National Electrical Code and local and state requirements.

Gas Utilization. Gas utilization equipment shall be designed and installed in accordance with standard engineering practice and the manufacturer recommendations. As a minimum, the installation will include a flare to burn off collected gas.

1. The flare shall be equipped with automatic ignition, powered by battery/solar or direct connection to electrical service. The flare shall have a minimum capacity equal to the anticipated maximum biogas production.

2. Gas fired boilers, turbines, and internal combustion engines, when a component of the system, shall be designed for burning biogas directly or shall include equipment for removing H_2S and other contaminants from the biogas.

Monitoring. When the purpose is to produce and capture biogas for energy, equipment needed to properly monitor the digester and gas production shall be installed as part of the system. As a minimum, the following equipment is required:

- A temperature sensor and readout device to measure internal temperature of digester.

- Gas meter suitable for measuring biogas.

Safety. Methane is a flammable gas. The gas collection, control and utilization system shall be designed to incorporate measures to prevent undue safety hazards. As a minimum, “warning flammable gas” and “no smoking” signs shall be posted.

Flares shall be located a minimum distance of 95 feet (30 m) from the biogas source and grounded or otherwise protected to minimize the chance of lightening strikes.

A flame trap device shall be provided in the gas line between the digester and points of use (flare, boiler, engine, etc.).

The location of underground gas pipe shall be marked with signs to prevent accidental disturbance or rupture. Mark exposed pipe to indicate whether gas line or other.

CONSIDERATIONS

Location. Location of the waste storage facility should consider elevation and distance from the covered digester to take advantage of gravity flow.

The covered digester should be located as near the source of manure as practicable and as far from neighboring dwellings or public areas (minimum distance of 300 ft (100 m)) as possible. Proper location should consider slope, distance of manure transmission, vehicle access, wind direction, neighboring dwellings, proximity of streams and floodplains, and visibility.

Using available gas to heat the digester can improve total solids destruction and further reduce greenhouse gas emissions. In geographic areas north of the 40th parallel (Figure 1) heat is required to maintain year around anaerobic digestion

The covered digester should be located near a suitable site for energy utilization equipment. Short distances for the transmission of methane through buried pipe are preferable.

Waste Transfer Pipe. It is standard practice to locate a clean out immediately upstream of the digester. Influent from the waste collection pit discharges below the digester operating level and depending on the installation, solids might have a tendency to build up in the inlet pipe. This is also a good location for venting any gas that builds up in the transfer pipe.

Visual Screening. Analyze the visual impact of the digester within the overall landscape context or viewshed. Screening with vegetative plantings, landforms, or other measures may be implemented to alleviate a negative impact or enhance the view.

Depth of Digester. Improved digester performance and reduced cover cost (less area for given volume) can be realized with deeper digesters.

Rainfall. Rainfall on the digester cover can result in increased effluent discharge into the storage facility. For normal rainfall events this is probably not a problem. In locations subject to high rainfall events (thunderstorms and hurricanes), a ported riser on the outflow pipe should be considered to provide temporary storage and reduce outflow rate.

Gas Transfer Pipe. Exposed pipe conveying flammable gas is generally painted orange.

PLANS AND SPECIFICATIONS

Plans and specifications shall be prepared in accordance with the criteria of this standard and good engineering practice. The plans and specifications shall include all details necessary for construction and completion of the work.

As a minimum, the plans and specifications shall provide the following:

1. Layout of livestock facilities, waste collection points, waste transfer pipe, digester and storage pond.
2. Location of all digester influent pipes, devices, pipe material, size and grade.
3. All digester and storage pond dimensions, type of lining material, and other parameters as appropriate.
4. Digester cover material and dimensions of covered surface. Means of rainfall removal or details of drainage.
5. Details of digester cover anchorage (ex: location and width of trench, depth, backfill material and compaction of fill).
6. Details of the gas collection system, including type of pipe, devices, sizes, location, material, and grades.
7. Details of gas control facility, piping layout, components, electrical service if required, and protection from the elements.
8. Appropriate gas safety equipment or protective measures.

Warranties. The cover manufacturer and or installer shall warrant the cover for the intended use and design life, provide maintenance instructions, and certify that the cover is properly installed.

OPERATION AND MAINTENANCE

An operation and maintenance plan shall be developed and reviewed with the owner prior to construction. The O&M plan shall be consistent with the purposes of the practice, its intended life, safety requirements, and the criteria for its design. The plan shall contain operation and maintenance requirements including but not limited to:

1. Proper loading rate of the digester and total solids content of influent.
2. Proper operating level of the digester.
3. Estimates of biogas production, methane content, and potential energy recovery.
4. A description of the planned startup procedures, normal operation, safety issues, and normal maintenance items.
5. Alternative operation procedures in the event of equipment failure.
6. Instructions for safe use and/or flaring of biogas.
7. Cover and gas collection system maintenance.
8. Daily inspection of the following:

   - Cover material – check for cracks, tears, or points of distress around perimeter

   - Check for excessive ballooning of cover or presence of odor

   - Check for excess rainwater on cover

   - Check gas control panel, check regulators, pressure gages, electrical power, flow meter, flare igniter, and flare operation

9. Provide a plan with frequency of measuring and recording digester inflow, operating temperatures, biogas yield, and/or other information as appropriate.

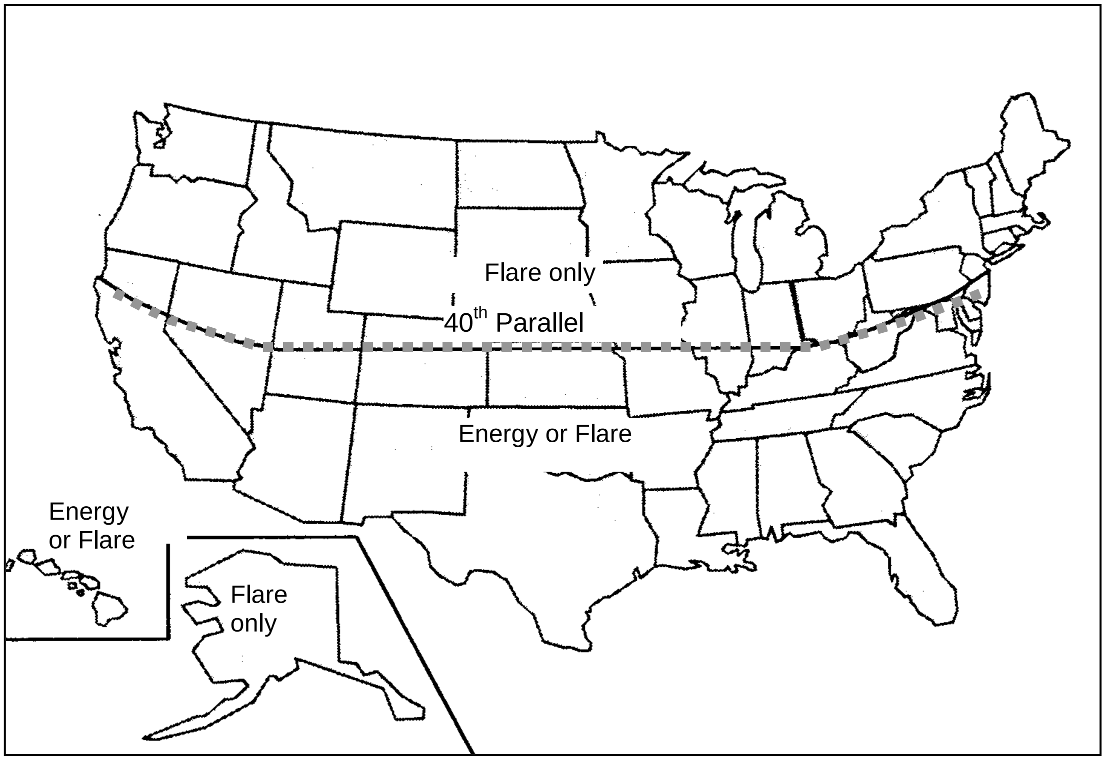


Figure 1. Ambient temperature digester. Locations suitable for energy production generally fall below the 40th parallel.

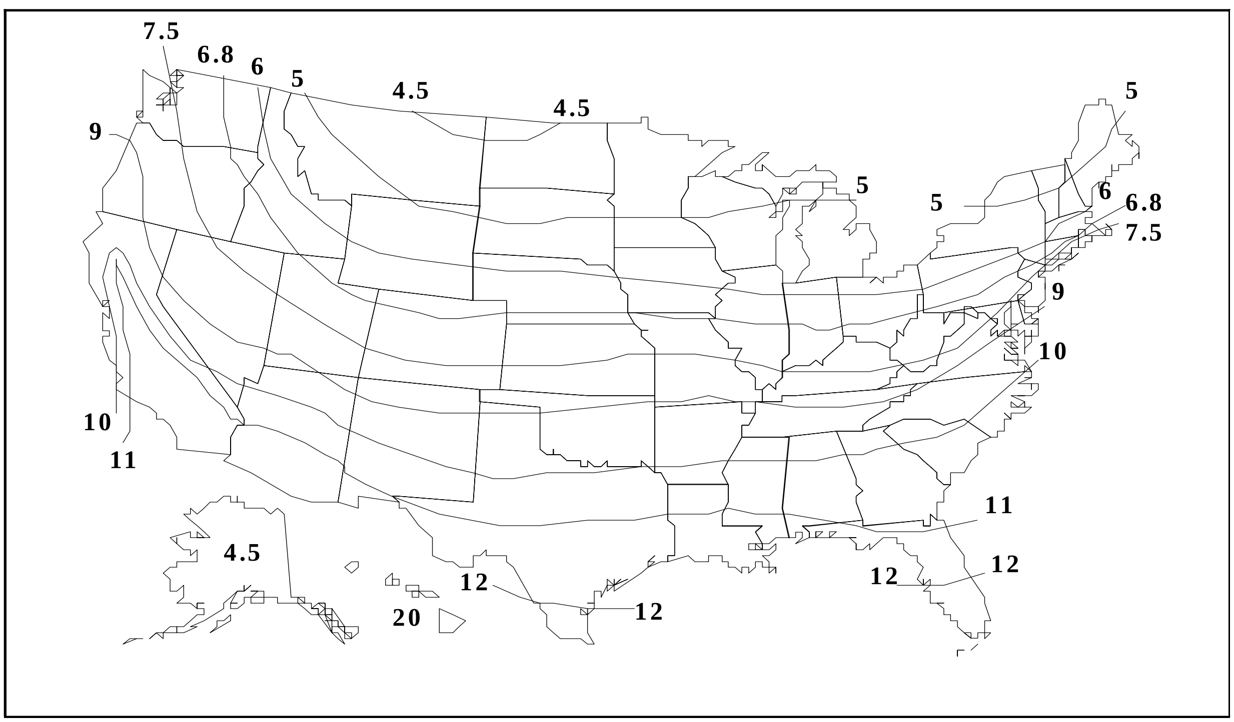


Figure 2. Covered anaerobic digester maximum loading rate (lb VS/1000ft^3/day)

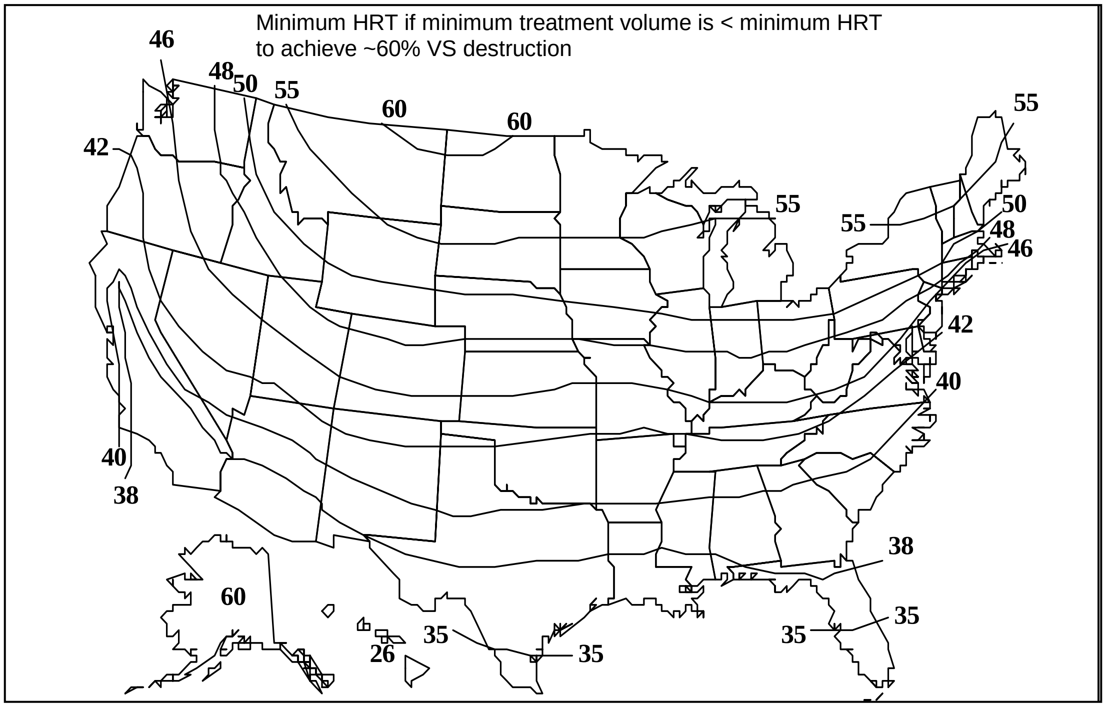


Figure 3. Covered anaerobic digester minimum hydraulic retention times (MINHRT), in days

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

ANAEROBIC DIGESTER – CONTROLLED TEMPERATURE

(No.)

CODE 366

DEFINITION

A managed temperature waste treatment facility.

PURPOSE

To biologically treat waste as a component of a waste management system to:

- produce biogas and capture for energy
- improve air quality
- reduce greenhouse gas emissions
- reduce pathogens
- improve nutrient management

CONDITIONS WHERE PRACTICE APPLIES

This practice applies where:

- Biogas production and capture are components of a planned animal waste management system.
- Existing facilities can be modified to the requirements of this standard or for new construction.
- Manure can be collected fresh and delivered to the digester with a total solids (TS) concentration up to 14%.
- The operator has the interest and training to monitor and maintain processes or contracts with a consultant to provide these services.

CRITERIA

General Criteria Applicable to All Purposes

Laws and regulations. Waste treatment facilities must be planned, designed, and constructed to meet all federal, state, and local regulations.

Manure Characteristics. This practice is applicable to manure that is collected fresh, generally less than 7 days. Manure shall be essentially free of soil, sand, stones or fibrous bedding material (including clumps of straw) or otherwise processed to remove or reduce such material.

Total Solids Concentration. The total solids of manure influent to the digester shall be as required by the digester type and process design. Except for any supplemental feedstocks and non-manure wastewaters as described in sectionsbelow, water or wastewater, other than needed for dilution to achieve the design total solids concentration, shall be excluded from the digester.

Treatment of Supplemental Feedstocks. Food wastes and wastewaters from food processing operations may be added as supplemental feedstocks to a digester when the following conditions are satisfied:

1. The digester is designed to treat such wastes, as documented in the Plans and Specifications.
2. The digester Operation and Maintenance Plan includes the handling and treatment of such wastes.

3. The farm's nutrient management plan accounts for the nutrient impact of such wastes.
4. The treatment of such wastes meets with all state and local regulations.

Treatment of Non-Manure Wastewaters. Wastewaters from farm operations, such as milking parlor wastewaters, barn floor wash water, and run-off from silage bunkers, may be added to a digester when the following conditions are satisfied:

1. The digester design has accounted for the use and treatment of such wastewater and included appropriate handling of such wastewater in the operation and maintenance plan.
2. The farm's nutrient management plan accounts for the nutrient impact of such wastewaters.

Safety. If the digester will create a safety hazard it shall be fenced and warning signs posted to prevent children and others from using it for purposes other than intended.

The effect of earthquake loads on the digester and biogas system shall be considered and appropriate protective measures incorporated into the design.

Biogas is flammable and highly toxic. The design of the digester and gas components must consider the hazards associated with normal operation and maintenance and provide adequate safety measures.

Digester Design. Digesters shall be designed to facilitate anaerobic digestion of animal manure and meet the minimum design and operational requirements below for the type of digester specified. The design documentation shall specify the type of digester and include a process diagram with the following minimum information:

1. Flow rates, influent and effluent
2. Design total and volatile solids content of influent and effluent
3. Digester volume
4. Retention time
5. Heating system, control, and monitoring
6. Methane yield
7. 12 month energy budget when applicable
8. Process control and monitoring

Digester Types

Plug Flow Digester

- For ruminant manure the total solids concentration of influent shall be 11% to 14%. For other manure sources the total solids concentration shall be 8% to 14%.
- Digester retention time shall be $\geq$ 20 days.
- Operational temperature shall be mesophilic (35ºC to 40ºC).
- The length to width ratio of digester flow path shall be between 3.5:1 and 5:1.
- The ratio of flow path width to fluid depth shall be less than 2.5:1.
- The shape of the floor and walls shall be uniform so as to minimize mixing.

Complete Mix Digester

- Total solids concentration of manure influent shall be from 2.5% to 10%.
- Digester retention time shall be $\geq$ 17 days.
- Operational temperature shall be mesophilic (35ºC to 40ºC).
- Appropriate mixing devices shall be provided to assure a complete mix process.

Fixed Film Digester

- Total solids concentration of influent shall be $\leq$ 5%. For total solids concentration $\geq$ 2.5%, the influent particle size shall be $\leq$ 0.25 inch.
- Digester retention time shall range from 1 to 6 days, depending on waste biodegradability.
- Operational temperature shall range from 15˚C (59˚F) to 40˚C (103˚F).

- Microbial support material with $\geq$ 3 inch openings

Alternative Digester Design Criteria

Design of digesters, not meeting the listed design and operational criteria or for a type other than listed in this standard, shall be based on the documented design and performance of such existing animal waste digester and certified as such by a registered professional engineer licensed in the state of the proposed installation.

Digester Vessel Characteristics. The digester vessel (tank) shall be a corrosion protected material or concrete structure, above or below ground, with allowances for entry and exit of manure, heat pipes and/or other appurtenances. Tanks shall be equipped with suitable covers designed for accumulation and collection of biogas. The tank and internal components shall be designed to facilitate periodic removal of accumulated solids.

Digester vessels shall meet the structural criteria for "Fabricated Structures" in Practice Standard (313), Waste Storage Facility, and the requirements of state and local seismic codes as applicable.

The following additional criteria applies:

1. Design Operating Volume. The digester shall be sized to retain the volume of manure and water, at the design total solids concentration, for the digester design retention time (days).
2. Configuration. The configuration of the digester tank is specific to the type of digester design and may be square, rectangular, circular, or as necessary to most effectively meet specific criteria listed under Digester Design. Tank dividers or flow separators can be utilized to increase efficiency.
3. Location of Inlet and Outlet. The inlet and outlet devices shall be located so as to facilitate process flow.
4. Inlet. Inlets shall be of any permanent type designed to resist corrosion, plugging, freeze damage, and prevent gas loss.
5. Outlet. The digester shall be equipped with an outflow device such as an underflow weir, which will maintain the operating level, maintain a gas seal under the cover, prevent gas loss, and release effluent directly to separation, storage, or other treatment facility.
6. Cover. The digester cover shall be designed for all internal and external loads and shall capture and convey the biogas to a designed gas outlet. The cover system shall be designed to exclude the entrance of air under all operating conditions. Where the cover is exposed to the weather, the design shall account for environmental conditions for its service life. Precipitation runoff shall be collected and discharged to suitable grassed or otherwise stabilized areas.

   Covers shall meet the requirements of Practice Standard (367), Waste Facility Cover.

Operating Temperature.

Digesters shall be maintained at internal temperatures appropriate to the digester type and design. The design shall include heat loss calculations to determine insulation, heat exchanger capacity, and energy requirements as appropriate for maintaining the digester operating temperature within acceptable limits.

Mesophilic Digesters - The digester shall be maintained between 35ºC and 40ºC (95º-103ºF) with an optimum of 37.5ºC (100º F) and daily fluctuation of digester temperature limited to less than 0.55ºC (1ºF).

Operating Level. The operating level of digesters shall be designed with appropriate freeboard and overflow or automatic shutdown devices to prevent accidental spillage of effluent or discharge into the gas collection system.

Gas Collection, Transfer and Control System. The biogas collection, transfer, and control system shall be designed to convey captured gas from within the digester to gas utilization equipment or devices (flare, boiler, engine, etc.).

1. Gas collection and transfer - Pipe and/or appurtenances shall meet the following:
   - The gas collection system within the digester shall be designed to facilitate rremoval exclude floating debris.
   - Pipe and components within the digester shall be securely anchored to prevent displacement from normal forces including loads from accumulated scum.
   - Pipe shall be designed for wet biogas. In colder climates, the pipe may need to be insulated to prevent frost buildup.
   - Pipes shall be constructed to enable all sections to be safely isolated and cleaned as part of routine maintenance.
   - Transfer pipe can be buried or installed above ground and must include provisions for drainage of condensate.
2. Gas Control
   - Equipment and components shall be conveniently located and sheltered from the elements.
   - Equipment and components shall have a service life of not less than two years and shall be readily accessible for replacement or repair.
   - The size of equipment and connecting pipe shall be based on head loss, cost of energy, cost of components and manufacturers recommendations.
   - Gas pipe installed within buildings shall be of type approved for combustible gas.
   - Where electrical service is required at the control facility, the installation and all electrical wire, fixtures and equipment shall meet the National Electrical Code and local and state requirements.

Gas Utilization. Gas utilization equipment shall be designed and installed in accordance with standard engineering practice and the manufacturer recommendations. As a minimum, the installation will include a flare to burn off collected gas and a means of maintaining the digester within acceptable operating temperature limits.

- The flare shall be equipped with automatic ignition, powered by battery/solar or direct connection to electrical service. The flare shall have a minimum capacity equal to the anticipated maximum biogas production.
- Gas fired boilers, fuel cells, turbines, and internal combustion engines, when a component of the system, shall be designed for burning biogas directly, in a mix with other fuel, or shall include equipment for removing H_2S and other contaminants from the biogas.

Monitoring. Equipment needed to properly monitor the digester and gas production shall be installed as part of the system. As a minimum the following equipment is required:

- Temperature sensors and readout device to measure internal temperature of digester
- Temperature sensors and readout device to measure inflow and outflow temperature of digester heat exchanger
- Gas meter suitable for measuring biogas

Safety. Biogas is a flammable gas. The gas collection, control, and utilization system shall be designed in accordance with standard engineering practice for handling a flammable gas and to prevent undue safety hazards. As a minimum:

- "Warning Flammable Gas" and "No Smoking" signs shall be posted.
- Flares shall be grounded or otherwise protected to minimize the chance of lightening strikes.
- A flame trap device shall be provided in the gas line between the digester and sources of ignition or as recommended by the flame arrester manufacturer.
- The location of underground gas lines shall be marked with signs to prevent accidental disturbance or rupture. Mark exposed pipe to indicate whether gas line or other.

Waste Storage Facility. When a waste storage facility is a component of the waste system, it shall meet the requirements of Practice Standard, 313, Waste Storage Facility. The volume of the digester shall not be considered in determining the storage requirement of the waste storage facility except that the sludge volume can be reduced by the anticipated percent destruction of total solids.

CONSIDERATIONS

Location. The digester should be located as near the source of manure as practicable and as far from neighboring dwellings or public areas (minimum distance of 91 m (300 ft)) as possible. Proper location should also consider slope, distance of manure transmission, vehicle access, wind direction, proximity of streams and floodplains, and visibility. The digester should be located near a suitable site for energy utilization equipment. Short distances for the transmission of biogas through buried pipe are preferable. Location of the waste storage facility should consider elevation and distance from the digester to take advantage of gravity flow.

Manure Characteristics. Aged manure can be fed to the digester if properly reconstituted to the digester design total solids content. The biogas yield from aged manure (generally less than 6 months old) is dependent on the biodegradation that has taken place during the storage period. If frozen, little biodegradation will have occurred whereas manure in a warm moist state, could be significantly degraded.

Collection/Mix Tank. A collection/mix tank may be included to accumulate manure, settle foreign material and pre-treat influent waste to the appropriate total solids concentration. A volume equal to two days of manure collection is recommended.

Digester Design. A digester operating fluid depth of 8 feet or greater is generally considered more economical for tank design.

Gas Collection Cover. In areas of extreme wind or excessive snow, appropriate structures may be necessary to protect inflatable and floating digester covers from damage.

Cover Design. A variety of digester cover designs can be considered to meet the needs of the farm. A secured, flexible membrane cover can be designed for significant storage of biogas whereas a rigid cover generally has limited storage.

Gas Utilization. The most beneficial use of the biogas energy must be investigated and selected. Depending on the design and climate, digesters may require up to 50% of the biogas heat value to maintain the design temperature in the winter season. Digesters can be heated by hot water from boilers burning biogas or by heat recovery from engines burning biogas for power generation.

Effluent Tank. An effluent tank to hold digester effluent for solids separation treatment may be considered due to the potential value of digested separated solids for bedding or soil amendment.

Visual Screening. Analyze the visual impact of the digester within the overall landscape context or viewshed. Screening with vegetative plantings, landforms, or other measures may be implemented to alleviate a negative impact or enhance the view.

PLANS AND SPECIFICATIONS

Plans and specifications shall be prepared in accordance with the criteria of this standard, sound engineering practice, and shall describe the requirements for applying this practice to achieve its intended use.

As a minimum, the plans and specifications shall provide the following:

1. Layout and location of livestock facilities, waste collection points, waste transfer pipe, digester, biogas utilization facilities, and digester effluent storage.
2. Grading plan showing excavation, fill, and drainage, as appropriate.

3. Materials and structural details of the digester, including all premixing tanks, inlets, outlets, pipes, pumps, valves, and appurtenances as appropriate to the complete system.
4. Details of gas collection, control, and utilization system including type of materials for pipe, valves, regulators, pressure gages, electrical power and interface as appropriate, flow meters, flare, utilization equipment and associated appurtenances.
5. A process flow diagram.

OPERATION AND MAINTENANCE

An operation and maintenance plan shall be developed that is consistent with the purposes of the practice, its intended life, safety requirements, and the criteria for its design. The plan shall contain operation and maintenance requirements including but not limited to:

- Proper loading rate of the digester and total solids content of the influent.
- Proper operating procedures for the digester
- Estimates of biogas production, methane content, and potential energy recovery
- A description of the planned startup procedures, normal operation, safety issues, and normal maintenance items.
- Alternative operation procedures in the event of equipment failure.
- Instructions for safe use or flaring of biogas.
- Digester and other component maintenance.
- Trouble shooting guide.
- Provide a plan for monitoring with frequency of measuring and recording digester inflow, operating temperatures, biogas yield, and/or other information as appropriate.

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

WASTE FACILITY COVER

(No.)

CODE 367

DEFINITION

A fabricated rigid, semi-rigid, or flexible membrane over a waste treatment or storage facility.

PURPOSE

To cover a waste facility for:

- water quality improvement
- air quality improvement
- capture of biogas for energy production

CONDITIONS WHERE PRACTICE APPLIES

This practice applies where:

- Exclusion of precipitation from an animal waste storage or treatment facility will improve management of an existing or planned system.
- Capture and controlled release or flaring of emissions from an existing or planned agricultural waste storage will improve air quality.
- Bio-treatment of emissions from an existing or planned waste storage or treatment facility will improve air quality.
- Biogas production and capture for energy are components of an existing or planned animal waste system.

CRITERIA

General Criteria Applicable to All Purposes

Laws and Regulations Cover systems for animal waste facilities must be planned, designed, and constructed to meet all federal, state and local regulations.

Service Life The cover and appurtenances shall be designed to provide a service life of not less than 10 years.

Materials The type, thickness and material properties of the cover and any supporting members shall account for all loads and stresses due to operational, environmental, and climatic conditions.

Flexible membrane materials, used for fabrication of inflated and floating covers, shall be certified by the manufacturer as suitable for the intended application.

Loads Where applicable, the membrane cover and support system shall be designed to resist snow and wind loads as specified in ASAE EP288.5, Agricultural Building Snow and Wind Loads.

Biogas Emissions The cover system shall provide for capture and control of biogas, bio-reduction and direct release of gaseous emissions, or contain and release of gaseous emissions, as appropriate.

Capture and Control

The cover system shall be designed to capture biogas emissions and transfer to point of discharge without mixing with air. The point of discharge shall be equipped with a flare or utilization equipment as appropriate.

Bio-reduction and Direct Release

The cover shall be fabricated of a permeable composite membrane designed to promote biological treatment of gaseous emissions. Gaseous emissions pass through the membrane for direct release to the atmosphere.

Contain and Release

The cover system is designed for rainfall exclusion and not to specifically capture biogas. Therefore special handling or treatment of biogas emissions is not required except as necessary to prevent undue safety hazards

Anchorage. The cover anchorage system shall be designed in a manner to resist internal gas pressures, corrosive environment, wind loads or other forces as appropriate to the cover system.

Repair. New and aged flexible cover materials shall be readily repairable by solvent, adhesive, or thermoplastic welding. Semi-rigid cover material shall be repairable by sectional replacement.

Precipitation. Impermeable covers shall direct precipitation to collection points for removal by pumping or by controlled release to suitable grassed or otherwise stabilized areas for discharge.

Access. Covers shall be removable or otherwise provided with suitable equipment access as necessary for normal operation and maintenance of the waste facility.

Safety. The cover shall include safety features, including fences and warning signs as appropriate to prevent undue hazards.

As a minimum all covers shall include the following:

- “Warning Flammable Gas” and “No Smoking” signs shall be posted.

Where biogas is captured, the gas collection and control system shall be designed in accordance with standard engineering practice for safely handling a flammable gas.

- Flares shall be grounded or otherwise protected to minimize the chance of lightening strikes.
- A flame trap device shall be provided in the gas line between the flare and the waste facility.
- The location of underground gas lines shall be marked with signs to prevent accidental disturbance or rupture.

Additional Criteria for Rigid Covers

- Rigid covers shall meet the structural requirements of Practice Standard 313, Waste Storage Facility.
- The cover or cover vessel design shall include provisions for fail safe pressure relief. Maximum pressure shall not exceed 12 inches water column.

Additional Criteria for Inflated Covers

Covers inflated and supported by forced air from mechanical means shall be:

- Equipped with a warning system to notify operator of blower failure.
- Provided with a support system to limit cover collapse in the event the blower fails and for access of equipment.
- Provided with a suitable access port for normal maintenance equipment.

Additional Criteria for Floating Covers

- Floating membrane covers shall be supplemented with floatation materials as necessary for proper function, operation, and maintenance.
- Minimum membrane or composite membrane thickness shall be 40 mils.

Additional Criteria for Energy Production

The cover materials and all appurtenances such as weights and floats shall be designed to capture and convey biogas to the gas collection system. The cover design shall provide for the following:

1. Air Infiltration. The cover system and appurtenances, including perimeter soil slopes above the water line for in-ground digesters, shall be designed to exclude the entrance of air under all operating conditions.
2. Material. The minimum material thickness for flexible geomembrane covers shall be:
    - 40 mils for non reinforced material
    - 36 mils for reinforced materials
3. Gas Collection, Control, and Utilization. The collection of biogas and flaring or other end use shall meet appropriate criteria in Practice Standard 365, Anaerobic Digester – Ambient Temperature.

CONSIDERATIONS

Animal waste storage facilities can release large amounts of biogas at certain times of the year. The cover and gas collection system should be designed for release of this gas.

Storage of biogas should be considered when installing flexible covers over storage impoundments (lagoons) to attenuate gas supply for end use or controlled release.

PLANS AND SPECIFICATIONS

Plans and specifications shall be prepared in accordance with the criteria of this standard and shall describe the requirements for applying the practice to achieve its intended use.

OPERATION AND MAINTENANCE

An operation and maintenance plan shall be developed that is consistent with the purposes of the practice, its intended life, safety requirements, and the criteria used for its design.

When gas storage is included in the system design, the plan shall contain instructions as to limits of cover ballooning and emergency procedures if control equipment fails.

Warranties. The cover manufacturer and or installer shall warrant the cover for the intended use and design life, provide maintenance instructions, and certify that the cover is properly installed.

Thermophilic Anaerobic Digestion: Theory, Practice and Benefits

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Agricultural applications of anaerobic digestion for waste treatment and biogas production have been known for decades and widely used in many parts of the world (Shuler, 1980; Stafford *et al*., 1980; Hobson *et al.*, 1981; China National Office for Biogas, 1982; Lusk, 1998; USEPA report, 2003). My laboratory has conducted a series of studies from laboratory research, pilot development to full-scale demonstration (reviews by Shih, 1987; 1993; 2000). It began with laboratory studies to determine the operational parameters to reach the maximal potential of biogas production. It was concluded that at elevated or thermophilic temperatures the efficiency of anaerobic digestion could be greatly improved. The laboratory results were verified on the NCSU research farm with a pilot-scale digester. In addition to energy production, many other benefits associated with the digester system were demonstrated. Based on the NCSU model, a full-scale thermophilic anaerobic digester (TAnD) for 50,000 laying hens in China has been constructed and operated since 1992. A full-scale TAnD for 1,500 finishing pigs is now under construction in North Carolina. The theory and practice of TAnD will be briefly discussed in this report.

Microbiology

In the absence of air, many kinds of facultative and anaerobic bacteria working together are able to convert organic matters or animal waste into a mixture of methane and carbon dioxide, called biogas. The total population of bacteria in the digester are generally classified into three groups (Bryant, 1979). One is the fermentative bacteria that hydrolyze or breakdown large molecules, such as polysaccharides, proteins, and lipids, to small molecules, such as sugars, alcohols, and organic acids. The second group is acetogenic bacteria that inter-convert small molecules to utilize hydrogen produced from fermentation. The third or the terminal group is methanogenic bacteria that produce biogas from acetate cleavage and carbon dioxide reduction by hydrogen. Typically, biogas contains 65-70% methane, 35-30% carbon dioxide and trace amounts of ammonia and hydrogen sulfide. It is combustible gaseous fuel.

Thermodynamics and Kinetics of Methanogenesis

Biogas production from simple molecules such as acetate, formate, and carbon dioxide are thermodynamically favorable reactions (Bryant, 1979; Hashimoto *et al.,*1980). Methanogens can thus derive energy for their growth. On the other hand, the rate of the overall digestion from waste to biogas is a slow process, especially at ambient (10-20 ^{o}C) or even at medium (30-40 ^{o}C) temperatures. As a result, waste digestion by anaerobic digestion previously was not a very efficient process. For example, operating anaerobic digestion at ambient and mesophilic (medium) temperatures for animal waste require retention times (RT) as long as 60-80 days and 15-20 days respectively. They are too slow to process the large amount of waste generated daily on the animal farm. RT, defined as the digester volume divided by the daily feeding volume of waste stream, is an operational parameter as well as a kinetic index of a digester. The shorter the RT, the more efficient the digester is. For long RTs, a digester has to be large and thus expensive. To improve the digestion rate and shorten the RT are thus critical for the development of this technology.

Like chemical reactions, biochemical reactions follow the Arhenius law. The law states that reaction rate doubles when every increase of 10 ^{o}C of the reaction temperature. Would it be possible to increase the digestion rate and thus shorten the RT of a waste digester by elevating the operational temperature? A systematic laboratory investigation was carried out to answer the question (Hunag & Shih, 1981). It proved that the law of chemical kinetics also dictates the rate of waste digestion. When a themophilic anaerobic digestion (TAnD) was established at 50 ^{o}C, the RT could be as short as 4 days and the concentration of total solids (TS), as high as 7-8%. This was first done with poultry manure and then confirmed with pig manure (Chen *et al*., 1990). A similar result was obtained with dairy waste (Varel *et. al*., 1977). In practice, a TAnD can be much smaller than the ambient and mesophilic digesters in processing the same amount of waste.

Energy Production from TAnD

A major concern about TAnD was the energy balance. How high is the energy input to maintain a high-temperature operation of the system? To answer this question, a TAnD (50 ^{o}C) and a mesophilic anaerobic digester or MAnD (35 ^{o}C) were set up in the laboratory for comparison (Shih, 1987b). Each was started up and operated to its optimal conditions and maximal biogas rate. The tightly controlled experiment and calculation have shown that the net energy gains were 85% and 74% for MAnD and TAnD respectively. The difference was only 11%. Furthermore, the design and operation of TAnD can be simple as demonstrated by a pilot digester on farm (Steinsberger and Shih, 1984). The on-farm TAnD had energy net gain 50% approximately because of heat loss.

Based on the laboratory studies, the potential of energy production from an animal farm can be estimated. A small egg producer with 100,000 hens, for example, produces 12 tons of manure each day. The manure can be processed daily by a 200 m^3 TAnD to generate 900 m^3 biogas. Combusted biogas can give 5.4 million Kcal or approximately 20 million Btu. Assuming a net gain of 50%, the egg farm can also produce 10 million Btu thermal energy. When converting to electricity with an engine-generator at 30% conversion efficiency, 900 kWh electricity can be produced everyday on the farm with 100,000 layers.

Simple and Low-Cost Digester

A simple and low-cost TAnD was designed and constructed on the NCSU poultry farm for the process of 4,000 laying hens (Steinsberg & Shih, 1984). It was a simplified plug-flow bioreactor constructed by a sausage-shaped plastic tube with insulation. Daily manure was scrapped, augered and conveyed by gravity flow into the TAnD. Hot water was heated by a heater fueled by the biogas. With a desirable volume at desirable temperature, hot water was added into the digester to give a final concentration at 6% TS and temperature at 50 ^{o}C. Biogas production was monitored and used for the hot-water heater. Influent and effluent of the TAnD was chemically analyzed. This digester was operated for three years without major problems, except the grits in the manure settled down in the digester. They reduced the internal volume of the digester and required periodic clean up by pumping. RT was maintained at 4-5 days. The average biogas yield (m^3/kg VS) and volumetric rate (m^3/m^3/day) reached 100% and 70% (due to the reduction of internal volume) of the laboratory markss respectively. It was a successful scale-up operation.

This pilot study proved that a simple and low-cost TAnD without mixer and heater is technically feasible. The construction was simple and the operation is highly efficient to reproduce the laboratory result. With the similar design, a TAnD for 2,000 finishing pigs was built in Taiwan (Chen *et al.*, 1990 and a TAnD for 50,000 laying hens was built in Beijing by international collaborative projects with the author. Unfortunately the pig farm in Taiwan was closed down many years ago. The TAnD in Beijing has been in operation for 10 years. The farm recoup their capital investment $100,000 in 2.5 years by selling bio-fertilizer and biogas as co-products (unpublished data). The TAnD system was patented by NC State University in 1996 (Shih, 1996).

Co-Products of TAnD

During the operation of the pilot TAnD on the research farm, a series of investigations were carried out to demonstrate the potential uses of all products of the system.

A drying bed heated by the biogas was installed. The solid sediment in the digester was pumped out onto the drying bed (Jiang et al. 1987). The dried solid or solid by-product (SBP) was odorless, rich in protein (10%), B-vitamins and balanced N:P:K (3-4% each). It was not only a good bio-fertilizer, but also tested for the use of feed supplement (Steinsberger *et al*., 1987). It was demonstrated that the SBP could be an available source of phosphorus in feed for growing chicks. No toxicity or ill effect was detected in the chicks. The bio-availability of phosphorus in SBP is exemplary. Nutritional values of protein and B-vitamins in the SBP are yet to be determined.

The effluent of TAnD is a liquid source of soluble nutrients. To test it as a nutrient source, tilapia fingerings were put in a fish pond that received TAnD effluent (Shih, 1987a). With a proper rate of addition, the effluent supported the growth of algae and plankton that subsequently feed fish. In five months, tilapia grew 3-4 times bigger than the control in the pond which did not receive TAnD effluent. The conditions for growing fish or aquaculture associated with animal production and TAnD require more studies. On the other hand, the preliminary result promised the potential of co-development of animal production and fish culture, with TAnD as the link between the two..

Pathogen Control

The fate of pathogenic microorganisms was studied in the laboratory. All pathogens tested, including fecal coliforms, fungi, viruses and protozoa, were completely destroyed by TAnD (Shih, 1988). High temperature, anaerobic condition and potential microbial antagonism are possible mechanisms of pathogen control. Study of the effect of TAnD on the oocysts of *Eimeria tenella* was carried out in the laboratory. The oocysts inoculated in TAnD were found structurally intact because of their heavy wall. In 24 hours, however, the recollected oocysts lost both their infectivity *in vivo* and sporulability *in vitro* (Lee and Shih, 1988). Some chemicals produced by the bacteria in TAnD must have the lethal effect, since high temperature alone did not have the same efficacy.

It is believed that TAnD can serve as a safe guard on farm. It destroys pathogens to stop the transmission of infectious diseases. As a result, it protects the health of farm workers and animals, the sanitation of farm products and, eventually, the food safety for the public. In this respect, the benefit of TAnD is very significant, if not more important than the production of energy and other co-products.

Holistic Farming

The concept of Holistic Farming was first proposed in 1985 (Shih, 1985,1987a,b). It is a new agricultural ecosystem that integrates energy, ecology, environmental health and agriculture production on the farm site. In the heart of the system is TAnD. TAnD processes animal waste to kill pathogens and generate three types of products. They are the biogas, the liquid effluent and the solid by-product. Biogas is the energy remained in feed post animal digestion. Liquid effluent supports aquaculture that subsequently produces fish meal for feed. Solid by-product, dried by the biogas heat can be used for fertilizer to cropland or feed supplement. In the system all carbon and nitrogen are recycled and re-utilized.

To date, Holistic Farming is still at the theoretical stage. In practice, a new paradigm must be introduced to make the agricultural ecosystem possible and real. It is called “horizontal integration”, the integration of different kinds of agricultural industries. Only when animal production, fertilizer industry, aquaculture, horticulture and crop production work together, the integration and cycle of re-utilization can be completed. With the linkage provided by TAnD, all those industries are believed to be able to develop cooperatively, not only on the farm site but also in business. On the other hand, horizontal integration may offer a new answer to the sustainability of modern agriculture.

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Sequential Batch Anaerobic Composting (SEBAC), a New Technology for the Management of Animal and Agricultural Waste.

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Abstract

A novel process for conversion of animal and agricultural wastes and other high-solids biodegradable feedstocks into valuable resources, in compliance with existing laws and regulations, has been developed and is now in the process of commercialization. Resources include a readily usable biogas and other useful by-products such as soil conditioner, in amounts that vary depending on the type of feedstock run through the process. This process has been patented by the University of Florida and has the identification of SEBAC (sequential batch anaerobic composting). The system involves sequential staging in high-solids leachbed reactors. SEBAC was developed to overcome inoculation, mixing and instability problems common to anaerobic reactor designs. Recycling leachate between new and active reactors resulting in addition of water, inoculum, nutrients, and buffer starts up a new run. Fermentation products such as acids produced during startup are conveyed to an active mature reactor for conversion. Consequently, the instability of the process is eliminated as well as the need for mixing. The entire process takes 15-40 days depending on the feedstock and operating temperature. Trial runs of a variety of waste feedstocks have been conducted at a pilot-scale SEBAC facility, including the organic fraction of MSW, yard wastes, brewery wood chips, blends of organic MSW and waste-activated sludge, animal manure, shredded paper and different biomass energy crops. In all cases the wastes were stabilized and generated methane and compost. Methane yields ranged from 0.07 to 0.35 m^3kg^{-1} (volatile solids) of organic feedstock with conversion efficiencies up to 94%. A recent application of this technology involved the processing of stall waste materials from a horse farm in Marion County, Florida. Results confirmed the capability of the SEBAC process to transform the problem of animal waste into a biogas rich in methane and other useful by-products that included, after screening: a coarse material to be used as a mulch like cover material, a fine soil conditioner that has proven to be equivalent to peat moss in germination and plant growth experiments when mixed with sand, and a liquid fertilizer that has shown good results in plant growth.

The SEBAC process is a stable, reliable, and net-energy producer. It is a natural process that can serve as a key element in the operation of sustainable integrated biodegradable waste management systems in animal and agricultural farms. Sigarca's modular products are cost-effective, because maintenance is economical, they are easy to operate with simple procedures, and their flexible modular design allows easy custom-tailored system configuration to accommodate to site-specific constraints of location and installation. This unique proprietary technology is able to transform the problem of animal and agricultural waste into useful resources without production of noxious odors and pollution. The SEBAC technology is in the process of commercialization after having been patented by the University of Florida and now licensed by SIGARCA, Inc. of Gainesville, FL. Three demonstration plants have been designed and are under construction for operation with animal waste, biomass and municipal solid waste at the 50-ton per day or greater scale. However, potential applications exist at a smaller scale (10 tons per day or less), such as animal raising facilities, apartment complexes, schools, resorts and camps. Each plant uses a unique modular system easy to expand, install, operate and maintain. Principle drivers for commercialization are the numerous advantages over anaerobic lagoons, current landfill, composting and incineration operations, which are now experiencing increased operating costs, negative environmental impacts and extended liabilities. In addition, the value of recovered products from the SEBAC system, including recyclables, methane, and compost are a decided plus.

KEYWORDS: anaerobic digestion, biogas, liquid fertilizer, compost, methane, solid waste, biomass, animal and agricultural waste

Introduction

With the increase of more stringent environmental regulations, interest in anaerobic technologies are growing due to their success in European countries with proven environmental advantages as well as the production of valuable resources such as methane gas and soil conditioner. A novel system, the sequential batch anaerobic composting (SEBAC) process has been successfully tested, proven and patented by the University of Florida on a pilot scale using a wide variety of feedstocks. On a pilot scale, the economics and performance of the process indicate that it is superior to existing aerobic and anaerobic competing technologies worldwide. As the interest in recycling of biodegradable waste continues its steady growth nationwide and compost and anaerobic soil conditioners get more acceptances from the public, the SEBAC technology will get its place in the market.

The SEBAC process, described in detail further along employs recycle of leachate between new and active cells (batch bioreactors) for inoculation and addition of moisture and nutrients for cell startup. The leachate also removes volatile organic acids formed during startup that would inhibit the stabilization process if allowed to accumulate in excess. It also eliminates the need for expensive aeration, mechanical mixing and substantial inoculation with effluent solids required in competing technologies.

The SEBAC process has shown to be an excellent and effective solution to many waste management problems in the animal and agricultural sector. This practical and relatively rapid process is able to transform those problems of biodegradable waste into renewable and valuable resources as byproducts with no odors or pollution.

Anaerobic composting of horse waste from stalls bedding is a feasible solution to the problem of in farm disposal practices, which are recognized as a big waste management problem in large farms and in the horse racing industry. A recent application of this technology, using the SEBAC technology, involved the processing of stall waste materials from a Paso Fino horse farm in Marion County, Florida. Results confirmed the capability of the SEBAC process to transform the problem of animal waste into a biogas rich in methane and other useful by-products that included, after screening: a coarse material to be used as a mulch like cover material, a fine soil conditioner mix formula that has proven to be equivalent to peat moss in germination and plant growth experiments, and a liquid fertilizer that has shown good results in plant growth.

Initial consideration to do this research using this kind of waste came from the fact that in Florida the problem of horse stall waste is significant. Florida has a population of 350,000 horses; and each horse produces approximately 80 lbs of waste bedding per day. Consequently, the quantity of wasted horse bedding produced daily is in the order of 28 million lbs or approximately 14,000 tons per day. This represents a significant problem for farms having horses that produce a volume of waste that cannot be managed in a sustainable way.

Horse bedding is an important component of horse maintenance and represents 80 % of the horse stall waste (the other 20 % includes the feces and urine). It is important for the sanitation and the maintenance of clean and healthy horses. Good bedding is critical for high valued animals that are maintained a large portion of time in barns. In Marion County alone, the center of Florida' s racehorse industry, there is a population of more than 40,000 horses and two thirds of these are on bedding. Industry sources estimate that one million bags of high quality bedding are used for horses annually in Florida. There are no estimates available for the amount of bailed or loose horse bedding also used in horse maintenance in addition to the bagged horse bedding.

Previous research done to a Utility company in Florida that involved the treatment of waste activated sludge from a wastewater treatment plant and yard waste from the tree trimming operations using the SEBAC technology proved to be successful and provided the initial experience for the processing of animal manure such as wasted horse bedding from stalls. Due to the net energy production capabilities of the SEABC process at a large or small scale; this technology could provide their heat and power requirements. These systems could play a significant future role in meeting local decentralized heat and power demands.

Tests runs were performed at the University of Florida SEBAC pilot plant, which was prepared to handle this type of feedstock. Waste horse bedding is composed of manure, urine 20 % and bedding material 80 %. This type of waste is ideal because the bedding material provides already the bulking agent required for the leached bed SEBAC anaerobic digestion process.

A typical operation cycle for the processing of materials from a horse farm is described as follows: wasted horse bedding is placed in a new cell. Leachate from a nearly completed (approximately 30 days) cell is recycled between that cell and the new cell providing inoculum, water and nutrients necessary for startup. Volatile organic acids formed during startup are conveyed via leachate to the active cell for conversion to methane and carbon dioxide. After startup, the new cell is actively methanogenic and is maintained by recycling of leachate upon itself. A controlled operating system would consist of several cells at various stages of operation. It takes only approximately 20 days to process a single or mixed batch of this biodegradable leachable feedstock. It does not require mixing, aeration or additives. It does not produce odors and is a carbon neutral process with respect to the global warming effect and prevents uncontrolled release of methane and carbon dioxide into the atmosphere that is typical of landfills. It does not pollute the environment but rather transforms the solid waste problem into valuable resources such as energy rich methane and a superior soil conditioner.

The objective of this paper is to provide a description of the SEBAC technology, present the concluding results of the processing of horse stall waste and to show the Sigarca, Inc.’s products available in the market.

The SEBAC Process

SEBAC is a high solids anaerobic digestion technology developed at the **University of Florida.** It is able to transform the problem of biodegradable waste into resources without polluting the environment in approximately 30 days. **SEBAC** was developed to overcome inoculation, mixing and instability problems common of anaerobic reactor designs. A liquid recycle method is used to provide water, nutrients and bacteria to the fresh feedstock. Fermentation products such as volatile acids formed during start-up are removed via the liquid handling system to a mature bioreactor where they are converted to methane. In doing so, the instability is eliminated, as is the need for mixing feed and effluent.

SEBAC is a net producer of energy and other valuable materials. It stabilizes a wide variety of biodegradable feedstocks including MSW, yard waste, brewery chips, paper, animal waste, agricultural waste, food waste, wood chips and sludge into a readily usable biogas and soil conditioner.

Attributes:

- Reliable and stable process,
- Easy to operate with simple procedures,
- Operation and maintenance is economical,
- Offers the capability of heavy metals removal if required,
- It is modular and allows for a flexible design,
- Can be used to mine landfills and/or reduce landfill use.

The current SEBAC technology applications include: Schools, Farms, Restaurants, Institutions, Apartment Complexes, Campsites, Communities, Hospitals, Residential, Industrial, Agricultural, Hotels, Resorts, Wastewater Treatment Plants, etc.

SEBAC represents the bridge to the future for sustainable integrated biodegradable solid waste management and could be used as the anchor tenant for sustainable economic development in the community. It complies with the most stringent environmental laws and regulations, and it is ahead of world trends concerning power decentralization and sustainable economic development and conservation.

The first SEBAC demonstration plant is located at the University of Florida where research and tests have been performed for different entities including Sumter County, Levi County, Anheuser Bush and GRU. A commercial demonstration plant will be located at the Leveda Brown Environmental Park in Gainesville Florida before the end of year 2003. The first overseas plant is in the procurement process for an initial capacity of 100 tons/day in Venezuela.

Special and Distinguish Features

Environmental

No environmental pollution
Transforms waste into resources
Eliminates noxious odors
Helps sustain the environment

Technical

Is modular
Flexible design: container, trench or cell
Stable, natural, anaerobic process
Relatively rapid manufacturing and installation
Technology developed, tested, proven and patented by University of Florida
Takes approximately 3 weeks to complete
Can be used to mine landfills

Social

Improves hygiene and aesthetics
Provides income for farms, municipalities, etc.
Provides a source of employment
Allows sustainable economic development
Improves public relations with the community
Handles a wide variety of biodegradable waste
Products are free of pathogens

Business

Relatively low capital investment
Allows for a controlled expansion with little risk
Is a net producer of energy and other valuable products
Can be use as anchor tenant
Row materials and products represent sources of income
Products access large market segments
Low operating and maintenance costs
Allows decentralization of power generation
Is the most economical method for the treatment of biodegradable waste

Legal

Minimize liabilities and leaves free land space

Complies with most stringent laws and regulations
Gives liberty, independence and return control to municipalities and farms

Results

SEBAC Performance during Processing of Horse Stall Waste

Following the SEBAC concept, several pilot studies at the University of Florida SEBAC pilot plant were conducted with horse waste from stalls from an Ocala Paso Fino horse farm using reactors each with a total volume of 800 L, including a bed volume of 400 L, head space of 200 L, and lower leachate reservoir of 200 L. The temperature was maintained at 55^{o}C. Initial runs were conducted with the objective of looking the feasibility of the project, and then next runs were performed with data collection in order to evaluate the performance of the SEBAC process.

It was our experience that first-time startup of the first reactor required a heavy inoculum (active digester effluent equivalent ~25% of the feed volatile solids), pH control, and longer residence time for completion. Start-up of subsequent runs improved until the fourth run, after which kinetics were reproducible with the same feedstock. In terms of startup, we also observed that new runs could be rapidly started up following months after a completed run remained dormant.

Table 1 shows the performance of the SEBAC pilot system on horse waste from stalls. The methane yield is limited by the biodegradability of the feedstock, which is independent of digester design. This parameter for several solid waste and biomass feedstocks has been determined using the biochemical methane potential (BMP) assay and is reported elsewhere (Owens and Chynoweth 1993; Chynoweth et al. 1993). Performance with this and other feedstocks has been predictable and consistently stable. Digester failure is always avoidable because of the option of leachate-mediated removal of volatile acids from their site of formation.

Feedstock Characteristics

Characteristics of feedstock used are shown on Figure 1. Runs were performed every three weeks using fresh horse stall waste from the day.

Figure 1. Characteristics of stall waste from Paso Largo horse farm.

Waste generation: 18 cu yds per week or 3.0 cu yds per day.
Waste composition: 80% bedding and 20 % feces and urine

Figure 2. *SEBAC performance during processing of waste from Paso Largo horse farm*.

Volume reduction: 25 %
Retention time: 21 days
Methane yield: 0.12 L/g VS added or 120 m³ per ton
Volatile Solids reduction: 31 %

Table 1. Performance data for SEBAC on horse waste from stalls at 55^{o}C.

Parameter	**Horse Waste from Stalls**
Methane Yield, L/g VS added	0.12
Volatile Solids Reduction, %	31
Volume Reduction, %	25
Solids Retention Time, days	21

By Products

The SEBAC process was successfully applied for stabilization of and recovery of energy and compost from horse waste from stalls. By products include a readily usable biogas and a soil conditioner that once blended with sand becomes an excellent material equivalent to Peat Moss for germination and plant growth. Peat Moss is a valuable non-renewable resource.

Biogas

Biogas produced from the SEBAC process is quite similar to “natural” gas in terms of usage. The average composition for the SEBAC biogas includes 60% methane, 40% carbon dioxide and traces of hydrogen sulfide, hydrogen, nitrogen and carbon monoxide. It has a lower calorific value than natural gas, approximately 21.4 MJ/m^3 for biogas and 39 MJ/m^3 of natural gas. During anaerobic composting of horse waste from stalls, approximately 120 standard m^3 (SCM) of methane are obtained for each ton of waste processed and 1.6 SCM of biogas is equivalent to 1.0 L of gasoline in energy content. In other words, approximately 80 L of gasoline are obtained during the anaerobic digestion of 1 ton of horse waste from stalls. Methane is the simplest of the hydrocarbons, burns to water and carbon dioxide, and is an excellent fuel for many uses. SEBAC Biogas can be used readily in all applications designed for natural gas. such as:

Combining hot water recovery with electricity generation, biogas can provide an overall conversion efficiency of 65-85%. A promising application for electrical generation is the use of gas turbines and fuel cells. Modern gas turbine plants and fuel cells are small, extremely efficient, environmentally friendly and visually unobtrusive. Overall gas turbine efficiency can be greater than 70 %.
SEBAC biogas, may be treated to remove carbon dioxide and hydrogen sulfide, compressed, and used as an alternative transportation fuel in light and heavy-duty vehicles. Natural gas vehicles are currently in commercial production and use. In many countries, biogas is viewed as an environmentally attractive alternative to diesel and gasoline for operating buses and other local transit vehicles. The emissions and sound level generated by methane-powdered engines are generally lower than those generated by diesel engines.

Digestate

During the processing of the horse waste from stalls, the SEBAC process also produces solid and liquid by-products, which can have a value as a fertilizer or soil amendment. The main product of this anaerobic composting of horse waste from stalls is a solid digestate. Small quantities of surplus liquor are also available.

After anaerobic digestion, the material usually needs more processing to improve its value and its use as a soil amendment for agricultural crops. The solid fraction of residuals after three weeks was unloaded from the bioreactor and then for approximately two days was left to dry for further screening. Two sub-products were obtained from screening: a coarse material that may be used as a mulch like cover material and a fine soil conditioner that has proven to be equivalent to Canadian Spagnun Peat Moss in germination and plant growth experiments when mixed with sand, and the surplus liquor.

The liquid fraction used in the germination and plant growth experiments indicated that it does not affect germination but improves dramatically plant growth. This by-product may also be applied to farmland as liquid humus.

Application of digestate or liquor from other feedstocks to farmland is dependent on its quality and local regulations. Consequently, the ability to utilize the residues of anaerobic digestion as soil amendments improves the economics and environmental benefits of the SEBAC process. Use of this residue depends on its agronomic characteristics and pollution potential, which can be assessed on the basis of physical characteristics, chemical characteristics and biological characteristics (Chynoweth et al. 2003). Anaerobic composting in addition to stabilize the biodegradable fraction of wastes in order to eliminate odors, pathogens and vermin attraction, reduces its volume and weight as a result in the reduction of volatile biodegradable solids.

Certain types of biodegradable urban wastes, agricultural waste and industrial by-products are beneficial to the production of biogas and valuable residuals. However, wastes from animal and human origin contain varying amounts of human and animal pathogens that may threat their health. Viruses, bacteria and parasites may survive for long periods of time at lower temperatures in manures and slurries. Many of those pathogens may also survive for longer periods in digester tanks, which operate at the mesophilic temperature range. It is quite typical that most pathogens are eliminated within some hours at the thermophilic temperature range between 50 ^{o}C and 55 ^{o}C. Treatment at 70^{o}C has been show to kill most pathogens.

SEBAC results indicated that no pathogens and no vermin attraction have been present in the by-products at the end of the process. Those results included SEBAC processed waste activated sludge from wastewater treatment plants

Improving Quality of Digestate for Marketing

The objective of this section was to find a substitute for Canadian Spagnun Peat Moss (an expensive non-renewable resource) using a blend of digestate, sand and other natural soil components. The SEBAC process has several groups of attributes as indicated above but the most attractive incentive to potential buyers is the profitability of the operation. Consequently, a procedure to determine a formula mix was developed that allows producing a soil conditioner blend that compete with Peat Moss.

Figure 3 shows comparison of different plant growth conditions in different compost mixes as compared to Peat Moss.

Figure 3. Plant growth experiment to determine good and marketable compost mixes.

Figure 3 shows the results of the concluding plant growth experiment. There are two rows of five plants each, top and bottom, and one plant alone on the right. Top row soil composition includes 50% compost and 50% Florida sand; and bottom row includes 45% compost, 5% humate (a natural mix of humic acid, fulvic acid and humine) and 50% Florida sand. The plant on the right is the control grown in 100% Canadian Spagnun Peat Moss. The top and bottom rows represent plants grown in the following same conditions, from left to right: 1) irrigation with only well water, 2) previous irrigation of compost mix with water and with 50% liquid humus after germination, 3) previous irrigation of compost mix with water and with 100% liquid humus after germination, 4) previous irrigation of compost mix with 50% liquid humus and with 50% liquid humus after germination, and 5) previous irrigation of compost mix with 100% liquid humus and with 100% liquid humus after germination.

Concluding results indicated that the optimum compost mix comparable to Canadian Spagnun Peat Moss for germination was 50% compost and 50% Florida sand. For plant growth the optimal compost mix was: 45% compost, 5% humate (a natural mix of humic acid, fulvic acid and humine) and 50% Florida sand and previous irrigation of compost mix with 50% liquid humus and with 50% liquid humus after germination.

Finally to test the compost mix developed, a cucumber plant was grown in the field in the compost mix adjusting the pH to approximately 6.5 with phosphoric acid. The plant produced large cucumbers steadily for more than a month. See Figure 4.

Figure 4. Cucumber tree grown under the developed compost mix formula.

Sigarca, Inc. Commercial Products

Commercially available reactor designs include different size modular systems (Figure 5. 1-2). The modules (reactors/containers) can be easily arranged and/or expanded in series, parallel or in a vertical assembly to accommodate the needs of the user, such as processing capacity, space, and transport of waste. Each module is a roll-off bioreactor container (EcoContainers).

Figure 5. SEBAC Reactors. 1) bioreactors size X; and 2) bioreactors size S


The chosen size and number of modules are connected with the appropriate leachate distribution, biogas collection and heating subsystems. Each EcoContainer is equipped with the necessary components for optimal performance of the SEBAC process and for easy loading and unloading of feedstock and compost. The Sigarca, Inc. modular system also requires external ancillary equipment, which includes a shredder, mixer, flare and roll-off trailer.

The following table includes characteristics of a 12-module system for different capacities and size containers (modules)

EcoContainer Type	Capacity, m^3	Length, m	12-modules, Capacity, tpd
S	7.6	3.7	3
M	15.3	4.9	6
L	22.9	6.1	8
X	26.8	7.6	10

For example, a system of Type X with 12 containers is able to process 10 tons/d of biodegradable waste in an area of approximately 464 m^2. This system will produce an average of 7432 m^3/d of biogas (60% methane, 40% carbon dioxide), corresponding to 40 gallons of gasoline or 7200 MJ, and 5 tons/d of compost. Biogas is a carbon dioxide neutral fuel because the carbon dioxide produced during the process becomes reabsorbed by plants during photosynthesis. Biogas, when used as a fuel, reduces emissions and ozone creation potential by 90%.

Sigarca, Inc.'s modular system offers economical, effective and sustainable advantages to cities, communities, resorts, hotels, farms and industries to dispose of their biodegradable waste. The operation and maintenance costs of a modular system are relatively low. The system can be installed, maintained and/or relocated relatively quickly and easily. The processing capacity can also be easily increased by the installation of additional modular units. These systems can potentially improve the sanitation and aesthetics of community landfill areas, and provide a source of income and employment.

Conclusions

SEBAC (sequential batch anaerobic composting) was developed, proven, tested and patented at the University of Florida. This process overcomes problems associated with inoculation, mixing and instability that frequently occur with other anaerobic reactor designs. A liquid recycle method is used to provide moisture, nutrients and bacteria to the fresh feedstock. Fermentation products such as volatile fatty acids formed during start-up are removed via the liquid handling system to a mature bioreactor where they are converted to methane. This method eliminates instability, and the need for mixing feed and effluent.

The SEBAC process was successfully applied for stabilization of and recovery of energy and compost from horse waste from stalls. This process achieved maximum bioconversion in less than three weeks and transformed horse waste from stalls into valuable by products. By products include a readily usable biogas and a soil conditioner that once blended with sand becomes an excellent material equivalent or better than to Peat Moss (non-renewable resource) for germination and plant growth.

The high quality compost and liquid fertilizer obtained will help improve yield and quality on crop production in agriculture, horticulture and gardening. SEBAC is a natural process that can serve as a key element in the operation of sustainable integrated biodegradable solid waste management systems especially for animal and agricultural farms. The SEBAC process does not produce bad odors or pollution.

Sigarca's modular products are cost-effective because their operation and maintenance is economical, they are easy to operate with simple procedures, and their flexible modular design allows custom-tailored system configuration to accommodate site-specific constraints of location and installation. The SEBAC system requires a relative low initial capital investment and can complement the aesthetics of the farm and community. It basically transforms the problem into valuable resources.

Acknowledgment

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Application of Phased Digestion for Cluster Dairies

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Keywords: Thermophilic and Mesophilic Digestion; co-digestion, Pretreatment, Hydrolysis

Inland Empire Utilities Agency (IEUA) provides wastewater treatment for seven member agencies in Southern California with a population of about 700,000. The service area also includes a large concentration of dairies with a total of over 300,000 cows. The salt, nitrate, and organic material from dairy manure has severely impacted the underlying Chino Groundwater Basin, one of the largest groundwater basins used for domestic water supply in Southern California. The air emissions from the dairies are also a significant source of odor, dust, ammonia, and volatile organic compounds (VOCs).

To address the concerns with animal waste, IEUA developed an integrated plan for maximizing energy recover from manure through digestion and co-generation. The goal of the pilot test program was to examine the ability of digestion technologies to maximize energy recovery and to examine options for providing a cost-effective technical approach for management of residual and recycles remaining after manure digestion.

One of the digestion systems is set-up at the IEUA's t Regional Plant N0.1 (RP-1). This system was set-up as phased digestion and consists of acid phase followed by gas phase anaerobic digestion with capability to use both centrifuge and belt press for dewatering. For this system, IEUA converted an existing concrete tank (150,000 gallons capacity) to acid phase digester and dedicated one of the existing complete-mix anaerobic digesters (700,000 gallons capacity) for manure digestion. The system can operate in both, thermophilic and mesophilic temperature ranges. The manure digestion system was put in service last year.

This paper discusses development and implementation of a test plan, based on the operational experience and system performance from the first nine month of facilities operation, to optimize energy recovery and reduce operation and maintenance (O&M) cost of manure digestion and dewatering facilities. The test plan components, operational experience, and the current system performance discussed in this paper are applicable to other large-scale manure digestion facilities suitable for dairy clusters.

During the past nine months, this digester system was operated in thermophilic and mesophilic temperature ranges. Typical loading during this period was over 10 dry tons of manure per day (4 to 5 truck loads) achieving volatile solids destruction of over 40-percent and average biogas production of about 110,000 cubic feet per day. Both, the centrifuge and belt press was tested for dewatering. Based on this operating experience a test plan was developed to address treatment of manure for removing foreign objects, optimizing biogas production and cellulose destruction through digestion and manure pretreatment (i.e., phased digestion, thermophilic digestion, thermal hydrolysis, co-digestion with food waste), biogas H2S treatment, improving the reliability/efficiency of dewatering equipment, and treatment of the recycles from dewatering. The main goal of this test plan was to make renewable energy production more affordable through maximizing the digester gas production, optimizing energy recovery and reducing the O&M costs associated with manure digestion.

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SEQUENTIAL BATCH ANAEROBIC COMPOSTING (SEBAC®) FOR ORGANIC SOLID WASTE MANAGEMENT

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ABSTRACT

This paper reports on development and commercialization of a patented process for odorless bioconversion of organic solid wastes to methane and compost by anaerobic digestion. The process has been patented with the trademark SEBAC® (Sequential Batch Anaerobic Composting). The process proceeds through three different stages over time within a given reactor, and at any time one reactor is functioning at each stage. Organic solid waste is packed into a reactor and started up by recycling liquid leachate from the mature Stage 3 reactor, which has undergone decomposition, thereby inoculating Stage 1 with needed moisture, nutrients, and active microorganisms. Once started (requiring 5-7 days), Stage 1 becomes Stage 2, the period when most decomposition and methane production occurs. The process moves into Stage 3 after most of the decomposition is complete. The entire process takes 15-40 days depending on the feedstock and operating temperature. Woody components of inedible biomass, for example, require longer time than food, feces or other organic wastes. A typical commercial system would consist of five reactors. One reactor is for feed collection and compaction, three for anaerobic composting, and one for post-treatment processing.

The SEBAC process, patented by the University of Florida, is now licensed by SIGARCA, Inc. of Gainesville, FL. Three demonstration plants have been designed and are under construction for operation with municipal solid waste management systems at the 50-ton per day or greater scale. However, potential applications exist at a smaller scale (10 tons per day or less), such as animal agriculture, remote military bases, rural/remote ranches, resorts and camps. Principle drivers for commercialization are the numerous advantages over current landfill operations, which are now experiencing increased operating costs, negative environmental impacts and extended liabilities. In addition, the value of recovered products from the SEBAC system, including recyclables, methane, and compost are a decided plus.

KEY WORDS

Anaerobic Digestion, Compost, Biogas, Methane, Solid Waste, Animal Waste

INTRODUCTION

Anaerobic digestion is an attractive option for stabilization of organic wastes and conversion of energy crops and organic wastes to methane and compost. In fact, that is the method used in nature under the anaerobic conditions that prevail in sites of concentrated organic matter. In general, anaerobic digester designs convert a large fraction (>50%) of organic matter to methane and carbon dioxide without the need for oxygen or hydrolysis as a pretreatment step or extensive external energy requirements to remove water (e.g. with thermal processes) or pretreatment and product recovery (e.g., with bioethanol). Biogas is a desirable energy product, which can be used directly or upgraded by removal of carbon dioxide and hydrogen sulfide. The resulting residues are stable and serve as excellent compost.

Of the many anaerobic digester designs that have been developed, the primary criterion for selection is feed suspended solids content. For example, the design of choice for feedstocks with low solids (<20%) is an attached film reactor that permits high loading rates without washout of organisms. Feeds such as the organic fraction of municipal solid wastes (OFMSW), agricultural crop residues, and energy crops (herbaceous and woody) are collected or harvested in a form of high solids content (>30%). This has led to reactor designs that can accommodate high-solids environments and not require dilute slurries typical of conventional designs; these may include batch, stirred, and leachbed designs.

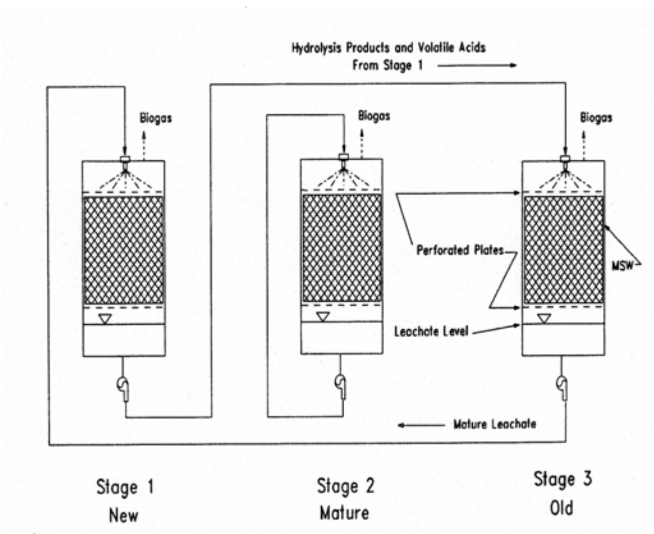
The objectives of this paper are to provide a general description of the SEBAC process, identify commercial applications and their rationale, and discuss the current status of commercialization.

PROCESS DESCRIPTION

Research at the University of Florida (References 1-5) led to the development of a leachbed anaerobic composting process for anaerobic digestion of high-solids organic feedstocks. As illustrated in Figure 1, coarsely shredded feedstock is placed into a bioreactor that is ready for a new cycle. Leachate from a nearly completed old bioreactor is recycled between that reactor and the newly loaded bioreactor providing moisture, inoculum, nutrients, and buffer necessary for start-up. Volatile organic acids formed during start-up are removed via leachate recycle to the active mature bioreactor for conversion to methane and carbon dioxide. After start-up, the newly loaded bioreactor becomes a methanogenic mature reactor and is maintained by recycling leachate upon itself. Near the end of the process, approximately three weeks later, leachate from the now mature reactor is used for the start-up of a new reactor that is once again ready to begin a new cycle. Biomass is not moved during the process; it progresses through these three stages during the course of a run in a single container vessel (reactor). After completion, Water from the composted biomass is transferred to a start-up reactor to supply water, conserve nutrients, and provide buffer to the new run. For some feedstocks additional make-up water may be required for the process.

Most of the work to date has employed leachate recycle for a period of 15-30 minutes once per day, using gravity for movement through the bed and a pump for recycle; the temperature was 50°C. This design requires leachable beds of feedstock, which may be characteristic of the feedstock (e.g. yard wastes) or achieved by blending leachable and non-leachable feeds (e.g. yard waste and biosolids). This process has been patented (Reference 4), designated Sequential Batch Anaerobic Composting (SEBAC), and licensed for commercialization by SIGARCA, Inc.

Figure 1. Schematic of Sequential Batch Anaerobic Composting Process (pre and post treatment rector stages not shown).



OPERATING PERFORMANCE EXPERIENCE

Following laboratory studies, several pilot studies with SEBAC were conducted with the organic fraction of municipal solid waste (OFMSW) using reactors each with a total volume of 800 L, including a bed volume of 400 L, head space of 200 L, and lower leachate reservoir of 200 L. The temperature was maintained at 55°C. Initial runs were conducted with the organic fraction of municipal solid waste, followed by experiments with yard waste, brewery chips, and yard waste/biosolids blend. First time startup of the initial reactor required a heavy inoculum (active digester effluent equivalent ~25% of the feed volatile solids), pH control, and longer residence time for completion. Start-up of subsequent runs improved until the fourth run, after which kinetics were reproducible with the same feedstock. New runs could be rapidly started up following months of dormancy.

Figure 2 shows performance data from a typical run of the fully started up system receiving OFMSW. The methane content of the biogas increased to ~60% in five days indicating that the system was fully started up. Volatile fatty acids increased to 3,000 mg/L for the first five days and then rapidly decreased to a baseline level of ~100 mg/L by Day 14; reduction may be attributed to removal by leachate recycle and metabolism by a developing methanogenic microbe population. The pH remained above 7 during the entire run. The methane yield leveled off at about 20 days indicating that conversion was more or less complete. Slowly metabolized compounds resulted in a long-term baseline low level of methane production. The second increase in methane yield (beginning at about Day 30) was a reflection of conversion of volatile acids generated from another new run.

Figure 2 - Performance data for a typical SEBAC run receiving 40 kg Volatile Solids from OFMSW, T = 55°C.

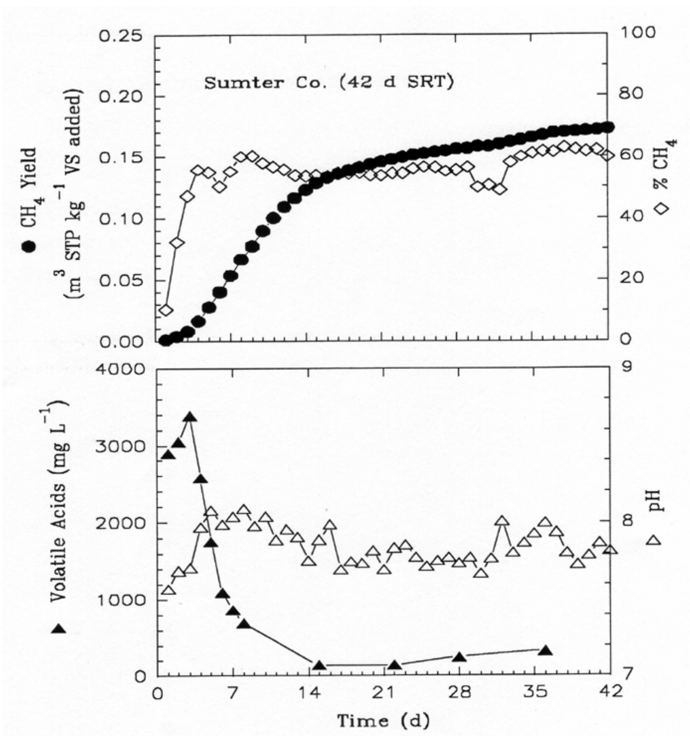


Table 1 compares performance of the SEBAC pilot system on several feedstocks. The methane yield is limited by the biodegradability of the feedstock, which is independent of digester design. This parameter for several solid waste and biomass feedstocks has been determined using the biochemical methane potential (BMP) assay and is reported elsewhere (References 6-7). Performance with these and other feedstocks has been predictable and consistently stable. Experience over the years with these pilot studies has shown that digester failure can often be avoided because by the option of leachate-mediated removal of volatile acids from their site of formation.

Table 1. SEBAC performance data for various feedstocks at 55^{o}C.

Parameter	MSW	Yard Waste	Brewery Chips	Shredded Office Paper
Methane Yield, L/g Volatile Solids added	0.30	0.07	0.06	0.35
Volatile Solids Reduction, %	57	20	26	96
Volume Reduction,%	65	15	15	94
Solids Retention Time, days	30	70	40	30

COMMERCIAL APPLICATIONS

The SEBAC process has been successfully applied to stabilization and recovery of energy and compost from the organic fraction of different wastes and energy crops, including municipal solid waste (MSW). As such, commercial potential stems from utililization of the two primary products derived from the process, biogas and compost.

BIOGAS

Biogas produced from the SEBAC process is quite similar to "natural" gas in terms of usage. The average composition for SEBAC biogas includes 60% methane, 40% carbon dioxide and traces of hydrogen sulfide, hydrogen, nitrogen and carbon monoxide. It has a lower calorific value than natural gas, approximately 21.4 MJ/m^3 for biogas and 39 MJ/m^3 for natural gas. During anaerobic composting of MSW, approximately 141 standard m^3 (SCM) of methane are obtained for each ton of trash processed and 5.7 SCM of biogas is equivalent to 3.7 L of gasoline in energy content. Methane is the simplest of the hydrocarbons, burns to water and carbon dioxide, and is an excellent fuel for many uses. SEBAC Biogas can be used readily in all applications designed for natural gas such as:

- direct combustion
    1. absorption heating and cooling
    2. cooking, space and water heating
    3. drying
    4. gas turbines
- fueling engines and fuel cells for production of
    5. mechanical work
    6. electricity
- gas pipelines
    7. illumination
    8. steam production
- methanol production

Combining hot water recovery with electricity generation, biogas can provide an overall conversion efficiency of 65-85%. A promising near term application for electrical generation is the use of gas turbines. Modern gas turbine plants are small, extremely efficient, environmentally friendly and visually unobtrusive. Overall gas turbine efficiency can be greater than 70 %.

SEBAC biogas, may be treated with a standard process to remove carbon dioxide and hydrogen sulfide, compressed, and used as an alternative transportation fuel in light and heavy-duty vehicles. Natural gas vehicles are currently in commercial production and use. In many countries, biogas is viewed as an environmentally attractive alternative to diesel and gasoline for operating buses and other local transit vehicles. The emissions and sound level generated by methane-powdered engines are generally lower than those generated by diesel engines.

RESIDUAL COMPOST

The SEBAC process yields solid and liquid by-products, which can have value as a fertilizer or soil amendment. The amount, quality and nature of these products depends upon the quality of the feedstock to the SEBAC process, the method of digestion (composting or co-composting), and the extent of the post-treatment refining process. The main product of anaerobic composting or dry digestion process is a solid digestate, which can be matured into a compost product. After anaerobic digestion, the material usually needs some kind of refining process before it can be used as a soil amendment for agricultural crops. The solid fraction of residuals can be matured aerobically for 2-4 weeks to provide a compost substitute, and the liquid fraction may be either applied to farmland as a liquid humus, or sent to a wastewater treatment plant. Application of digestate or liquor to farmland is dependent on its quality and local regulations.

The ability to utilize the residues of anaerobic digestion as soil amendments improves the economics and environmental benefits of the SEBAC process. Use of this residue depends on its agronomic characteristics and pollution potential, which can be assessed on the basis of the following physical, chemical and biological characteristics:

Physical Characteristics

Moisture - water holding capacity - 35%, controlled by drying time
Particle size - <50 mm, influence bulk density
Bulk density - > 550 kg/cubic meter
Color - dark brown in the range of 30-40% moisture, black above 40% moisture
Odor - none
Ion exchange properties - electrical conductivity < 2, cation exchange capacity (CEC) 100 meq/100g, low CEC = plastic-glass-metals

Chemical Characteristics

Ultimate analysis - C/N ratio - 15 to 20% - stable, NOx & SOx if used as a fuel
Heavy metals - 50% higher in digestate than feedstock but much less than aerobic
Fiber analysis - lignin % vs biodegrdability, if >25% - stabilized digestate
Nutrient content - K, P, N suitability for agricultural applications
Energy content - > % lignin and < % humidity - higher energy
Toxic compounds - organic
pH - between 6 and 7

Biological Characteristics

Presence of pathogens - thermophilic range will ensure elimination of pathogens
Biodegradable fraction - 80-83%volatile solids - converted to stable digestate
Phytotoxicity - i.e., acetic acid - inhibitory on plant growth and seed germination
Application rates - based on 60% germination
Organic matter content - 50%

The safe utilization of the liquid and solid residuals from the SEBAC process depends on their pollution potential which, depending on source material, can be related to:

Pathogen content
Vermin attraction
heavy metals content

Certain types of biodegradable urban wastes, agricultural waste and industrial by-products are beneficial to the production of biogas and valuable residuals. However, wastes from animal and human origin contain varying amounts of human and animal pathogens that may threaten their health. Viruses, bacteria and parasites may survive for long periods of time at lower temperatures in manures and slurries. Many of those pathogens may also survive for longer periods in digester tanks, which operate at the mesophilic temperature range. It is quite typical that most pathogens are eliminated within some hours at the thermophilic temperature range between 50 and 55 degrees Celsius. Treatment at 70^{o}C has been shown to kill most pathogens. This can be accomplished by passing heated air through the compost in the final aeration stage.

ADVANTAGES OF SEBAC

SEBAC has several advantages over other waste processing technologies. When compared with traditional landfill operations, it requires less space, has lower environmental impact in terms of air and groundwater pollution, and facilitates recovery of methane and compost. When compared with incineration, lower operating temperatures and pressures allow more energy recovery with lower levels of pollutants. SEBAC can also process wet or dry feeds. When compared with aerobic composting, methane production and lack of requirement for aeration and mixing result in net output of process energy. Aerobic composting also may go partially anaerobic resulting in release of undesirable odorous volatile products.

SEBAC also has advantages over other more traditional anaerobic digestion technologies. It is more stable and the design allows for easy removal of inhibitory products, which may lead to imbalance. The leachbed design facilitates rinsing of toxic substances, such as metals, from the final product and enrichment of biogas methane content to over 90%. The leachbed design also eliminates the need for solids movement and mixing.

STATUS OF COMMERCIALIZATION

The University of Florida Research Foundation has granted the rights to commercially develop and market SEBAC technology to a Florida based small business enterprise, SIGARCA, Inc., with the right to grant sublicenses to third parties. Commercially available SEBAC reactor designs include different size modular systems (Figures 6,7). The modules (reactors/containers) can be easily arranged and/or expanded in series, parallel or in a vertical assembly to accommodate the needs of the user based upon criteria such as processing capacity, space, and transport/handling of waste. Each module is a commercially available roll-off type container modified for operation as a bioreactor.

The chosen size and number of modules are connected with the appropriate leachate distribution, biogas collection and heating subsystems. Each container module is equipped with the necessary components for optimal performance of the SEBAC process and for easy loading and unloading of feedstock and compost. The SEBAC modular system also requires external ancillary equipment, which includes a shredder, mixer, flare and roll-off trailer. Specifications for a 12-module system of different capacities and size containers (modules) are given in Table 4.

Table 4. Specifications for a 12-module SEBAC system of different capacities and size containers (modules).

Container Type	Capacity, m^3	Length, m	12-modules, Capacity, tpd
S (small)	7.6	3.7	3
M (medium)	15.3	4.9	6
L (large)	22.9	6.1	8
X (x-large)	26.8	7.6	10

For example, a system of Type X with 12 containers is able to process 10 tons per day of biodegradable waste in an area of approximately 464 m^2. This system will produce an average of 7432 m^3/ per day of biogas (60% methane, 40% carbon dioxide), corresponding to 40 gallons of gasoline or 7200 MJ, and 5 tons/d of compost.

These modular systems offer economical, effective and sustainable advantages to municipalities, communities, resorts, hotels, farms and industries to dispose of their biodegradable waste. The operation and maintenance costs of a modular system are relatively low. These modular systems can be installed, maintained and/or relocated relatively quickly and easily. The processing capacity can also be easily increased by the installation of additional modular units. These systems can potentially improve the sanitation and aesthetics of community landfill areas, and provide a source of income and employment.

Figure 6 - Artist's rendition of commercial SEBAC modular system in operation

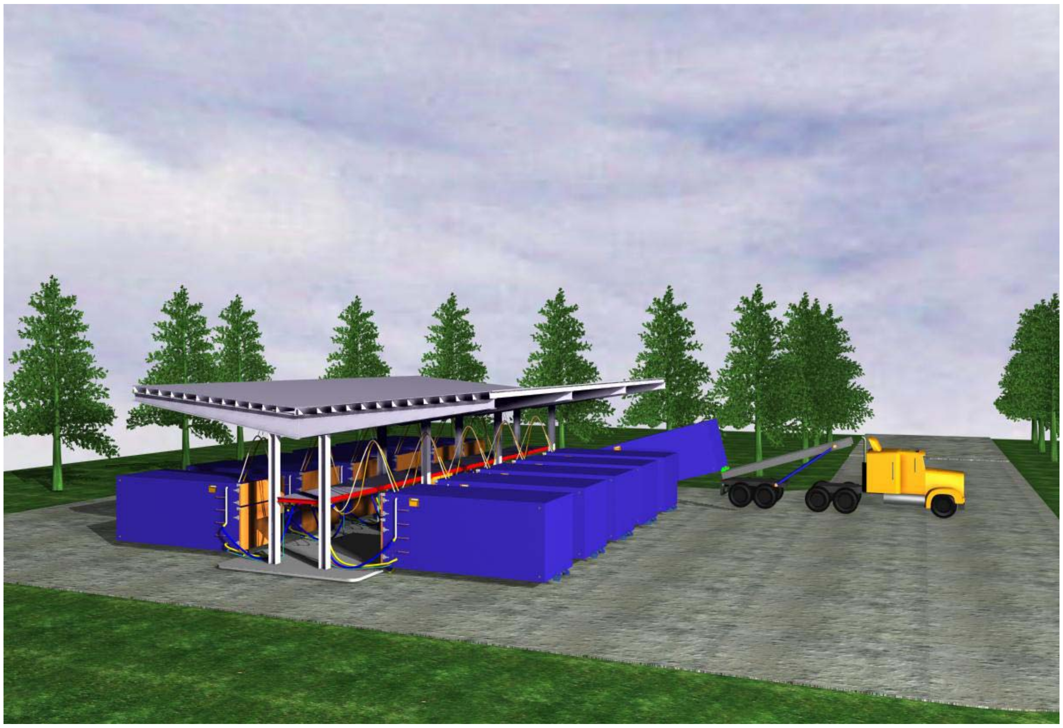


Figure 7- Photo of single large-size container or module ($27m^3$) awaiting modification for use as bioreactor in a commercial modular system.

CURRENT AND PLANNED COMMERCIAL INSTALLATIONS

Sigarca, Inc. has been continuously operating the SEBAC pilot plant located at the University of Florida to obtain operating performance data on industrial, agricultural and animal waste feedstocks. Previous research included the processing of municipal solid waste (MSW) from two west central Florida counties, as well as the waste from a large malt beverage brewery and a wastewater treatment plant for a regional public utility. The first commercial installation is currently in the start-up process. This will be a SEBAC commercial demonstration facility located at the Alachua County Environmental Park and Transfer Station in north central Florida. A 100-ton/day plant has been sold to a waste management authority in Venezuela to be installed during the latter part of 2003. Recent inquiries include a system to process leguminous biomass feedstock for a farm workers cooperative, a system to process yard waste in a small south Florida community and systems to process MSW in Hawaii and Minnesota. International requests include systems to process municipal solid waste in Brisbane, Australia, Ghana and Kuala Lumpur, as well as expressions of interest from India, Spain, Mexico, China and Brazil.

Other potential market applications include:

Processing of poultry litter in broiler house operations,
Processing of spent sugar beet pulp in beet sugar process operations,
Waste management in dairy and other animal farm operations, and
Waste management in remote campgrounds, dude ranches, resorts, and the like.

CONCLUSION

SEBAC (sequential batch anaerobic composting) was developed, proven, tested and patented at the University of Florida. This process overcomes problems associated with inoculation, mixing and instability that frequently occur with other anaerobic reactor designs. A liquid recycle method is used to provide moisture, nutrients and bacteria to the fresh feedstock. Fermentation products such as volatile fatty acids formed during start-up are removed via the liquid handling system to a mature bioreactor where they are converted to methane. This method eliminates instability, and the need for mixing feed and effluent. It has commercial applications in a wide variety of solid waste management operations including, regional, municipal and community organic solid waste; waste management in remote campgrounds, dude ranches, resorts, and military field bases; and processing of waste streams from farm animal and food processing operations. The technology is patented, licensed, and marketing and sale of commercial systems has already begun.

ACKNOWLEDGMENTS

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“Design, Construction and Start-Up of Two Large Covered Anaerobic Digesters Treating Swine Manure (10,000 Sows & 108,000 Finishers)”

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ABSTRACT

In 1999, after extensive preliminary studies, Premium Standard Farms (PSF) decided to proceed with the construction of a 10,000 sow, farrow-to-wean farm (S-5) and a 108,000 hog, wean-to-finish farm (WF-1) near Dalhart, Texas. The options available for manure treatment included lagoons systems or anaerobic digestion followed by an aerated lagoon. The proposed sites were somewhat unique because all of the barns were to be located on only two sites, one for the sows and one for the wean-to-finish operation. For the large wean-to-finish site, the challenge was to collect and treat all of the manure in one location from all 108,000 pigs. The initial concept was a two-stage lagoon treatment system. After reviewing two-stage lagoon design criteria based upon the projected design loadings, the sizes of the lagoons were hundreds of acres in surface area. Upon reviewing a covered anaerobic digester design with HDR Engineering, the costs appeared similar, the system footprint was much smaller and odor reduction potential was judged greater. PSF then contracted with HDR for design of digesters at both proposed farms.

Design and construction of the digesters has been completed. The S-5 digester has been successfully started up and the WF-1 digester is in the start-up mode with the wastewater approaching the 35º C (95° F) design operating temperature.

The design loadings for the anaerobic digesters are based on manure characteristic data from the American Society of Agricultural Engineers (1992). Design decisions involving solids concentration, automated pull-plug systems and segregation of flows were made to minimize water use on the farms and maximize manure solids concentrations entering the digesters. The design loading is a balance between the hydraulic detention time (between 20 and 30 days) and the volatile solids loading in pounds per 1000 cubic feet of digester volume (between 40 and 70). Also the BOD_5 loading was designed to be in the range of 15 and 26 lbs BOD_5/1000 cubic feet of digester volume. The design loading for the anaerobic digester also considered that the average temperature was to be maintained at 33º C (91.4º F) with the minimum temperature in the coldest month of 29º C (84.2º F) and the average temperature in the summer months of 35º C (95º F).

Table No. 1 shows the design loadings to the covered anaerobic digester based upon the 1992 American Society of Agricultural Engineers (ASAE) loading criteria.

Table No. 1
Covered Anaerobic Digester Loadings for S-5 & WF-1

	BOD_5	VS	TSS	VSS	Flow
Anaerobic Inf., S-5					0.100 mgd*
mg/l	6,385	16,595	15,960	13,274	
lbs/day	5,325	13,840	13,310	11,070	
Anaerobic Inf., WF-1					0.731 mgd**
mg/l	7,470	20,357	19,574	16,283	
lbs/day	45,540	124,105	119,330	99,270	

* The S-5 design digester volatile solids loading is 13, 840 lbs/day of which 60% or 8,304 lbs/day is assumed to be destroyed. The estimated quantity of biogas produced is based upon generating 13 cubic feet of biogas per pound of volatile solids destroyed in the anaerobic digester. The estimated quantity of methane produced, based upon the biogas being 65% methane, is 70,170 cubic feet per day or 70,170 MBTU/day or 2,924 MBTU/hour.
**The WF-1 design digester volatile solid loading is 124,105 lbs/day of which at least 60% or 74,463 lbs/day is destroyed. The estimated quantity of biogas produced is based upon generating 13 cubic feet of biogas per pound of volatile solids destroyed. The estimated quantity of methane produced, based upon the biogas being 65% methane, is 629,200 cubic feet per day or 629,200 MBTU/day or 26,220 MBTU/hour.

The biogas recovery systems at S-5 and at WF-1 are similar in that they both collect the biogas from under the HDPE cover using centrifugal compressors that discharge the biogas to a steam boiler. There is a flare to burn biogas that is in excess of the quantity required by the boiler to produce steam to meet the heating requirements. The design heating requirements are based upon heating the incoming water from 4.5º C (40º F) to 31º C (87.8º F).

For S-5, the BTU’s required to heat the wastewater are 799 MBTU/hour and the BTUs required to make up the heat loss through the anaerobic digester are 3,382 MBTU/hour in January. There is an energy input from the sun through the cover even in January of 1,311 MBTU/hour for a net heating requirement of 2,747 MBTU/hour.

For WF-1, the BTU’s required to heat the incoming wastewater are 5,843 MBTU/hour and replacing the BTUs lost through the anaerobic digester are 14,457 MBTU/hour. The energy input from the sun in January is 5,449 MBTU/hour for a net heating requirement of 14,236 MBTU/hour.

The size of the boiler for S-5 is 150 HP and the size of the boiler for WF-1 is 500 HP. Steam is direct injected into the Influent Manhole for the digester where the raw flow mixes with the recirculated flow from the digester. Direct injected steam was used rather than a hot water boiler and a heat exchanger to avoid the potential for a struvite build up in the heat exchanger, which was projected to be a major problem.

ANAEROBIC DIGESTER DESIGN

The effluent quality that is projected from the two anaerobic digesters is based upon the assumed percent reductions shown in Table No. 2.

Table No. 2
Projected Anaerobic Effluent Quality

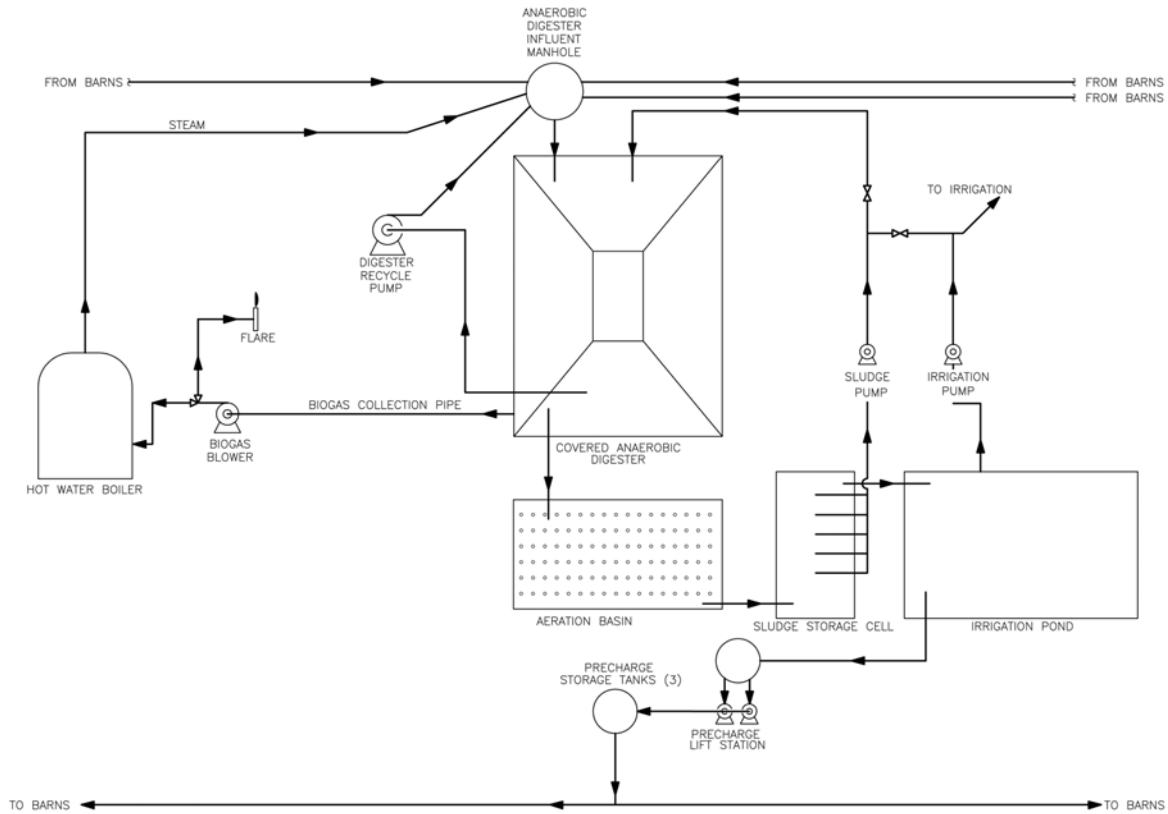
Parameter	Assumed % Reduction	Effl. Conc. S-5	Effl. Conc., WF-1
BOD_5	85%	1,295 mg/l	1,075 mg/l
VS	60%	8,985 mg/l	7,815 mg/l
TSS	85%	3,240 mg/l	2,820 mg/l
VSS	85%	2,695 mg/l	2,345 mg/l

The primary purpose of the covered anaerobic digesters is to reduce the BOD_5 by 85% without producing odors and to minimize the production of sludge. Reducing BOD in the anaerobic digesters reduces the horsepower required for the subsequent aerated lagoon. The aerated lagoon effluent discharges to an irrigation storage lagoon. Wastewater is maintained in an aerobic condition, which means that it can be land applied with a center pivot irrigation system with minimal odors. The treated wastewater is also the source of water for the pull plug system. The water is used to partially fill the pits below the hogs after the manure is flushed.

The following are design elements for the anaerobic digesters, including the flow schematic for WF-1, the design features and the projected biogas production:

1. **Flow Schematic:**

The flow schematic shows the complete treatment system, beginning with the flow from the barns and concluding with the flow pumped to the center pivot irrigation system.



2. Anaerobic Digester Design Features:

The anaerobic digester for S-5 has a water depth of 29.5 feet, a free board of 2 feet and the side slopes are 3:1. The anaerobic digester for WF-1 has a water depth of 30 feet, a freeboard of 2 feet and side slopes of 3:1. Both anaerobic digesters have a floating uninsulated cover made of high-density polyethylene (HDPE) material, which is highly UV resistant. The digesters are lined with compacted clay. There are weight pipes on the cover to direct rainwater to locations where it can be pumped off if necessary. Normally the water would evaporate.

3. Biogas Production:

The estimated quantity of biogas is based upon the factor of 13 cubic feet of biogas produced per pound of volatile solids destroyed. The anaerobic digester is assumed to destroy 60% of the volatile solids added daily. The biogas is assumed to be 65% methane. Based upon the foregoing assumptions for WF-1, and with a design digester volatile solids loading of 124,105 lbs/day, 74,463 lbs/day will destroyed. The estimated quantity of methane produced is 629,200 cubic feet per day or 26,220 MBTU/hour.

DIGESTER HEATING SYSTEM

1. Biogas Recovery System

The biogas recovery system collects biogas from under the HDPE cover using one centrifugal compressor at S-5 and two centrifugal compressors at WF-1. The compressors discharge the biogas to a boiler that produces steam to heat the digesters. There is a flare to burn the biogas that is in excess of the quantity needed by the boiler to produce steam to meet the heating requirements. There is a meter to measure the quantity of biogas that is in excess of the heating requirements to determine the quantities that would be available for future use.

2. Heating Requirements

The heating requirements for S-5 and for WF-1 are based upon heating the incoming water from 4.5 º C (40º F) to 31º C (87.8º F) and replacing the BTUs lost through the cover during the coldest month (January). There is also energy input from the sun through the cover that reduces the heating requirement. The following table summarizes the heating requirements:

DIGESTER HEATING REQUIREMENTS

Digester	Heat Incoming Water	Heat Loss From Digester	Heat Gain Through Cover	Net Heat Req'd.	Boiler Size
S-5	799 MBTU/hour	3,259 MBTU/hour	1,311 MBTU/hour	2,747 MBTU/hour	150 HP
WF-1	5,843 MBTU/hour	13,842 MBTU/hour	5,449 MBTU/hour	14,236 MBTU/hour	500 HP

3. Steam Heating System

Steam is generated in the boilers, which burn biogas. There is approximately 25 percent more energy available than the maximum design heating requirement during the coldest month. Steam is direct injected into the Influent Manhole, which receives the raw wastewater and the recirculated flow to the digester. A hot water boiler and heat exchanger were considered but discarded because of the potential for a build up of struvite (crystalline formation consisting of equal parts of magnesium, ammonium and phosphate) in the heat exchanger.

CONSTRUCTION

1. General

The design and construction of the anaerobic digester, biogas recovery system, heating system, aerated lagoon and the irrigation storage basins had to be completed within a relatively-short period of time because the sows were on a fixed schedule to be impregnated. The sows were then placed in the S-5 barns during the gestation phase and nursery phase to produce the weaned pigs that were then placed in the 52 barns at WF-1. The barns at WF-1 were scheduled to begin construction in order to be ready when the weaned pigs were available. Once the sows were impregnated, the clock, quite literally was "ticking" and no time extensions could be considered because impregnated sows and the weaned pigs were going to be placed in the barns and would be generating waste.

The waste treatment system for S-5 was scheduled to begin construction first because the impregnated sows were to be placed in the barns first. The design of the collection system and the anaerobic digester were the first treatment units to be designed because they would be needed first. The detention time in the anaerobic digester is probably 60 days during start-up period, which would provide additional time for the design and construction of the aerated lagoon, the recycle system for the pull plug barns and the irrigation storage basins.

The design of the wean to finish barns (WF-1) was begun as soon as the S-5 design was completed. Again the collection system and the anaerobic digester were the first elements designed at WF-1.

2. Organization

HDR Engineering, Inc. retained a subcontractor, Enviro-Ag Engineering, Inc. of Amarillo, Texas who designed the general site work and the utilities barns for the entire project. As the subcontractor to HDR, they were responsible for the earthwork design and they were on site during the construction of the waste treatment project. Premium Standard Farms (PSF) had construction managers who were responsible for managing the construction of the waste treatment system. The PSF construction managers selected the following six bid packages for the waste treatment system:

- Bid package No.1 ---- Earthwork, to be performed by the same contractor who was performing the earthwork for the entire WF-1 farm construction project.
- Bid Package No. 2 ---- HDPE liners for the Aeration Basin, side slopes of the Irrigation Storage Basin and Sludge Holding Cells.
- Bid Package No. 3 ---- The anaerobic digester floating HDPE cover. The contractor was Environmental Fabrics, Inc from Gaston, NC

- Bid Package No. 4 ---- Owner-furnished equipment, including surface aerators (S-5), aeration basin blowers (WF-1), lift station pumps, steam boiler, water softener and precharge storage tanks
- Bid Package No. 5 ---- Biogas handling system, including the centrifugal compressors, the boiler, the building and the flare.
- Bid package No. 6 ---- Aeration basin, blowers, water and sewers system, air and process water piping, aeration basin building, and electrical.

DISCUSSION

1. General

Construction of both waste treatment systems (S-5 and WF-1), including the anaerobic digesters has been completed and placed into operation. The S-5 project, which was constructed first, is completed and the WF-1 project is still in the “start up” phase. Consequently there in insufficient operating data from WF-1 to confirm how well the treatment system is doing. The anaerobic digester temperature has only reached 25º C (77º F). However, for S-5 the digester was started up during the summer of 2002 and reached an anaerobic operating temperatures of 32º C (89.6º F) or better. Consequently there is preliminary data to indicate how well the anaerobic digester is performing.

2. Analysis of Anaerobic Digester of Sow Farm (S-5)

The anaerobic digester at S-5 was completed in the early summer of 2002 because S-5 houses the sows that produce the weaned pigs that are placed in the Wean to Finish Farm (WF-1). The S-5 digester went through start up during the summer of 2002 and therefore had warmer operating temperatures during the start up.

The following results from September 9, 2003 through February 19, 2003 for the S-5 digester show the percent reductions for BOD_5, TSS and VS:

Table No. 3
Anaerobic Digester for a Sow Farm, S-5 (Results in mg/l)

Date	pH	Inf. BOD,	Effl. BOD	% Red	Inf. TSS	Effl. TSS	% Red	Inf. VS	Effl. VS	% Red
9/16/02		6006	647	89.2	4810	1831	61.9	4815	1820	62.2
11/05/02	7.47	1980	323	83.7	3260	1220	62.6	3495	1095	68.7
11/14/02		7383	568	92.3	19100	4200	78.0	18990	3275	82.7
1/07/03	7.12	4628	153	96.7	10800	1180	89.1	12390	1020	91.8
1/29/03	7.16	5933	600	89.9	25200	6900	72.6	22560	5070	77.5
2/19/03	7.48	18750	244	98.7	44000	1967	95.5	48600	2300	95.3
Average		**6216**	**422**	**91.7**[1]	**17861**	**2883**	**76.6**[1]	**18475**	**2430**	**79.7**[1]

[1] The values shown are an average of the % reductions. Also note that the reduction of VS does not mean destruction of VS because the calculation was based upon the influent VS minus the effluent VS and does not calculate the VS content in the digester.

The following table shows a comparison of the expected results for S-5 with the actual results achieved.

Table No. 4
Data from Sow Farm (S-5)
Comparison of Projected Anaerobic Effluent Quality with Actual Data

Parameter	Proj % Red.	Actual % Red	Proj. Effl. Conc.	Actual Effl. Conc.
BOD_5	85%	93.4	958 mg/l	422 mg/l
VS	60%	85.3	6,638 mg/l	2,430 mg/l
TSS	85%	82.2	2,394 mg/l	2,833 mg/l

CONCLUSIONS

1. General

Based upon the data from S-5, the design of the anaerobic digester for WF-1 appears to be effective in reducing BOD_5 and volatile solids. An assumption of 85% reduction of TSS may be too optimistic. An 80% TSS reduction may be a more realistic percent reduction. At least one years worth of data will be needed to be conclusive. TSS reduction is not a critical parameter since the inert fraction of the TSS would simply wash out in the Aeration Basin effluent and settle in the sludge storage basin along with the biological solids.

As noted in the comments below Table 3 showing the S-5 results, the VS reduction of 60 percent was estimated from literature data on the destruction of VS and is probably a reasonable assumption. However, the calculation is the sum of the VS destroyed and the VS that settled in the digester and was not destroyed. This may be why the VS reduction is so much higher that the assumed 60 percent value.

2. Lessons Learned

During the design, construction and start-up of the project there were some “lessons learned” that can be shared:

- The urgency to have waste handling facilities constructed within a short time frame, because sows were gestating and pigs were being weaned for placement in the WF-1 barns, caused an inadequate time to be taken for a thorough quality control check before the plans and specifications for each bid package were released for bidding and construction.
- Preliminary planning for the waste treatment system at both S-5 and WF-1 should have been initiated much earlier in the project to allow adequate time to resolve the many issues that are normally addressed during the preliminary planning phase. Completing the preliminary planning earlier would have saved significant time during the final design and drawing production phase when time was very short. Ideally

preliminary planning on waste treatment should be initiated along with the preliminary planning for the hog production facilities. The adage has been relearned **--- " If you don't have time to do it right, when are you going to find the time to do it over?"**

- Even if there was not adequate time for a thorough quality control check before the plans were issued for bidding and construction, time should be taken later for a quality control check even if it was after the plans have been released for bidding and construction. The secondary goal should be to at least review the plans and specifications before equipment is ordered and construction is performed.
- The Engineer needs to be actively involved during the construction phase and be "on-site" at least monthly. The reasons for this are to have the confidence that the project is being constructed as designed as well as to remain fully involved to be able to address problems and check on any constructed facilities on site that just don't "look right".
- The Engineer uses the shop drawing review phase as a critical final step to be sure the equipment, which suppliers are providing, is what was specified. This review phase is also important because it allows the Engineer the opportunity to confirm with the manufacturer that the equipment the manufacturer has proposed is suitable for the intended use on the specific project.
- Time should be taken at the beginning of the construction phase for a "partnering session" that involves the Engineer, the Owner's construction managers and the major contractors. The purpose of the partnering session is to be sure that all parties understand their roles during the construction and start-up phase including the need to communicate with each other throughout the construction phase of the project. All parties must commit the resources needed for the duration of the construction and start-up phase and should do whatever they can to minimize personnel changes.
- Project management of the construction phase by the Owner and construction administration by the Engineer are particularly critical when there are six bid packages with five different contractors, including four contracts for Owner furnished equipment all to be installed by Contractors.
- Prior to beginning the construction phase, the role of the Owner's construction manager and the role of the Engineer's construction administrator should be clearly delineated so they are each are aware of their own and the other's responsibilities. Both parties need to agree upon and consistently follow construction management procedures.
- Both parties need to commit to maintain experienced personnel in their assigned roles for the duration of the project.
- When steam was added to the Influent Manholes at both S-5 and WF-1 a considerable amount of foam was created that exited through the vents. The manholes were subsequently raised.
- Plastic products from the sow farm operation pass through the 1-inch screen openings. The openings need to be smaller but not so small that manure solids are captured.
- With an open aeration basin, there are tumbleweeds and plastic and paper bags that blow in and can become submerged and partially cover pipe openings. Oversize the gravity lines between treatment units to minimize pipe clogging.

WASTE-TO-ENERGY: AN OPPORTUNITY FOR ELECTRIC POWER AND AGRICULTURE

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ABSTRACT

Like agriculture, the electric power sector currently faces significant environmental challenges. Among these challenges is the production of carbon dioxide, a greenhouse gas, during electric power generation from fossil fuels. As part of its commitment under the President's Climate Change Initiative, the National Rural Electric Cooperative Association (NRECA) is looking for ways to reduce, avoid, and sequester greenhouse gas emissions. Waste-to-energy is one such opportunity. Anaerobic digestion of manure produces methane. When captured and used as fuel to generate electricity, greenhouse gas emissions are offset. The electricity produced is available for use on-farm or for sale to the power grid. However, market and technical barriers such as cost and interconnection issues remain. These issues and how rural electric cooperatives are addressing them are discussed.

KEYWORDS

Distributed generation, waste-to-energy, electricity interconnection, electric power, electric cooperatives.

INTRODUCTION

The electric power industry, like agriculture, is facing more stringent environmental regulations. The U.S. Environmental Protection Agency continues to tighten national ambient air quality standards under the Clean Air Act, reducing the amount of sulfur dioxide and nitrogen oxide emissions allowed from power plants. EPA also is in the process of promulgating a new regulation to limit mercury emissions, a byproduct of coal combustion. In addition, uncertainty over future climate policy and the potential regulation of greenhouse gases, such as carbon dioxide and methane, is slowing investment in new generation capacity as financial institutions assess their risk. As a result, the electric power industry is looking at the available options in this uncertain business climate, including renewable fuels and distributed generation.

Waste-to-energy and the production of methane or electricity from anaerobic digestion are such opportunities. While the cost of anaerobic digesters remains higher than that of coal-based electricity generation—the economic benchmark against which all generation technologies are measured—the economics are offset by the environmental regulation of the manure. That is, the livestock producer must pay the cost of environmental compliance anyway. The production of energy can offset those environmental costs through reducing on-farm energy costs and potentially creating a new revenue stream.

The electric power sector is a potential market for energy produced from anaerobic digestion. In this paper, we will first introduce the electric power sector, including electric cooperatives, then take a look at the opportunities and constraints of waste-to-energy, and finally examine what electric cooperatives are doing in this area.

ELECTRIC POWER INDUSTRY

The electric power industry is a complex system of electricity generation and delivery serving the entire U.S., from densely populated cities to remote rural areas. There are three major types of electric utilities: investor-owned utilities (IOUs), publicly owned utilities, and electric cooperatives. Additionally, there are federal utilities and non-utility generators (NUGs) that produce and sell power but do not service or distribute electricity. IOUs are for-profit, privately owned businesses with the objective of returning a profit for their shareholders. Traditionally IOUs are monopolies with regulated rates. Publicly owned utilities or municipals (munis) are nonprofit local government agencies that provide electric power at cost to their communities. Electric cooperatives are not-for-profit, consumer-owned businesses, owned by the consumer-members they serve. Cooperatives arose in rural areas where there were few customers per mile of line and IOUs considered electricity delivery uneconomical. Table 1 is a comparison of characteristics of IOUs, munis, and electric cooperatives.

Table 1 — Electric Utility Comparisons (EIA, 2003; Giles, 2001)

	Investor-Owned	Publicly Owned	Cooperatives	Industry
Number of Organizations	213	2,000	930	3,143
Size (median number of customers)	400,000	1,900	11,500	
Customers, % of total	73%	15%	12%	
Revenues, % of total	76%	15%	9%	
kWh sales, % of total	73%	16%	10%	
Miles of Distribution Line	50%	7%	43%	32.5
Customers per mile of line (density)	33.5	43.7	6.6	32.5
Revenue per mile of line	$58,981	$72,146	$8,558	$56,202
Generation, % of total	50%	9%	5%	

Electric Cooperatives

Electric cooperatives serve 36 million people in 47 states. They own and maintain 2.3 million miles of the nation's distribution lines, covering three-fourths of the nation's landmass. Chances are that if you are a farmer or rancher, you are served by an electric cooperative. It is important to note that cooperatives have only 7 customers per mile of line, in contrast to 34 for IOUs.

Cooperatives are of two basic types. Distribution cooperatives deliver electricity to the consumer. In some areas, distribution cooperatives have formed generation and transmission cooperatives (G&Ts) that generate and transmit electricity to serve them. In these cases, the G&Ts have long-term, all-requirements contracts with the distribution cooperatives to supply their electricity needs. Electric cooperatives generate only 5 percent of the electricity produced in the U.S. each year, and purchase the remainder from federal utilities and the wholesale power market. In comparison, IOUs generate about 50 percent of the electricity, and municipals 9 percent; NUGs (federal utilities, independent power producers, and others) generate about 35 percent.

A Changing Industry

The traditional model of an electric utility is a large, vertically integrated power system with central station generation and a system of transmission and distribution lines that deliver the power to the end user. The utility has the responsibility to deliver sufficient electric power to meet its consumers' demand, whether through generation or contractual arrangements with other generators. In this model, the utility maintains enough generation or rights to electric power to handle its peak electric loads, plus a reserve margin, and enough transmission and distribution to deliver it.

Over the last ten years, federal and state governments have begun restructuring the electric power industry to develop a competitive wholesale electric power market. In this deregulated, competitive model, electric power generation is unbundled from transmission and distribution. In theory, wholesale power generators have equal access to the electric transmission grid and sell their power to anyone anywhere in the U.S. market. In practice, the transmission and distribution grid does not support a freely competitive system.

The transmission grid, while interconnected in certain regions, has limited interconnections among regions and limited interconnection capacity within regions. As noted before, the system originally was built to ensure adequate and reliable power delivery on a local scale from the generation site to the end user (a one-way street), not as an interstate highway. Utilities established transmission interconnections to buy and sell power among one another, and as a backup in case of emergency. The federal government and electric utilities currently are working together to address this issue of inadequate transmission. In the meantime, it presents challenges to those who would sell power to the grid.

WASTE-TO-ENERGY: OPPORTUNITIES AND CHALLENGES

As electric cooperatives plan for future electric generation needs, they evaluate the cost of electricity generated, environmental requirements under the Clean Air Act, other requirements such as renewable portfolio standards, and the risk of greenhouse gas regulation, among other things. The cost of generation, including environmental compliance, is an important consideration. At about 3 cents per kilowatt-hour (kWh), coal-based generation is the benchmark against which other generation technologies are measured. It is then no surprise that coal constitutes more than 50 percent of the nation's electric generation, and for cooperatives more than 70 percent of generation. By comparison, natural gas-based generation costs about 5 cents per kWh. Much of the new capacity being built is natural gas-based because it has fewer air emissions, i.e., no sulfur dioxide or mercury and half the carbon dioxide per kWh as coal.

An alternative to fossil fuel-based, central station generation is renewable, distributed generation. Examples of renewable, distributed technologies include photovoltaics, wind, landfill gas, and anaerobic digesters. To date, the cost of renewable generation has limited their use; renewables account for just 1.9 percent of total annual U.S. electric power generation (EIA, 2003). With advances in technology, some renewables are becoming competitive. For example, wind is now just 4.5 cents per kWh. The renewable electricity production tax credit of 1.8 cents per kWh in 2003, available for electricity produced from wind, closed-loop biomass and poultry waste, makes wind cost-competitive with coal-based generation, but its reliability (30 percent capacity factor) is a problem.

Advantages of Anaerobic Digesters

Waste-to-energy technologies, such as anaerobic digesters, are also becoming economically competitive at 6 cents per kWh. In anaerobic digesters, methane is recovered from manure lagoons and then is used to fuel a generator. An advantage of anaerobic digesters, compared to other renewable technologies, is that the electricity is dispatchable. Methane from anaerobic digesters can be stored and electricity produced on demand, unlike wind or solar, which are available only when the wind blows or when the sun shines. Manure is also a steady and predictable fuel source at a dairy or feedlot.

Another advantage of manure digestion is that it produces methane, a greenhouse gas 23 times more potent than carbon dioxide (IPCC, 2001). By capturing the methane and using it to produce electricity and carbon dioxide, a utility can reduce greenhouse gas emissions to the atmosphere. From a carbon management perspective then, power from manure digestion is a promising option.

Interconnection of Distributed Generation

Interconnected distributed generation can provide benefits to both electric cooperatives and consumers. For electric cooperatives with low-density systems and few customers per mile, distributed generation can be a solution to relatively high transmission and distribution costs. Well-located and managed, distributed generation can increase a utility's peaking capacity, reduce losses for power transmission, allow a utility to defer transmission and distribution upgrades, provide voltage support, and lower air emissions. However, distributed generation also carries challenges to the safety and reliability of the electric grid.

The safety of utility workers charged with repairing distribution lines is paramount. Most distribution systems were built to deliver electricity one-way to the end user. When a line goes down, the utility must know whether the line is hot or cold so it can make safe repairs.

Distributed generation without adequate interconnection safeguards could pose a significant hazard to utility workers by energizing a line thought to be cold.

The reliability of the electric grid is another concern for utilities and consumers. For the electric grid to work properly, a utility must maintain the electric potential or voltage on the system through balancing generation with consumer demand. Failure to maintain the voltage or frequency of the system can cause, among other things, voltage spikes and drops that can ruin electronic equipment, start fires, and blow transformers.

Distributed generation can challenge a utility's ability to balance the system and operate it efficiently. Location matters. Generation that changes the direction of power flow may require expensive upgrades to the system to maintain reliability. On the other hand, optimally located generation can provide voltage support and eliminate transmission and distribution line constraints. Reliability impacts also vary with the type and size of generation. A small generator properly connected is unlikely to have any impact. But because the architecture of each distribution system is unique, solutions to reliability problems for similar technologies and situations may differ.

Electric cooperatives, recognizing the potential benefits of distributed generation to their systems, are in the forefront of developing interconnection standards for the electric power industry. NRECA has worked with the Institute of Electrical and Electronics Engineers (IEEE) to develop interconnection standards for distributed generation. The IEEE approved the draft standard for Interconnecting Distributed Power Resources with Electric Power Systems (P1547) in June 2003. P1547 establishes criteria and requirements for the interconnection of distributed resources with electric power systems. Because utilities' specific circumstances differ, these standards establish a floor for interconnection, and more safety equipment might be required. NRECA is also working with the Federal Energy Regulatory Commission and the North American Regional Utility Commission on standard-setting efforts.

NRECA TECHNOLOGY DEVELOPMENT

NRECA, the Cooperative Research Network (CRN, NRECA's research arm), and others have worked to provide electric cooperatives resources to address the legal, economic, and technical issues surrounding distributed generation. One such resource is the Distributed Generation Interconnection Toolkit, a set of guidance materials designed to educate cooperatives and consumers about the interconnection process, and help cooperatives develop their own interconnection policies. The Toolkit includes a business and contract guide for interconnection, consumer guidelines, model interconnection agreements, a rate manual, and a technical application guide. These materials are publicly available on the internet at www.nreca.org/leg_reg/DGToolKit.html.

CRN also has several research projects in progress to facilitate the use of distributed generation and biomass fuels by cooperatives. The development of a low-BTU microturbine will enable the use of gaseous fuels with low BTU content, i.e., 15 to 20 BTU per cubic foot. Standard microturbines use fuels above 350 BTU per cubic foot, compression and combustion being too difficult at lower energies. Potential applications include biogas from manure digesters and landfills, and syngas from the gasification of agricultural residues.

A second project will develop a set of software tools to provide cooperatives with a “Trubotax” approach to formulating a biopower business plan. Among the individual tools are ones to make informed decisions about using local biomass as a fuel source for generating electricity and to predict local economic benefits for a cooperative’s service territory.

CRN is also working with the Carnegie Mellon Electricity Industry Center to examine the available and proposed technologies to convert livestock waste into fuels suitable for generating electricity. This study will identify the most effective and promising waste-to-energy business models for cooperatives, and recommend needed technological and cost/performance improvements.

ONE COOPERATIVE’S SOLUTION

While electric cooperatives continue to develop the tools and technologies necessary to utilize distributed generation such as anaerobic digestion, some have begun to take advantage of this resource. Dairyland Power Cooperative is a G&T that serves 25 distribution cooperatives and 20 munis in five states (WI, IA, MI, IL, and MN). Dairyland was getting calls from its distribution co-op managers expressing interest in anaerobic manure digesters, so its engineers decided to look into what was available. What they found was an engineer’s nightmare. Every system was different. For Dairyland, this meant both a maintenance headache and inefficiency. The engineers decided to take a systems approach.

This year Dairyland launched a 25 MW Manure Digester Program to be implemented over five years. In order to standardize operations, Dairyland selected Microgy Cogeneration Systems, Inc. (a subsidiary of Environmental Power Corporation) to develop all the projects using its Danish anaerobic digester technology. The dairy or hog farmer will own the manure digester system and will sell the methane to Dairyland. The farmer is responsible for normal manure management, nothing else. Microgy has the systems maintenance and operations contract for the digester. Dairyland owns and operates the generator. Since Dairyland can store the methane, it can generate renewable electric power for the optimal benefit of the system. In addition, Dairyland anticipates significant carbon reduction as part of its efforts to increase its carbon emissions efficiency.

The revenue from the methane can offset the farmer’s manure management costs. The system will also provide ancillary benefits such as cogeneration of heat for hot water or other on-farm uses, pathogen control, and odor mitigation. Dairyland has developed a solution that will work for it and, hopefully, dairy and hog farmers in the Dairyland service territory.

CONCLUSIONS

Technology and market barriers to distributed generation remain. The good news is that both utilities and anaerobic digester developers are addressing the technology issues. NRECA, the

Electric Power Research Institute, and the federal government are developing standards for interconnection and improving waste-to-energy technologies.

On the market side, Congress is considering policies in energy legislation that would provide incentives for renewable energy. S. 1149, the Energy Tax Incentives Act of 2003, would reauthorize the production tax credit and extend the credit to bovine, swine, poultry, and sheep manure and litter, and other agricultural residues, making electric power from manure digesters cost-competitive with central station generation. Currently, electric cooperatives and other nonprofits are not eligible for tax credits. S. 1149 would provide tradable tax credits for cooperatives and municipals that invest in renewable power.

Cost-share programs, such as the Environmental Quality Incentive Program (EQIP) and the Renewable Energy and Energy Efficiency Improvements Program (2002 Farm Bill Sec. 9006) administered by the U.S. Department of Agriculture, can help buy down the cost of anaerobic digesters. NRECA is working with the Environmental Law and Policy Center, the Environmental and Energy Study Institute, farm groups, and others to ensure that these programs benefit agricultural producers and support the development of renewable energy.

Finally, those interested in waste-to-energy systems and selling electric power to the grid should work with their electric utilities. Utilities are the gateway to the grid and must ensure its safety and reliability.

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ANAEROBIC DIGESTION OF FLUSHED DAIRY MANURE

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1. Introduction

In Florida, dairies use water extensively for barn flushing and waste collection, because it is sanitary and less labor-intensive. However, the practice of hydraulic flushing results in greatly increased volumes of dilute wastewater. In addition, many dairies have incorporated fan and sprinkler cooling systems for cow comfort in the warm Florida climate, which contributes even more water to the waste stream. The use of large volumes of flushwater for dairy manure collection, however, means that conventional anaerobic digestion using complete-mix or plug-flow technologies is neither practical nor economical, since the dilute manure streams (typically less than 1% TS) would require excessively large digester volumes and higher heat inputs in order to achieve the hydraulic residence times and operating temperatures required for stable digestion (HRT > 15 days at 35^{o}C).

Figure 1: Hydraulically flushed alley.

Many dairies also use sand for freestall bedding, since sand provides a clean and comfortable inorganic bedding material. A sand trap may be used to recover some of the sand for reuse. However, the presence of sand in the waste stream presents additional problems for conventional digester designs.

Primary treatment (mechanical screening or sedimentation, or both) of flushed dairy manure is widely practiced in the dairy industry since it is helps to prevent clogging in wastewater irrigation systems. Solids removed by screening and sedimentation can be land applied to serve as a soil amendment, or exported off-farm to dispose of excess nutrients. Even after physical separation of suspended-phase solids, the liquid fraction of flushed dairy manure still poses a significant environmental challenge. However, the bulk of the methane potential remains in the wastewater fraction.

In Florida, the most common manure management system utilizes short-term holding ponds for flushed manure wastewater storage, with subsequent pumping to sprayfields to supply fertilizer nutrients and irrigation water for production of forage crops. Although effective for nutrient recycling, these systems tend to be odor intensive. Odorants in livestock manure result primarily from the partial decomposition of organic matter by anaerobic microorganisms. With short-term storage, just as the odorous intermediate products accumulate, the wastewater is sprayed onto cropland through pivot irrigation, thereby volatilizing the odorous compounds and creating a high odor nuisance potential.

2. Fixed-Film Digestion

The optimal manure management system should provide a sustainable approach designed to minimize environmental impacts and maximize resource recovery. Anaerobic digestion under controlled conditions offers a holistic manure treatment solution that not only stabilizes the wastewater but also produces a significant amount of energy in the form of biogas, controls odors, reduces pathogens, minimizes environmental impact from waste emissions, and maximizes fertilizer nutrient and water recovery for reuse. In anaerobic digestion, organic matter in the wastewater is microbiologically converted in the absence of oxygen to biogas, a mixture of mostly methane and carbon dioxide. The biogas produced can be collected and used on-farm, either as a direct energy source (e.g. for heating water) or converted to electricity. The choice of which digester design to use at a given livestock operation is driven by the existing, or planned, manure handling system.

Flushed dairy manure wastewater – defined as the liquid fraction of flushed dairy manure after particulate solids are removed – is usually too dilute for conventional anaerobic digestion systems. One practical alternative is to apply high-rate anaerobic digestion technology, such as fixed-film digestion, to recover energy and treat the flushed dairy manure wastewater at much shorter residence times (≤ three days) than allowed by conventional technologies. A fixed-film anaerobic digester – designed specifically for such dilute wastewaters – has recently been developed at the University of Florida. This unique anaerobic digester design allows biogas recovery and biological stabilization (permanent odor reduction) of the liquid portion of flushed dairy manure at ambient temperature conditions.

The basic fixed-film digester design consists of a tank packed with inert media on which a consortia of bacteria attach and grow as a biofilm – hence the term “fixed-film” digester. As the wastewater passes through the media-filled reactor, the anaerobic biomass converts the organic matter in the wastewater to biogas. Immobilization of the bacteria as a biofilm prevents washout of slower growing cells and provides biomass retention independent of hydraulic retention time. Fixed-film digesters, therefore, are ideally suited for treating large volumes of dilute wastewater because large numbers of bacteria can be concentrated inside smaller digesters operating at shorter hydraulic retention times than would be needed to achieve the same degree of treatment with conventional suspended-growth anaerobic reactors. Generally, the fixed-film design is suitable for any livestock waste that is subject to dilution with water for transport or processing, or the liquid fractions from physical separation processes. Also, fixed-film digesters have a smaller footprint than conventional designs – an important factor where land availability is limited.

Being a contained system, the fixed-film anaerobic digester controls gaseous emissions that contribute to the greenhouse effect. Methane is a potent greenhouse gas with a global warming potential 21 times that of carbon dioxide. Using the biogas as an alternative fuel reduces methane emissions from livestock wastes and conserves fossil fuel resources, thereby also decreasing overall emissions of carbon dioxide into the atmosphere. Being a completely closed system, a fixed-film digester also allows more complete anaerobic digestion of the odorous organic intermediates found in stored manure to less offensive compounds, producing an effluent with significantly reduced odor potential.

Although the volatile solids (VS) content of livestock manure is an indicator of potential methane production, the specific methane yield on a VS basis is not a constant. This is due to variations in the VS composition, which consists of both readily degradable organic compounds including lipids, proteins and carbohydrates, as well as more refractory organics which may include lignocellulosic materials, complex lipopolysaccharides, structural proteins (keratin), *inter alia*. In other words, "all volatile solids are not equal" and, therefore, exhibit different rates and extents of biodegradation during anaerobic digestion. Research has shown that fibrous solids have a low biogas potential because of the low biodegradation rates and refractory nature of lignocellulosic materials to microbial attack. Just as these fibers are not digested in the rumen they will also not degrade, in the short term, during anaerobic treatment. Since solids separation tends to remove a VS fraction that is high in fibrous solids, it also tends to remove the non-degradable portion of the VS, leaving the more degradable fraction in the flushed dairy manure wastewater. Therefore, fixed-film digesters achieve the highest treatment efficiency with diluted wastewater, or low concentrations of suspended solids.

Table 1: Wastewater Characterization

- Temperature
- pH
- Conductivity
- Alkalinity
- Total COD
- Soluble COD
- Total solids
- Volatile solids
- Total suspended solids
- Volatile suspended solids
- Total Kjeldahl nitrogen
- Ammonia
- Total phosphorus
- Soluble reactive phosphorus
- Sulfate

A primary benefit of separation of fibrous solids from flushed manure is the production of two fractions that are inherently more manageable than the original slurry. Minimizing waste stream solids avoids clogging problems and/or impaired biofilm activity in the digester. The benefits in terms of ease of materials handling, production of a high-fiber by-product, and reduction in digester volume requirements are substantial. The fibrous solids have potential use for bedding, refeeding and horticultural applications.

While many dairies utilize hydraulic flushing for manure management, the parameters of any waste management system are site-specific and may vary significantly from one dairy operation to the next. The bioenergy potential of the feedstock is an important parameter in sizing a fixed-film digester and calculating cost-benefit ratios.

Chemical oxygen demand (COD) reduction is linked to methane production – for every kilogram of COD converted, 0.35 m^3 of CH_4 is produced, which is equivalent to 12,000 BTU. For a given dairy farm, the COD concentration of the separated flushed dairy manure is a function of site-specific factors such as the number of cows and the flushwater volume contributing to the waste stream. Therefore, it is important to characterize the wastewater and compile baseline data with regard to number of animals, degree of confinement and type of bedding, feed ration/dry matter intake, volume of flushwater usage, extent of solids separation, and other relevant parameters, in order to design an appropriate fixed-film anaerobic digester for a given farm situation. Typical wastewater characterization parameters are listed in Table 1. A thorough characterization of flushed dairy manure wastewater, which examines fluctuations in soluble and particulate fractions under field-scale conditions, can aid the design and operation of fixed-film digestion by matching the appropriate reactor volume with the proper organic loading rate and hydraulic retention time. Higher organic loading rates serve to optimize volumetric methane productivity, while lower organic loading rates maximize treatment efficiency. Future plans for herd expansion should also be considered in sizing a digester so that adequate digester capacity is available.

3. University of Florida Digester

A demonstration-scale fixed-film digester has been built and is in operation at the University of Florida's Dairy Research Unit (DRU), located in Hague, Florida. The digester is an integral part of the overall waste management system at the 500-milking cow DRU and serves as a model for the dairy industry.

The milking herd at the DRU is confined to freestall barns, which are hydraulically flushed to a wastewater collection channel. The cows are bedded on sand. Milking parlor wash-down water, combined with udder-wash water, also flows to the wastewater channel. In summer, misters are used in the freestall barns to keep the cows cool, contributing additional water to the waste stream. The wastewater initially flows down the collection channel to a sand trap, where some of the sand is recovered for reuse. After the sand trap, the wastewater flows to a mechanical separator, which removes large fibrous solids. The wastewater then flows across a settling basin and over a weir into a sump. A portion of the flushed dairy manure wastewater is pumped from the sump to feed the digester, while the remainder flows directly to a primary storage pond.

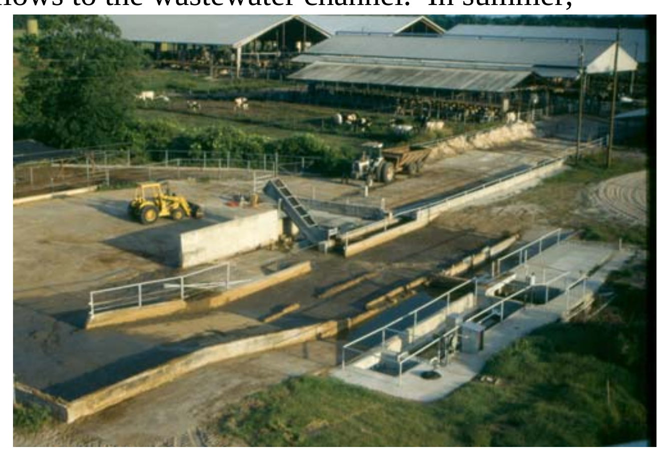

Figure 2: Mechanical separation and sedimentation.

The DRU fixed-film biogas digester demonstrates the application of fixed-film anaerobic digestion for bioenergy production and biological stabilization of flushed dairy manure wastewater at a working Florida dairy, under field conditions. As constructed, the complete digester system consists of a 100,000 gallon, fixed-roof digester tank; a biogas collection and flare system; feed, recycle and desludging pumps; and a mechanical building for housing pump controls and ancillary equipment. The digester is packed with media, which provides a large surface area for bacterial attachment. This enables stable biogas production at low hydraulic retention times (≤ 3 days), even at low ambient temperature conditions (< 20 ^{o}C). About half of the volatile solids in the flushed dairy manure is removed during pretreatment by mechanical separation and sedimentation. This material is not pumped through the fixed-film digester, but best serves as a soil amendment. Also, this fixed-film digester design can tolerate the presence of fine sand in the wastewater without affecting performance.

The separation of fibrous solids increases the COD to VS ratio of the flushed dairy manure wastewater. Fixed-film anaerobic digestion of the resulting wastewater removes 50% of the remaining COD at a 3-day HRT. Biogas (80% methane; 20% carbon dioxide) produced in the digester is flared continuously to reduce odors and methane emissions. A portion of the biogas is also used directly on-site to fuel water heaters, providing hot water for use in the milking parlor. Solids removed by the mechanical separator and from the settling basin are land applied. Currently, a local certified organic farm is also using the separated solids in vegetable production after a suitable curing period.

Figure 3: Fixed-Film Anaerobic Digester.

4. Conclusion

Since many dairies are heavily reliant on hydraulic flushing for manure management, large volumes of wastewater are generated. These dilute wastewaters represent a significant bioenergy resource if processed by anaerobic digestion. However, until now, there has not been an anaerobic digester design available to handle such dilute agricultural waste streams.

Fixed-film anaerobic digestion offers a 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 anaerobic 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 the milking parlor.

Generally, the fixed-film design is suitable for any livestock waste that is subject to dilution with water for transport or processing, such as dairy and swine manure. Effective implementation of fixed-film anaerobic digestion technology demands that the digester be integrated with the existing manure management system. This requires an understanding of this innovative technology and of the impact that site-specific waste management practices can have on both the energy potential of the feedstock and the efficient operation of the digester unit.

Anaerobic Digester Applications for "Environmentally Superior Technology": Research Status and Future Perspective

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Introduction

The annual value of production attributed to animal agriculture in the U.S. has increased dramatically during the past several decades and currently exceeds $100 billion[1]. However, the impact of this farm industry on the environment as well as human health effects attributed to concentrated animal feeding operations and how producers deal with those impacts are significant issues that will determine the future of meat, milk and egg agribusiness industries in many parts of the U.S. and world. Based on existing and emerging environmental issues, it is logical to assume that increasing or even sustaining the current production of these products will be dependent upon the industry adopting and implementing new animal waste treatment technologies. This paper summarizes some research efforts in North Carolina to develop and identify innovative animal waste treatment technology; anaerobic digester process applications are a critical component for many of the technologies noted.

Background: The Attorney General of North Carolina entered into Agreements in July and September 2000 with Smithfield Foods and its subsidiaries (Smithfield Foods), and Premium Standard Farms (PSF), respectively, to develop "Environmentally Superior Technologies" (EST) for implementation onto farms located in North Carolina that are owned by these companies.[2] In March 2002, the Attorney General also entered into an Agreement with Frontline Farmers in which its membership agreed to work cooperatively with the Attorney General and North Carolina State University (NCSU) to develop and implement EST.[3] The Smithfield Foods Agreement provides $15 million and the NC Attorney General allocated $2.3 million from the PSF Agreement for a total of $17.3 million for the EST identification and development initiative.

Environmentally Superior Technologies: The Agreements define EST as "any technology, or combination of technologies that (1) is permittable by the appropriate governmental authority; (2) is determined to be technically, operationally, and economically feasible for an identified

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[1] See *Agricultural Statistics*, published by USDA-National Agricultural Statistics Service, 2003
[2] See Agreements between Attorney General of North Carolina and Smithfield Foods and Premium Standard Farms (North Carolina Department of Justice, on file with Ryke Longest, 2000).
[3] See Agreement between Attorney General of North Carolina and Frontline Farmers (North Carolina Department of Justice, on file with Ryke Longest, 2002).

category or categories of farms as described in the Agreements and (3) meets the following performance standards:

1. Eliminate the discharge of animal waste to surface waters and groundwater through direct discharge, seepage, or runoff; 2. Substantially eliminate atmospheric emissions of ammonia; 3. Substantially eliminate the emission of odor that is detectable beyond the boundaries of the parcel or tract of land on which the swine farm is located; 4. Substantially eliminate the release of disease-transmitting vectors and airborne pathogens; and 5. Substantially eliminate nutrient and heavy metal contamination of soil and groundwater."

In addition, the Agreements mandate a comprehensive economic feasibility analysis for each technology candidate. The economic analysis must consider capital and operational costs as well as costs benefits. Inputs such as the value of products produced by the technology (e.g. biogas from anaerobic digesters) are considered.

Candidate EST: Selection of EST candidates to undergo performance verification and economic analysis involved a request for proposals that was issued nationwide to research institutions and industry. Selections were based on terms and conditions of the Agreements and competitive review (outside *ad hoc* review) as well as review by an Advisory Panel appointed per the Agreements and comprised of individuals that represent government, environmental and community interests, the companies (Smithfield, PSF and Frontline Farmers) and individuals with expertise in animal waste management, environmental science and public health, economics and business management. Collectively, this process yielded the following EST candidates:

1. In-ground ambient temperature anaerobic digester / energy recovery / greenhouse vegetable production system,
2. High temperature thermophilic anaerobic digester (TAnD) energy recovery system,
3. Solids separation / constructed wetlands system,
4. Sequencing batch reactor (SBR) system,
5. Upflow biofiltration system,
6. Solids separation / nitrification-denitrification / soluble phosphorus removal /solids processing system,
7. Belt manure removal and gasification system to thermally convert dry manure to a combustible gas stream for liquid fuel recovery,
8. Ultrasonic plasma resonator system,
9. Manure solids conversion to insect biomass (black soldier fly larvae) for value-added processing into animal feed protein meal and oil system,
10. Solids separation / reciprocating water technology system,
11. Micro-turbine co-generation system for energy recovery,
12. Belt system for manure removal,
13. High-rate second generation totally enclosed Bion system for manure slurry treatment and biosolids recovery,
14. Combined in-ground ambient digester with permeable cover / aerobic blanket - BioKinetic aeration process for nitrification-denitrification / in-ground mesophilic anaerobic digester system (this project represents 3 farm sites),

15. Dewatering / drying / desalinization system,
16. Solids separation / gasification for energy and ash recovery centralized system (this project represents 3 farm sites),
17. High solids high temperature anaerobic digester system, and
18. Solids separation / mesophilic anaerobic digestion / membrane filtration – reverse osmosis system.

EST candidates 1, 2, 6, 11, 14, 16, 17 and 18 involve various applications of anaerobic digester technology. The diversity of the processes includes temperature of digestion (ambient, mesophilic, thermophilic), solids content of influent (< 5% to as high as 50%), aboveground-enclosed containment vs. earthen covered structures, etc.

EST determination: Performance verification and economic feasibility analysis for candidate EST located on commercial farm sites involves a 15-step systematic process: 1) EST candidate selection through a pre-proposal and subsequent full proposal competitive review process, 2) selection of appropriate commercial farm or university research site for the technology study, 3) execution of farm owner agreement, 4) execution of technology design agreement, 5) development of technology design documents, 6) submittal, review and approval of design documents by NC Department of Environment and Natural Resources (NCDENR) for permitting purposes, 7) execution of technology construction agreement, 8) on-site construction, 9) execution of agreements for technology operation and post-evaluation decommission (if necessary), 10) construction closure approval, 11) establishment of functional operation of technology (e.g. steady state waste treatment conditions), 12) procurement of environmental performance data and economic feasibility data by third party research teams, 13) analysis of data and results reporting to the Advisory Panel, Designee, and public, 14) input and review process by the advisory panels, and 15) EST technology determinations per terms and conditions of Agreements.

Progress to date: Currently candidate EST (referenced above) 1, 3, 5, 6, 7, 9, 10, 12, and 17 are in various stages of operation and performance verification. Nos. 2, 4, 11, 13, 14, 16, and 18 are in various stages of design and/or permitting and/or construction. Candidate EST no. 8 (a portable unit process technology) is under fabrication in Germany and will be shipped to North Carolina as soon as possible; EST no. 15 (also a portable unit process) is under development out-of-state and a decision is pending regarding the location of the performance evaluation.

The 15-step process described above is grouped into 3 categories – 1) "on site" construction, 2) "on campus" technology development and objective environmental/economic performance verification, and 3) Advisory Panel review and technology determination reporting by the Designee named in the Agreements. A full service civil, agricultural, and environmental consulting engineering firm was retained in Year 1 of this initiative to provide project technical management assistance for the construction and permitting processes associated with all "on site" activities (items 2-10 in the 15-step process). Also during Year 1, request for proposals were issued for the "on campus" activities. Responses were subjected to outside *ad hoc* review and Advisory Panel review. Subsequently, successful project teams were identified and awarded grants/contracts for this scope of work. These teams are comprised of faculty and staff from

NCSU and also include faculty from the University of North Carolina – Chapel Hill (UNC-CH), Duke University, University of Georgia (UGA), and professionals from Research Triangle Institute (RTI), United States Department of Agriculture (USDA), United States Environmental Protection Agency (USEPA), United States Air Force Combat Climatology Center, MCNC, and NCDENR.

Environmental performance and economic assessment work in progress detail is provided on the college's waste management program web site. [4]

Summary: Environmental impacts associated with animal production agriculture threaten the continued productivity and sustainability of this industry in the U.S. Efforts underway in North Carolina are investigating innovative waste management technologies on commercial scale farms to address identified environmental concerns. Variables targeted include emissions of odor, ammonia, and pathogens as well as groundwater impacts of nutrients and metals. Approximately 1/3 of the 18 technology candidates include varying process applications of anaerobic digester technology. The economic feasibility and ability of producers to implement the technologies will be impacted by the value of energy or other products resulting from the manure treatment processes.

[4] See www.cals.ncsu.edu/waste_mgt/ Follow the prompts related to the summary descriptions, progress reports, presentations, etc. related to the development of "Environmentally Superior Technologies" per Agreements Between the Attorney General of North Carolina and Smithfield Foods, Premium Standard Farms and Frontline Farmers.

THE DIFFERENCES BETWEEN USING ANAEROBIC DIGESTION FOR DAIRY MANURE AND USING IT FOR MUNICIPAL WASTEWATER SOLIDS

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Inland Empire
UTILITIES AGENCY*
*A Municipal Water District

PRESENTATION OVERVIEW

- Economic and Philosophical Differences Between Municipal Solids Digestion and Manure Digestion
- Basic Design Differences
- The IEUA Dairy Manure Digester Project
  - Process Flow
  - Feedstock Characteristics
  - Gas Production
- Conclusions

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ECONOMIC AND PHILOSOPHICAL DIFFERENCES BETWEEN MUNICIPAL SOLIDS AND MANURE ANAEROBIC DIGESTION

- **Economics: Private Vs. Public Financing**
- **Economies of Scale**
  - **Dairy Units Small in Comparison to Utilities**
  - **Farmers May Not Have the Financial Means**
  - **Utilities Can Charge For Collection and Treatment of Residues**
- **Residual Utilization**
  - **Regulatory Constraints on Digested Class B Biosolids**
  - **Public Perception on Land Application of Biosolids vs. Manure**

BASIC DESIGN DIFFERENCES

- Design Differences are a Function of
  - Population (Animal or Human) Served
  - Financial Ability
    - Dairy – Small Units; Low Financial Resources; Privately Financed;
    - POTW – Large Units; Publicly Financed;
- Design Differences
  - POTW – High Tech (Large Egg Shaped; Large Circular Concrete)
  - Dairy – Low Tech – (Covered Lagoons; Small Circular Concrete)

DIFFERENCES IN CHARACTERISTICS OF MUNICIPAL SOLIDS AND MANURE

MUNICIPAL SOLIDS	MANURE
Consistent Solids Content	Variable Solids Content
No Contaminants	High Amount of Contaminants
Small Particle Size	High Cellulose Content
Steady Feed Rate	Variable Delivery
Very Homogenous	Variable % VS Due to Bedding Practices

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THE SOUTHERN CALIFORNIA SITUATION

- Over 300 Dairies
- Over 400,000 Cows, Heifers, Calves
- Produce Over 1,400,000 Tons of Manure Annually (60% TS)
- Over $1 Billion/Year Industry
- 25-Square Mile Area

Inland Empire UTILITIES AGENCY*
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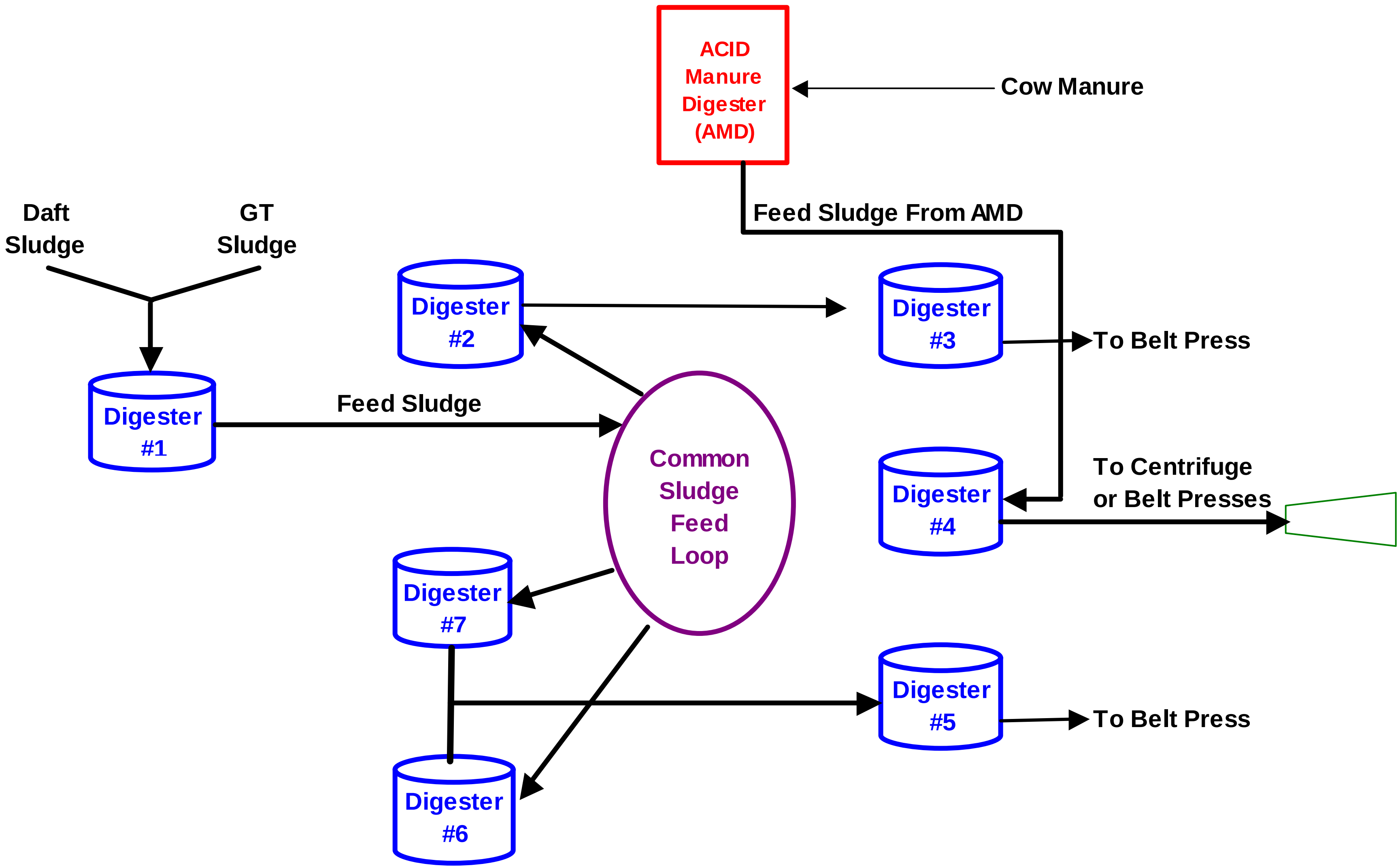
ANAEROBIC DIGESTION SCHEMATIC FOR RP-1 AT IEUA



DIGESTER OPERATING DIFFERENCES APRIL 2003

	WASTEWATER SOLIDS	***MANURE***
Temperature	**Thermophilic**	**Mesophilic**
Stages	**3**	**2**
Detention Time (total)	**~22-25 days**	**~18 days**
Mixing	**Complete Mix**	**Complete Mix**

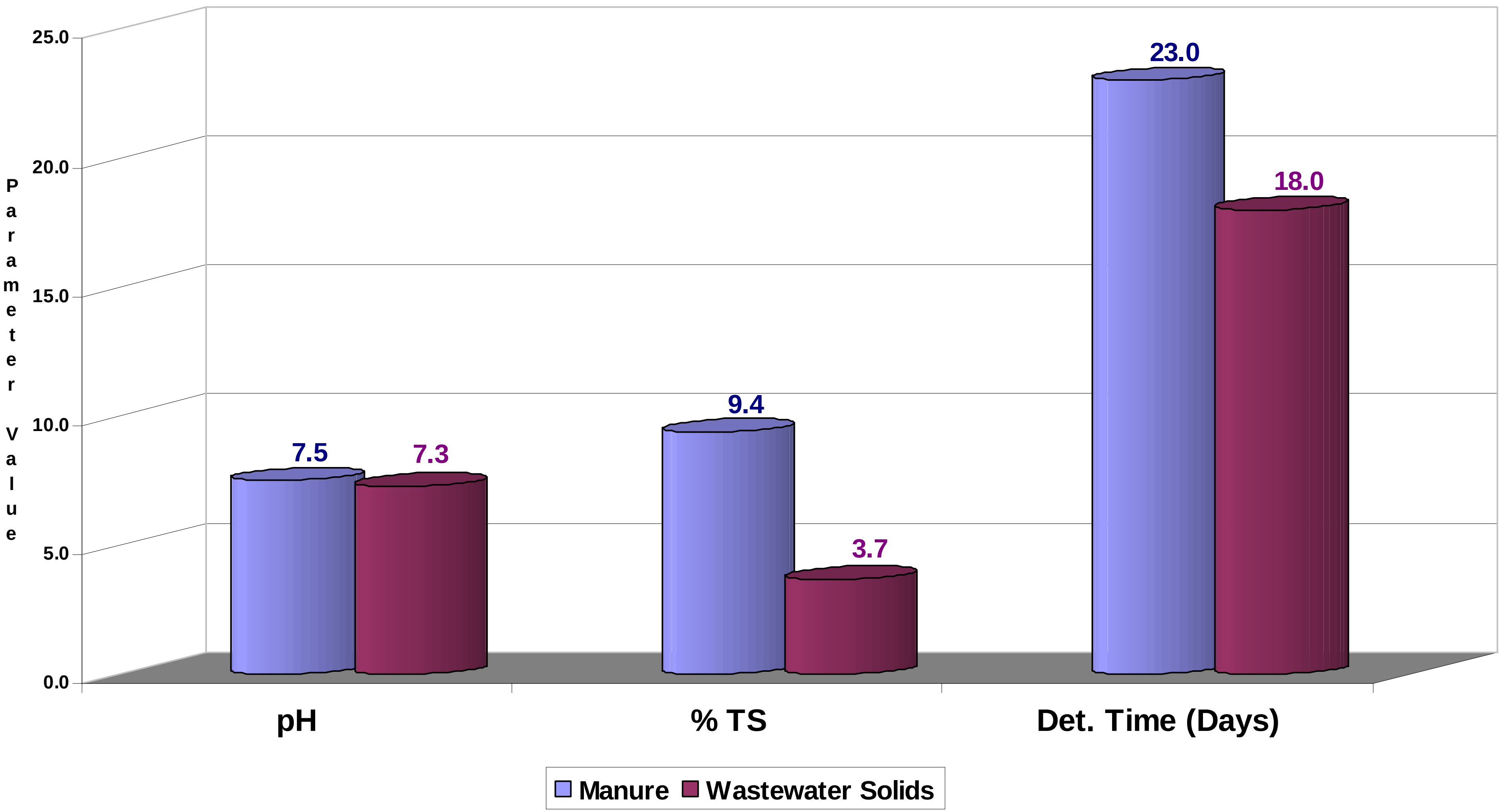
WASTEWATER SOLIDS PROCESS DESCRIPTION

- **DAFT & GT Sludge to 1st Stage**
  - **2 Days Detention Time**
  - **85ºF – 90ºF**
- **Transfer to Thermophilic Digesters**
  - **~ 15 Days Detention Time**
  - **Complete Mix**
  - **122ºF – 125ºF**
- **Transfer to Transitional Digesters**
  - **5 – 10 Days Detention Time**
  - **115ºF – 120ºF**
- **Dewatered by Belt Filter Press**

MANURE PROCESS DESCRIPTION

- Manure Delivered in Tank Trucks
  - Equivalent to ~2600 Cows
- Manure Pumped to Acid Digester (AMD)
  - Moisture Adjustment to 8-9%TS
  - Heat to 98°F
  - 2 to 3 Days Detention Time
- Transfer to Digester #4
  - Conventional, Mesophilic
  - Completely Mixed; Fill and Draw Operations
  - Detention Time Approximately 20 Days
- Dewatered by Centrifuge or Belt Press

COMPARISON OF pH, FEED % TS, and DT BETWEEN MANURE AND WASTEWATER SOLIDS DIGESTION



MANURE DELIVERY

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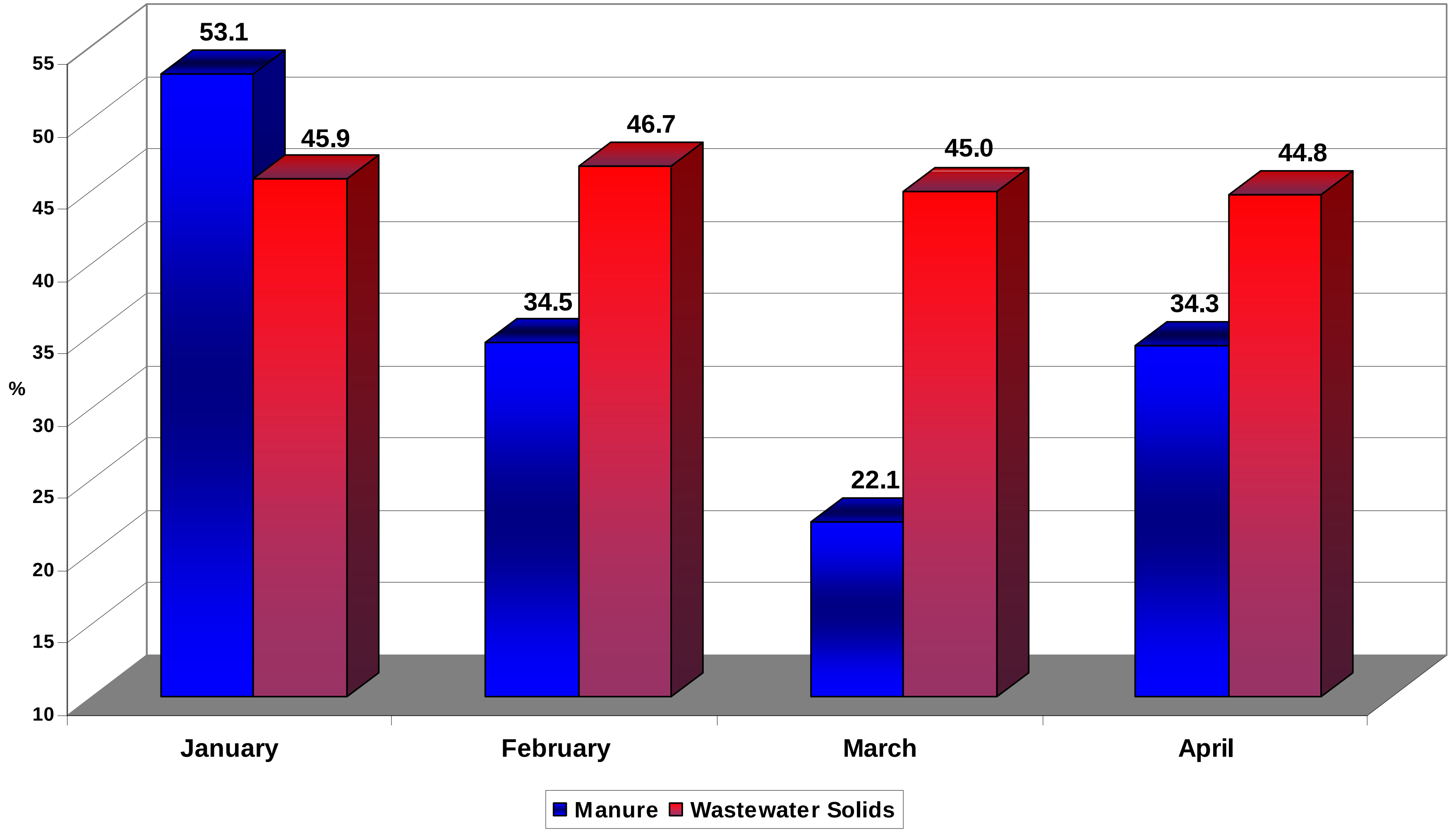
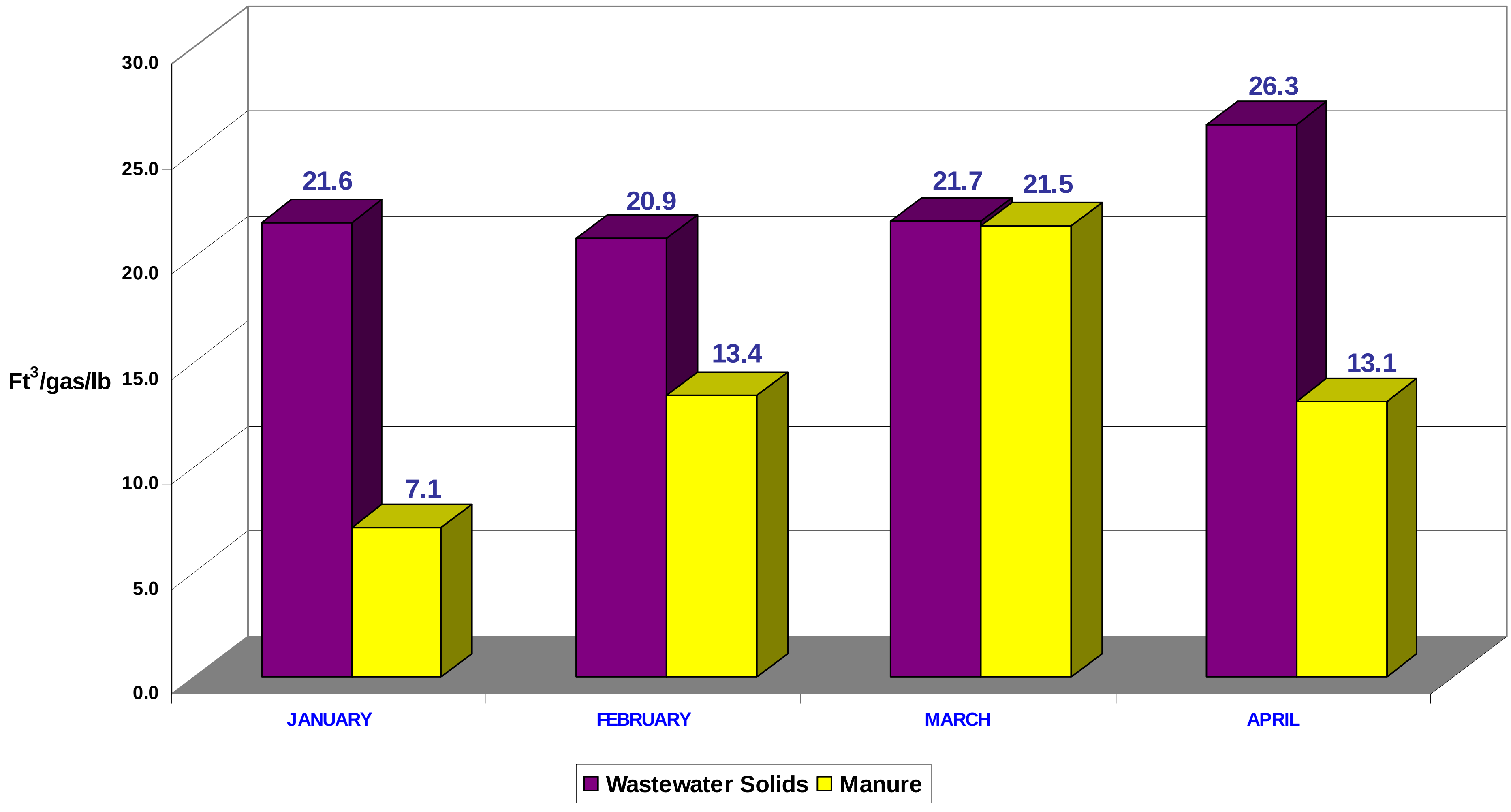
ACID MANURE DIGESTER

MANURE DIGESTER, CENTRIFUGE & LOAD-OUT

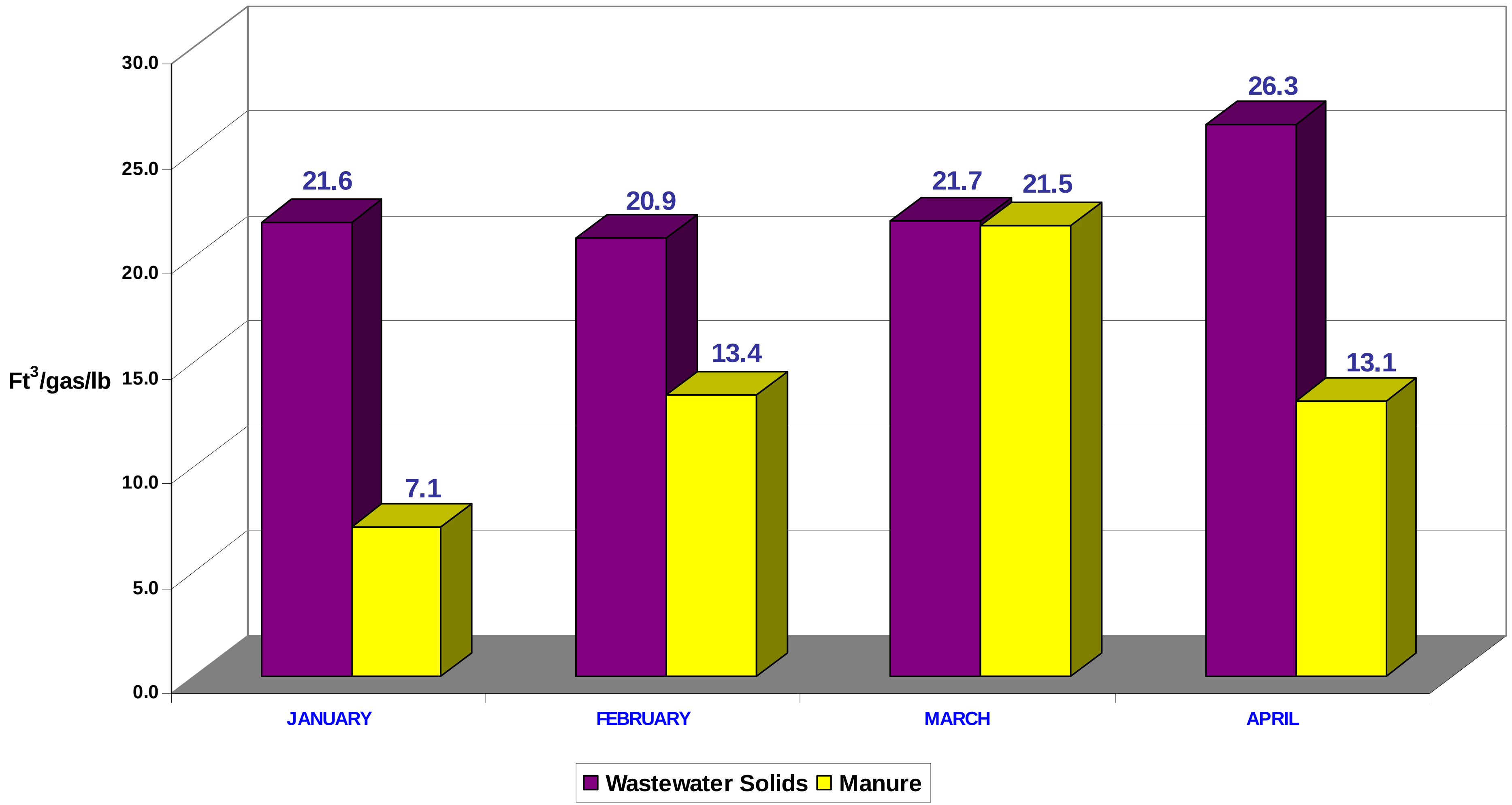
COMPARISON OF % VS REDUCTION BETWEEN MANURE AND WASTEWATER SOLIDS DIGESTION 2003



GAS PRODUCTION VERSUS VOLATILE SOLIDS REDUCTION



GAS PRODUCTION VERSUS VOLATILE SOLIDS REDUCTION



MANURE DEWATERING PERFORMANCE ISSUES

- **Belt Filter Press**
  - 24-28% TS Achieved
  - Higher Polymer Use than Wastewater Solids
  - Poor Filtrate Quality
    - High COD, Solids, Ammonia & Sulfur Content
- **Centrifuge**
  - Higher Cake Solids
  - Plugging Problems
  - Erosion Problems

MAJOR OPERATING COST COMPONENTS

- Filtrate Recycle Treatment
- Labor
- Foreign Object/Contaminant Removal
- Dewatering Chemicals
- Dewatered Cake Management
- Hydrogen Sulfide Removal from Biogas

IEUA RP-1 EXPERIENCE CONCLUSIONS

- **Present Manure Treatment Costs are Greater Than Power Generation Revenue**
- **Contaminants in Manure A Significant Issue**
  - **Filling of Digester w/Grit or Inorganics**
  - **Pump Clogging Problems**
  - **Prescreening is Required**
- **Gas Production Per Pound of VS Destruction**
  - **Mesophilic Manure Digestion is Only 60% of Thermophilic Wastewater Solids Digestion**
  - **Transitional Temperature Zone (110ºF) Increases Volatile Solids Destruction, but Decreases Gas Production per Pound Volatile Solids Destroyed**

IEUA RP-1 EXPERIENCE CONCLUSIONS

- **Dewatering Improvement is Needed**
  - Better Reliability
  - Decrease in Chemical Usage
  - Better Solids Capture
- **Planned Future Manure Digestion Evaluations**
  - Manure Pretreatment to Remove Contaminants
  - Thermophilic Digestion
  - Co-Digestion with Food Processor Wastes to Increase Biogas Production
  - Improving Cellulose Destruction
  - Evaluating Other Dewatering Technologies

CLEAN AND RELIABLE POWER AND HEAT FROM DIGESTER GAS

George Wiltsee and Holly Emerson
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Presented at
Anaerobic Digester Technology Applications in Animal Agriculture
A National Summit
Raleigh, North Carolina
June 2-4, 2003

ABSTRACT

During the last two years, the first commercial microturbine projects using digester gas at agricultural and municipal wastewater treatment facilities have demonstrated several advantages of small gas turbine technology over small internal combustion engine technology. These initial microturbine projects have also provided some important "lessons learned", which have led Ingersoll-Rand to develop a comprehensive solution, under the brand name EcoWorks™. The authors discuss the following subjects in turn:

- Microturbines as part of the solution to the CAFO manure treatment problem
- Microturbine technology versus small IC engine generator technology
- Lessons learned in early digester gas microturbine projects
- The Ingersoll-Rand EcoWorks product and service offering

INTRODUCTION

A number of issues relating to manure management are currently facing operators of Concentrated Animal Feeding Operations (CAFOs). The EPA estimates that the costs incurred from addressing these issues, as they relate to the updated 503 regulation, will result in the closing of 3% of all large CAFOs.[1]

In many cases the solution involves the installation of an anaerobic digester for manure collection and processing. This can be costly. Onsite generation of electricity and hot water can be an important element in making an anaerobic digester installation economically feasible.

In addition to providing a payback from a digester installation, a microturbine system can eliminate excess odors while producing minimal emissions, enhancing the farm's image among nearby communities.

[1] *NPDES Permit Regulation and Effluent Limitations Guidelines for Concentrated Animal Feeding Operations.* EPA Fact Sheet, January 2003

MICROTURBINES AS PART OF THE CAFO MANURE MANAGEMENT SOLUTION

Electricity Production

The most significant financial benefit of the use of digester gas for onsite energy generation is usually the reduction in the farm's electric bill. In many cases, revenues are derived from the sale of excess electricity to the utility company.

Odor Control

Odors associated with concentrated animal waste are not only a nuisance; the foul-smelling air is also a potential liability to the farmer due to perceived health risks. A recent article in the New York Times reported on the presence of hydrogen sulfide and ammonia in the air near hog farms. It has been alleged that these contaminants cause neurological damage to community residents.[2]

Although an anaerobic digester installation can reduce these odorous compounds by up to 97%[3] the collection and temporary storage of manure can also result in unwanted odors. It is possible that these 'excess' odors can be effectively eliminated by a microturbine.

Central Gas Manitoba and other partners conducted a collaborative study at the City of Winnipeg's wastewater treatment plant to test the control of odors and noxious gases using microturbines. It was determined that the high turbine inlet temperature effectively destroyed 99% of hydrogen sulfide and 95% of total odors from a highly intense point source odor stream fed through the combustion air inlet of the microturbine.[4]

Hot Water Production

A byproduct of the gas turbine combustion process is heat. This heat can be used directly from the exhaust or to produce hot water through the use of an air-to-fluid heat exchanger. The production and onsite use of both thermal and electrical energy is known as cogeneration or combined heat and power (CHP).

Some of the uses for hot water on a farm include:

- Digester heating
- Heating of the barn floor, home, office, and other facilities onsite
- Absorption chiller power (air conditioning, refrigeration)
- Thermal drying and pelletizing of biosolids for sale or land use

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[2] *Neighbors of Vast Hog Farms Say Foul Air Endangers Their Health.* Jennifer Lee, New York Times, May 11, 2003

[3] *Anaerobic Digesters and Methane Production…Questions that need to be asked and answered before investing your money*. University of Wisconsin – Extension, 2001.

[4] R. Parsons et al., *Energy and Cost Efficient Odour Control Using Microturbines.* 2000.

Cost Mitigation

Project costs can often be reduced through the use of grants, loans and utility net metering programs. Various state and federal incentives are available for renewable energy, and for agricultural biogas projects in particular.

Often these incentives can ensure the success of a project. One of the lessons learned in the Haubenschild Farms project was that the cooperation of the electric utility is important to the financial success of the project.[5]

Emissions Control

The capture and beneficial use of the methane generated from the digester reduces greenhouse emissions. In addition, some fossil fuel-derived energy and carbon dioxide emissions are offset by the biogas recovery and use.

A microturbine can offset its own weight in fossil fuel CO_2 emissions every day that it operates on digester gas. Additionally, microturbines emit very low emissions of NOx and CO, especially when compared to the more commonly used IC engine generator.

	Output (kW)	**NOx[1]**	**CO[1]**
Ingersoll-Rand[6]			
70kW	70	0.14[2]	0.09[2]
250kW	250	0.14[2]	0.09[2]
Hess Microgen[7]			
140	140	0.15[3]	0.60[3]
200	200	0.15[3]	0.60[3]
250	255	0.15[3]	0.60[3]
350	350	0.15[3]	0.60[3]
Dresser-Waukesha[8]			
VGF	750-185	1.25[4]	1.59[4]
VSG	173-59	18.0[5]	15.0[5]
Caterpillar[9]			
3406	150[6]	21.6	1.60
	190[6]	19.7	1.00

Table 1. Emissions Comparison

Notes:
1. g/bhp-hr
2. Exhaust directly from combustor.
3. Rich burn using optional emission technology.
4. Carburetor setting: T.A. Luft Emissions, 11:1 CR
5. Carburetor setting: Catalytic Conv. Input (3-way)
6. Continuous duty

All values are using 905 Btu/scf LHV natural gas

[5] *Final Report: Haubenschild Farms Anaerobic Digester.* Nelson and Lamb, August 2002.
[6] Source: www.irenergysystems.com
[7] Source: www.hessmicrogen.com
[8] Dresser Waukesha *Ref. S8483-4 Gas Engine Exhaust Emission Levels*. April 2001.
[9] Source: www.cat.com

THE INFLUENCE OF PROCESS MANAGEMENT ON POWER OUTPUT

An efficient anaerobic digester can often produce more electricity than the farm's electric load. Five to seven dairy cows can produce enough gas to generate approximately one kilowatt.[10]

Several factors can influence the amount and Btu content of biogas produced:

- Type of digester technology
- Specific digester design details, such as residence time, temperature, and mixing
- Type and quality of animal feed
- Scraping method
- Type of bedding

Probably the most important factor in maintaining high, steady power production from an anaerobic digester gas-to-energy system is careful system management.

The amount of time a farmer spends on daily maintenance and checks can be reduced with the use of a continuously running microturbine. An IC engine generator can require oil changes every 500 to 1000 hours. By contrast, a continuously operating microturbine requires as little as 24 hours of maintenance for every 8000 hours of operation.

Furthermore, a good service plan offered by the equipment manufacturer can virtually eliminate the cost risk associated with both planned and unplanned maintenance.

MICROTURBINE TECHNOLOGY VERSUS SMALL IC ENGINE GENERATOR TECHNOLOGY

A number of manufacturers or packagers supply IC engine generators for use with digester gas. Models range in size from less than 50 kW to greater than 800 kW. Some models accept digester gas at atmospheric pressure; others require compression of the gas. Hot water can be recovered from jacket cooling and from exhaust heat exchangers.

Project developers and mechanics are very familiar with IC engine generators, and generally prefer to select this technology despite its drawbacks, which can include:

- Frequent oil changes and overhauls
- Large number of moving parts and a resulting tendency to break down
- Dedicated maintenance personnel
- Noisy and dirty operation
- High emissions of NOx, CO and other pollutants

Microturbines, in contrast, are relatively new and unproven in these applications. The number of manufacturers is small, and model sizes range from 30 kW to 250 kW at present. Microturbines require digester gas to be compressed to about six atmospheres,

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[10] *Agricultural Biogas Casebook.* Great Lakes Regional Biomass Energy Program, Council of Great Lakes Governors, September 2002.

and require the compressed gas to be dried. Hot water can be recovered from exhaust heat exchangers.

To date, a small number of project developers and plant operators have chosen to install microturbines for digester gas applications. In general, they are seeking the following (projected) benefits from this relatively immature technology:

- Infrequent oil changes and overhauls
- Very small number of moving parts to potentially break down
- Unmanned, remotely controlled operation
- Quiet and clean operation
- Extremely low emissions of NOx, CO and other pollutants

LESSONS LEARNED IN EARLY DIGESTER GAS MICROTURBINE PROJECTS

The first microturbine tested on digester gas was a Capstone 30 kW unit, at the Palmdale wastewater treatment plant (Los Angeles County Sanitation Districts). The lead author of this paper supervised that test, and subsequently supported the installation and operation of more than 100 microturbines in more than 20 projects that used digester gas or landfill gas as fuel. Some of these projects have operated quite successfully and have achieved up to 16,000 operating hours per turbine. Other projects experienced problems, primarily due to difficulties encountered in fuel conditioning. Some of these projects have been converted to successful projects after replacing or reworking the fuel conditioning equipment. The lessons learned from this experience are summarized as follows:

- Drying of compressed digester gas is very important. Otherwise, compounds in the condensate foul the microturbine fuel control valves and fuel injectors.

- Several types of desiccant dryers have been utilized, with mixed success. Refrigerated dryers have proven much more reliable.

- Some compressor failures have also been caused by condensate. Gas/liquid separation and the design of the compressor cooling system are important.

- Materials of construction must address the corrosive properties of digester gas. Stainless steel is best. Carbon steel and yellow metals are not recommended.

- Siloxanes in sewage sludge digester gas and landfill gas convert to silica (ash) during combustion. This problem does not exist in agricultural digesters.

- When clean, dry fuel is supplied reliably to the microturbines, the systems operate continuously, with no attention required for months at a time.

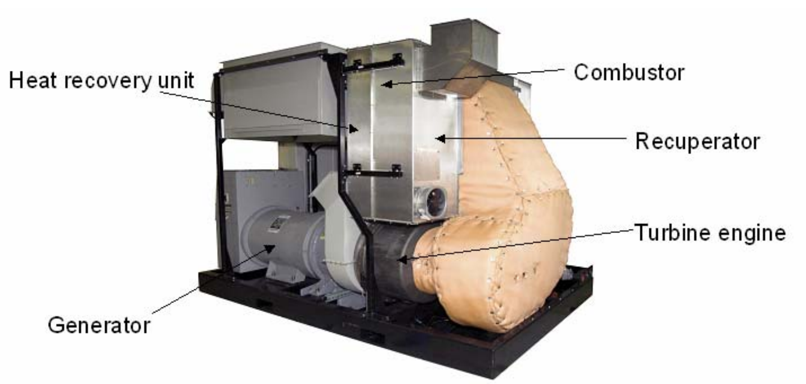
In general, projects that utilize experienced biogas engineers and fuel skid designers are successful from the start. Projects completed by people unfamiliar with biogas tend to produce serious “learning experiences”.

THE INGERSOLL-RAND ECOWORKS™ PRODUCT AND SERVICE OFFERING

By supplying a completely integrated package of equipment (fuel conditioners, microturbines, and switchgear), factory assembled and tested, Ingersoll-Rand reduces the risk of design error by the project engineer or consultant. By providing the customer with a bumper-to-bumper warranty and service package, Ingersoll-Rand removes much of the project operating and maintenance risk from the customer and the engineer.

Warranty and Service

Ingersoll-Rand currently offers two service agreements for renewable fuel applications. The Planned Maintenance (PM) agreement covers routine maintenance for a fixed annual cost. The Total Maintenance (TM) agreement includes everything covered in the PM agreement plus all other (unplanned) maintenance and repairs to the microturbine.



Biogas Experience

Ingersoll-Rand's primary experience with biogas since introducing its microturbine products in 2002 has been in the landfill gas-to-energy market. At smaller landfills, microturbines are a good technology for continuous, clean and efficient operation.

Six Ingersoll-Rand 70kW microturbines installed at the Operating Industries, Inc. Landfill in Los Angeles, CA are burning landfill gas with methane content as low as 29%. The installation's primary purpose is to meet the on-site power needs of the landfill. By reliably meeting the strict emissions requirements for this challenging application while producing power from free gas, OII has reduced its electrical costs by as much as $30,000 per month, resulting in a projected payback period of less than two years.

Jamacha Landfill in San Diego County, CA is using four Ingersoll-Rand 70kW microturbines to burn landfill gas with methane content as low as 30%. Ten percent of the power generated is being used to meet onsite demands; the remainder is sold to the utility company under a power purchase agreement. These microturbines have operated for more than 8000 hours with a very high availability factor.

DESIGN AND ANALYSIS OF AN ANAEROBIC BIO-NEST REACTOR

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ABSTRACT

A bioreactor, bio-nest, with simple design and operation with high treatment efficiency, was developed. This is the modification of design and operation of upflow anaerobic sludge blanket (UASB) and anaerobic biofilter reactor. A two-stage of bioreactor (10 l each), were operated for six months. They are filled with two layers of media which is 98% of void volume in the reactor. The reactors were operated in the ambient room of 22±2 ^{0}C. A loading rate ranged from 2.68 to 36 g/l/d of total COD (TCOD) using milk parlor wastewater was investigated. At organic loading rate of 36 COD g/l/d, the removal efficiency of total TCOD, soluble COD (SCOD) and total suspended solids (TSS) are 52%, 28.9% and 62% respectively. Methane gas production rate was 2.17 l/l/d with 57% methane content. If the recovery of methane gas and COD removal efficiency are the main objectives, the organic loading rate needs to be maintained at lower range. At organic loading rate of 3-4gTCOD /l/d, the removal efficiency of TCOD, SCOD and TSS are 81.8%, 59% and 79.9% respectively. Biogas production rate 2.6l/l/d with methane content of 73% can be achieved.

The unique operation of the bio-nest reactor is to achieve a higher COD removal efficiency with high organic loading rate by simple design and operation. This unique bioreactor could provide better sludge distribution, less dead zone and higher TCOD loading rate than conventional UASB does. Especially, the high fat content of milk wastewater was used in this study. The process performance, design and operation criteria were presented, discussed and compared with anaerobic filter reactor and UASB reactor. The simple design and operation of the bio-nest reactor investigated in this study can be easily integrated into the existing lagoon system (popularly in the United States) or integrated to the aerobic and intermittent aerobic treatment unit (e.g. EMMC, entrapped mixed microbial cell developed at UH) for further removal of carbon and nitrogen in order to dispose, discharge or reuse.

KEYWORDS. Anaerobic reactor, milk parlor wastewater, bio-nest, process performance, comparison, COD removal, biogas production, simple design.

INTRODUCTION

Various types of biological reactors have been developed for of dairy wastewater treatment and utilization in the U.S. Among them, the anaerobic lagoon has been popularly operated for dairy waste treatment because of the advantages including: cost effectiveness, simple management, and large quantity of storage volume wastewater. However, the operation of anaerobic lagoon system still has some disadvantages of odor generation, potential surface and groundwater contamination. In order to improve the application of anaerobic lagoon systems for dairy wastewater, various anaerobic reactors have been investigated for potential integration of existing anaerobic lagoon system or serving as an independent treatment / utilization biological unit process. This includes conventional completely mixed reactor, fixed film digester, continuous-flow mixed and non-mixed digester (Ghaly, 1989; Ghaly and Echiequ, 1992), fixed film sequencing batch reactor (Lo and Liao, 1995) , and tow- stage anaerobic sequencing batch reactor with thermophilic – mesophilic (35^0C) conditions(Dugba and Zhang, 1999). All of these bioreactors required higher temperature (35 ^{0}C) operation and complicated design/ operation. For more effective processes performance of treating dairy related wastewater, both anaerobic filter (Hawkes et. al., 1995) and UASB (Ince, 1998; Gaval et. al., 1999) were investigated. Again, mesophilic temperature (35 ^{0}C) needs to be maintained. Additionally, the problems of formation of granulation for applying UASB process occurred because of the high lipid/ fat content of dairy wastewater (Hawkes et al, 1995). As indicated by Hawkes et. al. (1995), the anaerobic filter applied for the treatment of ice cream wastewater is among the best compared to the contact anaerobic process, fluidized bed and UASB. However, the maximum organic loading rate of 6.38 kg COD/m3/ day to achieve 67% of TCOD removal efficiency was observed at 35 ^{0}C. Therefore, development of a cost effective, high removal of organic and production of biogas with simple design/operation anaerobic bioreactor at lower temperature is required.

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Bioreactor set up

A two-stage bioreactor (10 liter each), as shown in Figure 1, was filled with two layers of medium (bio-nest) which provided a 98% of void volume. Three sample outlets were made in order to take sample of the sludge to test the distribution at different height. The ‘bio-nest” provides the immobilization of microbial cell and serves as the baffle to retain the biomass in the reactor and to provide well mixing purpose for both the substrate and biomass. Biomass retained in the bioreactor was measured as solids retention time (SRT), as shown in the following equation:

SRT for both R1 and R2 was measured according the nitrogen mass balance. It was assumed that nitrogen in biogas could be ignored.

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Impact of various SRT on the process performance, thus, can be measured and compared to the other types of bioreactor. This bioreactor was operated and investigated in the room temperature of 22 ± 2^0C

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A milk parlor wastewater was used to investigate the process performance and operational stability for the bioreactor. The wastewater characteristics are presented in Table 1. By using various concentration of TCOD contained in the wastewater and controlling the flowrate, the system was operated by graduated increase of the TCOD loading rate from 2.68 g/l/d to 36 g/l/d. Steady state process performance data were collected and analyzed. Input and output samples were chemically analyzed. This includes total solids (TS), total volatile solid, TCOD, soluble COD(SCOD), ammonium nitrogen and total phosphorus by following the procedures provided by the Standard Methods (APHA, 1989). The pH value was measured by using and Orion ion analyzer (Model 501). A field gas meter measured biogas production. Methane content will be analyzed by using s Shimadzu Model GC-3BT gas chromatography connected to a Hewlett-Packard 3390A integrator.

RESULT AND DISCUSSION

Process Performance

The bioreactor was started up by a mixture of 2 l of anaerobic sludge with 6.2 l of raw wastewater using continuous recycling operation. After two weeks of starting up period, a 50% of SCOD was removed. The reactor was started to investigate the effect of various TCOD loading rate on the process performance measured as COD removal, biogas production and operational stability.

As shown in Figure 2, the effect of TCOD loading rate on the COD removal efficiency and methane gas content is presented. It can be seen that this bioreactor is able to achieve a TCOD removal efficiency of more than 69.4% and methane content of more than 69% at a TCOD loading rate of less than 25g/l/d. In order to observe the process operational stability, a constant hydraulic retention time (HRT) of 15 hours with fluctuated influent TCOD concentration ranged from 5300 -12000mg/l was investigated. As shown in Figure3, the effluent concentration of TCOD from R2 is very stable although various fluctuation of influent TCOD is applied. The stable process performance of operating this reactor at the HRT of 15 hours closely related to the SRT as shown in Figure4. It is apparent that the SRT of the reactor is relatively independent from the HRT operated while the system was operated at HRT>15 hours. Thus, it is able to be concluded that the stable operational performance can be achieved with more than 15 hours of HRT applied for this bioreactor at 22 $\pm 2^0$C using the milk parlor wastewater as substrate.

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The result generated from this study was compared to the others, such as anaerobic filter and UASB, using dairy wastewater as substrates. As shown in Table 3, the present study of using “bio-nest reactor” to treat dairy wastewater provides a comparable or better process performance compared to the others even at lower temperature of 22 ± 2^0C and high organic loading rate are applied. The unique design and operation of this “bio-nest reactor” includes:

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Compared to anaerobic filter and UASB, apparently, the present bioreactor is able to overcome the shortcoming of both anaerobic filter and UASB for the treatment of dairy wastewater and demonstrates its unique design/operation criteria for the achievement of high COD removal and biogas production operated at 22 ± 2^0C. As shown in Figure 5, this operation of the bio-nest reactor can be integrated into the existing lagoon systems, which are popularly applied in the dairy farm throughout the United States, or to be integrated the intermittent aerobic and completely aerobic treatments units (e.g., Entrapped Mixed Microbial Cell, developed at University of Hawaii) for further removal of carbon and nitrogen in order to dispose, discharge or reuse.

CONCLUSIONS

An anaerobic bio-nest reactor was designed and investigated for the treatment of milk parlor wastewater. The unique design of this bioreactor provides a high COD removal efficiency with high organic loading rate even the reactor is operated at 22 ± 2^0C. This is due to high SRT, better sludge distribution, less dead zone provided by this unique bioreactor. The shortcoming occurred in the anaerobic filter and UASB are corrected and made-up to design this bio-nest reactor. This bio-nest reactor achieves a comparable or better performance, measured as TCOD removal and methane production, than the anaerobic filter and UASB. Simple design and operation for the application of this bioreactor can be easily accepted by the producers. A pilot plant study has been planned and the fund is available for further investigation of this bioreactor. Process operation /maintenance problems will be investigated and distributed to the public.

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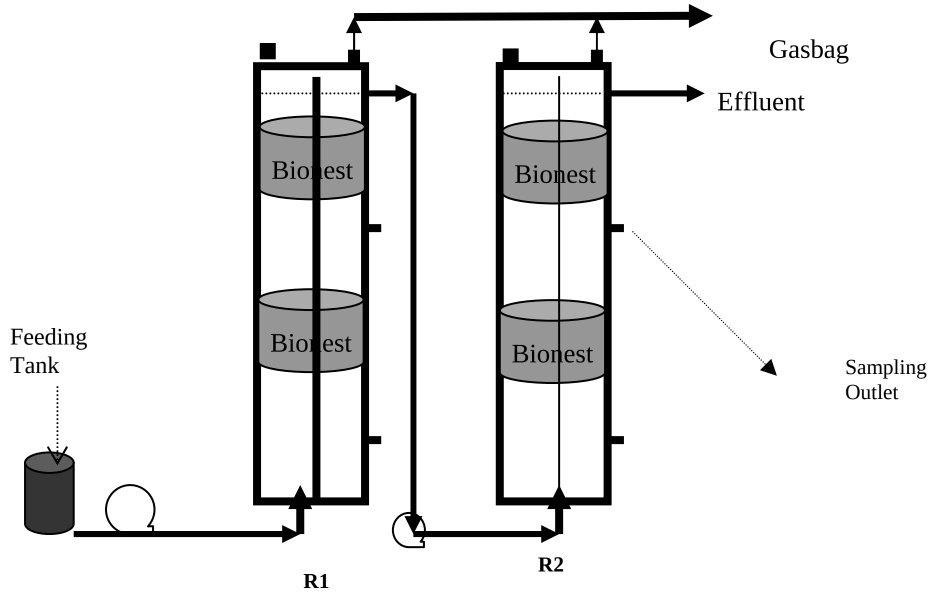

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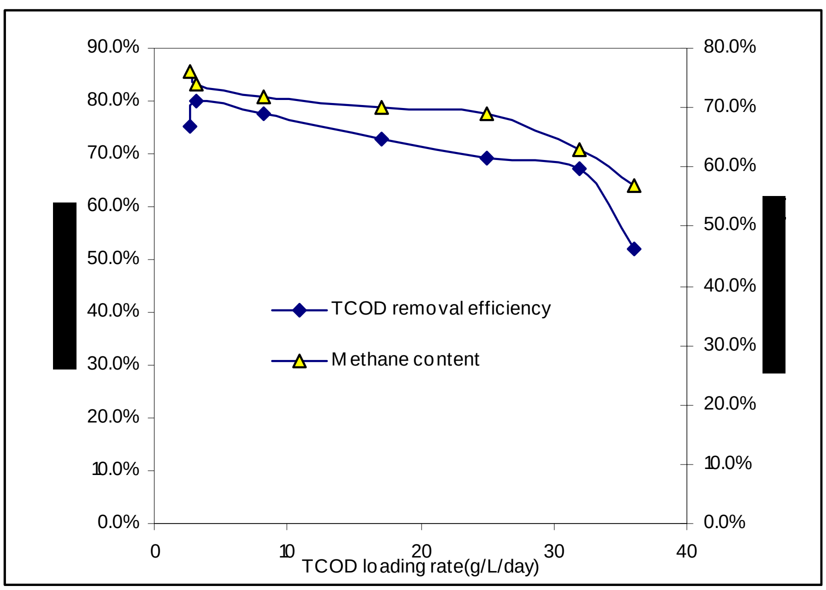

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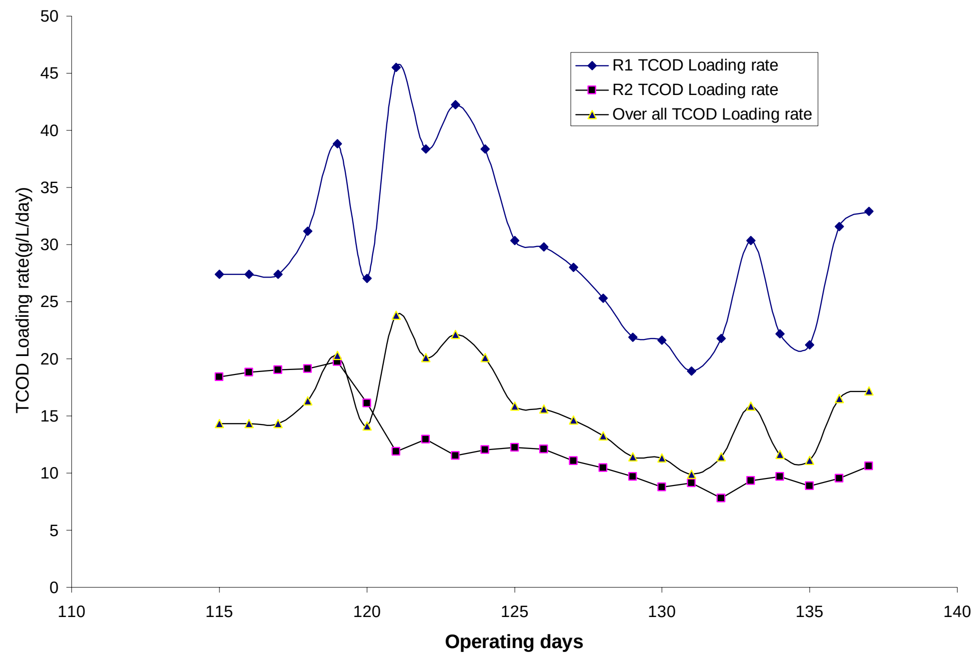

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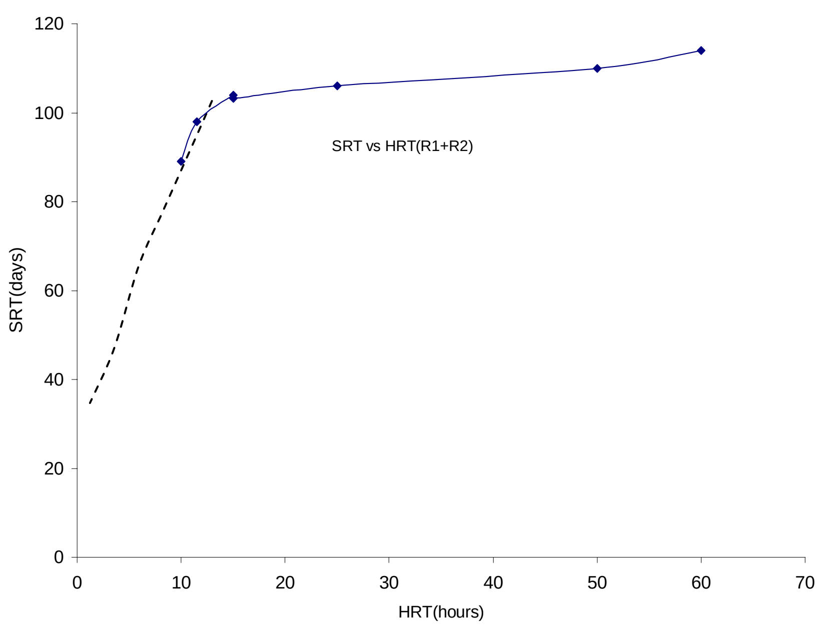

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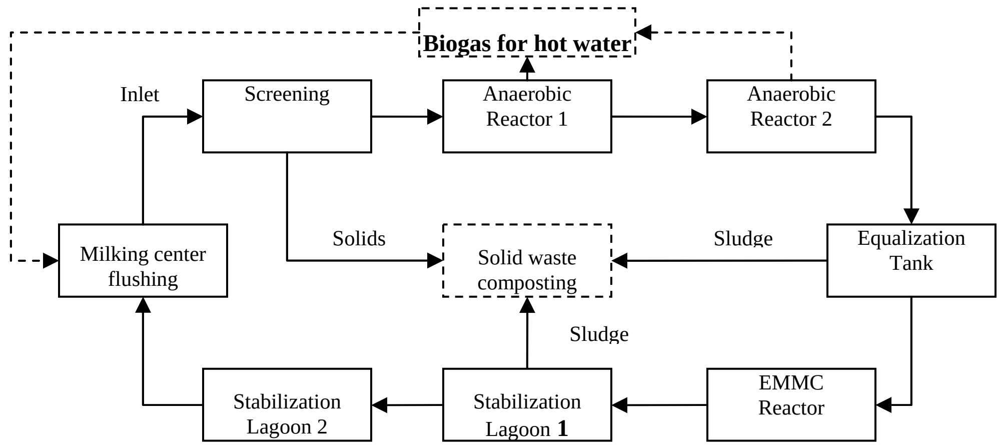

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Source of washing	Washing times/day	Temperature (^{0}C)	TSS(g/L)	VSS(g/L)	TCOD (mg/L)	SCOD (mg/l)	TKN (N mg/l)	Phosphorus (P mg/l)	Main component
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Average(26 of samples)		28	4.2	3.1	5200	1900	200	20.1	Mixed

Table 2 Sludge Layers and TSS Concentration

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(cm)	TSS(g/l)	TSS(g/L)
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19	47.2	43
40	32	30
46	22	26
65	23	23
70	18	25
85	26	27

Note: TVS/TSS at range of 78~84%

Table 3 Comparison of Different Reactors Performance under Different Operation Condition

Reactor Types	Wastewater (COD g/l)	Temperature (^0C)	Organic loading rate (COD g/l/d)	HRT (days)	TCOD Removal efficiency (%)	Source	Problem
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UASB	0.4-20	35	2.19	1.62	49	b	Granulation failed
UASB	Dairy 5.0-7.0	35	3.5-5	2	90	c	Granule support
UASB	Dairy 50-60	30	3.84		83	d	Digester
Anaerobic Filter	Dairy 4.9	35	6.38	0.93	66.9	b	
Bionest reactor	Dairy 5.0-13.5	20	15	0.63	70-75	Present study	

***a,** Cordoba et al, (1995)**; b** Hawkes et. al. (1995); **c** Ince (1998); **d**. Vartak et al., (1997).*

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DESIGN AND ANALYSIS OF AN ANAEROBIC BIO-NEST REACTOR

Liangjie Dong and P.Y. Yang

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ABSTRACT

A bioreactor, bio-nest, with simple design and operation with high treatment efficiency, was developed. This is the modification of design and operation of upflow anaerobic sludge blanket (UASB) and anaerobic biofilter reactor. A two-stage of bioreactor (10 l each), were operated for six months. They are filled with two layers of media which is 98% of void volume in the reactor. The reactors were operated in the ambient room of 22±2 ^{0}C. A loading rate ranged from 2.68 to 36 g/l/d of total COD (TCOD) using milk parlor wastewater was investigated. At organic loading rate of 36 COD g/l/d, the removal efficiency of total TCOD, soluble COD (SCOD) and total suspended solids (TSS) are 52%, 28.9% and 62% respectively. Methane gas production rate was 2.17 l/l/d with 57% methane content. If the recovery of methane gas and COD removal efficiency are the main objectives, the organic loading rate needs to be maintained at lower range. At organic loading rate of 3-4gTCOD /l/d, the removal efficiency of TCOD, SCOD and TSS are 81.8%, 59% and 79.9% respectively. Biogas production rate 2.6l/l/d with methane content of 73% can be achieved.

The unique operation of the bio-nest reactor is to achieve a higher COD removal efficiency with high organic loading rate by simple design and operation. This unique bioreactor could provide better sludge distribution, less dead zone and higher TCOD loading rate than conventional UASB does. Especially, the high fat content of milk wastewater was used in this study. The process performance, design and operation criteria were presented, discussed and compared with anaerobic filter reactor and UASB reactor. The simple design and operation of the bio-nest reactor investigated in this study can be easily integrated into the existing lagoon system (popularly in the United States) or integrated to the aerobic and intermittent aerobic treatment unit (e.g. EMMC, entrapped mixed microbial cell developed at UH) for further removal of carbon and nitrogen in order to dispose, discharge or reuse.

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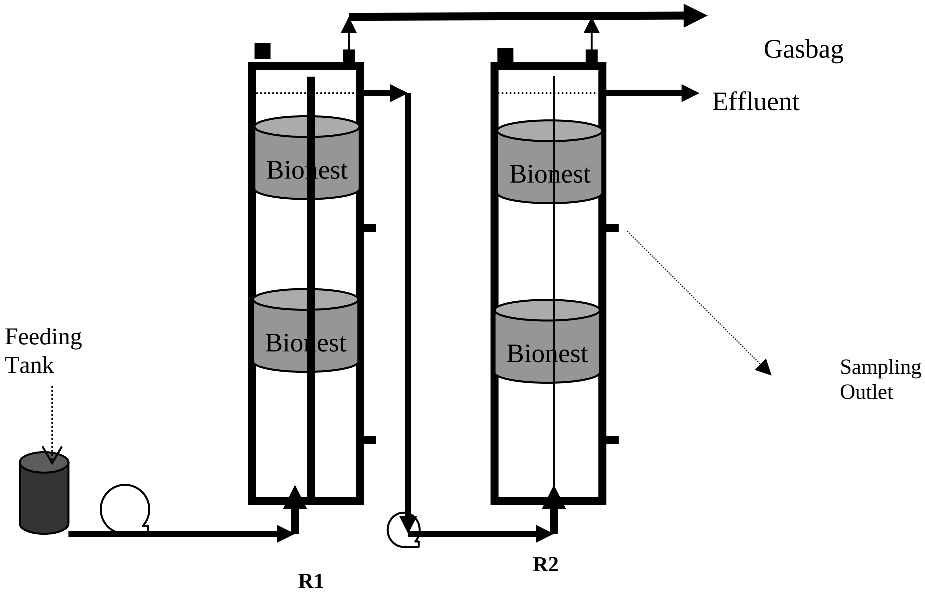

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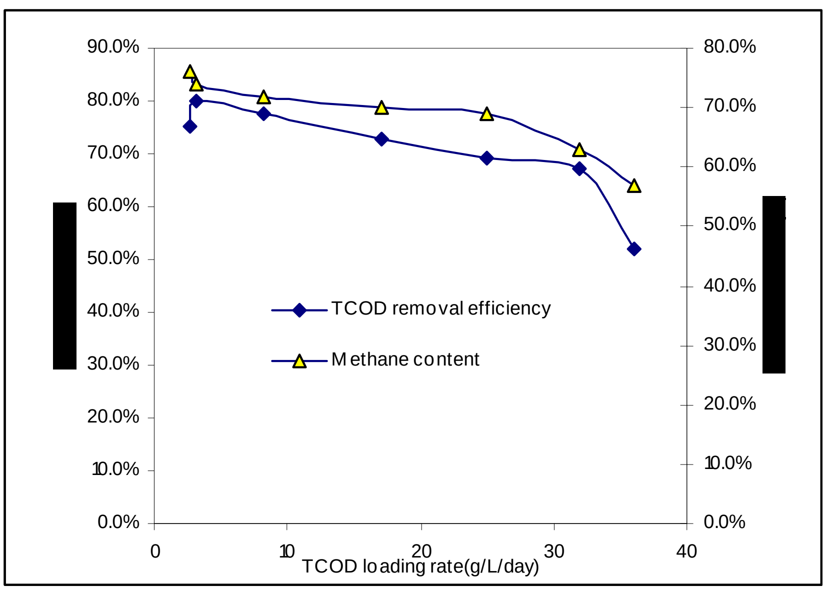

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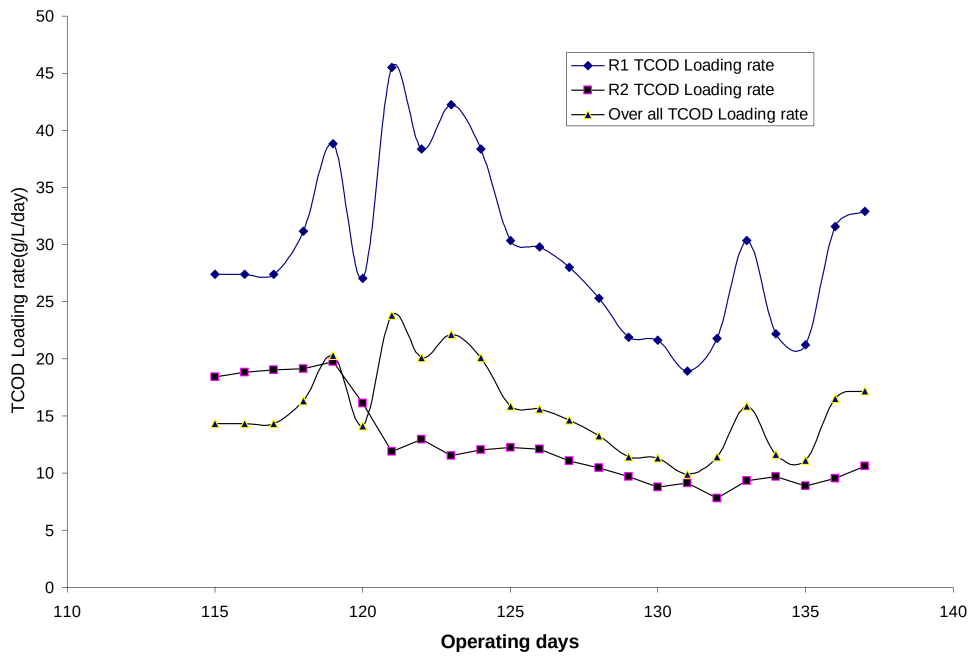

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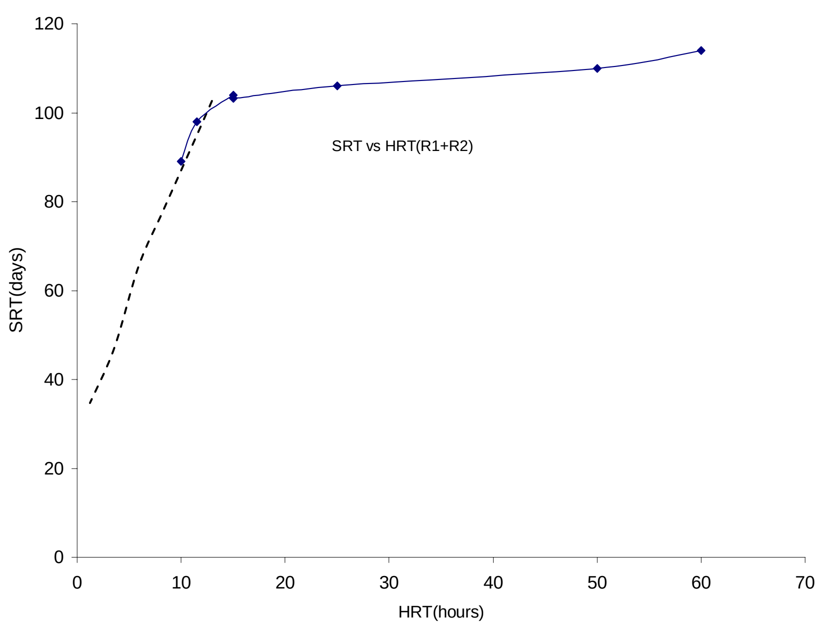

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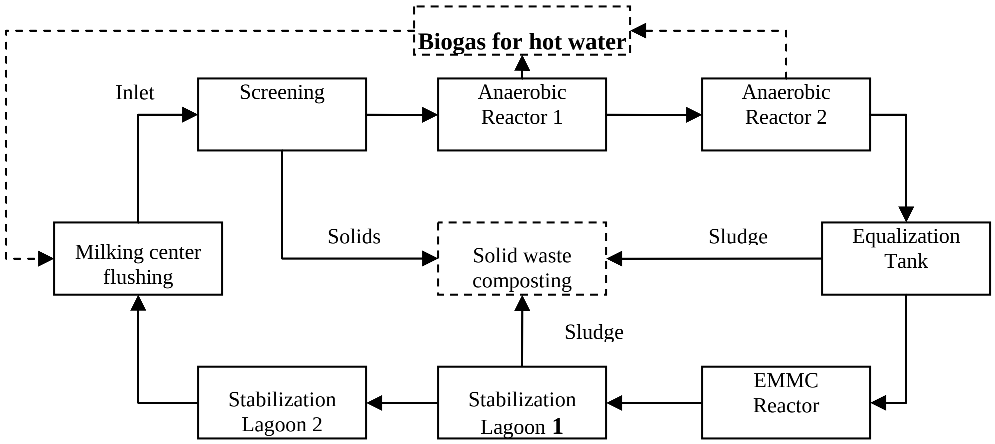

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Anaerobic Phased Solids Digester for Biogasification of Agricultural and Food Wastes

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A new advanced anaerobic digestion technology called Anaerobic Phased Solids Digester (APS-Digester) has been developed at the University of California, Davis. The APS-Digester is specially designed for biogasification of organic solid wastes that are normally difficult to process using conventional anaerobic digesters. A U.S. patent was issued for this technology. A typical APS-Digester system consists of one to four hydrolysis reactors and one biogasification reactor. The solids being digested is housed in the hydrolysis reactors, while most of the bacteria, especially methanogens, are housed in the biogasification reactor. The biogasification reactor is specially designed to maintain a high density of bacteria in the reactor for achieving efficient conversion. This paper reports the research results of applying the APS-Digester Technology for digestion of mixed agricultural and community biomass materials. Several types of organic solid wastes, including green waste, food waste, crop residue, and animal waste were co-digested thermophilically by the APS-Digester system. The digestion kinetics of individual waste and mixed wastes in different ratios were studied using laboratory experiments. The digester system was operated at 55°C. Recommended retention time, solids loading rate and mixing ratios of different wastes were developed for the APS-Digester system. Practical applications of the APS-Digester are presented.