Biogas:

Rethinking the Midwest's Potential

A report by:
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About Clean Wisconsin

Clean Wisconsin is an environmental advocacy organization that works to protect Wisconsin's clean water and air and advocates for clean energy by being an effective voice in the state legislature and by holding elected officials and polluters accountable. Clean Wisconsin was founded in 1970 as Wisconsin's Environmental Decade and is the state's largest environmental advocacy organization.

About the Author

Peter Taglia is a professional geologist who is currently working in numerous aspects of climate change mitigation with an emphasis on electrical generation, terrestrial and geological carbon sequestration and biofuels analysis. Peter has done extensive work with Governor Doyle's Task Force on Global Warming, the Midwestern Governors Association, and the Wisconsin Legislative Council. Prior to Clean Wisconsin, Peter worked as an environmental consultant, conducting environmental investigations and preparing environmental remediation plans and impact statements. Peter holds a BA in environmental geology from the University of Montana and a MS in hydrogeology from the UW-Madison.

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Definitions

This report includes a number of common and technical terms that have multiple definitions in practice. In particular, the different forms of combustible gases (e.g., biogas, syngas, producer gas, natural gas, etc.) can be confusing and are frequently used interchangeably. The following definitions are used in this report or are common sources of confusion with terms in this report:

Anaerobic Digestion: The breakdown of organic matter by bacteria in the absence of oxygen.

Biogas: A renewable gaseous fuel derived from biological materials that can be used as an energy source instead of fossil fuels, typically to replace conventional natural gas, propane, heating fuel oil, diesel fuel, or gasoline. Raw biogas is composed of a mixture of combustible gases (principally methane, but also including hydrogen and light hydrocarbons such as carbon monoxide, ethane, etc.), and various inert gases and impurities such as carbon dioxide and hydrogen sulfide. Many authors restrict the definition of biogas to only those gases produced by anaerobic digestion, while others use biogas to describe all combustible gases derived from biological sources.

Biomethane: Synonymous with renewable natural gas (see below)

British Thermal Unit (BTU or Btu): A standard unit of energy representing the amount of heat needed to raise the temperature of one pound of water from 60 to 61 degrees F (approximately equal to the heat of a single wooden match).

Methane: A combustible gas with the chemical formula CH_4 that can come from fossil or renewable processes.

Natural Gas: A gaseous fuel consisting of mostly methane and varying concentrations of other light hydrocarbons (e.g., propane, ethane, etc.) that is usually extracted from sedimentary deposits as a fossil fuel and distributed through an extensive pipeline network. Utilities and pipeline operators designate specifications for the energy content and purity of natural gas. The typical energy content of natural gas is 1,027 Btus per cubic foot.

Producer Gas: The combustible gases that are produced by low to moderate temperature biomass gasification. Producer gas includes methane, hydrogen, carbon monoxide, nitrogen as well as volatilized tars and other longer-chain hydrocarbons. Producer gas tends to have many more constituents and more impurities than the syngas that is created from high temperature gasification.

Renewable Natural Gas: Pipeline-quality natural gas produced from renewable resources. Renewable natural gas can be created by purifying biogas from anaerobic digesters or from biomass gasification through the chemical conversion of syngas or producer gas.

Substitute Natural Gas (SNG): Substitute natural gas, also known as synthetic natural gas, is pipeline-quality natural gas that is produced by a gasification process. SNG is typically produced by a methanation process that converts synthesis gas to methane using a nickel catalyst. The first large-scale SNG facility in the United States is the Dakota Gasification facility in Beulah, North Dakota, built in the late 1970s to produce natural gas from local coal. Additional SNG facilities have been built using petroleum coke as a feedstock. SNG produced from biomass is typically referred to as renewable natural gas.

Synthesis Gas (Syngas): A combustible mixture of hydrogen and carbon monoxide (CO). Synthesis gas is the product of the full conversion of a carbon feedstock (coal, oil, natural gas, and biomass) into the most basic components of hydrogen and carbon monoxide. Synthesis gas is widely produced from coal and natural gas as the first step in the creation of numerous synthetic compounds including plastics, ammonia fertilizers, synthetic diesel fuel and chemicals. Syngas can also be converted into methane (CH_4) in a methanation process.

Town Gas: Town gas is a mixture of combustible gases and volatile compounds, similar to producer gas, which was used for lighting and cooking application in cities during the late nineteenth and early twentieth century before natural gas pipelines were established. Town gas was created by gasifying coal and produced coal tar as a byproduct.

Executive Summary

The Midwest has a bounty of agricultural, forest, and urban resources suitable for producing biogas, a renewable substitute for natural gas that reduces fossil fuel use and global warming pollution. These resources, coupled with new and emerging conversion technologies and appropriate energy policy, can make biogas a powerful addition to the renewable energy landscape. Unfortunately, most people are not as familiar with biogas as they are with wind and solar power. And those who have heard of biogas may only know about its production at a few large dairy farms, an application that is both limited in potential and may raise other concerns in the environmental and sustainable agricultural community. This report explores the potential of biogas in the Midwest from current and emerging technologies, with examples of the various ways that biogas can be a major source of renewable energy.

The mainstay of biogas production, anaerobic digestion, has been employed for decades to harness the methane that is naturally produced when certain types of bacteria consume organic wastes. Traditional anaerobic digesters typically use fats and greases from large wastewater treatment plants or manure from large dairy farms to produce energy, but newer designs are expanding biogas energy production opportunities to smaller farms, while community digesters link multiple medium-sized farms to a single community digester via manure pipelines. Other anaerobic digesters in the Midwest divert food processing wastes from landfills and wastewater treatment facilities to directly produce biogas without any unnecessary equipment or treatment that would be required if these wastes were mixed with post-consumer non-degradable fractions. Some cities, such as Toronto, now use household organic waste collected from curbside bin programs to produce biogas, allowing individual homeowners to support clean energy, recycle nutrients, and avoid the need for additional landfill space.

New designs for anaerobic digesters that use dry or semi-dry organic wastes also contribute to the expansion of the Midwest's biogas potential. A dry digester being installed at the University of Wisconsin-Oshkosh will produce biogas from cafeteria waste, and other applications of dry digestion are converting agricultural byproducts into useful energy. In addition to the expansion of types of wastes that can be converted to biogas, both wet and dry digesters can take advantage of the benefits of co-digestion: the mixing of different waste streams in the same digester. An anaerobic digester near Fort McCoy, a military training facility in Wisconsin, will mix food waste with slaughterhouse waste to produce energy and reduce the need for new landfill space. A company in Ontario delivers grease trap waste to a series of small manure digesters in the area to dramatically boost the biogas output for these on-farm systems.

The rapid expansion of technologies to produce biogas from diverse waste streams not only provides an important energy source, but solves many problems associated with current waste disposal practices. Tens of thousands of large dairy, swine, and poultry operations in the Midwest produce millions of tons of manure that contribute to air and water pollution. In addition to the direct production of agricultural products, the Midwest also has some of the highest concentrations of food processing facilities in the country that produce large amounts of organic waste. Food processing waste, along with organic wastes from households, makes up a significant proportion of the waste sent to landfills, and policymakers have long looked for effective alternatives. Using anaerobic digesters to treat the various wastes associated with each step in the food production process reduces air and water pollution and returns more nutrients back to the land, lessening the need for synthetic fertilizers.

Another promising technology for replacing natural gas on a large scale is the gasification of biomass under heat and pressure. Gasification technology is well understood but has only recently reached larger scales that enable the economic production of renewable gases from biomass. These renewable gases, termed producer gas or syngas, depending on the process, are all closely related to traditional biogas in that they are readily combustible replacements for natural gas. Xcel Energy, a major Midwestern utility based in Minneapolis, Minn., was recently given approval by regulatory authorities to convert an older coal plant in Ashland, Wisconsin, to biomass gasification. The gasification process at the Bay Front power plant will convert wood waste and forest residue to a low Btu type of biogas that will be directly combusted in a boiler. A smaller biomass gasifier at an ethanol plant in Minnesota uses corn cobs to produce a similar type of biogas that drives the ethanol plant's distillation process, reducing the plant's natural gas use. The ability of biomass gasification to efficiently produce renewable gases from plant fibers greatly expands the potential resources and scale of the energy output of individual facilities, and increases the profile of biogas as a significant renewable resource in the Midwest.

Finally, new biogas end-use applications in the Midwest illustrate the versatility of biogas in multiple sectors of the economy. To date, most biogas production in the Midwest has been used in engines to produce electricity, but recent projects have compressed biogas for use as a vehicle fuel and cleaned biogas to natural gas quality for pipeline distribution, such as a large dairy in Michigan that is adjacent to a natural gas pipeline. Expanding the applications of biogas beyond electricity to vehicle fuel and renewable natural gas provides multiple benefits to biogas producers and raises the profile of biogas as a significant renewable resource in the Midwest. The new applications also provide economic benefits and new opportunities for renewable energy production in areas with challenging infrastructure.

To realize the large potential for biogas in the Midwest, additional policies are needed. Current large-scale renewable energy policies favor electrical production at the expense of higher efficiency opportunities to produce electricity and heat (known as "cogeneration") from biogas. Other policies, and most existing renewable fuel incentives, favor liquid transportation fuels such as corn ethanol instead of biogas. Renewable energy policies that better recognize the energy benefits of biogas have been proposed in the Midwest and Europe. These policies, like feed-in-tariffs, can be implemented in ways that recognize the benefits of smaller and more distributed generation technologies like biogas. Compressed biogas is particularly competitive as a transportation fuel under policies such as a low carbon fuel standard, which rewards fuels with very low lifecycle carbon emissions.

Policymakers and renewable energy advocates must carefully weigh the costs and benefits of all energy sources, and biogas is no different. Some applications of biogas are most cost-effective at large Concentrated Animal Feeding Operations (CAFOs), which can have large water, air, and environmental footprints. Bioenergy sources like biogas also must be scrutinized for sustainability criteria and ancillary impacts, such as the wildlife benefits or water impacts that may be reduced if a resource is diverted from an existing landscape to bioenergy production. The costs and carbon emission profile of biogas should also be compared to other renewable and non-renewable energy opportunities to determine the degree of public incentives that are warranted for biogas.

The energy landscape in the Midwest is changing rapidly and former niche energy sources, like wind turbines, have become established electrical generation technologies that are expanding rapidly. Biogas currently occupies a relatively small portion of the energy supply in the

Midwest, but numerous advancements in technology, deployment of biogas systems, and applications of biogas energy hold the potential for this renewable energy resource to play a much greater role going forward. This report explores the broad topic of biogas and helps inform what role biogas can and should have in the energy landscape in the Midwest.

PHOTO: Environmental Law & Policy Center

Introduction and Overview

Biogas is a flammable gas produced from renewable resources that can be used in many applications as an alternative to fossil fuel-based natural gas. The production and use of biogas is an established technology with a long history, but biogas currently only comprises a small percentage of the total energy used in most industrial countries. At the same time, new technologies and approaches to produce and use biogas are expanding rapidly. Unfortunately, biogas has been overshadowed by other renewable energy resources, including wind, solar, and ethanol, both in the lack of recognition of biogas's potential and the lack of renewable energy policies that either ignore important uses of biogas or fail to reward the high performance of various biogas energy systems. This report explored the potential for biogas in the Midwest and provides an overview of the role biogas can serve in the future energy landscape.

The report is divided into four major sections: biogas in our current energy and environmental landscape; emerging technologies and approaches to biogas production; biogas end-uses; and policies needed to foster the growth of the biogas industry. Each section includes examples that illustrate different biogas energy systems as well as the implications of biogas systems on a number of subjects, including water quality, greenhouse gas reduction, and economic benefits. A brief summary of each of the four sections is provided to guide the reader:

Biogas in the Current Energy and Environmental Landscape

This section will present the energy context for biogas by describing our current fossil-fuel dominated energy system and the existing sources of renewable energy; Germany's success in biogas development is described for comparison. This section also describes the current production of biogas in the United States from mature anaerobic digester technologies at wastewater treatment systems, landfills, and manure digesters. The expansion of anaerobic digesters at large Concentrated Animal Feeding Operations (CAFOs) can provide additional renewable energy in the Midwest. Unfortunately, this potential has also raised other concerns, as the potential for renewable energy production can overshadow air and water concerns and other potential environmental impacts of some CAFOs. A description of the benefits and limitations of anaerobic digesters on manure runoff management is provided.

Emerging Technologies and Approaches to Biogas Production

This section provides examples of innovations in conventional anaerobic digesters that are expanding the number and types of farms that can use this technology, and the many other food and agricultural wastes that can be used in anaerobic digesters. This section describes the emerging dry digester designs that allow anaerobic digesters to produce biogas from lower-moisture feedstocks, expanding the size of the resource base that can be converted to biogas. Finally, this section explores the opportunity for biomass gasification to produce combustible gases from woody and grass-based biomass resources.

Biogas End-Uses

This section describes biogas end-uses, from conventional electrical generation in large engines to facilities that upgrade biogas into renewable natural gas for use in existing pipelines or in compressed natural gas vehicles. New applications of biogas not only expand the potential for biogas as a resource, but also provide important options for facilities that cannot produce electricity due to electrical transmission restrictions or air quality issues.

Policies Needed

The final section describes policies needed to level the renewable energy playing field and help the Midwest realize its biogas potential. Four major policies can drive biogas growth: enhanced renewable electricity standards that credit biogas injected into the pipeline and cogeneration; renewable natural gas standards; feed-in tariffs, otherwise known as advanced renewable tariffs; and a low carbon fuel standard. These four policies, along with other financial incentives, can stimulate the demand for biogas as part of a comprehensive renewable energy and greenhouse gas emission reduction strategy.

1. Biogas in the Current Energy and Environmental Landscape

To better establish the potential role of biogas, it is useful to observe the current mix of renewable and non-renewable energy in the United States. Renewable energy here supplies 7% of the total energy consumption, a slight increase from 6% in 2000. Biomass makes up the largest portion of renewable energy consumed in the United States, followed by hydroelectric, wind, geothermal, and solar (Figure 1). The biomass definition, however, includes liquid biofuels (e.g., ethanol), waste, wood, and wood-derived fuels. For the biomass category, more detailed data from the Energy Information Agency (EIA) indicate that wood-derived fuels made up the largest portion of biomass energy in 2008 (53%), followed by biofuels (36%), and waste (11%). Current biogas production from landfills, wastewater treatment facilities, and manure digesters fall into the waste category along with municipal solid waste-to-energy facilities. Thus, the portion of biogas energy from all sources supplied less than one-half of one percent of the total U.S. energy consumption in 2008.

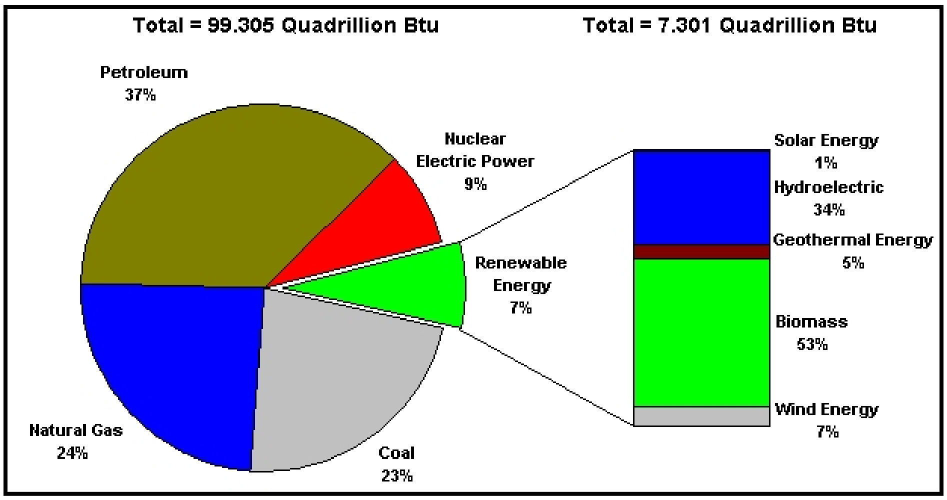

Figure 1: Renewable Energy Consumption in the United States, 2008.
Source: U.S. Energy Information Agency (EIA),
www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/rea_prereport.html

Note: This figure presents total primary energy consumption (i.e., total energy content of biomass or fossil fuels combusted) and therefore counts the energy that is wasted when fuels are burned to produce electricity. As a result, total consumption statistics will undervalue energy sources that produce electricity directly, like wind and solar photovoltaics.

In contrast to the United States, the proportion of total energy consumption in Germany in 2007 from renewable resources was around 14%, which is more than double the renewable proportion in that country in 2000 (6.3%)[1]. Much of the renewable energy expansion in Germany has occurred in the electrical sector, with renewable energy supplying 15.1% of gross electrical consumption in 2008, dominated by wind power (44% of the renewable electricity), hydropower, and biomass. Biogas supplied approximately 12 % of the renewable electricity in Germany in 2008, with the greatest output coming from dedicated biogas facilities (8.7% of renewable electricity), followed by wastewater treatment and landfill gas (1.1% each). By the end of 2008, Germany had approximately 4,100 biogas plants supplying approximately 1,435 megawatts (MW) of electric generation capacity. One MW of electrical capacity can meet the needs of approximately 1,000 average Midwestern houses[2]. According to the U.S. EPA AgSTAR Program[3], the United States has approximately 150 on-farm anaerobic digesters, less than 4% of

[1] Energy statistics for Germany used in this paper are from the Federal Republic of Germany's 2007 and 2009 reports to the European Parliament under Directive 2001/77/EC on the promotion of renewable energy.
http://ec.europa.eu/energy/renewables/electricity/doc/msreports/2009/germany_2009_english.pdf
[2] Average household consumption varies among utilities and demographics. A household using approximately 750 kWh per month in the Midwest is typical and requires the electrical generation of approximately 1 kW from a continuous source (e.g., baseload power plant). Thus, 1 MW of capacity from a continuous source can meet the needs of approximately 1,000 households.
[3] The AgSTAR Program is a joint effort of the U.S. Environmental Protection Agency (U.S. EPA), the U.S. Department of Agriculture, and the U.S.

the German total, despite having a much larger population and agricultural sector. In comparison to Germany, the world leader in biogas, the United States has vast potential to expand biogas production using established technology.

The majority of existing biogas is produced using anaerobic digesters, gas-tight high-moisture enclosures that provide a stable environment for methane-producing bacteria to flourish (Figure 2). The raw biogas is collected from the digester and then flared or processed and used in energy applications as a replacement for electricity, natural gas, propane, diesel fuel, or gasoline. The bacterial processes that produce methane from waste occur naturally in many environments where organic-rich material is isolated from oxygen, such as thick wetland sediments, the origin of the term “swamp gas.” It is likely that humans first harnessed methanogenic bacteria for waste processing thousands of years ago, based on historical references to covered sewage tanks, but the first documented anaerobic digesters originated in India and Europe in the mid to late 1800s.

The U.S. has tens of thousands of dairy, beef, swine, sheep, and poultry farms, all which produce significant quantities of manure each year that can be converted to biogas with conventional anaerobic digester technology (Figure 2). Midwestern states have over 8,000 large cattle farms, 2,000 large dairy farms, nearly 9,000 large swine farms, and over 200 large egg-laying operations (Figure 3).[4] If 75% of these farms installed conventional anaerobic digesters, approximately 500 MW of electricity could be generated using existing technology[5]. While this

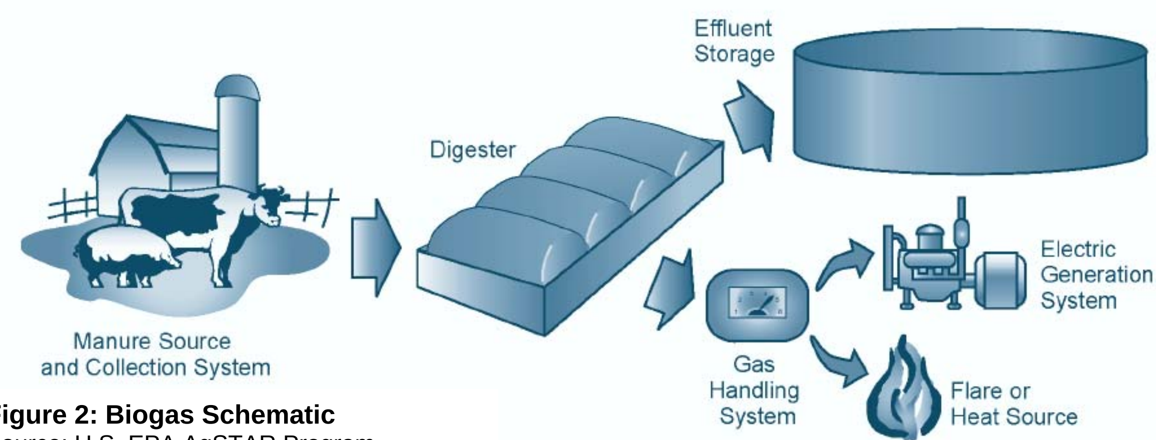

Figure 2: Biogas Schematic
Source: U.S. EPA AgSTAR Program

amount of electricity is approximately equal to the demand of a half-million households, the generation of this electricity will require a large expansion of existing anaerobic digester technology; it is unlikely that a majority of these farms have the desire or infrastructure to accommodate anaerobic digesters. Moreover, it would take many years to deploy the electrical energy produced by 500 MW of anaerobic digesters, and these digesters would still produce less than one-fifth of the total amount of electrical energy produced by *existing* wind turbines in the Midwest[6]. Fortunately, biogas energy systems are not limited to conventional anaerobic digesters at large farms, and the true resource potential for biogas in the Midwest, as discussed

Department of Energy. www.epa.gov/agstar/
[4] USDA National Agriculture Statistics Service. www.nass.usda.gov
[5] Using default biogas production values per head per day for cattle (13.6), dairy (65.9), swine (5.6) and layers (0.3), the total biogas output in the Midwest is approximately 130 billion cubic feet per year.
[6] The total wind power capacity in the Midwest was over 9,000 MW at the end of 2009. Because wind is more intermittent than biogas, the amount of electrical energy produced by these wind turbines is roughly equivalent to the electrical energy from approximately 3,000 MW of biogas generation.

in the next section of this paper, is much greater.

In addition to the energy potential of biogas, anaerobic digesters provide other benefits for managing waste. In fact, the non-energy benefits have resulted in some anaerobic digesters built with no provisions for the beneficial use of the biogas. In these cases, the anaerobic digestion process is providing other benefits to the farm, and the biogas produced in the system is simply flared. The U.S. AgSTAR Program lists the following non-energy benefits of anaerobic digesters for manure management[7]:

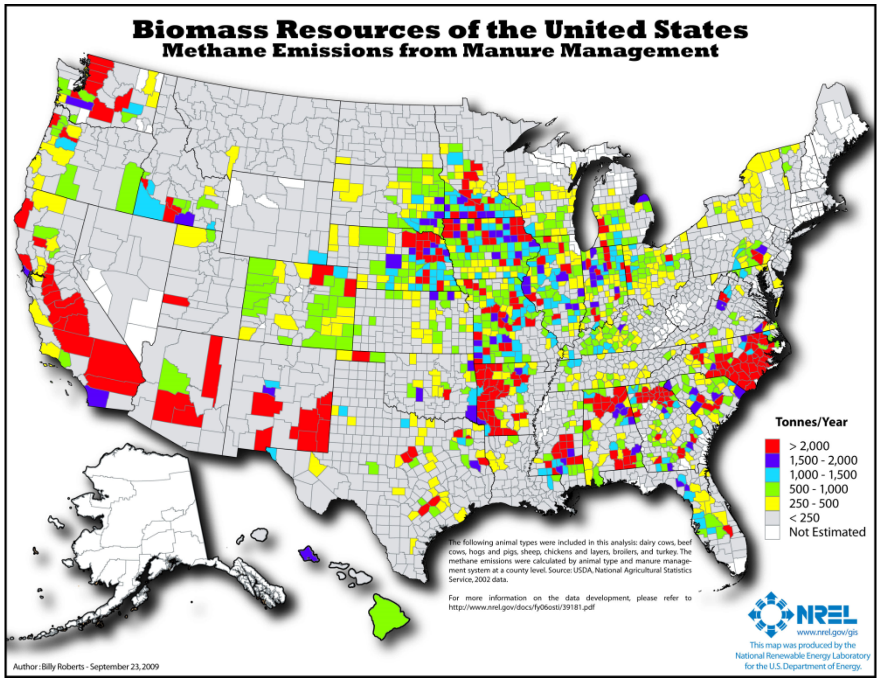

Figure 3: Biogas Manure Resource Map
Source: www.nrel.gov/gis/biomass.html

"**Reduced Odors**. Biogas systems reduce offensive odors from overloaded or improperly managed manure storage facilities. These odors impair air quality and may be a nuisance to nearby communities. Biogas systems reduce these offensive odors because the volatile organic acids, the odor-causing compounds, are consumed by biogas-producing bacteria.

High Quality Fertilizer. In the process of anaerobic digestion, the organic nitrogen in the manure is largely converted to ammonium. Ammonium is the primary constituent of commercial fertilizer, which is readily available and utilized by plants.

Reduced Surface and Groundwater Contamination. Digester effluent is a more uniform and predictable product than untreated manure. The higher ammonium content allows better crop utilization and the physical properties allow easier land application. Properly applied, digester effluent reduces the likelihood of surface or groundwater pollution.

Pathogen Reduction. Heated digesters reduce pathogen populations dramatically in a few days. Lagoon digesters isolate pathogens and allow pathogen kill and die-off prior to entering storage for land application."

[7] AgSTAR Handbook, Version 2, 2002. www.epa.gov/agstar/pdf/handbook/full_pdf.pdf

While the four non-energy benefits of anaerobic digesters identified by the EPA for manure management address important liabilities of conventional manure systems, the rapid expansion of biogas production from anaerobic digesters in the last decade is more likely to be attributed to renewable energy generation. This is especially true for Germany, where generous financial incentives and guaranteed energy buy-back rates (also known as feed-in-tariffs and discussed on page 36) have made Germany a global leader in renewable energy. The relationship between the non-energy uses of anaerobic digesters and renewable energy incentives, however, is complicated by a number of factors worth closer examination.

The primary complication related to anaerobic digesters and pollution reduction in the United States is not directly related to the function of the anaerobic digester itself, but the types of farms that are most likely to have these systems. According to AgSTAR, conventional anaerobic digesters are typically designed to process the amount of wet manure created by dairy herd sizes of at least 500 cows or 2,000 feeder pigs. Herds of this size and larger are difficult to pasture, therefore the animals are held in large buildings or covered enclosures called Concentrated Animal Feeding Operations (CAFOs) where at least 90% of the manure is collected regularly. The manure from these facilities is typically scraped or pumped from concrete floors and the volume of waste from CAFOs can result in potential manure management problems, with or without anaerobic digesters. While anaerobic digesters reduce odors and make manure easier to apply to the land, the overall volume of manure and nutrients do not change appreciably due to anaerobic digestion. The presence of large volumes of wet manure before or after treatment with an anaerobic digester will always entail some risk of spill or over-application of nutrients to farmland, resulting in nutrient runoff. Fortunately, manure digesters can also be part of the solution to nutrient runoff with appropriate design considerations (see Manure Nutrient Management and Community Digester example, Page 17).

One way to examine the tension between biogas energy production and manure management is to identify the types of questions typically asked about the net environmental impact of anaerobic digesters at large farms:

- Do large CAFOs have environmental impacts greater than what can be addressed by anaerobic digesters?
- Will additional incentives or policies that encourage the production of biogas from anaerobic digesters incentivize not only the energy systems themselves but also the expansion of larger herd sizes to the detriment of smaller farms? Or are other trends and regulations driving the expansion of farm sizes?
- Do anaerobic digesters at CAFOs distract or discourage farmers from moving toward grass-fed dairy or beef?

These questions typically come from the sustainable agriculture community that would normally be allies in the promotion of renewable energy, but in these instances, has concerns about the large CAFOs where most anaerobic digesters have been installed in the United States. The first way to answer these questions is to identify the relationship between biogas and CAFOs. While most of the anaerobic digesters in the United States to date have been installed at CAFOs, the expansion of biogas, for the reasons outlined in other sections of this paper, is likely to come from a much broader resource. The next section of this paper on emerging technologies and approaches to biogas illustrates the growing opportunities for biogas production at smaller farms, community digesters, even anaerobic digestion of manure collected from outdoors. Additional opportunities to harness energy from woody biomass, grass, and food processing and urban organic waste resources are also major biogas growth areas that can benefit a wide diversity of farms. The questions of biogas energy incentives driving the expansion of CAFOs are best answered by examining some of the drivers of larger dairy and other animal operations.

The consolidation of the dairy and livestock industries into fewer farms with more animals is not a new trend. Data from the U.S. Department of Agriculture (USDA) document this trend and shows that it has been accelerating since 1970 (Figure 4). The USDA Economic Research Service listed some economic and demographic differences between large and small dairies[8]:

> "Large farms usually purchase significant amounts of feed and contract with other operations to raise their heifers offsite. Small farms grow more of their own feed and raise their heifers onsite. Large operations tend to confine their milk cows in large barns or in dry lot feed yards, while small operations may graze their cows on pasture."

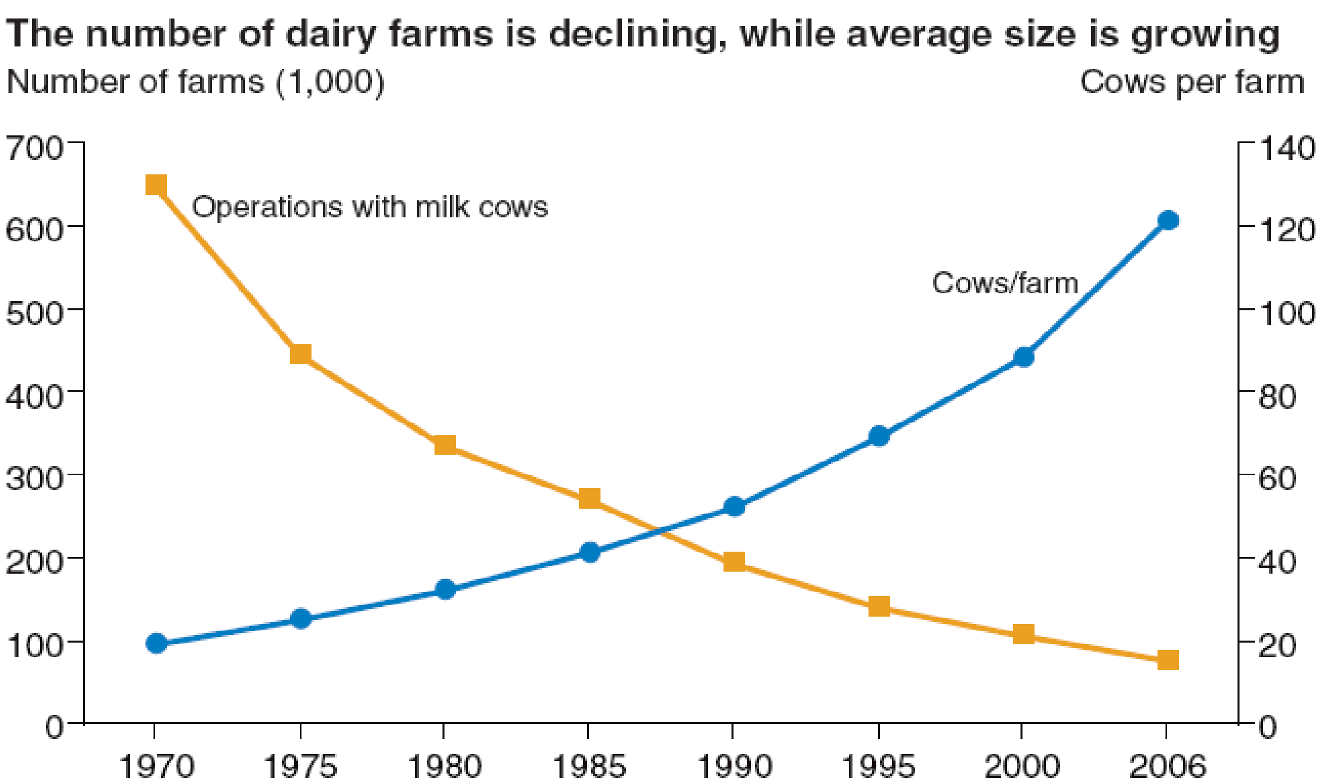

Figure 4: Fewer Farms, More Cows Per Farm
Source: USDA. NASS

Other trends that contribute to farm consolidation, such as smaller family size, aging rural populations, increasing availability of technology and mechanization, are pervasive in the

[8] Profits, Costs, and the Changing Structure of Dairy Farming / ERR-47 Economic Research Service/USDA www.ers.usda.gov/publications/err47/err47b.pdf

economies of developed countries. Finally, the data on the consolidation of dairy and livestock industries show that this trend began before anaerobic digesters became widely available and only a small percentage of large farms have installed anaerobic digesters; thus, the availability of anaerobic digesters has not been a primary driver for this trend.

Even if the drivers of farm consolidation are completely unrelated to energy policy, the question remains: Will policies like biogas incentives encourage *more* consolidation? One way to examine this question is to view biogas incentives in the context of overall environmental policy. The societal demand for renewable energy and greenhouse gas reductions that provide the major force behind renewable energy policies, including biogas incentives, are also leading to changes in agricultural trends. Many of the proposed state and federal climate policies that would expand biogas also provide incentives for reducing greenhouse gas emissions from agriculture through nitrogen fertilizer emission reductions, agricultural cropping systems that store carbon (tillage, cover crops, organic farming), and the planting of perennial grasses on highly erodible or degraded farmland. In addition to their advantages in reducing climate change, these agricultural processes provide benefits for water quality, soil fertility, and wildlife habitat. Finally, many agricultural advocacy groups that support smaller-scale farming and sustainable agriculture in the United States also support comprehensive clean energy policies, such as proposed federal carbon cap and trade legislation, that would encourage biogas production and the beneficial agricultural practices described above.

Example: Wisconsin, Leading the United States in Biogas Production

Wisconsin leads the United States in biogas production with approximately 30 anaerobic digesters, most of which use manure from dairy farms with herds of 800 cows to 4,000 cows (Figure 5). The total electrical production capacity of these digesters in 2009 was 11.6 MW (or the electricity needs of approximately 10,000 homes), an increase of 60% from the previous year. Given that Wisconsin had only a few operating digesters in 2000, the state has made significant progress in both expanding the use of on-farm digesters and illustrating new digester types and designs. In fact, of the 10 digesters built in Wisconsin in 2009, four of these digesters were off-farm systems using food processing wastes.

Wisconsin is also a useful state to examine the potential opportunities for electrical generation using conventional anaerobic digester technologies in comparison to wind. To date, wind power has been the dominant source of new renewable electricity used to meet renewable energy mandates in Wisconsin and the Midwest. Over one year, the electrical energy produced at Wisconsin's 11.6 MW of biogas generators is similar to the amount of renewable energy produced by one small, 30 MW wind farm. (For example, the Montfort, Wis., wind farm owned by NextEra Energy has twenty 1.5 MW turbines).

Following the initial startup period of an anaerobic digester, electric generation from biogas is more steady than wind power, so each megawatt of biogas installed capacity produces more energy (in megawatt-hours) than each megawatt of wind power capacity. Nevertheless, biogas generation in Wisconsin would have to grow over tenfold (to at least 150 MW) to equal the total electrical energy produced by the 300 commercial wind turbines currently operating in Wisconsin. As a whole, the difference in the current renewable energy output from wind power and biogas power in the Midwest region is

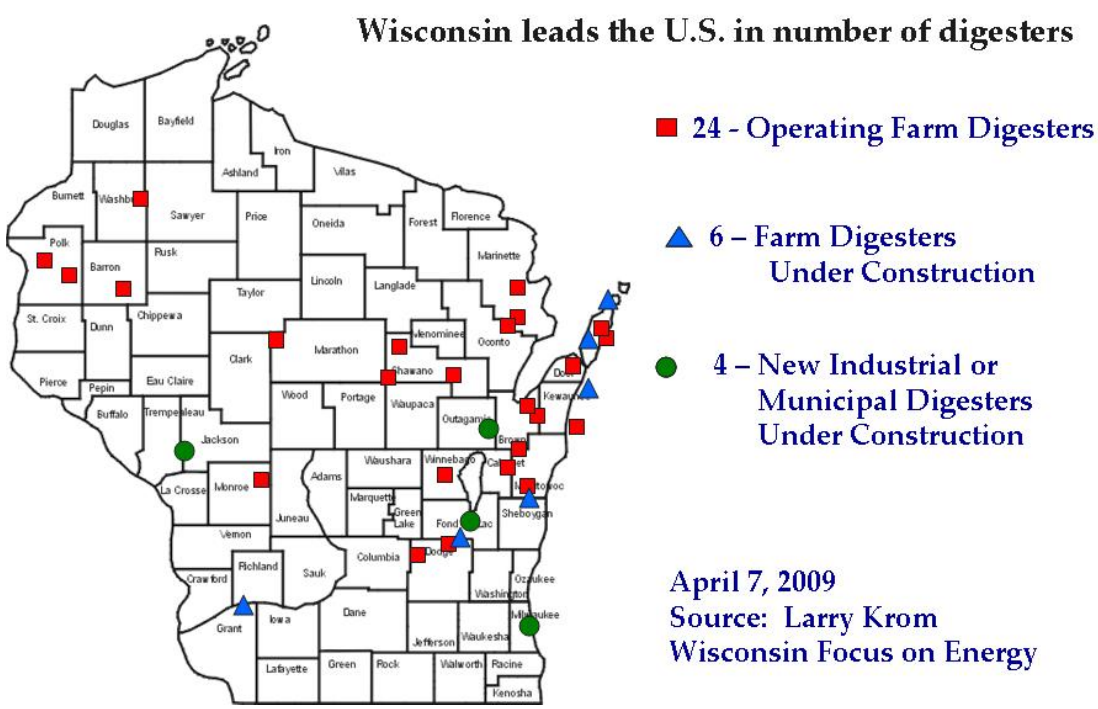

Figure 5: Anaerobic Digesters in Wisconsin
Source: Wisconsin Focus on Energy (2009)

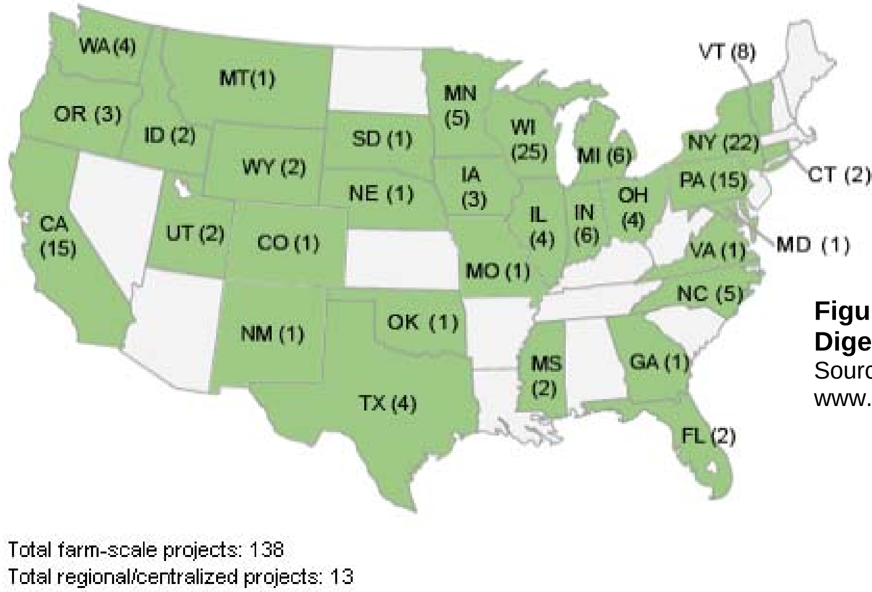

Figure 6: Agricultural Anaerobic Digesters, April 2010.
Source: AgSTAR, www.epa.gov/agstar/operational.html

even higher due to the much greater number of wind turbines in Iowa (3,604 MW), Minnesota (1,810 MW), and Illinois (1,547 MW), compared to Wisconsin (449 MW), and the fact that Wisconsin has roughly the same number of anaerobic digesters as all other Midwest states combined (Figure 6)[9].

The total potential electrical generation from cow manure with conventional anaerobic digesters at dairy farms in Wisconsin with more than 500 cows is approximately 39 MW[10]. This estimate is based on a simple calculation of the potential biogas output per cow, the number of dairy cows in Wisconsin at farms with more than 500 cows, and the electrical output for conventional biogas generators. Thus, using Wisconsin's example, conventional anaerobic digesters installed at every large dairy in the state would produce less than half of the current renewable electricity produced by the relatively modest number (compared to other Midwestern states) of existing wind turbines in Wisconsin. For this reason, biogas has not typically garnered the same level of recognition as a potential renewable energy resource as wind, biomass, and solar. But the simple calculations of biogas potential, based on large dairies, miss a number of factors that are already boosting biogas output at Wisconsin's anaerobic digesters. Nine on-farm digesters in Wisconsin add other substrates to the manure such as food processing wastes and agricultural wastes (chopped straw, moldy feed, unused feed, etc.) that can significantly boost biogas production from these existing systems[11]. Subsequent sections of this report explore the factors that are expanding biogas production from new and existing anaerobic digesters.

[9] U.S. Department of Energy National Renewable Energy Laboratory. 2009 year end wind power capacity. www.windpoweringamerica.gov/images/windmaps/installed_capacity_current.jpg
[10] Wisconsin's Strategy for Reducing Global Warming, Final Report to Governor Jim Doyle, July, 2008. Page 174. http://dnr.wi.gov/environmentprotect/gtfgw/documents/Final_Report.pdf
[11] Wisconsin Agricultural Biogas Casebook, Focus on Energy 2009, Joe Kramer, www.focusonenergy.com/files/Document_Management_System/Renewables/biogas09_casestudy.pdf

Example: Manure Nutrient Management and Community Digesters

Agriculture is the single largest contributor of excess nutrients to the Mississippi River basin and Gulf of Mexico. Fertilizing corn and soybeans for animal feed and spreading manure causes nutrient runoff in water bodies across the Midwest. Fortunately, innovative manure digester designs integrated with wastewater treatment systems can remove problematic nutrients, providing a convenient opportunity to improve water quality and produce renewable energy.

Nitrogen and phosphorus are principal nutrients in common agricultural fertilizers, making up the first and second nutrients in the common N/P/K fertilizer nomenclature (i.e., a "20/20/20" fertilizer refers to the proportions of nitrogen, phosphorus, and potassium in the fertilizer). These two nutrients are also the largest contributors to excess algae and aquatic plant growth in the Mississippi River basin and ultimately result in the seasonal hypoxia zone, commonly called the "Dead Zone," in the Gulf of Mexico (Figure 7). According to a recent comprehensive analysis of water quality data and models of agricultural runoff created by the U.S. Geological Survey, corn and soybean crops are the single largest source of nitrogen and animal manure is the single largest source of phosphorous delivered to the Gulf of Mexico by the Mississippi River[12]. The impacts of nitrogen and phosphorus pollution, however, extend across the entire Midwest. According to the U.S. EPA, "State water quality reports indicate that over-enrichment of waters by nutrients (nitrogen and phosphorus) is the biggest overall source of impairment of the nation's rivers and streams, lakes and reservoirs, and estuaries[13]." In addition to the human health and environmental impacts of excess nutrients in impaired water bodies, a formal designation of impairment under the Clean Water Act results in costly restrictions on nitrogen and phosphorus discharges from industrial sources and wastewater treatment systems upstream of the impaired water body, even though the largest contribution comes from nonpoint source agricultural runoff.

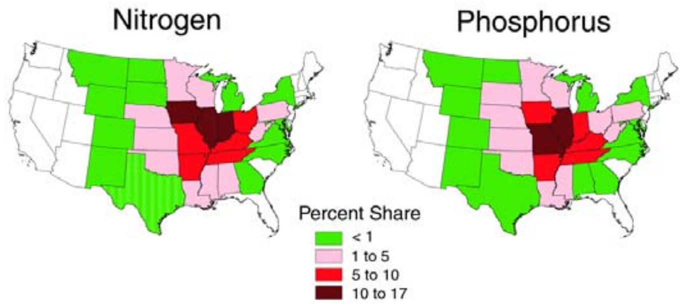

Figure 7: Nutrient Contributions to the Gulf, by State.
Source: USGS, http://water.usgs.gov/nawqa/sparrow/gulf_findings/by_state.html

Nutrient pollution from agriculture is called "nonpoint;" it does not originate in individual discharge pipes but over large areas of farmland that collectively contribute a sufficient mass of nutrients to individual water bodies to overwhelm their natural chemistry. The diffuse nature of nonpoint runoff from agricultural fields makes it difficult to address the problem, since reducing the nutrients that run off farm fields requires changing the methods of fertilizer application over large areas. Phosphorus runoff occurs from the application of both conventional commercial fertilizers and manure, but is a greater problem with manure fertilizer applications; the concentrations of different fertilizer nutrients can be adjusted in commercial mixes but there is little control of the nutrients found in animal manure. Commercial fertilizers containing little or no phosphorus are available and can be applied to farm fields that already have excess phosphorous. Removing phosphorus from manure, however, requires costly liquid-solid separation and the chemical removal or export of the phosphorous. In addition, animal manure is created year-round and must be applied to fields during seasons when no crops are growing or stored in large lagoons. Large manure spills from flooded storage lagoons or the spreading of manure on frozen soil prior to a

[12] Richard Alexander et. al. 2008."Differences in Phosphorus and Nitrogen Delivery to The Gulf of Mexico from the Mississippi River Basin". Environmental Science and Technology. http://pubs.acs.org/doi/abs/10.1021/es0716103
[13] USEPA Clean Water Action Plan, February 19, 1998. Summary at www.epa.gov/history/topics/cwa/03.htm

major melt or rain event result in fish kills and widespread water impacts across the Midwest.

In Dane County, Wisconsin, a community manure digester under development provides a new model for the production of renewable energy and the protection of water quality. The Clean Energy, Clean Lakes project near the Village of Waunakee links three dairy farms, including one dairy with less than 500 cows, to one anaerobic digester and water treatment system (Figure 8). The project will produce approximately 2 MW of electricity and the wastewater treatment system will remove approximately 70% of the phosphorus from the digester effluent for export out of the area. Manure digesters do not directly remove phosphorous from manure, but provide a convenient opportunity to add water treatment systems that can remove phosphorous. In addition to its innovative phosphorous treatment, the Dane County community digester is designed with an unloading dock to process additional manure in the event of an emergency, such as floodwaters threatening a manure lagoon at one of Dane County’s 400 dairy farms. The combination of the emergency manure handling, the phosphorus removal system, and the partnership among three local farms make this community digester system a unique approach to biogas production and water quality protection.

Figure 8. Community Digester in Dane County, Wisconsin, with Phosphorous Removal System.
Source: Dane County Public Works

2. Emerging Technologies and Approaches to Biogas Production

The total biogas energy potential in the Midwest from *conventional* anaerobic digesters, as detailed in the previous section, is only a fraction of the energy potential of other renewable energy resources such as wind. But newer designs detailed in this section are expanding the amount and type of resources that can be used for biogas production and increasing the total potential. These resources include manure from smaller farms, food processing wastes added to existing anaerobic digesters, dry digesters that can produce biogas from solid manure livestock operations, other agricultural and urban resources such as food scraps, spoiled food, even grasses and mulches. Emerging biomass gasification technologies employ a different approach to the production of renewable gases, using high temperatures and pressures to convert more traditional biomass resources like wood and wood waste into biogas-like gases.

Background

Brief descriptions of different conventional anaerobic digester designs provide context for the new technologies and approaches that make up the remainder of this section. Conventional anaerobic digesters already take many forms; from simple designs that are little more than flexible covers over concrete manure lagoons to various above-ground round tanks and below-ground U-shaped channel designs. In all cases, the wet manure or other waste material must be delivered to an environment favorable to the growth of the bacteria that drive the process. The rate at which these bacteria grow and produce biogas depends on a number of factors, with temperature being the most important. The simplest anaerobic digesters, covered lagoon systems, cannot effectively operate during the typical cold, Midwest winter and are more common in warmer climates. Most anaerobic digesters in the Midwest use a heat source to maintain the waste material at a constant temperature for digestion.

The two major categories of heated digesters are mesophilic, operating at temperatures around 95 degrees F, and thermophilic, operating at higher temperatures of around 120 degrees F. The thermophilic designs can potentially produce more biogas in a shorter period of time from the same amount of waste, but also require more energy to heat the digester. The design temperature of a digester is chosen based on the objectives of the owner and other site-specific factors, such as the percent moisture, nitrogen content, volume of waste to be treated, and the available heat sources for the digester[14]. The other major characteristic that varies among conventional anaerobic digester designs is the method used to process the wet waste. Plug-flow digesters introduce waste that flows in one direction during the digestion process, while complete mix digesters use paddles and propellers to mix the waste during the digestion process. Another design, the fixed-film digester, is filled with plastic media onto which bacteria attach, thereby maintaining a sufficient microbial population and avoiding washout, which frequently occurs in waste with lower solids content. The diversity of digester designs allows developers to produce biogas from waste with a wide range of characteristics such as fiber content or potential sand contamination. In all cases, the waste being treated is wet, typically with no less than 85% liquids.

[14] The U.S. EPA AgSTAR program has the most comprehensive description of commercially available anaerobic digestion technologies for the livestock sector. www.epa.gov/agstar/index.html

The diversity of conventional digesters demonstrates the innovation and ingenuity of the farmers and engineers who harness the power of biogas-producing bacteria in different environments. Until recently, however, conventional anaerobic digesters were limited to wastes with high moisture content and have been economical only at sites where a large volume of waste of consistent quality is continuously produced. New innovations now greatly expand the utility and reach of anaerobic digesters to produce biogas from more waste types. Adding additional wastes, especially food processing wastes, to anaerobic digesters can greatly increase biogas production from both new and existing anaerobic digesters. Another approach to increase the biogas potential from conventional anaerobic digesters is through community digesters that link smaller farms to a single facility.

Manure Digesters for Smaller Farms

The development of manure digesters for smaller farms can greatly increase the biogas potential from manures. In the Wisconsin example (Page 17), the electrical generation potential from conventional anaerobic digesters at the state's 242 dairy farms with greater than 500 cows was calculated to be 39 MW. The same calculations for all dairy cows at Wisconsin's 13,000 dairy farms, based on the biogas produced by the manure from individual cows, provide a potential of 413 MW, a greater than tenfold increase[15]. While many dairy farms in Wisconsin do not have the type of wet scrape manure collection that can be used by conventional wet digesters, many of these farms are suitable for anaerobic digestion but are limited by the technological and economic availability of designs for smaller farms. USEMCO, a waste treatment technology provider in Tomah, Wisconsin, recently received a major grant to commercialize anaerobic digesters for farms with 150 to 200 cows[16]. A small digester project was installed at the Jer-Lindy Dairy in Stearns County, Minnesota. The Jer-Lindy Dairy has a total of 300 cows, of which 140 milking cows are feeding a small anaerobic digester[17]. Increasing the biogas potential from smaller farms is also facilitated by the opportunities in co-digestion, dry digesters, and community digesters, discussed later in this section.

Co-digestion: Boosting the biogas from manure with off-farm wastes

Pound for pound, manure produces relatively low amounts of biogas compared to other wastes (Figure 9). The high volume of manure produced at many farms, as well as the other benefits of anaerobic digestion described in the previous section, contribute to the success of manure digestion. Adding even small amounts of other substrates to a manure digester, however, can greatly increase the biogas production and provide a beneficial disposal option for other wastes. Many anaerobic digesters in Germany already use a diversity of wastes, including other farm products such as corn silage, that contribute to that country's prodigious biogas output. A few farms in the United States use co-digestion and the owners of many existing and proposed digesters are exploring this opportunity, but waste disposal restrictions can put an upper limit on a farmer's ability to use off-site substrates.

15 Wisconsin's Strategy for Reducing Global Warming, Final Report to Governor Jim Doyle, July, 2008. Page 174. http://dnr.wi.gov/environmentprotect/gtfgw/documents/Final_Report.pdf
16 www.wisgov.state.wi.us/journal_media_detail_print.asp?prid=5014&locid=19
17 www.mnproject.org/e-biogas.html

Biogas Potential of Substrates

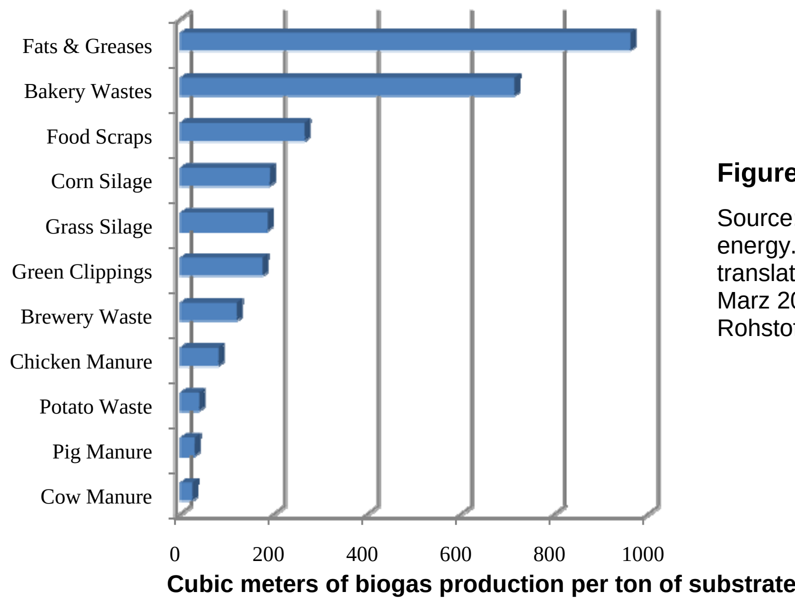

Figure 9: Biogas Potential of Substrates

Source: Data derived from www.biogas-energy.com, © 2007 Biogas Energy, Inc., translated from: Basisdaten Biogas Deutschland, Marz 2005, Fachagentur Nachwachsende Rohstoffe e.V.

The increased biogas output from co-digestion can be substantial. For example, digesters proposed by many developers, including Toronto-based StormFisher, combine off-site waste disposal with large manure digesters sited adjacent to farms. These digester designs can produce as much as five times as much biogas as a conventional anaerobic digester of a similar size but by processing only manure. Another approach, also promoted by a Canadian company, Organic Resource Management, collects waste grease from institutions and businesses for co-digestion at numerous farm-based digesters. The waste grease is aggregated and processed in a central facility by the grease disposal company, then hauled to a series of conventional manure digesters in the area. The company develops contracts with farmers for the grease disposal and the resulting increase in biogas production. While existing anaerobic digesters in the Midwest already take advantage of the benefits of co-digestion, the high density of food processing and waste grease sources in the region provide a large resource for greater biogas production.

Additional assessments are needed in the Midwest to quantify the amount of wastes eligible for co-digestion and the logistics of bringing these wastes to existing or new on-farm digesters. Macro-scale analyses of food production waste and disposal, however, illustrate the large potential for biogas production if some of the waste streams associated with the production, processing, and disposal of food is diverted to anaerobic digestion. Globally, researchers at the United Nations have estimated that as much as 50% of the food produced is wasted or discarded[18]. In the United States, food and other organic wastes are the second largest component of landfills. As noted in the U.N. report:

[18] Nellemann, C. et. al. (Eds). February 2009. "The environmental food crisis – The environment's role in averting future food crises." A UNEP rapid response assessment. United Nations Environment Programme, GRID-Arendal, www.grida.no/publications/rr/food-crisis/

> "In the United States 30% of all food, worth US$48.3 billion (€32.5 billion), is thrown away each year. It is estimated that about half of the water used to produce this food also goes to waste, since agriculture is the largest human use of water. Losses at the farm level are probably about 15–35%, depending on the industry. The retail sector has comparatively high rates of loss of about 26%, while supermarkets, surprisingly, only lose about 1%. Overall, losses amount to around US$90 billion–US$100 billion a year (Jones, 2004 cited in Lundqvist et al., 2008)."

While some of the organic waste sent to landfills can end up as biogas, this process is much less efficient than separating the waste and sending it directly to anaerobic digesters. Moreover, landfills do not effectively capture all the methane produced in the piles of mixed wastes, resulting in fugitive emissions of methane that contribute to global warming. In fact, landfills in the United States are the second largest contributor of methane emissions, with a carbon footprint equivalent to the emissions of approximately 20 million cars in 2008[19]. Thus, non-manure food wastes comprise a large potential resource for biogas production and an alternative to current disposal practices such as landfilling or landspreading, and the associated adverse environmental and climate impacts.

Conventional biogas production from animal manure, wastewater treatment plants, and landfills represent different parts of the movement of organic compounds through the food cycle, either in various stages of food production or the disposal of waste. Under almost any measure, the United States, and the Midwest in particular, use abundant natural resources to produce globally significant amounts of food. American food processing accounts for 26% of world output, and Midwestern states are consistently at or near the top of dairy, meat, bakery, fruit, vegetable, grain and oilseed production[20]. With new and emerging technologies, the energy potential of biogas in the United States, particularly the Midwest, may be much larger than what is assumed by policymakers and the public.

Community Digesters

Many of the previous descriptions of anaerobic digesters, including co-digestion, are based on a model of single digester ownership. Even farmers who accept off-site waste still typically own the digester and the majority of the volume of waste sent to the digester originates from manure at a single farm. The community digester takes a different approach. Community digesters are larger, centralized systems designed to process the waste from multiple sources. Community manure digesters, like the Clean Energy, Clean Lakes project in Dane County, Wisconsin (Page 17), link multiple dairy farms with manure pipelines. These projects can take advantage of the economies of scale in building the digester, and in the Dane County example, water treatment and phosphorous removal equipment. Community manure digesters also make manure treatment from smaller farms possible.

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[19] According to the U.S. EPA Greenhouse Gas Inventory landfill gas emissions in 2008 were 126 million metric tons of carbon dioxide equivalents. http://epa.gov/climatechange/emissions/downloads10/US-GHG-Inventory-2010_ExecutiveSummary.pdf

[20] The U.S. Combined Heat and Power Association, Oak Ridge National Laboratory, the U.S. EPA and Sentech provide a clearinghouse of food and beverage manufacturing energy opportunities at www.sentech.org/CHP4foodprocessing/potential.htm

Figure 10: Toronto's Dufferin anaerobic digester.
This digester treats approximately 40,000 tons per year of organic waste collected in a curbside bin program.
Credit: CCI Bioenergy, Newmarket, Ontario.

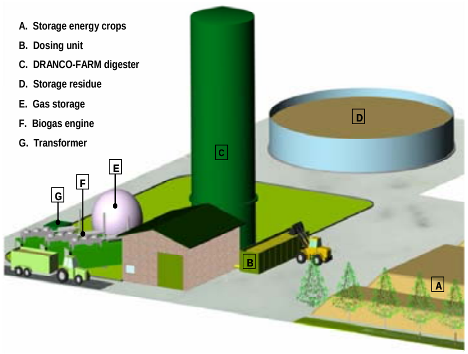
The community digester approach is also effective for collecting organic wastes from cities. The City of Toronto's Dufferin organics processing facility (Figure 10) treats approximately 40,000 tons of organic waste collected from the City's Green Bin program using wet anaerobic digestion[21]. This project illustrates how anaerobic digesters are producing biogas from new waste streams, including the diffuse production of waste at tens of thousands of households in an urban area. Even more surprising is that the processing facility is able to handle a wide diversity of household organic waste that is normally excluded from other types of waste diversions programs such as municipal composting systems: used diapers and sanitary products, meat and fish wastes, domestic animal wastes, and soiled paper packaging and serving materials. The ability of the system to handle these wastes, and the plastic liners that residents are allowed to collect them in, is a result of the system's innovative separation process and the ability of anaerobic digesters to reduce pathogens. The success of the anaerobic digester project, operational since 2005, resulted in a 2007 decision by the city council to upgrade and expand Toronto's anaerobic digestion facilities and add biogas to energy systems. Toronto's successful organics collection and anaerobic digester experience has also spurred many other communities in North America to propose similar approaches and is an innovative example of the urban waste opportunities for biogas production.

Dry Digesters and Other Innovations

Expansion of waste sources increases the biogas production potential and utility of anaerobic digestion. Traditional anaerobic digesters use wet wastes, which are easier to handle and process in an environment that excludes oxygen. This limits the application of anaerobic digestion to wastes such as wet manure and food processing wastes, or in the case of the Toronto anaerobic digester, wastes that are processed with water. However, new anaerobic designs, that incorporate innovative systems to produce biogas from organic wastes with as little as 60% to 70% moisture are emerging and becoming commercially available.

The first dry digestion technology was developed by Organic Waste Systems of Belgium in 1983 and has been used commercially at 25 sites worldwide, each producing from 1 MW to 5 MW[22]. The technology is useful for solid or semi-solid materials from agricultural, commercial, residential, or urban sources. The digester is a silo-style design with a conical bottom and totally external mixing, which allows incorporation of substrates ranging from 3% to 98% total solids (Figure 11). This operating range

[21] www.toronto.ca/legdocs/mmis/2007/pw/bgrd/backgroundfile-3867.pdf
[22] Organic Waste Systems, personal communication, June, 2010.



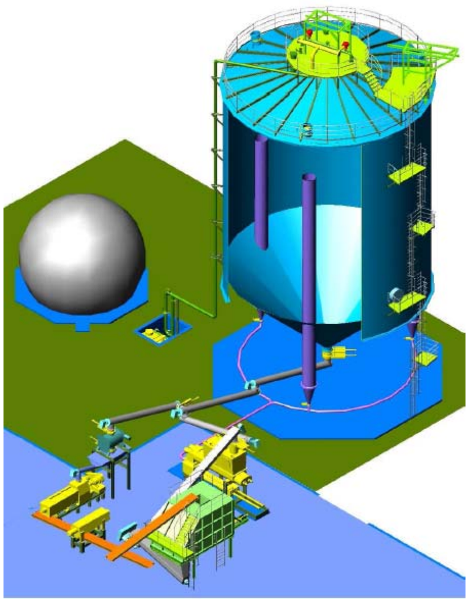


Figure 11: Dry digesters

Top: A typical DRANCO farm configuration. Bottom: a silo-style dry digester.
Credit: Organic Waste Systems

provides an expanded opportunity to digest solid manures without dilution, plus crop residuals, food processing wastes, and yard waste. The conical bottom also eliminates the settling issues normally associated with sand-laden manure or feedstocks contaminated with other heavy, non-degradable materials. In contrast with gasification, anaerobic digestion of solid organic matter retains the beneficial fiber and nutrients for subsequent use as fertilizer or compost. Organic Waste Systems is currently working with farms in Ohio, Iowa, and Minnesota and seven municipal sites for design and installation of plants that will process 25,000 tons to 150,000 tons per year.

Another dry digestion technology, called dry fermentation, relies on a series of airtight containers, called fermentation chambers, similar to a storage garage, that can be loaded with traditional tractor buckets (Figure 12). Once loaded, airtight doors close the containers and liquid containing anaerobic microorganisms is circulated through the organic material using sprayers in the top of the container and collected by drains in the floor. Dry fermentation digesters operate in a batch mode, with each container loaded and unloaded once. Biogas is produced from the same bacterial processes as a wet digester and the other benefits of anaerobic digestion — odor control, pathogen reduction, nutrient transformation — are maintained.

The first dry digester in the Midwest is scheduled to be installed at the University of Wisconsin-Oshkosh in 2010 in a joint partnership between the university and BIOFerm Energy Systems, a subsidiary of Germany's Viessmann Group.[23] This dry digester will be sized to convert 5,000 tons of waste per year from food service, agriculture, and yards and produce up to 400 kilowatts of electricity from biogas. The design of the dry fermentation digester was developed in Germany where approximately 27 biogas plants from the same company operate. Larger dry digester plant sizes are designed to process up to 70,000 tons of organic material per year, with installed biogas-to-electricity capacities of up to 2 MW[24].

In addition to food scraps and other wastes, dry digestion creates biogas production opportunities from new agricultural sources including residues, grasses, and energy crops. As previously noted, manure has been the mainstay of traditional anaerobic digestion, but only when collected or processed in wet form. With dry digestion, the dry manure collected from

[23] www.uwosh.edu/news/?p=2526
[24] www.biofermenergy.com/us/wp-content/uploads/2010/02/BIOFerm-Biogas-Technology.pdf

dry cows, replacement heifers, and from small dairies (less than 100 cows) can be used for biogas production, but also beef feedlots, horse stables, poultry, and sheep. In addition to the opportunities for new wastes, dry digestion offers greater potential energy production in some applications. This is a result of lower energy needs to operate the digester because less water needs to be pumped, heated, and disposed in these systems.

Figure 12: Four Fermentation Chambers of a Dry Digester Facility.
Source: BIOFerm Energy Systems

While dry digesters offer many benefits to expanding anaerobic digestion to more types of waste, it is useful to note that new waste collection and separation approaches can be applied to traditional wet anaerobic digesters and allow these facilities to process different manures. A pilot project at a large biogas plant located near Vegreville, Alberta, uses a unique separator system to prepare manure collected from outdoor feedlots for anaerobic digestion. Normally, manure collected from outdoor feedlots has up to 40% silt, sand and, mud that would quickly clog a conventional wet digester[25]. The innovative separation system successfully produces 1 MW in the pilot project, and the owners are now expanding the biogas system to approximately 5 MW.

Biomass Gasification

Another promising approach to produce large amounts of renewable energy is biomass gasification, a technology that can convert a broad range of wood, grass, and agricultural residues into producer gas or syngas[26]. In contrast to anaerobic digestion, biomass gasification is a thermochemical process. During the gasification process, heat and pressure convert the compounds in biomass into a combustible gas similar to the biogas created from anaerobic digestion. Like conventional biogas, the biogas created from biomass gasification can be used to produce electricity, heat, cogeneration, or cleaned to natural gas pipeline standards. The types of resources needed for biomass gasification, however, are drier and more like the resources used for conventional biomass combustion, such as wood and wood wastes.

Gasification is an established technology that has been used since the early 1900s to produce an energy substitute for petroleum from solid fuels such as coal, wood, and charcoal[27], and interest in gasification has coincided with periods of petroleum fuel shortages. During World War II, small-scale wood gasifiers were used to run vehicles in many parts of the world and large-scale coal gasifiers were used to produce synthetic diesel and jet fuels. Development of gasification technology waned in the later part of the 20th century when electricity, natural gas, and oil became widely available. Recent

[25] "$100 million invested in bio-energy expansion and energy plant" Tony Dryzanowski, Manure Manager, January/February 2009. P.8
[26] The type of gasification process determines the properties of the resulting gas. Additional detail about producer gas and syngas can be found in the "Definition" section of this report.
[27] "Wood gas as an engine fuel." U.N. Food and Agriculture Organization (FAO) Forestry Paper 72. 1986. ftp://ftp.fao.org/docrep/fao/t0512e/t0512e00.pdf

interest in the gasification of both coal and biomass for energy centers on the ability of gasification to produce a very clean-burning substitute for natural gas.

The Midwest has large biomass resources that are technically feasible for energy production. These include agricultural residues (the nonfood portion of crops), forest residues (the portion of timber harvests that cannot be used to make paper or lumber), lumber and paper mill residues, and urban wood (Figure 13). While some biomass that could be used for energy currently provides ecosystem services such as habitat and nutrients, much of the available biomass is simply discarded or allowed to degrade because no markets or incentives exist to convert this biomass to energy. For example, when forests are harvested for paper or lumber, the branches and tops of trees are commonly left in slash piles in the forest. A portion of these residues could be collected and used for energy while leaving a portion for nutrient cycling and animal habitat. Likewise, a portion of the agricultural residues such as corn stover (the stalks and leaves) can be used for energy production. Lastly, some biomass resources, such as perennial grasses, can be effectively harvested from highly erodible or degraded farmland to provide an energy source and important water quality and wildlife benefits.

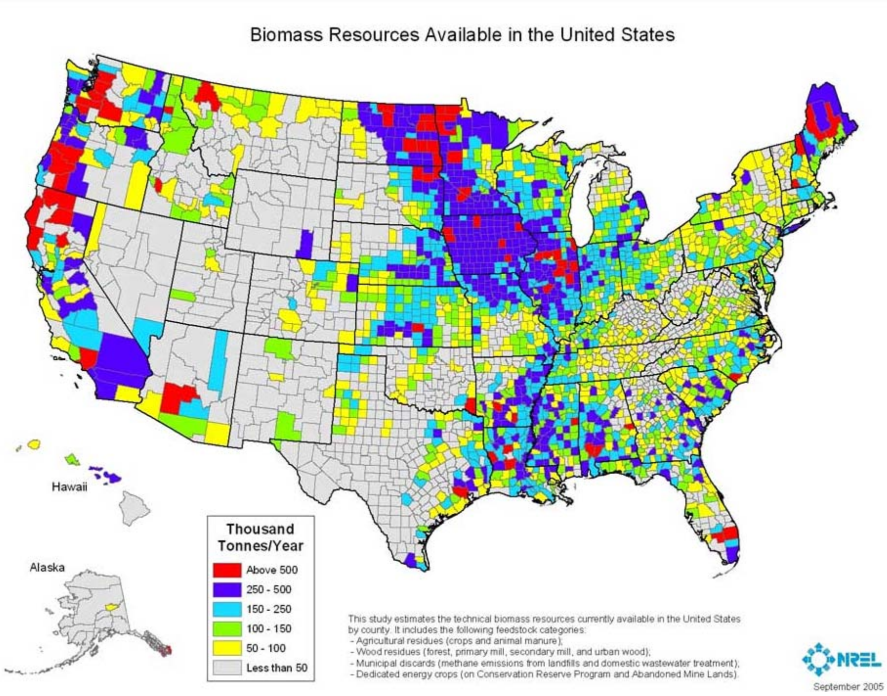


Figure 13: Biomass Resource Map.
Source: National Renewable Energy Laboratory

Energy production potential in the Midwest from biomass gasification is very large due to the high volumes of biomass that are technically feasible for gasification. This same biomass resource, however, could also be converted to energy using conventional combustion processes, such as large-scale power plant boilers as well as smaller-scale wood pellet stoves and pellet boilers. In contrast, most of the alternative uses of the waste resources previously discussed do not have any energy production benefits. For example, landspreading or composting wet waste does not provide any energy benefit. But, as with anaerobic digestion, recent advancements in biomass gasification technology change the dynamics of this energy source. A series of new biomass gasification projects illustrate the environmental and fuel-diversity advantages of biomass gasification over other biomass-to-energy approaches.

A number of biomass gasifiers operate in commercial and industrial settings at the scale of 5,000 tons to 10,000 tons per year. The Central Minnesota Ethanol Coop (CMEC) in Little Falls, Minnesota, was the first ethanol plant in the United States to use biomass gasification as a means to produce a substitute for natural gas. In 2006, a wood gasification unit at CMEC began supplying process heat to distill ethanol, dry the distiller grain byproducts, and produce more than 1 MW of electricity. Two other biomass gasification projects in Minnesota are using corn cobs to produce natural gas substitutes. Chippewa Valley Ethanol Company (Figure 14) and University of Minnesota-Morris[28] use flexible biomass gasification units to produce a substitute for natural gas from wood, corn cobs, and corn stover. These systems illustrate the advantages of biomass gasification systems and the ability of these systems to handle a wide variety of biomass feedstocks. This is particularly important for the development of new sources of biomass, including corn cobs that can be harvested at the same time as corn and with little to no impact on the soil or nutrients[29].

Figure 14: Biomass Gasification at Chippewa Valley Ethanol Company.
Source: Frontline BioEnergy

Biomass gasification is advantageous at larger scales as well. Xcel Energy received approval from the Public Service Commission of Wisconsin in November 2009 to convert a coal boiler at the Bay Front power plant in Ashland, Wisconsin to biomass gasification. The project will use approximately 250,000 tons of forest residues from the surrounding area to produce a type of low-Btu syngas that can then be used instead of coal in an existing boiler to produce 20 MW of electricity. By substituting biomass for coal, nitrogen oxide (NOx) emissions will be reduced by over 60%, and sulfur dioxide and particulate emissions by over 80%[30]. These pollutants have major health impacts, comprising three of the five criteria pollutants in the Air Quality Index used to inform the public of health concerns and precautions for sensitive groups[31]. In addition, NOx and sulfur dioxide are the major causes of acid rain.

Two aspects of the Bay Front gasification project are noteworthy: First, this project will be one of the largest biomass gasification facilities in the United States and will help establish biomass gasification as a cleaner alternative to conventional large-scale biomass combustion. Second, the gasification unit at Bay Front will produce biogas that will be burned in an existing coal boiler that is not otherwise suitable for biomass. Most other biomass conversions of coal plants in the Midwest have been minor modifications

[28] http://renewables.morris.umn.edu/biomass/facility/
[29] "Because most of the corn residue remains following a cob and grain harvest, and since the nutrient removal is relatively low from cob harvest (approximately 5 lb N/a), the impact of cob harvest on soil erosion or soil organic matter levels is likely to be low." www.extension.org/pages/Corn_Cobs_for_Biofuel_Production
[30] www.xcelenergy.com/SiteCollectionDocuments/docs/BayFrontNewsRelease1109.pdf
[31] www.airnow.gov/index.cfm?action=aqibasics.aqi

of coal stoker-type boilers, an old solid fuel boiler design that was supplanted by pulverized and cyclone boilers for most coal power plants built in the United States since the 1950s. The Bay Front boiler that is being converted to biomass gasification is a cyclone design, common at many medium- and large-sized coal power plants in the United States and tend to have particularly high nitrogen oxide (NOx) emissions[32]. If successful, the Bay Front biomass gasification project could become a model for replacing other coal-burning power plants with biomass[33].

3. Emerging End Uses of Biogas

The new approaches and technologies in anaerobic digestion and biomass gasification described in the previous section create a large resource base for the production of biogas in the Midwest. Fortunately, the same innovation expands the potential ways that biogas energy can be used (Figure 15). These developments are highly complementary: One of the best ways to tap new resources for the production of biogas is to provide diverse end-uses for biogas that can overcome site-specific infrastructure or economic constraints. The most common use for biogas is electrical production and heating, but new technologies can create renewable natural gas and compressed renewable natural gas vehicle fuels. In addition, the versatility of biogas allows facilities to provide multiple end-uses at the same location, further increasing the ability of biogas to play an increasingly large role in the energy landscape.

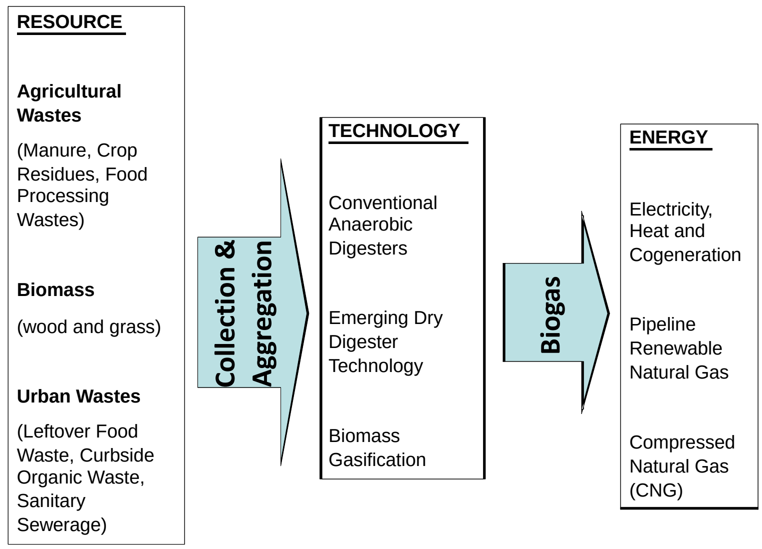


Figure 15: Diverse End Uses of Biogas

Electricity

The mainstay of biogas energy systems is the generation of electricity. Electricity remains the most versatile form of energy and a convenient application for many biogas facilities. Most biogas-to-electricity systems use gas-fired internal combustion (IC) engines, derivatives of large industrial diesel engines. The first IC engines commercially available in the United States for biogas were made by Caterpillar of Peoria, Illinois and deployed at a landfill near Chicago in 1983[34]. Modern IC engines reliably and efficiently convert biogas into electricity and share parts and design features with natural gas engines used in the petroleum and natural gas industries. A wide range of IC engines

[32] www.iea-coal.org.uk/site/ieacoal_old/clean-coal-technologies-pages/clean-coal-technologies-cyclone-fired-wet-bottom-boilers-?
[33] In May 2010 Xcel Energy updated the cost estimate for the biomass gasification project to $79.5 million based on additional engineering results. The new estimate is greater than the initial cost margin in the February 2009 approval by the Public Service Commission of Wisconsin and creates some uncertainty for this project. www.xcelenergy.com/North%20Dakota/Company/Newsroom/Pages/2010-05-05-biomassprojectinAshland.aspx
[34] www.methanetomarkets.org/expo/docs/postexpo/plenary_deshpande.pdf

with outputs from 250 kW to 4 MW are designed specifically for biogas applications. With an IC engine, heat can be easily captured from its cooling system and used to heat anaerobic digesters instead of burning biogas directly, resulting in higher efficiency. Additional waste heat can be captured from engine exhaust and used for other thermal applications, further increasing the total energy efficiency.

Continued developments in biogas-to-electricity technology expand the potential of biogas. Two emerging technologies increase the electrical conversion efficiency of biogas: IC-combined cycle produces additional electricity from the waste heat of the engine, and fuel cells directly convert biogas to electricity without combustion. These systems can produce more electricity from a given amount of biogas, with total electrical conversion efficiencies approaching 50%,[35] nearly double the efficiency of older biogas IC engine systems[36]. In other biogas applications, microturbines, which resemble small jet engines, can be used to produce electricity from smaller biogas systems or multiple units can be installed to provide greater electrical generation flexibility for variable output sources of biogas. Microturbines provide a particular advantage for small biogas facilities because the 30 kW units are smaller than a refrigerator and have lower noise, vibration, and emission characteristics than IC engines[37]. Microturbines are also inherently simple, with only one moving part (the turbine shaft), no oil, and no coolant, which results in lower maintenance needs compared to IC engines. The microturbine design, however, can require greater biogas cleanup and pressurization than an equivalent IC engine and have a lower electrical generation efficiency.

Cogeneration, Heat, and Absorption Chilling

Many facilities, like dairies, have large heating and cooling needs and associated expensive electrical and heating bills. Fortunately, biogas can be used to produce electricity, heat, chilling, and combinations of these energy resources to meet the specific needs of different facilities. The beneficial use of the heat produced from electrical generation is called combined heat and power, or cogeneration, and increases the overall energy efficiency of these systems. Most biogas-to-electricity applications at anaerobic digesters already use waste heat from the IC engine or microturbine to heat the digester, but this application is not truly cogeneration since that energy is an input into the overall production of biogas. But many biogas-to-electricity systems capture additional heat that can be beneficially used to replace other heating fuels at the farm, wastewater treatment facility, or even an adjacent commercial or industrial facility. Many biogas electricity systems benefit from small amounts of cogeneration, such as heating small buildings with waste heat instead of natural gas or propane, but larger biogas systems can produce significant amounts of heat and substantial reduction in heating fuels. The biomass gasification facilities at ethanol plants highlighted in the previous section reduce the natural gas heating needs of those plants by as much as 90%. Finally, biogas heat used in absorption chillers can offset the need for expensive refrigeration units on dairies.

[35] Bloom, a manufacturer of solid oxide fuel cells lists their electrical generation efficiency for dedicated biogas at > 50%. www.bloomenergy.com/products/data-sheet/

[36] Older IC engines convert between 20 and 30% of the energy in biogas to electricity, and newer models have reached 40%. www.ruralenergy.wisc.edu/renewable/biogas/default_biogas.aspx

[37] BioCycle March 2009, Vol. 50, No. 3, p. 41. “Wastewater plant in Sheboygan, Wisconsin succeeds with project to cut energy costs while increasing energy production in its anaerobic digesters.” Diane Greer, www.jgpress.com/archives/_free/001831.html

Renewable Natural Gas

One of the most promising new end-uses for biogas is renewable natural gas, also referred to as biomethane, a form of biogas that meets all quality specifications of pipeline natural gas. Biogas converted to renewable natural gas is the first major renewable energy source to tap into the natural gas grid in the United States and its more than 2 million miles of underground pipelines[38]. This expansive pipeline network can deliver renewable natural gas to millions of existing clean and efficient natural gas heating appliances at over half the homes in the United States and an even higher percentage of commercial buildings and businesses. As a proportion of total energy supply, natural gas is second only to petroleum, and ahead of coal and nuclear power in the United States.[39] In the Midwest, natural gas is by far the dominant household heating fuel accounting for approximately 75% of the total heating expenditures and an even greater percentage of the total energy used for heating.[40]

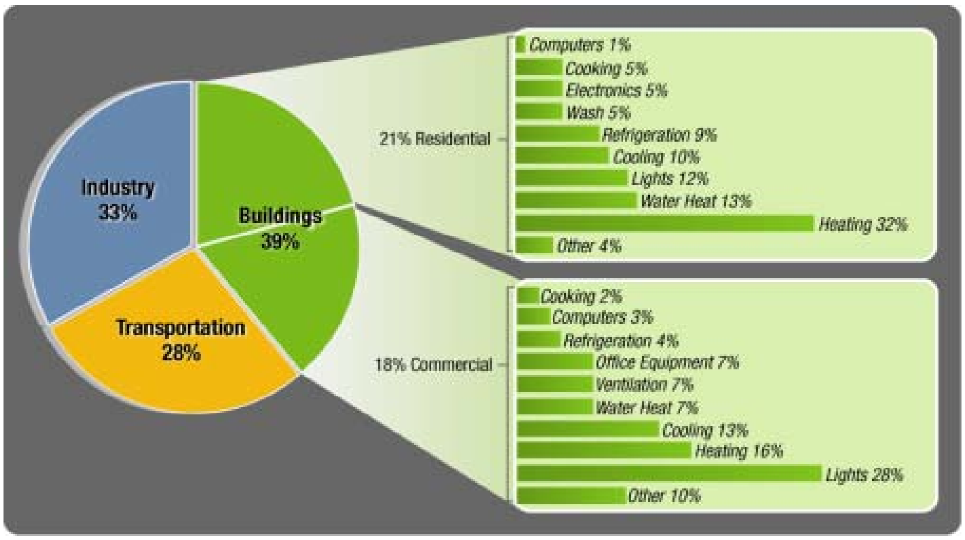


Figure 16. Energy Consumption by Buildings and Appliances

A recent report from Lawrence Berkeley National Laboratory (Figure 16) illustrates the importance of natural gas and energy use in buildings[41]: "Buildings in the U.S. today consume 72% of electricity produced, and 55% of U.S. natural gas use. They account for about 40% of total U.S. energy consumption (costing $350 billion per year) and greenhouse gas emissions. Reducing the GHG emissions associated with buildings is essential to reducing overall U.S. emissions." The focus of the report was on reducing building energy consumption with building efficiency, but the data also show the importance of heating energy as a proportion of building energy consumption. Energy efficiency and renewable energy complement each other; reducing energy demand and increasing the proportion of renewable energy are able to compound greenhouse gas reductions from energy use.

Until the introduction of renewable natural gas, few renewable resources have been able to lower the carbon footprint of heating energy in widespread applications. Solar water heating, passive solar heating and biomass pellet stoves all provide opportunities for

[38] http://www.aga.org/Kc/aboutnaturalgas/
[39] EIA Primary Energy Consumption by Source, 2008. www.eia.doe.gov/emeu/aer/pdf/pages/sec1_8.pdf
[40] Total household expenditures for heating in the Midwest in 2005 were $16.75 billion, with natural gas expenditures for heating at $12.44 billion. Since natural gas had the lowest cost per Btu of energy, the proportion of total heat consumption from natural gas in the Midwest is higher than the proportion of expenditures. www.eia.doe.gov/emeu/recs/recs2005/c&e/spaceheating/pdf/tablesh5.pdf
[41] U.S. Department of Energy, Lawrence Berkeley National Lab. http://newscenter.lbl.gov/feature-stories/2009/06/02/working-toward-the-very-low-energy-consumption-building-of-the-future/

reducing the carbon footprint of heating, but each of these options has a much smaller potential than renewable natural gas and their own limitations. Solar water heating and passive solar designs are restricted to houses with sufficient sun exposure, biomass heating systems can contribute to air quality problems in urban areas, and all these solutions require expensive retrofitting, new appliances, or new construction. In contrast, renewable natural gas provides a much greater opportunity for the vast majority of energy consumers in the Midwest to purchase renewable energy. The potential benefits and ability to deploy renewable natural gas in the existing pipeline and appliance infrastructure is analogous to renewable electricity developed and delivered by utilities. In the case of electricity, the massive expansion of renewable resources has been driven mainly by utility-scale projects, and not customer-owned solar panels or wind turbines. One advantage of renewable natural gas over renewable electricity, however, is the wide availability of natural gas storage in the United States, while electrical storage is limited to a few pumped hydroelectric facilities and experimental pilots.

Fortunately, renewable natural gas projects are beginning to enter the natural gas pipeline grid, and utilities and states are starting to recognize the opportunity. Renewable natural gas is created by cleaning, or upgrading, biogas to remove carbon dioxide and increase the Btu content. Biogas from anaerobic digestion contains approximately 60% methane and 40% carbon dioxide (with other trace contaminants) and has an energy content of approximately 600 Btus per cubic foot. Conventional pipeline natural gas has less than 1% carbon dioxide and, since carbon dioxide does not have energy, an energy content of approximately 1,027 Btus per cubic foot[42]. Various treatment options remove carbon dioxide and other trace impurities in biogas from anaerobic digestion to meet the energy content and quality specifications of pipeline natural gas. Producer gas and syngas from biomass gasification have variable concentrations of the combustible gases methane, hydrogen, and carbon monoxide, depending on the chemical properties of the biomass and the specific gasification process, and generally a lower Btu content, between 100 to 200 Btus per cubic foot[43]. Catalytic and chemical conversion applied during the gasification process and/or to the producer gas and syngas can increase the methane concentration and quality specifications to meet pipeline natural gas standards.

Scenic View Dairy in Fenville, Michigan was the first farm-based project in the United States to upgrade biogas to renewable natural gas and inject it into the interstate pipeline grid, and the first biogas system in the United States to produce both electricity and renewable natural gas when it went online in 2006[44]. Manure from 2,200 cows at Scenic View mixes with grease trap waste in three above-ground mesophilic anaerobic digesters. Biogas from the digesters is routed to two 400 kW IC engines that produce electricity and heat for the three digesters, while the renewable natural gas conditioning system can produce approximately 4.5 million Btus of natural gas per hour for injection into the local natural gas pipeline (Figure 17)[45]. The total energy production of the Scenic View Dairy is sufficient to meet the electricity needs of approximately 800 homes and the natural gas use of approximately 370 homes.[46]

[42] Pipeline natural gas is a mixture of hydrocarbons that meets a specification for energy content in British Thermal Units (BTUs). www.naturalgas.org/overview/background.asp
[43] http://www.uaex.edu/Other_Areas/publications/PDF/FSA-1051.pdf
[44] www.terrapass.com/projects/details/scenic-view-dairy-i-fennville.html
[45] www.jgpress.com/archives/_free/001420.html
[46] Electrical consumption in the Midwest is equivalent to approximately 1 kW/household or 1 MW per 1,000 households. Natural gas consumption per household in the Midwest in 2001 was a weather-normalized 107 MCF/customer/year, which is equivalent to approximately 107 mmBTU. Natural gas

Figure 17: Renewable Natural Gas Injection into Pipeline.
At the Scenic View Dairy in Fennville, Mich.
Source: Michigan Gas

The production of renewable natural gas is growing rapidly; last year 22 biogas projects injected into the natural gas pipeline in the United States.[47] The total amount of renewable natural gas from these projects, as a proportion of the total United States natural gas supply, remains negligible. The total resource potential for renewable natural gas, however, is recognized as a major renewable energy and greenhouse gas reduction opportunity. As with conventional anaerobic digesters, Europe is far ahead of the United States, and Germany, the biogas leader, has a 6% renewable goal for natural gas by 2020 and 10% by 2030[48] while the United Kingdom has a goal of 12% renewable heat by 2020[49]. One analysis of the renewable natural gas development in Europe, commissioned by the German Biogas Association and based on continued growth at current rates, found that approximately 40% of Europe's natural gas supplies could come from biogas by 2020; this same study found that Europe's total potential renewable natural gas production over the next two decades is roughly equivalent to its total current natural gas consumption[50].

Relative to Europe, the U.S.'s greater amount of agricultural, forestry, and waste resources likely provide a greater potential for renewable natural gas. The California Energy Commission identifies renewable natural gas as one of the major growth areas of renewable energy for that state, with a potential output of approximately 100 billion cubic feet per year by 2020 coming from anaerobic digestion, or approximately 5% of current in-state natural gas consumption[51]. When renewable natural gas from biomass gasification is included in California's resource potential, the total technical potential is over 15% of California's current natural gas supply[52]. The diversity in projections for the resource potential of renewable natural gas is likely a reflection of the early stage of this type of energy, but the potential is certainly sufficient for many years of very rapid growth.

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consumption data from AGA. www.aga.org/NR/rdonlyres/B889D152-64E5-4CD6-B10B-A0D63E16B10F/0/0712CONSUMMPTIONPATTERNS.PDF
[47] www.truebluenaturalgas.org/thoughts-from-the-briefing-for-congressional-staff-on-renewable-natural-gas
[48] www.thebioenergysite.com/articles/379/injecting-biomethane-into-the-german-grid
[49] http://chemguideeurope.com/news/2010/02/04/uk-launches.html
[50] www.gruene-bundestag.de/cms/publikationen/dokbin/166/166883.pdf
[51] http://biomass.ucdavis.edu/materials/reports%20and%20publications/2006/2006_Biomass_Roadmap.pdf
[52] Mark Kolb, PG&E, presentation to the Biomethanation RFI Networking Forum, 3/5/08, Assumes 27 million bone dry tons of thermochemical biomass converts to renewable natural gas at 10 dth/ton. Note that some of the biomass resource identified for thermochemical biomass conversion is also eligible for dry digestion at potentially higher conversion efficiencies.

Renewable Compressed Natural Gas (CNG) Vehicle Fuel

Compressed natural gas is a clean-burning vehicle fuel made from biogas in a similar process to renewable natural gas. In fact, nothing precludes renewable natural gas from entering the pipeline at a biogas plant and then leaving the pipeline at a conventional CNG fueling station. But biogas can be used to generate renewable CNG vehicle fuel directly onsite as well. The advantages of producing CNG vehicle fuel directly from biogas are twofold: First, both natural gas pipelines and CNG require compression of natural gas, but producing CNG directly from upgraded biogas reduces the number of times the natural gas is compressed. Second, many CNG vehicles run on biogas subject to less-stringent upgrading than what is required to meet pipeline natural gas standards. For example, CNG vehicles operate on natural gas with lower energy content, albeit with reduced power, but pipeline natural gas standards are designed so the energy content of the natural gas is consistent to meet expectations of all pipeline users and the diversity of natural gas appliances.

CNG vehicles are modifications of conventional gasoline and diesel cars and trucks with similar operating characteristics. Automotive manufacturers build CNG versions of many cars and third-party companies make conversion kits for many conventional vehicles. Dual-fuel CNG vehicles can switch between conventional petroleum fuels or natural gas, but dedicated CNG vehicles must use CNG fueling stations. Globally, there are over 11 million CNG vehicles and over 11,000 CNG fueling stations[53]. The United States has approximately 110,000 CNG vehicles and 1,100 CNG fueling stations, with the greatest concentration on the coasts. Fleet vehicles, such as municipal transit buses, are the largest CNG users, but some infrastructure serves personal vehicles. CNG vehicle infrastructure offers economic and energy security; natural gas is frequently cheaper than petroleum in many countries and requires less refining infrastructure. Furthermore, CNG vehicles emit low amounts of air pollutants.

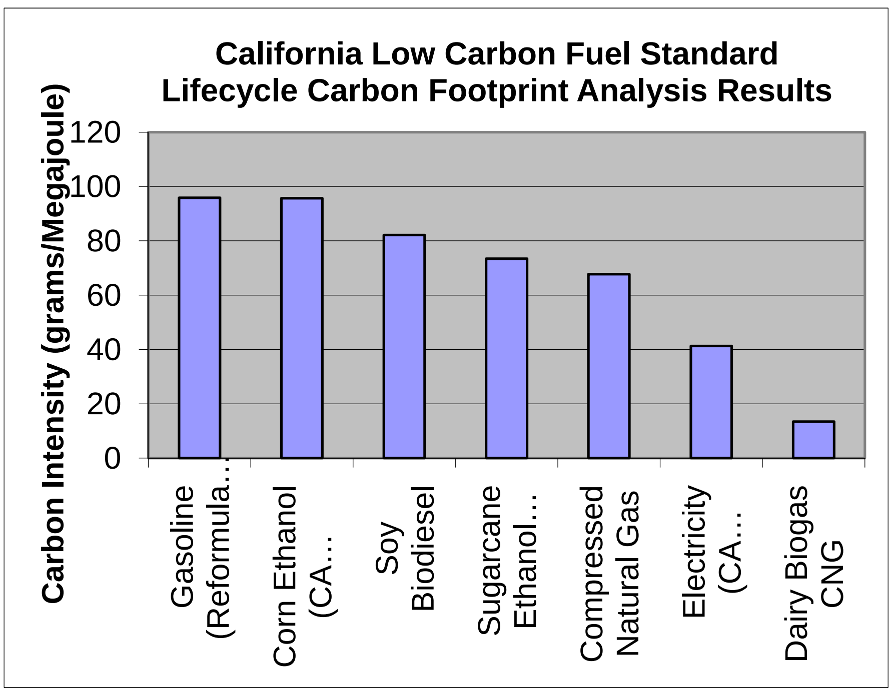

Figure 18: Vehicle Fuel Carbon Footprint Comparison.
Source: California LCFS lookup table, 12/14/09
Note: Electric drivetrain efficiency factor of 3 used.

Only recently has CNG been recognized as a lower carbon fuel than petroleum; fossil

[53] www.iangv.org/tools-resources/statistics.html

natural gas CNG vehicles emit approximately 25% fewer greenhouse gases over the entire fuel lifecycle (extraction, refining, and combustion) compared to petroleum[54]. Biogas, however, is a very low carbon fuel; carbon dioxide emitted during combustion originated in the atmosphere during the biological growth of plants. The overall carbon footprint of biogas CNG depends on how much energy is used to produce the biogas and compress it into CNG, as well as the overall carbon balance of the farm or forest system that feeds the biogas production. Lifecycle analyses of the total carbon footprint of biogas CNG and many other vehicle fuels performed by the California Air Resources Board have the lowest carbon footprint of any fuel analyzed (Figure 18), lower than corn ethanol, sugarcane ethanol, cellulosic ethanol, soybean biodiesel and electricity for electric cars[55]. Compared to petroleum fuel, biogas CNG has less than one-sixth the greenhouse gas emissions. Since many other low carbon fuels like electricity and cellulosic ethanol are not yet commercial, the very low carbon footprint of biogas CNG using existing technology is even more profound.

Biogas is being used to produce CNG directly at a small number of locations in the United States, but has been used in Europe for at least 15 years. One of the longest running biogas-to-CNG projects is the municipal bus system in Lille, France, which began using biogas in a few buses in 1995[56]. This successful project expanded to 167 buses by the end of 2005 on a mixture of biogas CNG and conventional CNG. A municipal organic waste center provides biogas fuel for 100 buses. The organic recovery center converts 100,000 tons per year of household, garden, market, and cafeteria waste into 105 million cubic feet of biogas and 34,000 tons of compost for large farms. This project provides an example of the co-location of a municipal organic waste recycling center and transit vehicle fueling depot providing ultra-low carbon mobility and sustainable waste management with biogas (Figure 19).

Figure 19: Municipal Organic Waste Recovery and Biogas CNG Bus Fueling Station, Lille, France.
Source: Lille Métropole, Yves Baesen presentation to USDOE Clean Cities Program.

Large-scale biogas CNG fueling systems have also been applied to farm-scale anaerobic digester systems[57]. Hilardies Dairy of Lindsay, California installed a biogas upgrading, compression, and vehicle fueling system in 2009 using biogas from its covered lagoons. The skid-

[54] California Low Carbon Fuel Standard Carbon Intensity Lookup Tables, www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf
[55] Ibid.
[56] Lille metropolis cleancities presentation. www1.eere.energy.gov/cleancities/pdfs/baesen.pdf
[57] This system was installed by Phase 3 Renewables (now OWS). Source: Norma McDonald (OWS), personal communication, June 2010.

mounted system can produce 775 gallons of diesel fuel equivalent each day; the plant currently operates eight hours per day due to the limited number of vehicles that have been converted so far. The biomethane is compressed to 3600 psig, stored in cylinders, and then dispensed into milk trucks and pickup trucks using a conventional CNG pump. The dairy also produces 750kW of electricity.

Smaller-scale biogas CNG vehicle fueling systems are under development in the United States, providing another opportunity to expand the uses of biogas. A consortium of Midwestern businesses, a utility, and a technical college are developing a compact, economic biogas-to-CNG vehicle fuel system to allow farmers, municipalities, schools and industries to produce their own fuel[58]. The lead company, Cornerstone Environmental Group, has developed biogas vehicle fueling projects in California and Ohio to provide customers with stable low-cost fuel from waste products. A demonstration trailer of the compact biogas CNG vehicle fuel system generates strong interest in the Midwest and the first project is under development for Dane County, Wis. to provide biogas CNG fuel for the county's public works trucks. This system produces biogas CNG from a small portion of the biogas produced at existing biogas to energy systems to supply the energy equivalent of approximately 100 gallons of diesel fuel per day. Depending on the price of petroleum, the small-scale biogas CNG fueling systems can be paid for in as little as two years to four years through fuel savings[59].

The ability of biogas to provide energy for a diversity of uses, including electricity, heating, cooling, renewable natural gas, and vehicle fuel, distinguishes it from other renewable resources. In addition, the examples provided in this section show how many biogas uses can be combined at a single biogas energy facility. The tremendous flexibility of the biogas energy system is also beginning to attract businesses and university research to the Midwest, providing the potential for the Midwest to apply its global-leading agricultural output and research capabilities to biogas. One example of this multipronged approach to biogas research is the recent opening of a renewable energy anaerobic digestion system at The Ohio State University's Agricultural Research and Development campus in Wooster, Ohio[60]. This partnership between the nation's largest university agbioscience research center and Cleveland's quasar energy group includes a 550,000-gallon integrated anaerobic digester, with electric generation, thermal heat, renewable natural gas and vehicle fuel demonstration (Figure 20).

Figure 20: Ohio State University and quasar Anaerobic Digester Facility.
Source: www.ag.ohio-state.edu/~news/story.php?id=5526

[58] Cornerstone Environmental Group, Alliant Energy, Dane County and Madison Area Technical College in Madison, WI; ANGI International of Milton, WI; and Unison Solutions of Dubuque, Iowa.
[59] Mark Torresani, Senior Project Manager, Cornerstone Engineering, Testimony to Wisconsin Legislature on 2/10/2010.
[60] http://bioproducts.osu.edu/index.php/news-room/222-gov-strickland-tours-bionergy-project-at-oardc-touts-digestion-technology

4. Policies Needed

The energy potential from biogas energy in the Midwest is large and varied, with new technologies pushing the potential higher as new waste streams and biomass resources become available for conversion to biogas. At the same time, biogas has a greater potential to provide a diversity of end-uses than any other renewable resource, including electricity, heating, cooling, cogeneration, renewable natural gas and vehicle fuel. Unfortunately, the benefits of biogas are not widely recognized by the public, legislators, or policymakers. The current regulatory landscape in the United States not only fails to recognize the potential of biogas, many existing renewable energy incentives actually discourage the most efficient uses of biogas.

The rapid expansion of biogas in Europe and that continent's leadership role in developing and commercializing renewable energy are widely attributed to public policies and incentives. While the United States recently made considerable progress in deploying renewable energy, there are major differences in the approaches taken on either side of the Atlantic. In Europe, and Germany in particular, feed-in-tariffs have been the principal renewable energy policy tool, while in the United States the principal policy tools include renewable electricity and renewable fuel standards. Each approach has advantages, described in this section, but the European model is likely to favor biogas more than the United States model. Fortunately, policies proposed at the state and regional levels in the United States would encourage biogas. Implementing new policies in the Midwest will help this region tap into the vast renewable energy potential of biogas.

Feed-in-Tariffs: Driving Europe's Renewable Energy Diversity

Feed-in-Tariffs (FITs)[61], also known as Advanced Renewable Tariffs (ARTs) or renewable energy buy-back rates, are guaranteed payments made by utilities for the output from renewable energy systems. FITs are traditionally set for electrical generation tied into the grid but have expanded to include renewable natural gas injected into the pipeline system. FITs usually have these important characteristics:

- **Rates are differentiated by technology and size:** Each different renewable resource (wind, solar, biogas, etc.) receives a rate based on the specific characteristic of that resource. In addition, rates vary by size (e.g., biogas systems from 250 kW to 1MW will get a higher rate than biogas systems from 1 MW to 5 MW).
- **Rates set on the cost of generation plus profit:** The value of the rate is based on the cost of the resource. Thus, solar photovoltaics receive a higher rate than wind or biogas to reflect the higher costs of generating electricity from solar panels. The profit can be set at a similar rate to what a utility would earn on large-scale generation projects, or at a lower rate.
- **Long contract terms:** The contract between the utility and the renewable energy generator are set with long terms of 10 years or more. The long contract terms are crucial to enable a prospective project to acquire financing.

FITs are established through legislation or rulemaking, and the actual rates offered for a new renewable resource can change over time as the cost of technologies changes. But once the renewable energy resource contract is set, the rate is fixed for that project. A

[61] The rates paid for energy are called tariffs in Europe, hence a Feed-in-Tariff is a rate paid for energy that is generated and "fed" into the electrical or natural gas grid.

variety of administrative details are incorporated into FIT policies, including program caps for specific technologies or generator sizes that provide greater certainty of the cost of these policies and limits on the number of installations. In general, the rates and conditions for biogas electricity and biogas renewable natural gas resulted in rapid growth of the European biogas industry.

Renewable Electricity and Fuel Standards: The United States Market Approach to Renewable Energy

The United States approach to renewable energy policy has traditionally relied on renewable electricity and fuel standards, which are different in many ways from a FIT policy. Renewable electricity standards (RES), also called renewable portfolio standards in the United States, require that a specific percentage of electricity sales for a utility must be generated by a qualified renewable resource; most policies include electrical generation from biogas. The utility has the obligation to secure renewable energy resources sufficient to meet the standard, such as 25% renewable electricity by 2025. Twenty-eight states plus the District of Columbia have RES targets, which vary in design state to state, qualifying resources, and other characteristics (Figure 21). In almost every case, a potential renewable energy provider must negotiate with the utility, which decides what renewable energy projects the utility will use to meet the standard[62].

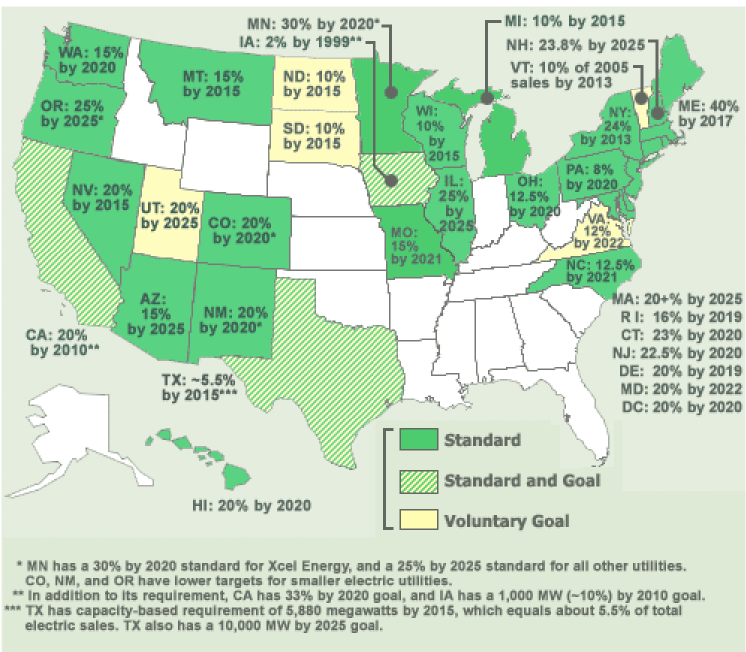

Figure 21: Renewable Electricity Standards in the U.S.

Source: Union of Concerned Scientists, www.ucsusa.org/clean_energy/res/overviewtargets.html

Under most RES policies, the utility must meet the renewable electrical energy needs in the lowest cost manner. What constitutes a reasonable cost estimate, and any alternatives available to a utility, are usually hotly debated between the utility that proposes a project and ratepayer advocacy, environmental, and industrial energy user groups. In general, however, the lowest cost forms of readily available renewable electricity are utility-scale wind turbines (e.g., 1.5 MW and larger) and utility-scale biomass. Solar and biogas projects are not typically used to meet RES requirements, although some RES policies have “carve-outs” or "set-asides" that specify a sub-percentage of the standard to be met with a specific technology; for instance, Nevada requires that 5% of its 20% by 2015 standard be met with solar. While no RES has specific carve-outs for biogas, Arizona’s

[62] There are varying levels of oversight of utilities through Public Utility Commissions (PUCs), with generally more oversight in so-called regulated states and less oversight in deregulated states. In addition, utilities are constrained by Federal Energy Regulatory Commission requirements under the Public Utilities Regulatory Policy Act (PURPA) legislation of 1978 and subsequent amendments.

RES requires a small percentage of renewable energy to come from distributed resources located at a customer's premises, including biogas[63]. Despite the best efforts of renewable energy advocates, no RES policies have been enacted in much of the Southeast, and Congress has failed to pass a federal renewable electricity standard.

Renewable fuel standard (RFS) policies are similar to RES policies in that a specified percentage of fuel sold in a state or the United States, as a whole, must be renewable. Twelve states have RFS policies, such as Iowa's requirement that begins at 10% renewable fuel by 2010 and increases to 23% by 2018[64]. Most activities for RFS policies waned following the large expansion of the federal RFS program passed in the December 2007 (Energy Independence and Security Act) and recently promulgated by the EPA as the RFS2 program. This policy specifies a specific volume of renewable fuels that must be sold in the United States, reaching a total volume of 36 billion gallons by 2022. The RFS2 program further divides the volumetric goal into subcategories for advanced biofuels and cellulosic biofuels.

Limitations of Existing United States Renewable Energy Policy for Biogas

Most renewable energy policies in the United States fail to recognize and stimulate biogas energy. RES and RFS policies miss important attributes of biogas, and there are few large-scale policy examples that encourage renewable natural gas, heat, or cogeneration from biogas. These limitations restrict the ability of biogas to serve the diverse energy uses that make it a unique form of renewable energy.

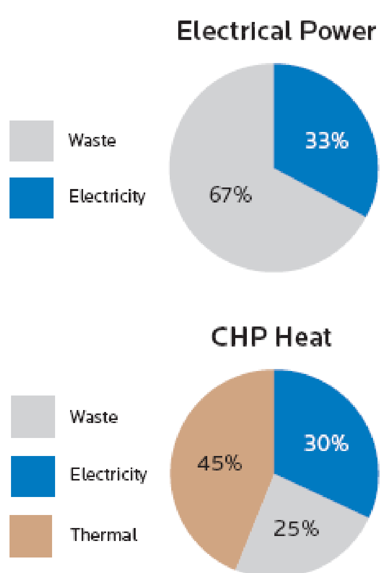

Figure 22: Comparison of Electric Power to Combined Heat and Power (CHP) or Cogeneration.

Source: Biomass Energy Resource Center

RES policies currently recognize only direct electrical production. Renewable natural gas injected into the grid, then subsequently burned in efficient utility-scale natural gas power plants, is not typically credited under RES policies. Biogas-to-electricity projects are unique among small renewable energy resources in their ability to provide combined heat and power (CHP) or cogeneration, but current RES policies do not typically recognize this benefit. This oversight of the benefits cogeneration is significant, because it favors biogas electrical generation at the expense of efficiency (Figure 22). Systems designed to maximize the electrical output from biogas will convert less of the total biogas into energy than systems that balance electrical output and heat output. Finally, biogas systems can provide important benefits to the electrical grid and are much more reliable than intermittent sources of renewable electricity (wind and solar), yet are not recognized for this benefit under typical RES policies that treat all kilowatt-hours of electricity the same.

RFS policies also exclude or minimize the benefits of biogas.

[63] www.ucsusa.org/assets/documents/clean_energy/arizona.pdf
[64] The U.S. DOE alternative fuels and advanced vehicle data center maintains information on vehicles, fuel policy, and fuel availability. www.afdc.energy.gov/afdc/laws/matrix/reg

Most state-based RFS policies promote corn ethanol and biodiesel from plant oils or grease, and do not recognize renewable gaseous fuels. The federal RFS2 also benefits liquid transportation fuels, making it more difficult for biogas-derived CNG to generate credits under the rule and limiting the potential of biogas CNG under a small subcategory of fuel volumes[65]. Finally, RFS2 has no mechanism to incentivize or credit renewable fuels with the lowest carbon footprint, thus neglecting one of the principal benefits of biogas CNG.

The lack of effective renewable energy policies recognizing the versatility of biogas results in lost opportunities. As an example, potential anaerobic digester projects can face difficulties when trying to design or obtain environmental permits for electrical generation equipment. Many rural electrical distribution lines have insufficient capacity to handle the three-phase power generated by biogas projects and require prohibitively expensive upgrades. Some areas where biogas projects can be located have nonattainment designations for air quality that make it difficult or impossible to obtain an air permit for a biogas engine. In both cases, alternative biogas energy options, such as using smaller-output microturbines and creating more useful heat from the biogas, producing renewable natural gas for pipeline injection, producing biogas CNG vehicle fuel, or a combination of these options could provide a viable alternative to conventional biogas engines for electricity generation. Unfortunately, without renewable energy policies to recognize nonconventional uses of biogas, these alternatives lack the additional incentives to be competitive with fossil fuels.

The biogas energy installation at Scenic View Dairy is an example of how the current incentive structure for biogas use limits expansion of these types of diverse projects[66]. When the system was installed, NYMEX pricing on natural gas was \$12 to \$13 per million Btu and the electrical grid was only paying \$0.03 per kWh. Currently, NYMEX pricing is below \$6 per million Btu, while pricing under power purchase agreements have risen above \$0.10/kWh due to the passage of a renewable electricity standard in Michigan, which incentivized the utility. With no similar incentive, gas utilities are unwilling to pay a renewable premium. The dairy has discontinued upgrading biogas and is now evaluating installation of additional compression equipment for vehicle use.

Despite the lack of comprehensive renewable energy policies for biogas, a number of projects have moved forward and some parts of the country are seeing more development than others. Outside of large-scale renewable energy policies, federal and state grants, tax incentives, and economic development bonding can be used to expand biogas production in the Midwest. In addition, smaller-scale policy initiatives by individual utilities can help to encourage biogas projects.

In Wisconsin, two major factors have resulted in a comparatively large number of biogas projects: The state-based energy efficiency and renewable energy funding program known as Focus on Energy, and the establishment of experimental feed-in-tariffs by individual utilities. Focus on Energy collects funds through a surcharge on most utility bills in the state and distributes these funds as grants and incentives for energy efficiency

[65] The generation of renewable fuel credits under RFS2 for conventional liquid biofuels is promulgated in the final rule and provides certainty of the market for these fuels. Biogas CNG can count toward RFS2, but producers have to petition the EPA to generate credits toward the RFS, and it only counts toward advanced biofuels, the smallest subcategory.

[66] Norma McDonald, OWS, Personal Communication, June, 2010.

and renewable energy. The renewable energy program at Focus on Energy uses a formula based on the energy generation potential of a biogas system and the cost of the system and can provide grants of up to $250,000 to fund the construction of systems that provide electricity, heat, cogeneration or renewable gas production[67]. Utilities in Wisconsin have also established special FITs for biogas projects funded through voluntary customer renewable energy programs.

Other states and utilities provide varying levels of support for biogas projects. The ability of biogas energy systems to export electricity or natural gas into the energy grid varies considerably from state to state and utility to utility. Some states and utilities provide simple and transparent interconnection policies and logistical support, while others charge excessive fees and put regulatory hurdles in place, making it difficult to export renewable energy[68]. Even when a willing utility is helpful and provides incentives for biogas energy generation, it is of little use to a farmer in the territory of an adjacent utility and the patchwork of renewable energy interconnection quality makes it difficult to develop a robust biogas industry.

A comprehensive review of the available policy mechanisms for biogas projects is outside the scope of this report. The Great Plains Institute performed a series of interviews with biogas industry stakeholders in 2010 and will be producing a report in July, 2010 that examines a suite of policies for biogas projects including sources of funding, opportunities to combine different areas of funding, opportunities to structure tax credits and broad market based policies.[69] This forthcoming report will also detail federal policies such as the Rural Energy for America Program (REAP), proposed nutrient trading opportunities and infrastructure development funds.

Proposed Biogas Energy Policies

Four major renewable energy policies are needed to capture the potential of biogas energy in the Midwest: enhanced renewable portfolio standards that recognize efficient applications of biogas cogeneration and renewable natural gas; renewable natural gas standards; advanced renewable tariffs or FITs that provide robust, level tariffs across the entire state; and low carbon fuel standards that recognize and incentivize fuels based on energy content and carbon footprint (Figure 23). Various state and regional processes, including state governor's task forces on global warming or climate change and energy initiatives of the Midwestern Governors Association have endorsed one or more of these policies. To realize the full potential of biogas energy in the Midwest and create

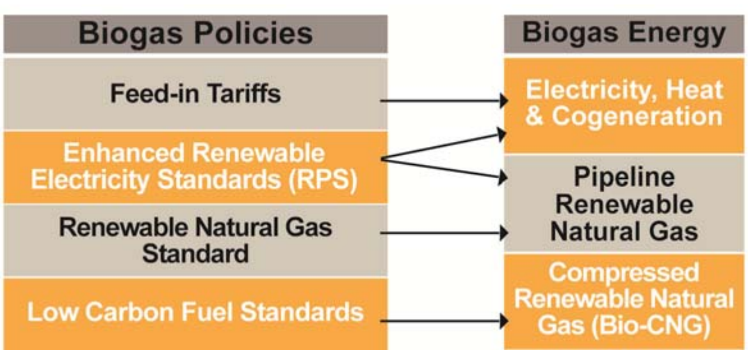

Figure 23: Renewable Energy Policies and Biogas Energy Diversity.

[67] www.focusonenergy.com/Incentives/Business/renewable_incentives.aspx
[68] Examples of regulatory hurdles include requirements that the renewable energy generator conduct detailed interconnection studies, meet non-transparent or arcane standards, limit eligibility or charge standby and other fees. See www.newenergychoices.org/uploads/FreeingTheGrid2009.pdf
[69] The biogas policy report from the Great Plains Institute will be available in July 2010 at www.gpisd.net

a level playing field across the energy landscape, all major uses of biogas energy should benefit from renewable energy policy based on their ability to provide a renewable, clean, and economic resource.

Enhanced Renewable Electricity Standards

RES policies in the Midwest are the largest factor in the recent expansion of large-scale renewable energy across the region. With minor enhancements, RES policies can also benefit highly efficient biogas energy systems. Two changes to the definition of renewable resources can benefit biogas and maintain the integrity and objectives of RES policies as drivers for displacing fossil fuel energy and pollution with local, homegrown and renewable sources: recognizing the electric and thermal energy from combined heat and power (cogeneration) systems and renewable natural gas injected into the natural gas pipeline.

Crediting the heat portion of cogeneration and the energy of renewable natural gas toward an RES will require the establishment of conversion ratios to convert heat or natural gas energy into electrical equivalents used to comply with the RES. The calculation of the electrical equivalent can be made in one of two manners:

- Direct conversion based on the heat content of the biogas that gets used for thermal or natural gas applications using the theoretical energy equivalent of heat and electricity (3,412 Btus = 1 kilowatt-hour of electricity or kWh). This conversion factor would provide the most incentive for heat and renewable natural gas injections, but may tip the balance too far away from electricity. This is because electricity is generally a more useful form of energy and a direct conversion factor implies a 100%-efficient conversion from electrical energy to or from heat energy. In reality, electricity can be converted to heat at close to 100% but converting heat to electricity is much more difficult. With a direct conversion, biogas systems would have little incentive to create any electricity since electric generators are more expensive than heating systems.
- Conversion based on available heat to electricity technologies. Conventional electrical generation technologies for unrefined biogas combustion are equivalent to approximately 9,000 Btus to 14,000 Btus per kilowatt-hour, while renewable natural gas can be converted to electricity in modern combined cycle generators at a rate of approximately 7,000 Btus per kWh or lower. Using these factors to credit the heat portion of biogas cogeneration and renewable natural gas injected into the pipeline provides a better balance between incentivizing cogeneration and renewable natural and providing electrical output. A public utility commission can develop rules for the appropriate rate based on the average combustion efficiencies of biogas or natural gas in the state or the marginal combustion efficiencies for the same fuels in new installations in the state.

Renewable Natural Gas Standards

An alternative to including renewable natural gas as a qualifying resource under a renewable electricity standard is to establish a requirement that a percentage of the natural gas in the pipeline system is renewable. A renewable natural gas standard would be similar to a renewable electricity standard in that utilities would be required to obtain a percentage of the natural gas sold in their territory from renewable sources. One Midwestern natural gas utility, Integrys, already provides a small percentage of renewable natural gas to customers in Ohio who choose Integrys as their gas provider. This program, called Ecovations™, offsets 8% of the carbon dioxide emitted from their natural gas sales through a blend of renewable natural gas and carbon offsets[70].

FIT/ART Policy in United States

As discussed previously, limited FITs have been deployed by utilities as a part of voluntary renewable energy programs offered by utilities. A mandatory FIT policy can also be enacted for a state that is complementary to a RES but targeted at smaller-scale renewable resources (i.e., less than 20 MW) like solar, small-scale wind, and biogas. These FITs would meet a portion of the renewable sales for a state that already employs an RES. For example, a statewide FIT can be designed to meet 2% to 3% of electrical sales by 2025 in a state with an RES of 25% by 2025. Energy generated under the FIT would also comply with the RES, but the fixed-rate tariff would still provide the benefits that have proven successful at stimulating smaller distributed forms of energy generation in Europe. The remainder of the RES (e.g., 22% to 23% by 2025) would be met with conventional large-scale least-cost renewable energy technologies. Public utility commissions could still establish caps for the total renewable energy contribution for FITs and caps for individual technologies (e.g., a FIT program cap of 200 MW for solar).

Low Carbon Fuel Standards

An LCFS rates different types of transportation fuels by their energy content and carbon footprint and allows fuel providers to choose what mix of fuels will be used to meet the requirement. The flexibility of an LCFS is unique among fuel policies, allowing all transportation fuels, including ethanol, biodiesel, natural gas, electricity for electric cars, and biogas CNG, to compete with petroleum to meet the standard. By increasing the diversity of fuels in a market, an LCFS will also reduce fuel price volatility that comes from over-dependence on petroleum. Most importantly, an LCFS is based on the carbon footprint of fuels and the energy content, thus recognizing the ultra-low carbon advantage of biogas CNG. LCFS policies have been enacted in California; proposed at the federal level; and proposed in 11 Northeast states, Washington, Oregon, British Columbia, and Europe. The specific approach of an LCFS can be established to reflect the unique aspects of the fuel market in a state or region.

Design principles for an LCFS in the Midwest are under development by a stakeholder group from the Midwestern Governors Association[71]. LCFS policies, however, need to be established by state legislators and could utilize credit-sharing or other mechanisms to interact with adjacent states. The benefit for biogas CNG, however, is significant. Biogas producers that supply biogas CNG to vehicles, such as bus fleets, would generate credits that could be sold to petroleum suppliers in the state. Since biogas CNG has the lowest carbon footprint of available fuels, credits generated by biogas CNG vehicle use are likely to have significant value to an LCFS credit market.

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[70] http://www.integrysenergy.com/naturalgas/residential/OH/ecovations.aspx
[71] www.midwesterngovernors.org/LCFS.htm