Got Gas?
An Analysis of Wisconsin's Biogas Opportunity

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FOREWORD

This paper is a product of the Fall 2010 capstone course for the CHANGE (Certificate on Humans and the Global Environment) program in the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison. CHANGE was originally created as the training component of an NSF-IGERT (National Science Foundation – Integrative Graduate Education and Research Traineeship) program that funded graduate students at UW-Madison. Several of the researchers on this project are IGERT recipients. This capstone project was completed under the direction of Gary Radloff, Policy Director for the Wisconsin Bioenergy Initiative, and we are grateful for his commitment and insight.

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EXECUTIVE SUMMARY

Much research has addressed the potential for "green" technologies—such as anaerobic digestion—to provide clean, renewable alternatives to fossil fuels that can meet the nation's energy needs. However, few analysts have addressed the other potential impacts of these technologies. This report analyzes the potential suite of benefits that anaerobic digestion offers to the state of Wisconsin, beyond its utility as an energy resource.

At a statewide biogas stakeholder summit hosted by the Wisconsin Bioenergy Initiative in October 2010, producers, utilities, policy experts, researchers, and financial industry representatives identified the four most significant categories of biogas benefits in Wisconsin. Specifically, biogas may offer opportunities for:

1. *Waste Management:*
   Protecting Wisconsin's scenic waterways & drinking water, promoting public health, improving property values, and extending the life of municipal waste systems by:
      - Offering **LIVESTOCK** operations opportunities for nutrient management, odor control, pathogen reduction, & weed-seed reduction
      - Offering **FOOD PROCESSING** operations opportunities for solid & liquid waste management, & odor control;

2. *Energy Independence:*
   Reducing reliance on fossil fuel imports by supporting a versatile, predictable, and storable Wisconsin-made energy source;

3. *Additional Economic Opportunities*:
   - Creating "green jobs" and new industry in Wisconsin
   - Offering new income sources and/or avoided costs for dairy producers that utilize digested solids for animal bedding and/or fertilizer
   - Capitalizing on the potential for linking with emerging carbon markets

4. *Greenhouse Gas Emissions Reductions*:
   Providing a clean, sustainable future for generations of Wisconsinites.

We offer qualitative and—when possible—quantitative assessments of each of these benefits. We identify challenges, controversies, and information gaps in need of further analysis. In addition, we include a scenario analysis of each benefit for three systems: (1) an average Wisconsin dairy farm (~100 head of milk cows), (2) a Wisconsin Concentrated Animal Feeding Operation (~1000 head of milk cows), and (3) a Wisconsin food processing plant.

According to our analysis, biogas does appear to offer Wisconsin a host of benefits. However, this document is not a definitive assessment of these benefits. Rather, it is intended as a starting point for researchers, policy makers, producers, and other experts to critically examine Wisconsin's biogas opportunity.

INTRODUCTION

What is Biogas?

Biogas is produced when microorganisms break down organic waste—such as manure, crop residues, or food waste—in the absence of oxygen. Biogas is a complex mixture of several gases, but the majority of the product is methane (typically 40-75%), the main component of natural gas. Biogas can be used in any of the ways conventional natural gas would be used. It can be combusted to produce electricity and heat, cleaned and upgraded for injection into existing natural gas pipelines, or cleaned and compressed to create transportation-grade fuel. In addition to producing gaseous methane, biogas systems also generate liquid and solid products. The digested solids are rich in phosphorous and can be used on-farm as animal bedding or sold as a soil additive. The liquid effluent can be land-applied directly as a nitrogen-rich fertilizer.

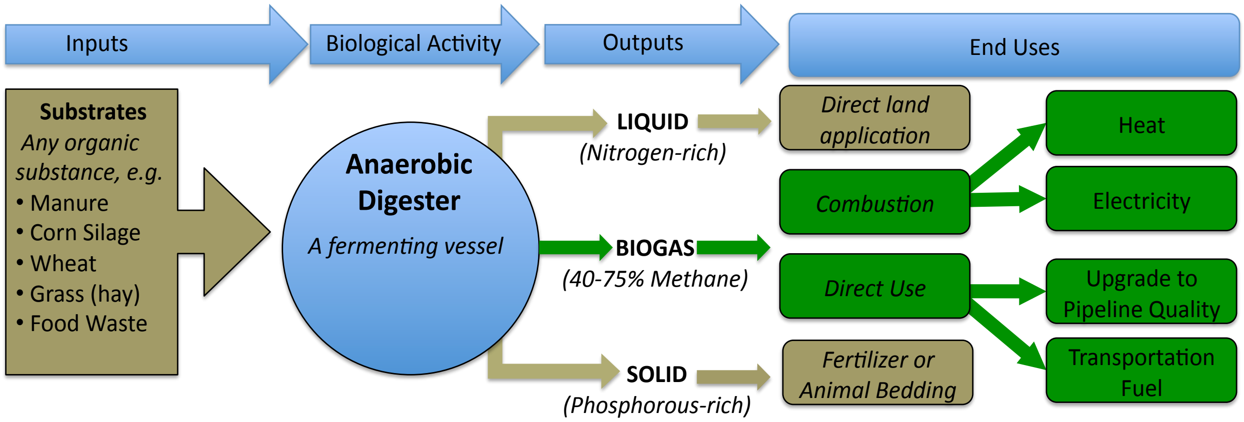

Figure 1. Schematic representation of the process of anaerobic digestion.

Figure 2. From left to right: (a) An on-farm anaerobic digester, (b) a facility that upgrades biogas to pipeline quality renewable natural gas near Freiburg, Germany, and (c) a combustion engine that coverts biogas to electricity.

Farming Microbes: Small-scale Husbandry

Anaerobic digestion is carried out by a naturally-occurring community of many species of bacteria that thrive in areas with low oxygen and plenty of organic matter—such as in the gastrointestinal systems of cattle and people. The rate and efficiency of this digestion depends upon both the chemical structure of the substrate and the stability of the bacterial communities. Selecting a consistent mix of substrates with high energy content that is readily available to the bacteria (like simple sugars and fats) maximizes biogas production. On the other hand, feeding the digester highly variable substrates with nutrients locked away in compounds that bacteria cannot digest (like lignin and cellulose) leads to poor biogas yields.

Manure is actually among the least efficient substrates for biogas production (25-45 m^3 biogas per ton). Microbial communities in the gastrointestinal system of the cow have already digested the organic material, and thus much of the energy/nutrients have already been extracted. In contrast, maize silage produces several times more methane than manure (202 m^3 biogas per ton). Other substrates, such as food wastes, can yield even more biogas; for example, food scraps (265 m^3 biogas per ton), bakery wastes (714 m^3 biogas per ton), and fats and grease (961 m^3 biogas per ton).[1]

Each digester should be individually designed and maintained based on the unique conditions of its site. A mixture of co-substrates from agricultural, municipal, and industrial products can be combined to optimize biogas production. There is not one "magic mix" that will work for all digesters, and each producer should analyze the trade-offs inherent in selecting an appropriate mix of substrates.

Substrate considerations:

- How much energy is in the substrate?
- How consistent is the substrate energy/nutrient content over time?
- How reliable is the substrate source?
- What is the cost of collecting/transporting the substrate to the digester site?

Like all living things, these microbial communities must be nourished and cared for in order to grow. Microbes will perish if exposed to toxins such as detergents, high salt concentrations, antibiotics, high concentrations of metals, bleach or other harsh chemicals. They will flourish if kept at a constant temperature and fed an energy-rich, high-quality feedstock. A well-designed and operated anaerobic digester will provide the optimal conditions for these microbes to survive and reproduce.

Research Priorities:
Which substrate combinations will…

- Optimize biogas production?
- Support optimal microbial community compositions?
- Utilize Wisconsin's existing resources or address its existing challenges?

Technology Spotlight:
Digester Additives

New small businesses in Germany offer customers monthly microbial monitoring services. A lab analyzes samples from the digester and identifies key micronutrient and enzymatic additives that will optimize digester performance.

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[1] Substrate yields derived from http://www.fnr-server.de/cms35/index.php?id=399 and http://biogas-energy.com/site/BiogasEnergy.pdf

Basic Biogas Systems

Anaerobic digestion, like all biologically mediated processes, is dependent upon several operational conditions, that when optimized, will generate the most gas production. Some of the operational conditions that can be optimized include:

Reactor Configuration

There are several different design configurations available. In Wisconsin, the most common configurations are *completely mixed* and *plug-flow* processes. The completely mixed configuration induces mixing by mechanical (e.g. stirrers) or convection (e.g. mixing induced by the gas produced inside the reactor). This design is used to ensure that fresh manure and the microorganisms are brought together efficiently and that crust layers are prevented from forming—resulting in less time required for the digestion to be completed. The plug-flow reactor treats waste in such a manner to move the waste through the reactor as "plug" with minimal mixing in the direction of flow. This can result in a very efficient process that can decrease the amount of time for reactions to be completed.

Temperature

Reactors can be run at different temperature regimes—*mesophilic* and *thermophilic*. The temperature for mesophilic operations is 35°C whereas thermophilic operations use temperatures of 55°C to 65°C. The temperature impacts several operational parameters including the rate of chemical reactions and the ability for specific organisms to survive under these conditions.

Dairy and Food Processing: Wisconsin's Biogas Potential

Wisconsin's dairy industry contributes $26.5 billion per year to the state's economy.[1] Each year, the 1.26 million dairy cows in the state's 12,500 licensed milk herds generate approximately 23 million tons of manure, 14 million pounds of nitrogen, and 6 million pounds of phosphorous.[2, 3] Dairy operators spend $48.5 million annually on manure management to protect Wisconsin's watersheds.[2] Despite the best efforts of these producers, manure-related phosphorous loading in Wisconsin's waterways remains a serious concern for homeowners, fishermen, recreational users, and others across the state. If anaerobic digestion can provide a new tool for manure management, this technology would provide a critical secondary benefit of pollution control in addition to energy production. Properly promoted and regulated, biogas could offer America's Dairyland a new source of on-farm income not subject to commodity price fluctuations while contributing to Wisconsin's long history of environmental stewardship.

Wisconsin is home to more than 1000 food-processing facilities with large numbers of brewers, cheese producers, and processors of meat, fruit, vegetables, and grains. These industries generate nearly $10 billion in revenue each year and employ over 60,000 Wisconsinites.[4] These facilities also generate a large amount of solid and liquid organic waste that put increased strain on the state's landfills and wastewater treatment plants—a cost for industry and the public alike.[5, 6] Anaerobic digestion is a cost-effective way to treat food-processing waste.

Wisconsin currently boasts at least 31 on-farm anaerobic digesters, the most of any state in the United States, and at least 27 food processing anaerobic digesters[7].[2] The installed electric generating capacity of the on-farm systems alone is approximately 12 MW – enough to power over 10,000 homes. An upcoming industrial digester case study report by the Energy Center of Wisconsin analyzes the current capacity of anaerobic digesters at food processing facilities in Wisconsin, and suggests that their use is expanding. However, the overwhelming majority of dairy farms and food processors are not employing anaerobic digestion to manage their waste. In recent years, the state has experienced a relative plateau in the creation of new digesters despite the range of policies and programs that could propel biogas expansion in Wisconsin.[3] This leads to the question: why hasn't biogas been more successful in Wisconsin?

Assessments of Wisconsin's biogas potential have only described the *direct* benefits of energy use without carefully considering of all the potential benefits associated with anaerobic digestion. This has created a policy environment that may not value the real potential for biogas production in the state of Wisconsin. Wisconsin has specific assets (such as a thriving dairy industry and a high concentration of food processors) and specific needs (such as reduced nutrient loads on recreational waters) that can be directly addressed by anaerobic digestion.

To properly evaluate Wisconsin's biogas potential, we must assess not only the obvious energy benefits of this technology, but also the previously unquantified co-benefits or avoided costs that may accompany its use in Wisconsin. Could these biogas benefits ultimately support the dairy industry in Wisconsin, create new jobs for Wisconsinites, and improve the state's air and water quality? If so, biogas offers the state a triple bottom line worthy of further evaluation.

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[2] This study does not differentiate between food and non-food industrial processors, so the specific number of food processing facilities with anaerobic digestion is difficult to determine.

[3] For a complete analysis of these policies, see the Bilek (2010) report on how federal, regional, and state policies could contribute to provisions outlined in Wisconsin's Renewable Portfolio Standards (RPS) of 10% renewable energy production by 2015.

METHODS AND OBJECTIVES

Wisconsin Stakeholder Engagement

Representatives from the dairy industry (producers), government agencies (natural resources and agriculture), the finance sector, environmental groups, energy utilities, the biogas industry (facility design, construction, and operation), university researchers, and policymakers gathered at the Wisconsin Bioenergy Institute Summit on October 14-15, 2010 in Madison. Together, these stakeholders identified a suite of benefits associated with biogas technology, hurdles to adopting this technology, and creative policy ideas to spur biogas development in Wisconsin. We documented these discussions and used them as a starting point for our research.

Wisconsin Biogas Benefits Analysis

Guided by the ideas offered at the Wisconsin Biogas Stakeholders Meeting, we reviewed the academic and industry literature to provide a qualitative assessment of the potential magnitude of each biogas benefit for Wisconsin. Then we used existing data and software to conduct a preliminary quantitative analysis of these benefits for Wisconsin. For this quantitative analysis, we present three scenarios that we believe represent the typical range of promising biogas applications in Wisconsin: an average size farm (<100 head milk cows), a concentrated animal feeding operation (CAFO), and a food processing operation. This analysis does not report definitive values for each scenario. The calculation of co-benefits will always depend on site location, previous activities, and other external influences. Instead, this analysis explores whether anaerobic digestion can be used in each scenario as a tool to provide opportunities for improved waste management, support energy independence, offer a range of new economic opportunities, and reduce greenhouse gas emissions. Information gaps and future research priorities are identified. Assumptions regarding these three scenarios (average farm, CAFO, food processor) and other inputs into our models can be found in the References section (please see Quantitative Source Data and Assumptions).

Future Analyses: Understanding Wisconsin Biogas Challenges

Our analysis focuses exclusively on understanding and quantifying biogas *benefits* in Wisconsin. However, we acknowledge that important *challenges* with this technology require careful consideration by policymakers and others interested in anaerobic digestion. Although we do present possible hurdles to biogas expansion and some of the suggested solutions identified by the stakeholders, this report *does not conduct an analysis of these challenges*. We urge future researchers and interested policymakers to carefully consider these challenges and costs in light of the benefits that we assess in this paper.

BIOGAS BENEFITS IN WISCONSIN

Here we explore the range of benefits and avoided costs, beyond energy production, that anaerobic digesters can offer to Wisconsin. Our goal is not to provide a definitive answer to the question of what biogas is worth to Wisconsin, but rather to jumpstart the discussion among policy makers, researchers, economists and energy experts. We evaluate four types of benefits identified by stakeholders at the October 14-15, 2010 Wisconsin Bioenergy Initiative (WBI) Biogas Stakeholder Meeting in Madison, WI:

1. *Waste Management:*
   Protecting Wisconsin's scenic waterways & drinking water, promoting public health, improving property values, and extending the life of municipal waste systems by:

      - Offering **LIVESTOCK** operators opportunities for nutrient management, odor control, pathogen reduction, & weed-seed reduction
      - Offering **FOOD PROCESSING** operations opportunities for solid & liquid waste management, & odor control;

2. *Energy Independence:*
   Reducing reliance on fossil fuel imports by supporting a versatile, predictable, and storable Wisconsin-made energy source;

3. *Additional Economic Opportunities*:
   - Offering new income sources and/or avoided costs for dairy producers that utilize digested solids for animal bedding and/or fertilizer
   - Creating a new industry in Wisconsin
   - Capitalizing on the potential for linking with emerging carbon markets

4. *Greenhouse gas emissions reductions*:
   Providing a clean, sustainable future for generations of Wisconsinites.

Benefit 1: WASTE MANAGEMENT

Key Points

DAIRY FARM WASTE AND NUTRIENT MANAGEMENT

Wisconsin dairy farmers spend $48.5 million a year on manure management. Anaerobic digestion has the capacity to improve manure management by mitigating:

- *Nutrient Loading*: Anaerobic digestion can mitigate nutrient loading by
  - (1) Converting nitrogen & phosphorous to forms easily absorbed by terrestrial plants.
  - (2) Reducing the volume of manure produced through evaporative loss.
  - (3) Using post-digestion solid-liquid separation to retain phosphorous in the solid waste and nitrogen in the liquid potion.
  - (4) Using other post-digestion technologies to maximize phosphorous extraction.
- *Odor*: Odor reductions offered by anaerobic digestion could increase rural property values while reducing odor complaints.
- *Weed-Seeds*: Anaerobic digestion reduces weed-seed content, but not more than other treatments.
- *Pathogens*: Reducing pathogen-loads in manure via anaerobic digestion has the potential to:
  - (1) Reduce health-care costs associated with water- & food-borne illness.
  - (2) Increase state park revenues by reducing beach-day advisories.
  - (3) Reduce strain on Wisconsin's aging municipal water facilities.

FOOD PROCESSING WASTE AND NUTRIENT MANAGEMENT

Food processing plants produce large volumes of liquid and solid waste. Aerobic waste treatment is energy-intensive and thus very expensive. On-site anaerobic waste treatment offers the industry:

- The lowest cost option for wastewater treatment for many systems.
- A decrease in wastewater strength (BOD) by about 90% without external input of energy.
- Potential saving of over $500,000 per year for a representative facility compared to treatment at the municipal wastewater treatment plant.
- Reductions in the cost of landfill tipping fees by reducing solid waste volume.
- An effective tool for reducing odor emissions from waste treatment and/or disposal (analysis presented in 'Dairy Farm' section).

Research Priorities

- Identify digester designs & operational practices which optimize:
  - Nitrogen & phosphorous nutrient conversion.
  - Phosphorous retention in the solids and nitrogen in the liquid portion.
  - Manure volume reductions.
  - Pathogen reductions.
  - Weed-seed reductions.
- Create a standardized pathogen monitoring system for anaerobic digesters with a recommended set of indicators that can be assessed with rapid, molecular diagnostics.
- Quantify the capital costs of investing in on-site anaerobic treatment technology at food processing plants.
- Explore alternative feedstocks, including blending food processing waste steams with off-site waste sources and the potential of co-locating agricultural and food processing digester systems.
- Combine theoretical and empirical approaches to better estimate optimal conditions for anaerobic microbial communities for decomposing waste streams and maximizing methane output.
- Identify the best opportunities for installation of anaerobic systems.
- Develop policies and/or incentives for the adoption of anaerobic treatment best management practices, both from environmental and energy cost saving perspectives.

1. Dairy Farm Waste and Nutrient Management

Nitrogen and Phosphorous Loading: A Wisconsin Challenge

In Wisconsin, dairy farmers spend $48.5 million annually on manure management. Manure management influences the nutrient levels in soils, adjacent surface waterways, and groundwater reservoirs. Increased nutrient loads from land-application of manure has resulted in degraded water quality in Wisconsin's scenic waterways, causing eutrophication of lakes from increased phosphorous, decreased dissolved oxygen concentration from organic compounds, and contamination of groundwater from nitrate and nitrite. In Wisconsin, 172 lakes are listed by the DNR as polluted by phosphorous.[8, 9] Cost-effective strategies to reduce nutrient inputs to waterways will improve ecosystem services and help local and regional economies that depend on recreational activities. From 2000-2007, the Wisconsin DNR issued over 1.3 million angler permits, corresponding to nearly $17 million dollars in revenue.[10] Hypoxic conditions created by nutrient-rich waters pose a threat to Wisconsin's fishing industry. The implementation of anaerobic digestion on dairy farms in Wisconsin can be the integral part of an effective nutrient management program that mitigates the negative effects of nutrients on our waterways.

To protect water sources as promulgated under the Clean Water Act, all dairy producers need to comply with the Natural Resource Conservation Service Nutrient Management Standard (590) that limits liquid manure application rates in surface water quality management areas. Additional solid and liquid manure winter application restrictions are outlined in Wisconsin's DNR regulations on Animal Feeding Operations (WI NR 243). Farmers are required to calculate the amount of nitrogen and phosphorous that can be applied to the land each year based upon site-specific parameters.[11-15] The DNR has also imposed phosphorous bans in certain regions in order to protect water quality, particularly in recreational waters such as the Yahara and Fox Valley Watersheds. Regional calculations for phosphorous budgets have been published for specific lakes and selected Wisconsin areas.[16, 17]

Estimating the "Cost" of Phosphorous in Wisconsin

Pilot studies of potential nutrient credit trading programs in the Lower Fox River Valley Basin of Wisconsin have tried to estimate the cost of preventing watershed-level phosphorous contamination.[18] The researchers from these studies concluded that the optimal phosphorous management strategy—the strategy that would successfully reduce non-point source run-off to levels specified in the watershed's published phosphorous budget—could cost non-point sources up to $138 per year to prevent one kilogram of phosphorous from entering the watershed. Understanding how much phosphorous run-off can be attributed to a typical dairy operation is a sensitive and highly contentious issue. Dairy producer manure management strategies vary widely, and farm-level phosphorous contributions are a direct result of farm-level practices. Rough estimates based on empirical site studies suggest that dairy farms *could* contribute 1-3 kg of phosphorous per acre. Using these rough estimates, we suggest that the "real" value of phosphorous pollution on Wisconsin farms could be somewhere between $138 and $414 per acre.

Anaerobic Digestion: A Wisconsin Nutrient Management Solution

Anaerobic digestion can mitigate dairy farm nutrient loading in four ways. First, the digestion process converts nitrogen and phosphorous into forms that are more readily available for terrestrial plant uptake thereby minimizing the portion that comprises non-point source discharge and enters water bodies as runoff. Second, anaerobic digestion significantly reduces the volume of manure produced through evaporative loss. Third, when used in conjunction with solid-liquid separation systems, anaerobic digestion retains more phosphorous in the solid digestate, simplifying phosphorous handling. Finally, anaerobic digestion allows for the use of post-digestion technology that improves effluent phosphorus management. Taken together, these processes allow for easier and more effective on-farm nutrient management.

Anaerobic digestion does not change the total *mass* of nitrogen and phosphorous in the manure, but it does change the *chemical form* of nitrogen and phosphorous in the manure.[19] Specifically anaerobic digestion converts phosphorous into orthophosphates and nitrates/nitrites into ammonia.[20] Orthophosphates and ammonia are the forms of phosphorous and nitrogen found in commercial fertilizers. These particular chemical compositions of phosphorous and nitrogen are more readily utilized by plants, and rapid plant uptake prevents these nutrients from leaching into Wisconsin's waterways.

Scientists still debate *how much* of the nitrogen and phosphorous in manure is converted to biologically available forms during anaerobic digestion. Wright (2004) estimates that 30-37% of the nitrogen is converted to ammonia while orthophosphate increases by 26% from the digestion process. Another study reports orthophosphate conversions of 3-60%.[19] A more recent study in New York reports that manure ammonia-N and orthophosphate levels increase by an average of 24% and 15%, respectively, as a result of anaerobic digestion.[21] Conversion success is highly dependent upon operational conditions of the digester, the manure composition (animal feed used and substrate additions), and the storage time. Storage time of the digestate can result in a loss of ammonia due to volatilization and released as nitrogen gas.[19] To further complicate this issue, the use of substrate additions to increase biogas yield may result in large surpluses of potassium and low phosphorus returns.[22, 23]

Anaerobic digestion also effectively reduces the volume of manure by 22-62%.[19] These reductions are caused by evaporative loss during the digestion process, creating highly concentrated post-digestate slurry. Although evaporative loss does not result in any changes to the total nutrient content of manure, it does make the effluent easier to handle on-farm by reducing strain on manure lagoons.

Post-digestion technology can make this reduced volume of effluent even more manageable. Anaerobic digesters can be easily coupled with a solid-liquid separator. Phosphorous is largely captured in the solid waste, while nitrogen remains in the liquid portion. A comprehensive study conducted on six farms in Wisconsin that employ anaerobic digestion reported that anaerobic digestion successfully stabilized 70-80% of phosphorous in the solid waste.[20]

Finally, new technology can be incorporated into anaerobic digesters to precipitate the phosphorous in various forms (an example is the Ostara process to produce struvite – a phosphorous-rich precipitate or crystal of magnesium ammonium phosphate). In these systems, phosphorous is captured in a pellet form that prevents it from being discharged in the plant effluent and makes a product suitable for sale as fertilizer.[24] A struvite recovery system is planned for the Dane County community digester project, as Dane County is especially concerned with phosphorous loading in its waterways.[25]

Integrating Anaerobic Digestion into Existing Nutrient Management Tools

Although anaerobic digestion is mentioned as a best management practice in some of manure management guidelines produced by the DNR and other agencies, more explicit recognition and quantification of the potential benefits of this technology on nutrient management is needed before dairy producers can be given clear guidance and support. Integrating incentives for anaerobic digestion into the existing manure management framework holds great promise for Wisconsin.

If the nutrient management benefits derived from anaerobic digestion could be consistently quantified, they could also be incorporated into existing programs that are designed to help producers create manure management plans. For example, the Wisconsin Natural Resource Conservation Service has certified nutrient management planners that assist farmers in determining the amount of nutrients that can be applied to the land based upon crop plans, previous practices, and applicable regulations.[11] These planners could be trained to include anaerobic digester calculations as part of their assessments.

In addition, the University of Wisconsin offers *The Wisconsin Nutrient Management* software SNAP-Plus that integrates the current regulations into the nutrient management plan and estimates outputs of nutrient by farm fields. Each farm has to provide a yearly plan and state how their current practices, such as the manure storage structures, barnyard, biogas, and timing for spreads, along with manure/soil test and crop management, would provide runoff controls to improve manure management and protect water quality. This strategy offers the advantage of managing nutrients within large tracts of land that might be under the management of one farmer or within a very sensitive portion of the watershed. Creating an additional component for the SNAP-Plus scenario tool could incorporate nutrient management benefits of anaerobic digestion.

Finally, anaerobic digestion can be integrated into new approaches for nutrient management focus on watershed management nutrient-trading schemes. In these strategies, a "total maximum daily load (TMDL)" representing a level of phosphorous and other nutrients that are permissible to be discharged in the watershed, is established based upon the soil characteristics, topography, and hydrological conditions of each watershed. Phosphorous credits are then established and allocated to farms, municipalities, and other point and non-point sources of phosphorous pollution. These credits can be traded in the marketplace, providing financial incentives for best management practices that minimize nutrient additions. Additional credits for anaerobic digester installation could be incorporated into such programs.

A watershed-based pollutant trading pilot-study was initiated in Wisconsin in 1998 for the Red Cedar River, Lower Fox River/Green Bay, and Rock River Valleys. Anaerobic digestion was *not* considered as a best management practice for credit trading purposes.[9] Future nutrient credit trading strategic plans should consider the potential impacts of anaerobic digestion on mitigating phosphorous release.

Odor Reductions

Anaerobic digesters offer significant opportunities for odor reductions on farms, an important benefit for neighboring communities. Noxious odor emissions from livestock waste are a result of sulfides (H_2S) from sulfate-reducing bacteria, the conversion of organic nitrogen to ammonia, and volatile organic compounds (VOCs) from the incomplete decomposition of other organic substances. In a study in Ohio, 92% of those living near and 79% of those living far from large-scale dairy operations identified the odor of manure as a concern.[26] Between 1998 and 2007, more than 1,289 complaints associated with agriculture operations were recorded in the state of Michigan alone. Over 75% of these were associated with odor and surface water. In this study, even farms employing commonly accepted best management practices for manure handling were often sources of odor complaints.[27] This highlights a limitation of current approaches to on-farm best management practices for manure.

Many dairy producers wish to limit odors in order to be better neighbors. John Pagel, owner of Pagel's Ponderosa Dairy, a farm in Kewaunee with an on-farm digester, expresses this sentiment:

> It's hard to put a value on nearly eliminating odor. When we decided to house so many cows in one location, it was our responsibility to make sure we'd still be good neighbors. We have had no complaints from neighbors and they love that we are making renewable energy [28]… In fact, the most important benefit of a digester may be odor reduction.[29]

Odor reduction is also frequently cited by food processing plants as a motivation for installing anaerobic waste treatment technology.[7, 30, 31] Odor emissions from the treatment and disposal of food waste can be significant, negatively affecting communities near food processing plants. Compared to other waste treatment techniques, anaerobic digestion is more effective at controlling odor emissions.[5] While the analysis below focuses on odor reduction using anaerobic digestion for livestock operations, it is also applicable to food processing facilities.

Best management practices

Currently, a wide-range of methods and management practices are employed to address odor issues. The Wisconsin Department of Agriculture Trade and Consumer Protection (DATCP) and Department of Natural Resources (DNR) evaluated the ability of four on-farm best management practices to reduce odors: anaerobic digestion, permeable covers, impermeable covers, and solid separation/aeration treatment.[32] Each management strategy decreased odor emissions when operated correctly; however only the impermeable covers reduced odor emissions almost entirely. Evaluation of the anaerobic digestion was based upon the odors coming from digested manure stored in an open location. Partially digested manure can result in increased odorous emissions, but optimized operational conditions that ensure complete digestion will reduce this concern. It is important to note that, unequivocally, anaerobic digestion will decrease manure hydrogen sulfide content—a major component of odor emissions—but based upon system design (mesophilic vs. thermophilic) ammonia emissions—another source of unwanted odors—may either increase or decrease. Anaerobic digesters typically include an impermeable cover as part of the gas collection system. Digested solids that are stored under an impermeable cover will provide added reduction in odors as moisture content is minimized and eliminate the ensuing bacterial growth of the nuisance microbes responsible for noxious emissions.

Other odor reducing strategies that were not included in the DATCP study are currently being used in Wisconsin. These include biofilters (emissions are collected and routed through a tank filled with peat, promoting the removal of the noxious odor), chemical additives that attempt to reduce the microbes responsible for odors, as well as other odor source reduction techniques. According to Wisconsin's DATCP regulation on Siting of Feedlot Operations (WI ATCP Rule 51), there are several management strategies listed to reduce the impact of odor emissions from livestock operations. These practices focus on the reduction of emissions from the housing of the animals (diet changes, frequency of cleaning manure stalls, etc), lot operations (moisture control, windbreaks), and storage facility designs (covered, anaerobic digestion, composting). In establishing specific actions within the required odor management plan, an odor index is established by considering factors such as typical wind patterns, development density, distance to the nearest neighbor (those within 1300 feet), and the control/management practices integrated into current or future operations as outlined above.

Methods to quantify odor emissions

Odors can be measured using olfactometry measurements, recording annoyances (complaints), and sophisticated analytical air measurements to identify known odor generating compounds. Olfactometry measurements rely upon trained analysts that subjectively categorize the intensity of an odor that is statistically translated into an odor index value (ODI). Sophisticated air sampling that uses gas chromatography (GC) to detect common odorants can be very costly. Incorporating these methods has resulted in several approaches that can be used to quantify the impact of livestock operation odor emissions upon the quality of life for neighbors. Two methods, the OFFSET Tool and the hedonic price model, offer policymakers opportunities to quantify the reduction of odors by anaerobic digesters.

OFFSET Tool

The University of Minnesota Extension consolidated empirical results from studies of different management practices and their impact on odor reduction on over 200 livestock farms (dairy, swine, beef, and poultry) to create the OFFSET (Odor From Feedlots Setback Estimation) tool.[33] This model enables livestock producers to estimate their odor emissions and is similar to the worksheet required in the WI ATCP Rule 51 application process for livestock operations.

In order to quantify the benefit of odor reduction, the OFFSET tool correlates annoyance reduction with separation distance based upon a total odor emission factor (Figure 3). Better odor management practices and greater distance from the farm result in fewer annoyance complaints. The odor emission factor is based upon livestock operation practices and technologies employed on-farm. This strategy suggests that to decrease annoyance, livestock producers should increase the distance from the farm to the closest neighbor. However, increased land use pressure from suburbanization has resulted in new subdivisions in closer proximity to farms, making reliance upon setback distance to mitigate the effect of noxious odor emissions more challenging.

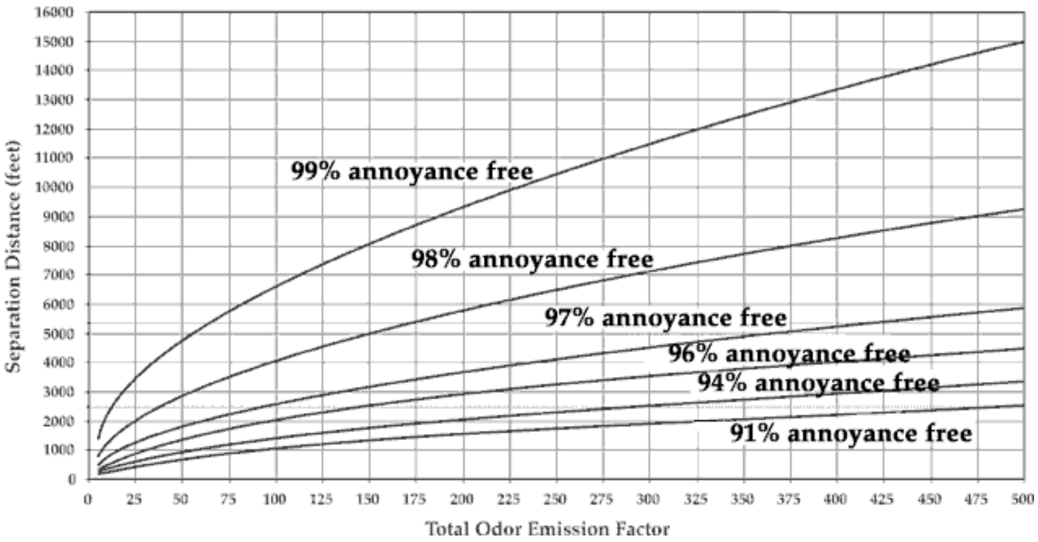

Figure 3. The University of Minnesota OFFSET Annoyance Reduction Setback Tool. This figure shows that better odor management practices and greater distance from the farm result in few annoyance complaints.
Source:
http://www.extension.umn.edu/distribution/livestocksystems/images/7680chart.gif

Hedonic Price Model (HPM)

There are several studies that combine GIS data with a hedonic price model to study the impact of proximity to feedlot operations upon residential real estate values. A hedonic price model attempts to explain the selling price of a house in terms of its physical attributes and surrounding environment by evaluating factors such as the lot size, square feet of living area, age of the house, number of bathrooms, distance to the nearest park, and proximity to agricultural operations. The impact of agricultural operations is usually expressed as the density of animals divided by the distance from the operation. In one study conducted in North Carolina, proximity to hog operations that were not using optimal odor mitigation strategies resulted in a 3-4% decrease in property value for homes that were located 800-meters (approximately a half-mile) away.[34] In suburban and urban areas, others have reported that increased proximity to livestock operations can decrease property values by as much as thirty percent.[35] A reduction in residential property values can have wide ranging economic impacts including decreases in taxable revenue at the county-level.[36]

A conservative estimate of what odor reductions could mean for Wisconsin property values demonstrates how financially significant this benefit could be for the state. According to the 2000 census, about 1.5 million people reside in rural areas in Wisconsin. Let us assume that 5% of these people are affected by livestock odor, and that the average size of a rural household in Wisconsin is 3 persons. If we assume the average value of home in Wisconsin is worth $100,000, we can quickly calculate that the total value of homes affected by livestock odors is somewhere around $2.5 billion dollars:

> 1.5 million people * 5% affected ÷ 3 persons per household * $100,000 per house = $2.5 billion

If property values increased by only 4% in response to reductions in offensive odors, the cumulative value of these homes would increase by $100 million.

Scenario Analysis

There are three recommended approaches to quantifying the co-benefits associated with odor emission reductions. These approaches include monitoring the number of complaints from a specified farm over time, olfactometry measurements (detected odor emissions as a function of the distance from the animal operation), and property values. Based upon the data available in this study, the OFFSET tool was applied to each scenario. In this analysis, an odor emission factor with and without anaerobic digestion was calculated for each operation (Table 1). The setback distance, reported in miles, was then calculated for the operational conditions with and without an impermeable cover. Values for 91% and 99% annoyance reductions were included. For the industrial food processor, a concrete tank was assumed in the OFFSET model. Introducing anaerobic digestion results in a 100-fold decrease in odor emissions. In general, this magnitude of odor reductions means that neighbors could live roughly four times closer to farms without experiencing an increase in odor distress.

Table 1. Odor Emission Analysis With and Without Anaerobic Digestion (AD)

Scenario	**Odor Emission Factor (AD/without AD)**	**91% Annoyance Free**		**99% Annoyance Free**	
		With AD (miles)	**Without AD (miles)**	**With AD (miles)**	**Without AD (miles)**
Avg. Farm (100 cows)	8 / 84	0.04	0.16	0.35	1.15
CAFO (1000 cows)	84 / 840	0.16	0.69	1.15	3.74
Food Processor	28 / 280	0.08	0.34	0.65	2.13

Weed Reduction

Anaerobic digestion decreases the viability of common weed seeds found in raw manure.[37-39] However, reductions in weed seed viability from anaerobic digestion are not significantly greater than reductions that would occur under other manure management strategies, such as dry storage or composting. Recent research by Cook et al. (2007) suggests that manure spreading on Wisconsin corn crops did not result in any additional weed introduction.[40] Although a reduction in weed seed viability is certainly a measurable benefit offered by anaerobic digestion, the magnitude of this benefit may not justify assigning any financial value to this service because weed introduction is not a major concern with other manure management strategies.

Pathogen Reduction

Manure contains many pathogenic - or disease-causing - bacteria, viruses, and parasites. Anaerobic digestion can reduce, but not eliminate, pathogen loads in manure, thereby deceasing the potential for these zoonotic agents to enter soils and watersheds.[41, 42] This reduction has the potential to reduce health care costs, avoid revenue lost to beach closures, and ease the strain on aging municipal water systems.

Many of the pathogens present in livestock manure do not present a risk to human health either because they are biologically unable to infect human hosts, or because they cannot survive long enough in the environment to reach human hosts. The subset of these pathogens that poses the most common risk to human health is generally the one that includes zoonotic, enteric pathogens. These disease-causing agents are commonly transmitted by the oral-fecal route because they can survive in moist environments. They usually infect both human and animal hosts (zoonotic) and they often cause gastrointestinal distress (enteric). Such pathogens can enter waterways from farm run-off following heavy rains, or may seep into the watershed due to land application of manure where they contaminate recreational waters and drinking water, leading to water-borne illness. Alternatively, these pathogens may enter irrigation waters used to grow fruits or vegetables and cause food-borne illnesses.

The most common pathogens associated with livestock manure that pose a risk to human health include *Cryptosporidium*, *Giardia*, *Campylobacter, E. coli 0157-H7,* and *Salmonella*.[43-48] Anaerobic digestion reduces the prevalence of some—but not all—of these common pathogens, making digested solids and liquids safer for land application (Table 2).[41, 42] Importantly, there are several emerging pathogens that are believed to be associated with manure, such as adenoviruses, hepatitis E, noroviruses, mycobacteria and microsporidia. The effects of anaerobic digestion on these organisms are not sufficiently evaluated by scientific literature, and the potential health effects of reductions in their incidence are not certain.

Table 2. Pathogen Reductions Due to Anaerobic Digestion

Pathogen Category	**Pathogen**	**Reported Reduction due to Anaerobic Digestion (log units)**		**Reference**
		Mesophilic	**Thermophilic**	
Bacteria	*Escherichia coli* O157:H7	1 – 2	>4-log	49, 50
	Salmonella spp	1 – 2.23	>4-log	49, 50
	Campylobacter spp	No impact	>4-log	49, 50
	Mycobacterium avium paratuberculosis	No Data	No Data	49, 51
	Listeria monocytogenes	2.23	No Data	49-51
Protozoa	*Cryptosporidium parvum*	4-log (12 weeks)	4-log (3 days)	49
	Giardia lamblia	4-log (12 weeks)	4-log (3 days)	49
Helminths	*Ascaris suum*	0.5 – 1	2	49
Virus	Human polyomavirus (HPyV)	1 log	No study found	52
	Norovirus (NV)	Increased	No study found	52
	Human Adenovirus (HAdV)	1-1.5 log	No study found	52
	Enterovirus (EV)	1 log	No study found	52
	Hepatitus A Virus	Not Detected	No study found	52

(There are pathogens contained in animal waste that may be pathogenic to animals other than humans, and these are excluded from this table.)

Digester design and operation strongly impacts the degree of pathogen reduction. Higher temperature thermophilic systems exhibit stronger reductions than mesophilic systems, and longer residence times in digester tanks result in higher rates of pathogen inhibition.[39, 41, 53] Pathogen survival appears inversely related to methane production, suggesting that optimized systems most effectively inhibit pathogens.[53] Researchers have proposed that both physical changes (e.g. effluent pH, temperature, water content) and biological changes (e.g. resource availability and direct competition with methanogenic microbes) may be responsible for these patterns.[53]

Because the degree of pathogen reduction is highly dependent on the unique characteristics of each anaerobic digester, site-specific case studies provide the most accurate assessment of pathogen reductions. Although rapid, highly-sensitive, molecular diagnostics have reduced pathogen monitoring costs, testing for *all* potential pathogens in every digester would be prohibitively expensive. Instead, indicator species that often co-occur with pathogens can be used to monitor systems. Fecal coliform counts are a relatively standard and inexpensive way to estimate pathogen-loads, although this method is not without its critics. To best assess pathogen reductions from anaerobic digestion, additional case studies such as the AgStar/EPA supported assessment of the Gordondale digester in Nelsonville, Wisconsin should be pursued. The Gordondale case study reported a 99% reduction in fecal coliform counts as well as more than 90% reduction in *Streptococcus* density in the evaluated digester.[54]

Effects of Reductions in Manure Pathogen Loads for Wisconsin

Healthcare Savings

Because gastrointestinal illnesses are often under-reported - only the most acute and severe cases make it to clinics or hospitals - it is difficult to estimate the true cost of illness caused by agricultural run-off. In the past ten years, *reported* incidences of water-borne disease in Wisconsin affected fewer than 70 individuals annually.[55] The vast majority of these cases were caused by ingestion of infected drinking water or exposure in public swimming pools and whirlpools. From 1995-2005, Wisconsin announced five outbreaks of waterborne illness due to contamination of public waterways, resulting in no reported fatalities.[55] These five outbreaks were not definitively associated with water contamination from livestock manure. However, documented cases of waterborne illness associated with runoff from livestock manure are common, and research suggests that residents in areas of high livestock densities - especially households that mainly utilize well water - are at a greater risk of gastrointestinal symptoms.[43-48]

Food borne illness outbreaks are far more common than waterborne illness outbreaks in Wisconsin and affect approximately 700 Wisconsinites each year.[55] Fatalities are rare, and determining the source of the outbreak can prove challenging. Once again, gastrointestinal symptoms are generally underreported, so the true "cost" of food borne illness in the state is hard to estimate. Anaerobic digestion does not prevent cases of food borne illness caused by poor sanitation during food preparation. However, the national spotlight on recent outbreaks of *E. coli* in spinach, tomatoes, and other fresh vegetables has highlighted consumer concerns about food safety that could potentially be addressed by anaerobic digestion. The use of undigested manure as fertilizer is far more likely to result in pathogen contamination of field crops than fully digested manure.[38, 41, 42]

Recreational Water Use Revenue

Over 14 million visitors each year enjoy Wisconsin's natural areas to camp, swim, fish, boat, and hunt. The state collects nearly $66 million a year in fees from these recreational users, which are in turn used to support outdoor recreation activities in the state.[10] Between 2004 and 2009, an average of 76 of Wisconsin's 193 Great Lakes Beaches had at least one swim advisory per season because *E. coli* concentrations exceeded 235 CFU/100 mL, making the waters less safe for swimmers. Over this same time period, the total number of daily advisories posted at Wisconsin's beaches has ranged from 402-779 per year. The total number of "beach-days" in Wisconsin can be calculated by multiplying the total number of beaches by the total number of days the beaches are open each year:

193 Wisconsin beaches * 14 week season * 7 days/week = 18,914 beach-days[56]

Thus, water quality advisories affect 2-4% of Wisconsin beach days each year.

We estimate that 2.8 million people are swimming in our lakes each year if we assume that 20% of Wisconsin's recreational users visit state parks to swim. If we also assume that an average of 4 visitors arrive in each vehicle, and that each vehicle pays about $7 to enter the park, nearly $5 million dollars in revenue are collected. By these conservative estimates, beach closures could cost the state $100,000-$200,000 each year in lost admissions fees.

Reduced Strain on Municipal Drinking Water

Wisconsin's wastewater infrastructure is aging as the state faces an increasing demand for clean water. The 2007 *Drinking Water Infrastructure Needs Survey and Assessment* estimated that Wisconsin will need nearly $6.2 billion dollars over the next 20 years to install, upgrade, or replace aging equipment needed to keep our drinking water safe.[57]

Reducing the pathogen and nutrient loads in our waterways reduces the strain on existing systems thereby extending the life of these municipal resources. In addition, if investments in Wisconsin's municipal water supplies must happen anyway, there is great opportunity to include anaerobic digesters in these water treatment facilities.

2. Food Processing Waste and Nutrient Management

Similarly to how anaerobic digestion improves manure management for dairy operations, it offers food processing plants a suite of waste management benefits. Anaerobic digestion represents a low-cost waste treatment technology for the food processing industry. In fact, the primary motivation of many food processing facilities for installing anaerobic digesters is the cost-effective treatment of processing waste, with the energy from biogas cited as a secondary benefit.[6, 7, 31] This section presents the economic benefits of using anaerobic digestion to manage food processing waste.

Wastewater

For most food processing operations, wastewater is the waste stream of greatest concern.[5] Food processing produces high volumes of wastewater because water is used at many stages in the production process (e.g. washing and filtration). For example, the McCain Foods plant[4], a potato products facility located in Plover, WI, produces 2.3 million gallons of wastewater per day at full capacity.[30] In the state of Michigan, the volume of wastewater generated from processing the top 13 fruits and vegetables is over 3.4 billion gallons per year or nearly 7 gallons per pound of food processed.[58]

These process wastewaters contain high concentrations of organic material resulting in high biochemical oxygen demand (BOD). BOD, a conventional pollutant in the U.S. Clean Water Act, is defined as the amount of oxygen bacteria will consume while decomposing the organic matter in water. Because bacteria under normal conditions decompose organic matter using dissolved oxygen, the measure of the concentration of dissolved oxygen in water is connected to the amount of organic nutrients in the water. Thus, the more organic waste in water, the more oxygen needed for bacterial decomposition. A low BOD indicates good water quality, while high BOD levels indicate poor water quality. We follow convention in calling wastewater with low BOD levels "low-strength" and that with high BOD values "high-strength." Typical BOD levels for a pristine river are approximately 2 mg/L (milligrams per liter).[5] Average BOD values for wastewater from potato processing like at the McCain Foods facility is about 2,000 mg/L, a thousand times higher than levels for pristine water. Typical BOD values for other food processing wastewater streams are shown in Table 3.[5]

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[4] The McCain Foods plant currently employs anaerobic technology to treat wastewater.

[5] Obtained from http://www.ilpi.com/msds/ref/bod.html.

Table 3. Typical Food Processing Wastewater Organic Loads

Wastewater Source	BOD (mg/L)
Brewery	850
Dairy	1,000 – 4,000
Fish	500 – 2,500
Fruit	1,200 – 4,200
Meat	1,000 – 6,500
Potatoes	2,000
Poultry	500 – 800
Slaughterhouse	1,500 – 2,500
Vegetable	1,000 – 6,800

To prevent deterioration of water quality, the Wisconsin DNR and the U.S. EPA strictly regulate the discharge of wastewater from all industrial sources.[59] Wastewater from food processing plants with high BOD values cannot be discharged into natural waterways without treatment. Food processing plants typically send wastewater to the municipal treatment plants and/or use *aerobic* techniques to manage waste on-site. For most applications, on-site *anaerobic* digestion represents a lower cost option for wastewater treatment than both of these options.[7] [5]

Currently, more than 80% of food processing waste is treated at municipal treatment plants, either without pretreatment or with partial pretreatment at the food processing plant.[5] The cost of treating this high strength wastewater at municipal plants is passed on to food processing plants in the form of sewer charges. In most areas, sewer charges are based on both the volume and strength of wastewater. For example, sewer fees for the City of La Crosse, WI are higher for higher-strength wastewater.[60] The structure of sewer rates in most municipalities in Wisconsin is similar to that presented here for La Crosse. For wastewater with BOD levels below 250 mg/L, the total sewer rate is the sum of a quarterly fixed charge and a rate based on the volume of wastewater:

$$\text{Total rate} = FC + (V \times VR) \qquad (\textit{Equation 1})$$

FC = Fixed charge of $13.10 per metering device
V = Total volume of wastewater (ft^3)
VR = Volume unit price = $1.07 per 100 ft^3

However, for wastewater with BOD levels above 250 mg/L (which is characteristic of almost all untreated food processing wastewater), there is an additional fee based on the strength of wastewater[6]:

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[6] Typically, there are other fees for high levels of total suspended solids, phosphorus, and total nitrogen in addition to the fee for high levels of BOD. Because anaerobic digestion has the largest effect on BOD levels, this section only considers the BOD surcharge.

Total rate = FC + (V x VR) + (PB x BR) (*Equation 2*)

FC = Fixed charge of $13.10 per metering device
V = Total volume of wastewater (ft^3)
VR = Volume unit price = $1.07 per 100 ft^3
PB = Pounds of BOD discharged in excess of domestic strength (250 mg/L) wastewater
BR = BOD unit price = $0.212 per pound

Thus, for wastewater with high BOD levels, the additional fee adds significant cost to the total sewer rate for the food processing plant. The use of on-site anaerobic treatment to pre-treat wastewater would largely eliminate these additional costs. While anaerobic digestion does not significantly reduce the volume of wastewater, anaerobic treatment does significantly reduce wastewater BOD. With anaerobic digestion of wastewater, more than 90% of the organic waste is converted to methane gas, decreasing wastewater BOD levels by more than 90%.[5] Therefore, for a potato processor like the McCain Foods plant with typical wastewater BOD levels of 2,000 mg/L, anaerobic digestion would reduce BOD levels to 200 mg/L, which are low enough to eliminate the additional fee for high-strength waste in the sewer rate. Applying the La Crosse sewer charge structure to the McCain Food plant example shows that this type of high-strength surcharge can significantly increase total sewer charges. Assuming this kind of sewer charge structure, eliminating the high-strength surcharge through wastewater treatment with anaerobic digestion decreases the yearly total sewer charge by 31% and saves over $500,000 per year (Table 4). As a result of these potential costs reductions from anaerobic treatment, and because many municipalities are planning sewer rate increases in the future, more food processing facilities are considering on-site anaerobic digestion to pre-treat wastewater.[5] Digester capital costs are highly variable depending on the specific characteristics of each system, making a general system cost difficult to determine. The costs of installing such systems are not estimated here, and are not accounted for in the cost savings presented.

Table 4. Sewer Charge Comparison With and Without Anaerobic Digestion (AD)

	Without AD	**With AD**
BOD level *(mg/L)*	2,000	200
Wastewater volume *(million gallons/yr)*	839.5	839.5
Total BOD *(lb/yr)*	2,882,921	288,292
Excess BOD *(lb/yr)*	2,522,555	0
Yearly Volume Charge	$1,200,804	$1,200,804
Yearly High-strength Surcharge (HSS)	$534,782	$0
Yearly Total Sewer Charge	$1,735,586	$1,200,804

In addition to generating cost reductions from lower sewer charges, anaerobic digestion can reduce the cost of wastewater treatment relative to the cost associated with using aerobic techniques. Aerobic treatment, like anaerobic digestion, is a form of biological waste treatment. While anaerobic processes involve microbial decomposition of organic waste in the absence of oxygen, the microbes in aerobic process require oxygen to decompose organic matter. Although aerobic treatment is typically as effective as anaerobic treatment at reducing BOD levels in many wastewaters, this type of treatment has two main disadvantages with the high-strength wastewater typical of food processing operations. First, because aerobic techniques require oxygen to be added to the water, aerobic treatment of large volumes of high-BOD wastewater is very energy intensive and very expensive.[5, 58, 61] Second, significant quantities of solid waste are generated from aerobic treatment of wastewater, and the disposal of these solids can significantly increase the overall cost of wastewater treatment.[5, 30, 61] Because anaerobic treatment is much less energy intensive than aerobic techniques and generates smaller quantities of solid waste, it represents a significantly more cost-effective way to treat wastewater on-site.

For food processors that send all their untreated wastewater to municipal treatment plants, anaerobic digesters offer cost reductions by significantly reducing the BOD content of wastewater and eliminating the high-strength sewer charges. Likewise, for food processors that are partially or fully treating wastewater on-site using aerobic treatment, anaerobic digesters represent a much more cost-effective technique of reducing wastewater BOD than aerobic treatments. Whether food processing facilities choose to fully treat wastewater on-site or only partially treat wastewater and send the lower-strength water to a municipal treatment plant, employing anaerobic digestion will in most cases reduce their overall treatment costs.

Solid Waste

In addition to producing wastewater, many food processing operations also produce significant amounts of solid waste. Some examples of solid waste from food processing include spent grains from breweries, crop residuals such as fruit pits or skins, and rumen contents (partially digested feed in stomach) from meat processing.[6, 61] These wastes are typically disposed of in landfills, resulting in additional costs for processing plants due to the disposal, or tipping, fees. In addition, any solid waste resulting from aerobic or other wastewater treatment techniques is generally sent to landfills, resulting in additional tipping fees.[5] As of 2009, the average tipping fee for landfills in Wisconsin was $50 per ton of solid waste, and the tipping fees for Wisconsin are slightly higher than in most surrounding states.[62] However, it is difficult to determine the average landfill tipping fees paid by food processing plants because many industrial customers have private contracts with landfills and receive volume discount pricing.[62]

Anaerobic digestion can reduce the costs of landfill tipping fees by reducing the volume of the waste to be handled.[39, 63] Therefore, using anaerobic digestion to process solid wastes from food processing will decrease solid waste disposal costs. In the past, only waste with less than 50% solids content was considered for anaerobic digestion.[6] However, new digester designs such as dry digesters are expanding the types of waste that can be treated with anaerobic technology.[64] As such, installing an anaerobic digester on-site at a food processing plant creates the possibility of blending food processing wastewater and/or solid waste with off-site waste sources such as livestock manure. In addition to the increased biogas yield from additional substrates, the food processing plant would receive additional revenue (tipping fees) for accepting the additional waste stream.[6, 58]

Benefit 2: ENERGY INDEPENDENCE

Key Points

- Wisconsin sends over $18 billion dollars out-of-state to pay for energy.
- Unlike other forms of renewable energy, biogas is versatile, predictable, and storable.
- Current on-farm biogas systems - operating at capacity - could offset $2.2 million of coal.
- If these systems upgraded biogas for the pipeline, they could offset $15 million of natural gas.
- All of the manure in Wisconsin, if digested, represents the same energy potential as $185 million of natural gas.
- Biogas utilized in combined heat and power systems could save even more money that would be spent out-of-state to purchase energy.

Research Priorities

- Investigate whether Wisconsin's natural gas infrastructure can accommodate renewable natural gas.
- Estimate how much of the state's transportation fuel costs could be offset by biogas.
- Quantify the amount of coal or natural gas potentially offset by biogas from food processors.
- Define the energy savings offered by combined heat and power.
- Analyze the costs and benefits of biogas as a base-load or peak-load source of energy.

Wisconsin's Energy Spending

Wisconsin lacks any domestic sources of coal, oil, or natural gas, making the state completely dependent upon imports to meet fossil fuel needs. This situation makes homegrown, distributed energy sources such as biogas attractive to supporters of energy independence. Because Wisconsin's current electrical generation capacity exceeds actual demand in the state, advocates for a homegrown system of clean, renewable energy have been challenged to justify additional investments in the state's already over-built energy infrastructure. The state therefore needs an economic analysis to better assess the impact of biogas production on Wisconsin's economy as the economic opportunities offered by biogas production have not been well characterized.

An analysis of the impact of biogas production must begin with the current state of Wisconsin's energy system. In 2008, Wisconsin sent about $18.6 billion[7] to Wyoming, Louisiana, Texas, Oklahoma, Kansas, and Canada to pay for its fossil fuel energy needs.[69, 70] The state spent over $13.1 billion on petroleum, over $4.3 billion on natural gas ($3.9 billion for primary use and $0.43 billion for electricity generation), and nearly $1.1 billion on coal ($0.15 billion for primary use and $0.93 billion for electricity generation).[69, 70] Given that the US Bureau of Economic Analysis estimates that Wisconsin's gross domestic product is approximately $244 billion, that means that Wisconsin sends 7.6 cents on every dollar out of the state just to pay its energy bills. Retaining even a fraction of these expenditures could translate into substantial savings for Wisconsin. To date, researchers have not directly quantified how much biogas could save the state on its energy expenditures.

Biogas: Versatile, Predictable, Storable Energy

Biogas offers a number of unique advantages as a homegrown renewable energy resource. First, biogas is a versatile energy source. While other renewables such as wind and solar are only used for electricity generation, biogas can generate electricity, replace natural gas as a heating fuel, or even be used for transportation. Thus, while increased deployment of wind and solar technology would only offset electricity generation from fossil fuels, biogas could offset fossil fuel electricity, natural gas heating, and/or petroleum use for transportation.

Biogas offers the additional benefit of being a reliable, predictable source of energy. Because renewable resources like wind and solar are highly variable and difficult to predict, integrating large amounts of wind and solar capacity into Wisconsin's electricity system presents a number of technological and operational challenges. On the other hand, well-managed biogas systems are stable, predictable, and easily controlled, making them much easier to integrate into the electricity grid. Because of these attributes, biogas could be used to meet baseline (constant) power demand that is currently met with coal-fired power plants.

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[7] Electricity expenditures were calculated using electricity utility average fuel costs for 2008 ($1.90 per MMBtu for coal, $9.97 per MMBtu for natural gas) from the Office of Energy Independence.

Alternatively, with technologies such as floating/flexible digester roofs, biogas can be stored for short periods of time (hours to days) and be used to meet peak electricity demand. Because of its versatility, predictability, and storage capacity, biogas complements both existing energy resources and other renewable technologies.

Biogas Energy Contribution

If all the on-farm biogas currently produced in Wisconsin were to be used for electricity generation, how much coal could this offset? According the 2009 Wisconsin Agricultural Biogas Casebook, the current installed capacity of on-farm biogas production in Wisconsin is approximately 11.6 megawatts.[71] If all of these biogas systems were to operate at full capacity (24 hours a day) for one year, they could theoretically generate about 102,000 MWh of electricity. If the fuel cost for one million BTUs of coal for Wisconsin's electric utilities is $1.90, and we assume a 30% efficiency for converting coal energy content to electricity (typical for coal-fired power plants), then the electricity potential of Wisconsin's on-farm anaerobic digesters would offset nearly $2.2 million in out-of-state coal purchases each year.[72]

What if we used all of this biogas instead as a source of renewable natural gas? As of 2009, the 22 dairy farms with biogas systems currently operating in Wisconsin process roughly 1,275,000 gallons of manure a day, or over 1.84 million tons per year.[71] Approximately 43 cubic meters of biogas can be generated per ton of manure, meaning that these systems could potentially generate almost 2,825 million cubic feet of biogas each year.[73] Assuming that one half of this gas could be recovered as methane and upgraded to pipeline quality gas, Wisconsin's on-farm biogas systems could theoretically produce 1,400 million cubic feet of gas, or 0.35% of the annual 400,580 million cubic feet of gas purchased from other states each year.[72] Although 0.35% might not seem like much, consider that Wisconsin spends over $4.3 billion each year on importing natural gas.[69] A 0.35% reduction in that bill would represent over $15 million of revenue retained within Wisconsin's borders. By these calculations, the 23 million tons of manure[2] produced each year from all of Wisconsin's dairy farms could produce nearly 4.4% of the state's natural gas needs and represent a $185 million under-utilized opportunity.

Scenario Analysis

Other digester feedstocks available in Wisconsin, such as food processing waste or crop stover, could substantially increase the fossil fuel offset potential of biogas in the state. Utilizing the potential of combined heat and power would only further offset out-of-state fossil fuel consumption by replacing other sources of heat generation with the "waste" heat from biogas combustion. In the scenario analysis below (Table 5), we calculate the potential coal and natural offset of combined heat and power (CHP) generation of biogas. This analysis was conducted using the RETScreen® International Clean Energy Project Analysis software (Version 4, 2010). This modeling software is a free, publically available decision support tool developed with the contribution of numerous experts from government, industry, and academia.[8]

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[8] More information can be found at http://www.retscreen.net/ang/home.php.

Table 5. Potential Coal and Natural Gas Offsets from Anaerobic Digestion (AD)

	Avg. Farm (100 cows)	**CAFO (1000 cows)**	**Food Processing Plant**
Potential Biogas Output *(m^3/yr)*	40,000	400,000	2,002,025
CHP Electricity Generation *(MWh/yr)*	131	1,310	6,560
Coal offset *(MMBtu/yr)*	1,490	14,900	74,630
Coal (electricity) offset *($/yr)*	$2,832	$28,320	$141,800
CHP Heat Generation *(MWh/yr)*	52	520	2,600
Natural Gas (heat) offset *(MMBtu/yr)*	177	1,770	8,874
Natural Gas offset *($/yr)*	$1,769	$17,690	$88,470

Benefit 3: ADDITIONAL ECONOMIC OPPORTUNITIES

Key Points

- Biogas has been largely absent from discussions about the renewable energy economy, but could offer new job opportunities and industry growth in Wisconsin.
- Wisconsin dairies have suffered losses due to volatile commodity prices and could benefit from a stable source of on-farm income.
- The use of dried solids as bedding offers a significant avoided cost to dairy producers.
- Dried solids can also be sold as soil additives, creating a new on-farm income stream.
- If the U.S. engages with international carbon markets in the future, dairy farmers with digesters could create value from their reduced carbon emissions.

Research Priorities

- Quantify potential “green jobs” and industry growth created by biogas expansion.
- Determine whether biogas could prevent agricultural/dairy job loss.
- Assess the potential of biogas as a stable source of on-farm income.
- Determine whether biogas can reduce waste management costs.
- Clarify the relationship between using dried solids as bedding and mastitis occurrence.
- Create improved, cost effective technologies to remove moisture from bedding.

Green Jobs and New Industry

Because biogas keeps the revenue from energy expenditures in the state of Wisconsin, the growing biogas industry has the potential to spur economic development and create new jobs within the state. In the current economic climate, "green" jobs have been widely promoted as America's next great economic opportunity. Although the 2010 Wisconsin Clean Energy Jobs Act did not pass, it did generate a flurry of economic analysis regarding the impact of green policies on employment. Unfortunately, biogas remains noticeably absent from larger discussions about the renewable energy economy. Existing assessments from prominent advocacy organizations and think-tanks such as the Center on Wisconsin Strategy, The Workforce Alliance, The Apollo Alliance, and the state's own economic experts at the Office of Energy Independence have documented the employment opportunities generated by renewable technologies in general, but have not explicitly stated what biogas has to offer Wisconsin.[72, 74]

The analysts for the Governor's Task Force on Global Warming predicted that the Clean Energy Jobs Act would have created a minimum of 15,000 new jobs in Wisconsin, mostly within the construction and manufacturing sectors.[72] Importantly, the state's economic assessment only included new jobs associated with wind and photovoltaic systems and did not consider the impact of biomass or biogas production. In addition, the assessment did not account for the economic benefits of expanding Wisconsin's renewable technology manufacturing base; that is, it failed to consider the potential benefits of stimulating the development of Wisconsin-owned companies to manufacture products such as anaerobic digester system components.[72] Thus, the specific economic benefits of biogas in Wisconsin have not been carefully considered.

Analysis of green jobs should consider not only biogas's potential to stimulate the development of new manufacturing and construction jobs, but also the support biogas offers to Wisconsin's dairy industry. Due to rising production costs and fluctuating commodity prices, many of Wisconsin's dairy farms are struggling to stay afloat. The most recent Wisconsin Agricultural Statistics Service (WASS) Dairy Producer Survey revealed that one-quarter of all dairy producers in the state plan to discontinue their operations within five years. Over 40% of respondents indicated that they are unable to meet basic living expenses, and 92% of farms reported decreasing the number of paid workers on their farms.[75] This crisis in America's Dairyland serves as an important reminder that any serious analysis of biogas in Wisconsin must take into account the potential economic benefits for Wisconsin's dairy farmers. Could biogas systems offer an additional, stable source of income for dairy farms that is not subject to fluctuating commodity prices? Does it significantly reduce manure management costs? Might biogas prevent or help limit job loss in the state's agricultural sector?

The world leader in biogas production, Germany, has demonstrated that the biogas industry does have the capacity to generate new jobs. In 2007, Germany boasted 249,000 jobs in the renewable energy sector, and 5.4% of those jobs were related to the biogas industry.[76] The German Federal Ministry of Economics and Technology reports that 11,000 persons were employed in the biogas industry as of 2009.

Co-products and Avoided Costs: New Opportunities for Dairy Producers?

Most anaerobic digestion analysis focus upon the uses and co-benefits associated with the biogas portion of the process. However, the solid and liquid phase product streams can produce co-benefits as well. For Wisconsin, the primary benefits derive from the use of solids for bedding and from use of the liquid and solid portions for fertilizer.

Bedding

The solid portion of digested manure can be used for application as animal bedding material. Dairy producers can reduce the costs of providing bedding by using dried manure solids as bedding material, which have the added benefit of increased cow comfort. In Wisconsin, farms that have anaerobic digesters, 20 farms report using the digested material for bedding, representing a savings of $7.25 per cow per month.[23] Of these farms, 12 produce enough bedding to sell to other farmers, creating an additional income stream.[23]

Using the digested solids on-farm for bedding provides an added operational benefit of not having to separate sand from the manure input into the digester. Sand has the advantage of being a very inert bedding material; moisture quickly passes through or evaporates from sand, preventing the colonization of potential disease or odor-causing bacteria. However, sand causes operational conditions of extensive abrasion in pumps and is not removed in the anaerobic digestion process.

Because the digested solids are not inert (like sand), there are concerns with this bedding material becoming wet, promoting the growth of pathogens, and inducing cases of mastitis, or udder infection, in cows. This pathway for mastitis is referred to as "environmental mastitis." Mastitis represents a serious concern for dairy producers (as animals with udder infections must be taken out of production) and constitutes a loss of revenue. Some farms have been using digested solids without an increased mastitis occurrence, and it is still unclear if more intensive management can offset the risks of increased infection. Innovative technological approaches to decreasing the moisture content in the bedding that include screw presses and drying (use the heat from on-farm combined heat and power projects) could help to minimize the risk from this bedding.[77]

Fertilizer

The liquid and solid portions of animal effluent contain important nutrients that are readily available as fertilizers – specifically nitrogen as ammonium in the liquid portion and phosphorous in the solid portion. Several studies have been conducted to assess the effectiveness of these portions to replace commercially manufactured fertilizers. In a study conducted in West Virginia on poultry manure, the solids portion resulted in an increase in the phosphorous content of the soil, but did not produce as much yield as field crops receiving manufactured fertilizers. Application of the liquid portion to land with grass and vegetable crops resulted in similar yields to those on land that had been applied with other available fertilizers.[78]

Dairy cows excrete approximately 250 lbs N, 55 lbs P_2O_5 and 120 lbs K_2O per year in manure which has an estimated annual value of $300 per cow.[79] On farms that do not wish to use the solid portion for bedding, the digested manure solids bedding can be sold as a soil additive for $20 per ton.[23] In fact, farmers in Wisconsin paid $465 per ton for commercially produced Superphosphate (a type of fertilizer) in 2010, suggesting a substantial market for manure-based fertilizer.[80]

Scenario Analysis

Based on conversations with Wisconsin dairy producers, we estimate that commercially available organic bedding generally costs of $7.25 per cow per month.[81] In this scenario analysis, we evaluate the potential avoided cost of purchasing commercial bedding by using dried manure solids as bedding (Table 6). It is assumed in this analysis that there would be no bedding benefit incurred by a food processing plant.

Table 6. Avoided Costs of Bedding Purchases for Anaerobic Digesters

Scenario	**Dried Manure Solids Bedding Avoided Cost ($ per annum)**
Avg. Farm (100 cows)	$8,700
CAFO (1000 cows)	$87,000
Food Processor	N/A

Carbon Markets and Carbon Credits

Another economic opportunity for biogas producers is the potential of carbon credits for greenhouse gas emission reductions. Under a 'cap and trade' system designed to limit emissions, a carbon market is created where economic value (credits) is given to greenhouse gas emissions reductions. These carbon credits can be sold to buyers in the market, creating income for the emission reducer. Thus, biogas producers could generate additional revenue from the greenhouse gas emissions reductions achieved through anaerobic digestion. Presently, however, no carbon markets exist in Wisconsin where producers can sell credits; the voluntary Chicago Climate Exchange[9] terminated trading at the end of 2010. Though the state of California recently instituted a cap and trade program, and other carbon markets such as the Regional Greenhouse Gas Initiative in the Northeast U.S. are in the early stages, it is unclear when a market for Wisconsin producers may exist. The current trading price as of January 19, 2011 for a metric ton of CO_2eq reduction in the European Union Emissions Trading Scheme (EU ETS)—the world's largest carbon market—was 14.50 Euros, or about $19.75 US.[10] At this carbon price, a dairy farm with 100 head of cattle could earn about $10,025 per year from selling carbon credits generated

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[9] http://news.nationalgeographic.com/news/news/energy/2010/11/101103-chicago-climate-exchange-cap-and-trade-election/.

[10] Current trading price obtained from http://www.nytimes.com/cwire/2011/01/20/20climatewire-european-commission-halts-transfers-of-carbo-22394.html.

from manure methane emission reductions (Table 7). See the 'Benefit 4: Greenhouse Gas Emissions Reductions' section for calculation details.

Table 7. Potential Carbon Credits from GHG Emissions Reductions

Scenario	**Potential Carbon Credits ($)**
Avg. Farm (100 cows)	$10,025
CAFO (1000 cows)	$100,250
Food Processor	*not calculated*

Benefit 4: GREENHOUSE GAS EMISSIONS REDUCTIONS

Key Points

- Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_20) are the greenhouse gases of primary concern and have different warming potentials.
- Both the energy sector and agriculture are important sources of greenhouse gas emissions in Wisconsin.
- Anaerobic digestion can
  - 1) reduce direct emissions from manure,
  - 2) reduce emissions from synthetic fertilizer application, and
  - 3) offset fossil fuel emissions through biogas energy production.
- Using biogas for combined heat and power (CHP, producing both electricity and space heat) represents an effective way to maximize CO_2 emissions reductions.

Research Priorities

- Obtain better data on agricultural greenhouse gas emissions in Wisconsin and the Midwest.
- Research the agricultural emission reductions achieved by anaerobic digestion specific for the U.S. and Wisconsin.
- Complete a full emissions life-cycle assessment for biogas energy to better quantify the offset of fossil fuel emissions, production.

Greenhouse Gas Emissions and Sources

The threat of global climate change has received an unprecedented amount of attention in public and scientific discourse. Caused by increasing emissions of greenhouse gases from human activities, climate change (or global warming) is likely to have a negative impact on the environment and human livelihoods in Wisconsin and worldwide. Because of this potential threat, determining the most effective strategies for reducing greenhouse gas emissions has been a focus of scientific research and public policy debate. Employing anaerobic digestion in Wisconsin can significantly reduce greenhouse gas emissions from the state's agricultural and energy sectors.

Greenhouse gas emissions come from a variety of anthropogenic or human sources and represent multiple gases. Fossil fuel combustion for energy produces carbon dioxide (CO_2), the most prevalent and well-known greenhouse gas. On a global scale, the CO_2 emissions from the energy sector are the primary driver of climate change and have received the most attention in mitigation strategies. However, agriculture emissions are also an important contributor to climate change, namely the greenhouse gases methane (CH_4) and nitrous oxide (N_2O). These two gases are more powerful than carbon dioxide at warming the climate[11] and are receiving greater attention in climate mitigation strategies.[82] Agricultural emissions of methane and nitrous oxide originate from two main sources: livestock and soil management.[83] Methane is emitted from the digestion process (called enteric fermentation) of certain livestock, through animal belching or flatulence, and the decomposition of livestock manure. Nitrous oxide is produced as part of the nitrogen cycle and can be emitted from livestock manure or as a result of certain nitrogen-increasing soil management practices such as synthetic fertilizer application.

How Anaerobic Digestion Can Reduce Emissions

Anaerobic digestion of livestock manure and food processing waste, with effective management, can reduce greenhouse gas emissions in three main ways. First, digestion can significantly reduce direct emissions of methane and nitrous oxide from waste. The high volumes of manure on dairy farms are typically stored in pits or lagoons. Because anaerobic decomposition usually prevails under these conditions, direct methane emissions from the manure result. Digesting manure in a closed system prevents the vast majority of this methane from being emitted to the atmosphere.[84] Similarly to its effects on manure emissions, anaerobic digestion would also significantly reduce methane emissions from food processing solid waste that is ultimately landfilled or land-applied. Furthermore, digestion can decrease nitrous oxide emissions from manure, both when in open storage and when applied to fields.[85] Studies do show that digested manure can emit small amounts of methane and nitrous oxide depending on digester retention time and other

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[11] To compare the effects of these greenhouse gases with CO_2, the relative scale of 'global warming potential' is utilized. Global warming potential is typically expressed as a mass of CO_2 equivalence. Methane has a global warming potential of approximately 21, meaning that one molecule of methane is 21 times more powerful than CO_2 at warming the planet and contributing to climate change. The global warming potential of nitrous oxide, about 310, is an order of magnitude higher than that of methane. Therefore, a per-ton reduction in methane and/or nitrous oxide emissions will have a much greater effect on mitigating climate change than the same per-ton reduction in CO_2 emissions.

factors.[84] While it is clear that anaerobic digestion of manure can significantly reduce methane and nitrous oxide emissions, few studies have examined these effects in the United States, making it difficult to quantify these reductions.

Second, using digested manure as an organic fertilizer will reduce nitrous oxide emissions from synthetic fertilizer application. Application of nitrogen-rich synthetic fertilizers is cited as a major source of nitrous oxide emissions from cropland soils, and improving soil nitrogen management could significantly reduce these emissions.[83] Studies show that field application of digested manure results in lower nitrous oxide emissions than application of synthetic fertilizers.[84] In addition, over-application of synthetic fertilizers is common in Wisconsin, resulting in unnecessarily high soil nitrogen levels and greater nitrous oxide emissions. Use of digested manure in place of synthetic fertilizers would limit over-application and thus largely eliminate these emissions. Furthermore, the production and transport of synthetic fertilizers is an energy intensive process, resulting in an estimated three pounds of CO_2 emissions per pound of nitrogen fertilizer.[86] Replacing synthetic fertilizers with digested manure would help to reduce fertilizer production emissions as well. For more details on using digested manure as a fertilizer, see the "Fertilizer" subsection in the 'Benefit 3: Additional Economic Opportunities' section.

Third, the biogas produced from anaerobic digestion can be used for energy production, thus offsetting the CO_2 emissions of carbon-intensive fossil fuel combustion. Over 82% of Wisconsin's energy is derived from fossil fuel combustion. Using a renewable energy source like biogas to offset fossil fuel energy generation could significantly decrease energy sector CO_2 emissions.[70] While the combustion of biogas for electricity, heat, or transportation does produce CO_2 emissions, these emissions are qualitatively different from fossil fuel CO_2 emissions: fossil fuel emissions introduce *new* carbon (from geologic sources) into the Earth-atmosphere system, whereas emissions from biogas simply cycle *existing* carbon in the system.[12] However, the cycling of this existing carbon is very complex, and new greenhouse gas emissions can be introduced within this cycling through, for example, fertilizer use for growing livestock feed. Furthermore, there are additional factors that play a role in the CO_2 offset potential of anaerobic digesters such as digester efficiency and digester fugitive methane emissions.[87] Therefore, it is likely that biogas does not fully offset the CO_2 emissions from fossil fuels. More complete accounting of the greenhouse gas offset of energy from biogas in Wisconsin is needed.

Greenhouse Gas Emissions in Wisconsin

Given current greenhouse gas emission levels in Wisconsin, the potential for reductions is large. In 2003, Wisconsin's anthropogenic emissions of greenhouse gases totaled 123.1 $MtCO_2eq$.[82] Greenhouse gas emissions from Wisconsin's energy sector top 105.6 $MtCO_2eq$, or 86% of total emissions.[82] Another 10.9 $MtCO_2eq$, or about 9%, originate from agricultural sources. While it is difficult to determine the exact proportion of emissions from specific agricultural practices for Wisconsin, it can be estimated using U.S. data that

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[12] Combustion of biogas emits CO_2 into the atmosphere; plants take up atmospheric CO_2 through photosynthesis and store carbon as tissue/starches; livestock consume carbon in plant tissue/starches; and livestock digest carbon in plant tissue/starches and release it as methane to the atmosphere (through manure emissions and belching); etc.

about 50% of the state's agricultural emissions originate from soil management practices and about 15% from livestock manure.[83] Through processes previously described, however, anaerobic digestion has the potential to significantly reduce greenhouse gas emissions in Wisconsin. How much are greenhouse gas emissions being prevented by on-farm anaerobic digestion in Wisconsin? We begin with the assessment of the direct methane emissions from manure.

According to the 2009 Wisconsin Agricultural Biogas Casebook, the manure of about 44,300 dairy cows is currently being digested in the state. To calculate manure methane emissions, we assume that undigested manure from one cow emits about 1.13 cubic meters of methane per day, a typical density of methane of 0.65 kg per cubic meter, and that digested manure emits only 10% of the methane of undigested manure. Given these assumptions, digestion of manure from 44,300 dairy cows prevents the emission of about 10,700 tons of methane per year, or about 225,000 tCO_2eq.[88, 89] If the manure from all of Wisconsin's 1.2 million dairy cows were digested, this would prevent the emission of about 290,000 tons of methane per year, or about 6 $MtCO_2eq$. While this calculation represents a significant amount of uncertainty, the order of magnitude demonstrates that anaerobic digestion has the potential to significantly reduce Wisconsin's agricultural greenhouse gas emissions. In addition, these figures do not even include the decrease of nitrous oxide emissions from anaerobic digestion.

Next, we focus on the avoided CO_2 emissions from fossil fuel combustion for energy. This analysis focuses on the emissions offset from coal-fired electricity as coal is one of the most CO_2-intensive fossil fuels.[88] As of 2009, the state's biogas digesters had an electric capacity of about 11.6 megawatts and could theoretically generate 102,000 MWh of electricity (see "Benefit 2: Energy Independence" section).[23] Given that one MWh of electricity generated from coal produces about 1,020 kg of CO_2, electricity generation from Wisconsin's digesters instead of coal would result in a CO_2 emission reduction of about 104,000 tCO_2eq.[86,13] The report from the Wisconsin Governor's Task Force on Global Warming hypothesized that if biogas electricity were produced from all of Wisconsin's 1.2 million dairy cows, this would result in a reduction of nearly 3.0 MCO_2eq per year, representing over 2% of the state's total greenhouse gas emissions.

Using biogas for combined heat and power (CHP, producing both electricity and space heat) represents an effective way to maximize the CO_2 emission offset of biogas production. Figure 4 below shows the CO_2 emissions reductions associated with different forms of biogas end use compared to fossil fuel-based production of energy.

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[13] For the purpose of these calculations, we assume that biogas-fired electricity fully offsets the emissions of coal-fired electricity.

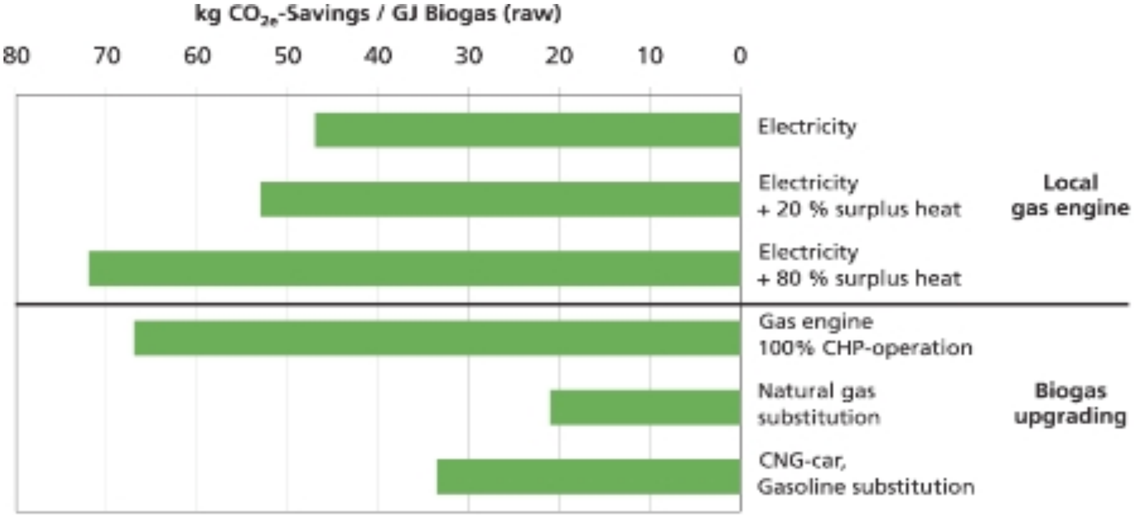

Figure 4. CO_2 Emission Savings of Biogas Energy End Uses. Source: http://www.renewableenergyworld.com/rea/news/article/2009/10/boosting-biogas-with-heat-bonus-how-combined-heat-and-power-optimizes-biogas-utilization.

The top half of the figure displays the emission savings for biogas electricity generation and waste heat utilization. Electricity generation (from 'local gas engine') without heat utilization (top bar) results in about 47 kg of CO_2 equivalent savings per GJ of raw biogas. In contrast, generation with 80% usage of waste heat, an optimal scenario, can increase CO_2 equivalent savings by more than 50% compared to no heat usage. The bottom half of the figure shows the CO_2 emission reductions associated with different biogas end use options after upgrading to natural gas quality (renewable natural gas). Overall, this shows that the CO_2 emission offsets of biogas electricity increase substantially when waste heat is utilized and that CHP results in larger offsets than renewable natural gas.

Scenario Analysis

Because GHG emissions reductions from anaerobic digestion of manure can vary drastically among biogas digesters of different sizes and designs, we performed an energy analysis of 'typical' Wisconsin biogas digesters. In this analysis, we focus on the offset of fossil fuel emissions. Here, the amount of GHG emissions (tons of CO_2) that can be reduced for each system is calculated by comparing the electric and heating needs for each system to a base case emissions load. The CO_2 emissions for each biogas system are calculated assuming that all biogas produced was combusted and converted to electricity with waste heat utilization (CHP, 75% heat recovery). Base case emissions are derived by meeting the same electricity/heat demand from the table's second column using the current Wisconsin fuel source mix (each of their current percent contributions). This analysis was conducted using RETScreen® software.

Table 8. Offset of Fossil Fuel Emissions by Biogas CHP

Scenario	**Base Case Emissions (tCO_2)**	**Biogas CHP Emissions (tCO_2)**	**Emission Reduction (tCO_2)**
Avg. Farm (100 cows)	291.4	12.6	278.8
CAFO (1000 cows)	2915	126	2789
Food Processing Plant	*not calculated*		

UNDERSTANDING WISCONSIN'S BIOGAS CHALLENGES

The purpose of this report was to assess the potential for biogas benefits in Wisconsin. However, biogas implementation faces many challenges that also deserve a careful analysis by policymakers and researchers. Here we present some of the concerns raised by Wisconsin stakeholders as well as common critiques of the technology often cited by advocates and researchers.

Stakeholder Concerns

At the Wisconsin Bioenergy Initiative (WBI) Biogas Stakeholder Meeting in Madison, WI stakeholders identified a series of challenges to biogas expansion in Wisconsin. Specifically, stakeholders expressed their concerns about:

- High capital costs for biogas system installation.
- Long return (greater than 10 years) on capital investment.
- Policy uncertainties and inconsistencies that cause investors to question long-term profitability.
- Unequal terms of negotiation with utilities resulting in unfavorable rates and contracts for producers.
- Permitting difficulties with multiple feedstocks that stifles creative utilization of substrates.
- Logistical hassles for producers with limited time and little experience with biogas.
- Biogas incompatibility with grazing systems and concern about including small dairy farms in production.
- Missing economies of scale that results in concerns about technical support and capacity.

Other Perspectives

The main concerns about supporting anaerobic digestion in Wisconsin most commonly cited are:

- *Food vs. Fuel.* Because manure is one of the least efficient feedstocks for biogas, some have suggested that biogas producers will soon turn to field crops as digester substrates for greater biogas production. This shift to field crop substrates could result in market pressures that displace the amount of land producing food for consumption. In turn, increased demand could increase the chances that marginal lands would be converted to active production to produce more feedstock. In Germany, biogas producers did convert many systems to utilize field crops as the primary substrate, so this concern is not without its merits. However, this report argues that one of the greatest benefits biogas production offers to Wisconsin is the opportunity for waste management. If Wisconsin utilizes biogas production as a waste management strategy and incentivizes the use of manure, food waste, and municipal waste as feedstock, the food vs. fuel debate may not be an issue the state will need to confront.

- *Supporting CAFO production systems at the expense of grazers and small farms*
  Currently all the biogas systems in Wisconsin are on large farms classified as concentrated animal feeding operations. Some advocates for small farms and grazing systems have warned that policies that subsidize biogas systems on large farms incentivize industrial agriculture at the expense of small family farms. Given the recent trends toward consolidated farms, this issue is particularly sensitive in Wisconsin. In Germany, biogas systems can be found on dairy farms with less than 100 head of milk cows—the average size farm in Wisconsin—suggesting that small scale systems are possible.

CONCLUSIONS

Anaerobic digestion has the potential to offer the state of Wisconsin a suite of economic, social, and environmental benefits beyond its obvious utility as a source of clean, renewable energy. Public and private decision makers should recognize and value these benefits when assessing whether biogas is an appropriate public or private investment.

Specifically, anaerobic digestion can help to improve **waste management** for livestock operations and food processors. In some cases, this waste management with anaerobic digestion results in direct savings for private interests. For example, reduced odor emissions resulting from the implementation of anaerobic digestion in rural areas could increase rural property values by over $100 million dollars. Likewise, privately owned food processors could potentially save $500,000 in sewer charges each year. In other cases, the benefits of anaerobic digestion offer more indirect or secondary waste management benefits to the state. Reduced agricultural run-off means cleaner public drinking, recreational, and irrigation waters. These cleaner waters could translate into reduced healthcare costs from food-borne & waterborne illnesses as well as increased revenue for Wisconsin's state parks due to fewer beach closures. Employing on-site anaerobic digestion for food processing wastewater reduces the strain on Wisconsin's aging municipal wastewater treatment systems, conserving the state's limited resources by extending the life of these systems.

Anaerobic digestion also offers opportunities for promoting **energy independence** in Wisconsin. Currently, Wisconsin sends about $18.6 billion per year out of the state to meet its fossil fuel energy needs. Existing on-farm biogas systems already have the potential to offset $2.2 million of coal for electricity or, if upgraded to create pipeline quality natural gas, nearly $15 million in natural gas. If all the manure in Wisconsin was used to generate natural gas, Wisconsin could offset 4.4% of its annual natural gas usage. This suggests that rather than viewing the 23 million tons of manure generated each year in the state as a $48 million dollar management headache, Wisconsin could view its manure as a $185 million underutilized economic opportunity.

A host of other **economic opportunities** also accompany anaerobic digestion. Specifically, biogas could generate new green jobs and stimulate the growth of a new industry while offering a stable source of on-farm income not subject to commodity price fluctuations. In Germany, over 11,000 people are employed by the biogas industry. Dairy producers may also benefit from new revenue streams created by the co-products of biogas generation. Specifically, digestate may be used as bedding or fertilizer. These products can be used on-farm, creating a closed loop system, or sold off-farm as a value-added product. Finally, if regional or national carbon markets materialize, dairy producers stand to reap great benefits for methane reductions. At current EU carbon prices, a 100 head farm could qualify for as much as $10,000 each year.

Greenhouse gas emission reductions are another under-appreciated benefit of biogas production in Wisconsin. Anaerobic digestion reduces greenhouse gas emissions in three ways: (1) reduces direct emissions of methane and nitrous oxide from manure, (2) offsets nitrous oxide emissions from synthetic fertilizers by utilizing digested manure as a fertilizer, and (3) offsets CO_2 emissions from carbon-intensive fossil fuel combustion through biogas energy production. Reducing greenhouse gas emissions in Wisconsin helps to prevent climate change, ensuring the preservation of a sustainable future for generations of Wisconsinites.

A full economic assessment of Wisconsin's biogas potential should build on the qualitative and quantitative analysis of the four categories of benefits presented here. Despite the demonstrated magnitude of these benefits, biogas production is not without its costs. Public and private decision-makers should carefully weigh the challenges to biogas production identified by the state's stakeholders. In addition, decision-makers should carefully consider the potential benefits and drawbacks of using non-waste substrates in digestion. Finally, although examples such as Germany demonstrate that anaerobic digestion can be profitable on small farms (<100 head), biogas production in Wisconsin does have the potential to incentivize industrial animal production at the expense of small farms. These challenges, while potentially significant, can be overcome if biogas is properly promoted and regulated.

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Quantitative Source Data and Assumptions

Concentrated Animal Feeding Operations (CAFO)

The CAFO calculations are considered the business-as-usual scenario as all of Wisconsin's 31 on-farm digesters have a herd size greater than 825 (thereby meeting the USEPA categorization as a CAFO). All data used in development of this scenario are taken from the 2009 Wisconsin Agricultural Biogas Casebook.[23]

- Herd Size: n = 21
    - 825 – 4600 (Median = 1400)
- Temperature Profile - Digester: n = 30
    - 27 mesophilic (3 thermophilic)
- Type Mixing - Digester: n = 30
    - 19 mixed-plug flow (11 complete mixed)
- Biogas Use: n = 21
    - 20 farms use the biogas for combined heat and power (electricity)
- Manure Volumes: n = 21
    - 20K – 160K gallons (Median = 55K gallons)
- Substrates: n = 21
    - 11 farms are manure only
    - Industrial waste added at 6 farms (typically 10%) – this volume range is 4K gallons to 8K gallons
- Energy Generation: n = 16
    - Installed capacity (kW): 140-1200 (Median = 600)
    - Production sold to utility (kWh): 1,120,100 – 15,912,086 (Median = 4,518,330).
- Digested Solids
    - 8 farms use on-farm as bedding or soil amendment
    - 12 farms sell digested solids off-farm
    - Median price is $20/ton

Typical Dairy Operation

According to the 2007 Department of Agriculture, Trade and Consumer Protection (DATCP) and Wisconsin Agricultural Statistics Service (WASS) data, 82% of the state's 12,500 registered herds are 100 milk cows or less.[2, 90] Typical values associated with herd operations of this size were courtesy of Professor Emeritus James Converse (University of Wisconsin, Madison).

- 100 head of cows
- 35 gpd/cow (manure and straw)
- 25 day retention time
- 87,500 gallons = 11,700 cubic feet
- Assume a 15 foot tank depth; need a surface area of 780 square feet
- Assume a circular tank; diameter = 16 feet
- 46 cubic feet methane per day per cow (300 m^3 methane per animal unit (1000 pounds so a cow = 1.5 AU))

- 4600 cubic feet of methane per day

Industrial – Food Processing

Wisconsin is home to over 1000 food processing firms encompassing the dairy, meat, and produce industries.[90] Currently, the Energy Center of Wisconsin is conducting a detailed study to categorize the role of anaerobic digestion in treating waste streams from food processing firms. However, in the absence of this comprehensive review, typical published values for the food processing industry have been used.[5, 63]

- Assume flow of 8,706 m^3/day and BOD of 2,000 mg/L
- Assume waste stabilization at 90%
- Methane generation is 5,485 m^3 CH_4 per day (assumes 0.35 m^3 CH_4/kg BOD)

Other assumptions and inputs used in our quantitative assessments

- Solids content of manure = 11.6-12.5%
- Methane per cow per day = 46 cubic feet (1.31 cubic meters)
- Electricity export rate = 5 cents per kWh
- Engine efficiency = 70%
- ATTRA cost estimates of AD
- Interest rate = 6%
- Inflation = 3%
- Lifetime = 30 years

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