SUSTAINABLE DAIRY

SCIENCE FOR SUSTAINABLE PRODUCTION

UW Extension
University of Wisconsin-Extension

Horacio Aguirre-Villegas
Biological Systems Engineering,
University of Wisconsin-Madison

Rebecca A. Larson
Biological Systems Engineering,
University of Wisconsin-Madison

Matthew D. Ruark
Soil Science,
University of Wisconsin-Madison

SUSTAINABLE DAIRY PARTNERS

UNIVERSITY OF WISCONSIN-MADISON

CORNELL UNIVERSITY

PENNSYLVANIA STATE UNIVERSITY

UNIVERSITY OF ARKANSAS

UNIVERSITY OF MARYLAND

UNIVERSITY OF MICHIGAN

UNIVERSITY OF WASHINGTON

NORTH CAROLINA AGRICULTURAL AND TECHNICAL STATE UNIVERSITY

INNOVATION CENTER FOR US DAIRY

USDA ARS DAIRY FORAGE RESEARCH CENTER

USDA ARS PASTURE AND WATERSHED MANAGEMENT

USDA ARS NATIONAL LABORATORY FOR AGRICULTURE AND ENVIRONMENT

USDA NATIONAL AGRICULTURE LIBRARY

Sustainable Dairy Fact Sheet Series

Dairy Anaerobic Digestion Systems and their Impact on Greenhouse Gas and Ammonia Emissions

An Overview

Introduction

Anaerobic digestion is a process in which microorganisms degrade organic material, such as dairy manure, in the absence of oxygen to produce biogas and digestate. Biogas is composed mostly of methane, which is the main constituent of natural gas (Table 1). Digestate is the degraded organic material that exits the digester after the digestion process. Digestate contains nutrients that can be used as an organic fertilizer. Although many of the nutrients change form, the total amount of nutrients remains nearly constant (<1% of nitrogen is lost in biogas). Anaerobic digestion produces renewable energy while also reducing odors, pathogens, antibiotics, and greenhouse gas emissions.

Table 1. Biogas composition

Gas	Content
Methane (CH_4)	50-80%[1]
Carbon dioxide (CO_2)	20-50%
Hydrogen sulfide (H_2S)	<1%
Trace elements[2]	<1%

[1]Ileleji et al. (2008)
[2]Including nitrogen (N_2), ammonia (NH_4), and hydrogen (H_2)

As of 2015, there were 260 agricultural-based anaerobic digesters in the U.S., with 206 of them located on dairy farms (AgSTAR 2016). Wisconsin and New York have the most agricultural anaerobic digesters of any state, with 39 in Wisconsin and 34 in New York. There are many digester designs, however the four most common agricultural digester designs are complete mixed, mixed plug-flow, horizontal plug-flow, and covered lagoons (Figure 1). Regardless of the design, the microbial processes are the same. Extensive information and resources on agriculturally-based anaerobic digestion systems can be found at the AgSTAR project, a cooperative effort among the U.S. Department of Agriculture, the U.S. Department of Energy and the EPA to promote biogas projects in the U.S. (AgSTAR 2016).

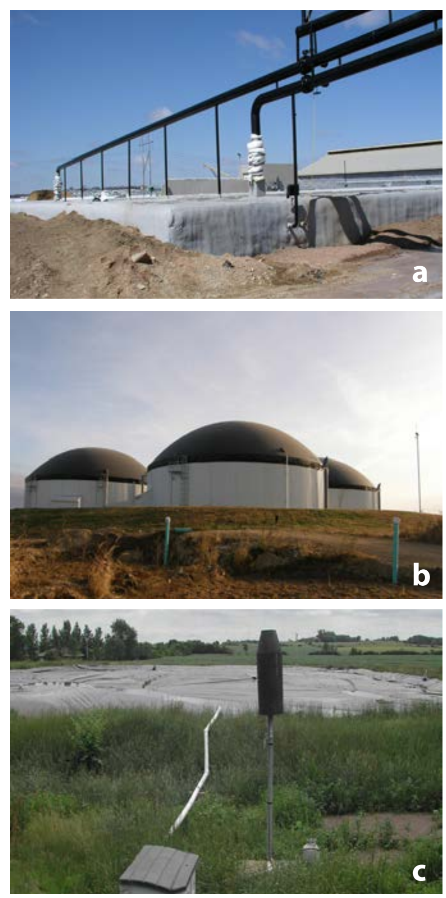

Figure 1. Types of anaerobic digesters: a) plug-flow b) complete mixed, and c) covered lagoon

Inputs for Anaerobic Digestion

Inputs, or feedstocks, for digesters include animal manure, crops and grasses, fats and oils, food waste, and sewage, among others. Despite its low biogas potential when compared to other organic materials (Figure 2), manure is a preferred feedstock in agricultural digestion systems in the U.S. due to its continuous availability in one location, its capacity to resist changes in pH, and its relatively easy integration into existing manure management systems. On average, dairy manure produces approximately 0.023 m^3 of methane per kg (0.37 ft^3 per lb) of manure on a wet basis, or 0.19 m^3 of methane per kg (3.04 ft^3 per lb) of manure on a dry basis. These figures are highly variable depending upon the manure characteristics (Moody et al. 2011). Many farms will incorporate other organic wastes with their manure,

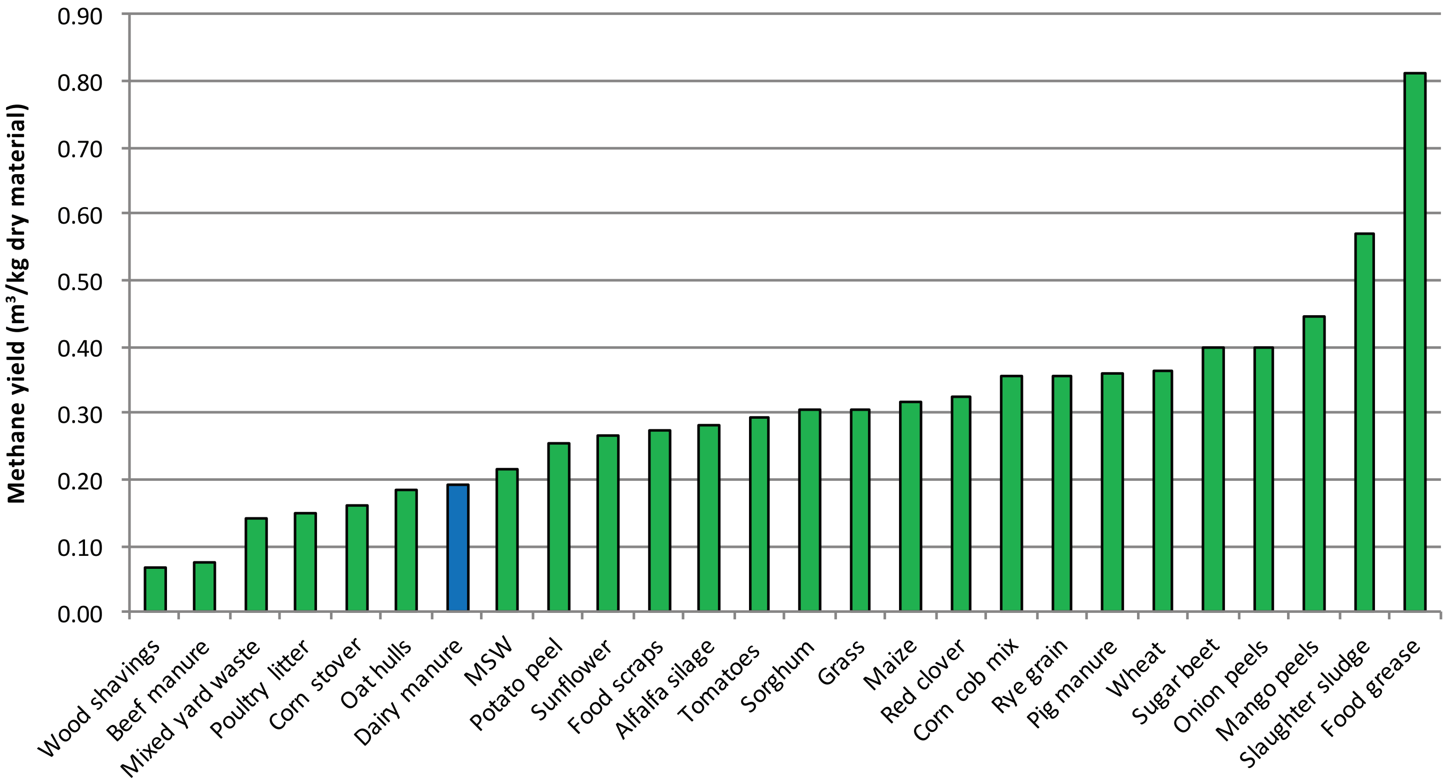

Figure 2. Methane yield per kilogram of dry material of some common organic inputs to produce energy through anaerobic digestion (Source: Table 5 in Moody et al. 2011 and Tables 1, 2, 3, and 4 in Appels et al. 2011)

known as co-digestion, to increase biogas production. This includes addition of on-farm by-products, such as milk house waste or spoiled silage, as well as by-products transported from other locations off the farm, such as food waste.

The Anaerobic Digestion Process

The digestion process on a dairy farm starts with the daily collection and transport of manure to the digester where it typically resides for 5 to 28 days depending on the temperature inside the digester (Figure 3). If straw or other organic bedding is used in the barns, it is common that some bedding material is collected and digested along with the manure. However, if sand is used as bedding, a sand separation process to remove the sand prior to the manure entering the digester is necessary to prevent buildup in the digester. Manure is transported into the digester multiple times per day to minimize the holding period, as manure immediately begins to break down, reducing the biogas production in the digester. For digesters that operate at thermophilic temperatures (41-57 °C) the time required for digestion will be much shorter compared to those at mesophilic temperatures (18-40 °C). Thermophilic systems can reduce the time needed for digestion, thereby reducing digester size, but they also require more energy to maintain the high temperatures and can require more management as the systems can be less stable than mesophilic systems. Thus, the majority of the anaerobic digesters in the U.S. operate in the mesophilic range (AgSTAR 2016). Biogas is produced continuously during the digestion process and either immediately converted to energy or stored for later conversion.

Outputs of Anaerobic Digestion

Biogas can be captured and burned to produce heat and generate electricity, cleaned and injected into the natural gas grid, or cleaned and compressed to be used as a transportation fuel. Despite its numerous potential uses, biogas is commonly used to generate electricity for the grid. Table 2 shows estimated energy values of methane and biogas when processed in a generator to produce electricity. On average, it is estimated that one cow provides 0.14 kW of energy (AgSTAR 2004).

Digestate is most commonly land-applied for fertilizer. Nearly all dairy digestion systems adopt solid-liquid separation systems, which add value and flexibility to manage the digestate. The liquid fraction is generally land-applied as organic fertilizer, and the solid fraction is commonly land-applied on-farm, sold to other farms as fertilizer or soil amendment, or used as bedding for cows given that the majority of the pathogens are killed in the digestion process (Burkholder et al. 2007). The digestion process increases conversion of nitrogen from organic forms into inorganic forms (i.e. nitrate and ammonium), which increases the amount of plant-available nutrients and increases the relative fertilizer value of the manure.

Table 2. Energy values of biogas and methane

Description	Unit	Energy value	
		MJ	kWh
Biogas	1 m^3	21[1]	5.8[1]
Methane	1 m^3	35	9.7
Electricity	1 m^3 of methane	9.4	2.6[2]
Heat	1 m^3 of methane	13.3	3.7[3]

[1]Depends on the CH_4 content in biogas, assumed to be 60% CH_4
[2]Assuming a 30% generator electric efficiency and 10% downtime
[3]Assuming 50% generator heat efficiency, 85% heat exchanger efficiency, and 10% downtime

Effects of Anaerobic Digestion on Greenhouse Gas and Ammonia Emissions

Methane is a fuel, but it's also a potent greenhouse gas. Digestion can reduce the impact to climate change by capturing methane produced from manure that would otherwise be lost to the atmosphere. The reduction to global warming potential occurs when the methane is converted to carbon dioxide when combusted; a molecule of carbon dioxide has a 28 times lower global warming potential than a molecule of methane (Myhre 2013).Greenhouse gas emissions from manure storage, handling, and processing can be reduced by more than 50% when integrating an anaerobic digester (Aguirre-Villegas et al. 2014). This reduction is mostly a result of the digestate emitting less methane during storage after digestion when compared to undigested manure. The majority of the volatile compounds (i.e. the carbon compounds that are easily degraded by microorganisms) responsible for those emissions are decomposed during anaerobic digestion. If not digested, these volatile compounds decompose during storage and emit methane directly to the atmosphere. In addition, by producing renewable energy on farm, the digestion system can replace fossil fuel use from grid electricity that is produced from nonrenewable sources such as coal. According to a life cycle assessment study, overall greenhouse gas emissions from the entire dairy farm can be reduced by 35% when biogas-based electricity replaces grid-based electricity (Aguirre-Villegas et al. 2015).

One drawback of anaerobic digestion is the potential increase in ammonia emissions. The digestion process makes nitrogen more available to crops, but also more prone to volatilization (gas lost as ammonia). This could result in an increase in ammonia emissions from uncovered manure pits or from soils if not incorporated when applied (Chadwick et al. 2011). To avoid these losses, it is important to couple digestion systems with management practices that minimize ammonia losses such as manure storage covers and injection during land application.

Other benefits from using anaerobic digesters to process manure include reducing odor, pathogens, and antibiotics. The digestion process can convert many compounds that cause odor found in manure, and it can inactivate pathogens and degrade antibiotics when they are exposed to the high operating temperatures and anaerobic conditions in the digester.

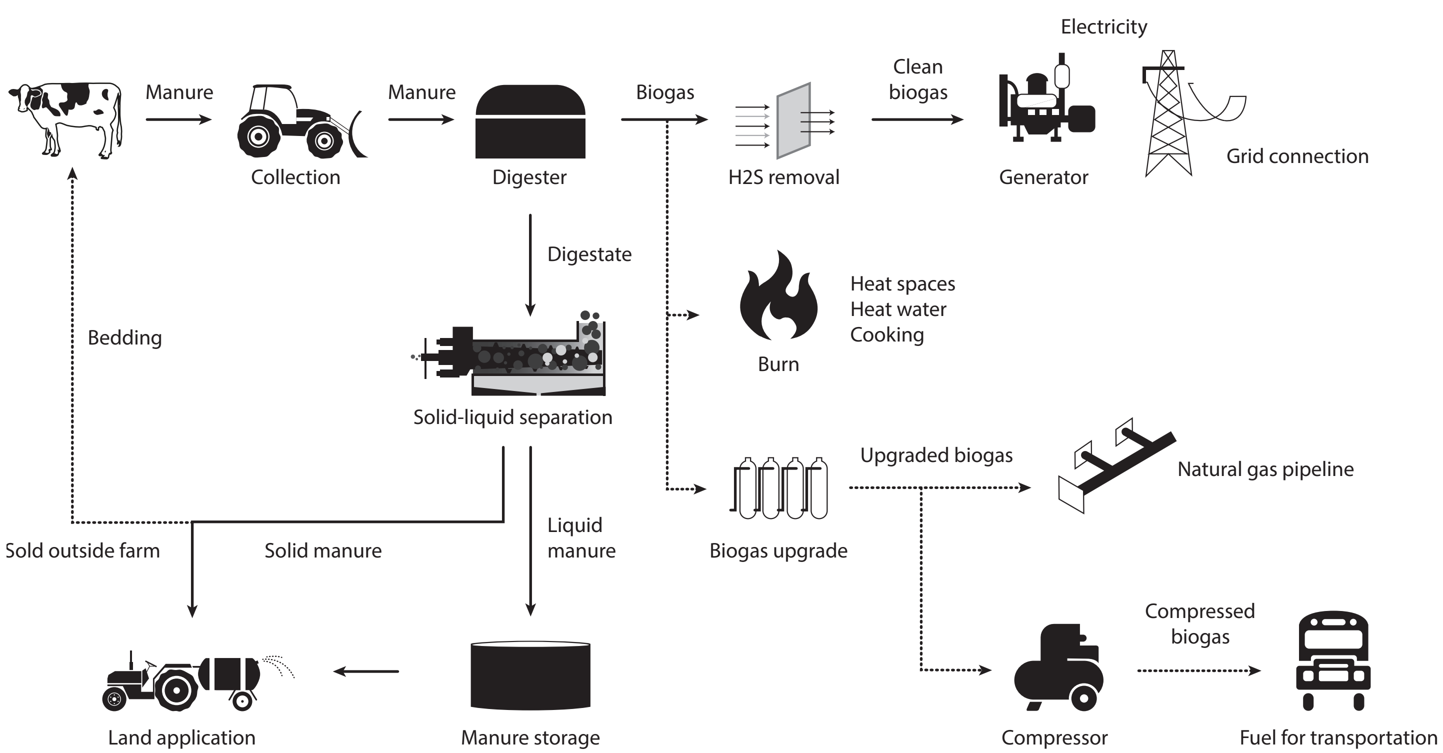

Figure 3. Scheme of the anaerobic digestion process and its potential products. Solid lines represent most common practices. Dotted lines represent alternative options for biogas and digestate processing and use.

Summary

Anaerobic digestion is a technology that provides many economic, agronomic, and environmental benefits when installed at a livestock facility. The degradation of the compounds responsible for methane emissions in the digester reduces methane emissions from digestate during storage when compared to systems without a digester. The production of biogas-based electricity can replace the use of fossil-based grid electricity, further reducing greenhouse gas emissions. In addition, the high operating temperatures in the digester can reduce odor, pathogens, and antibiotics contained in the manure. Despite its multiple benefits, the adoption of digestion systems is still limited by high investment and operating costs. Strategies that reduce costs and increase potential revenues and profitability are needed to promote the adoption of these systems by dairy farmers.

References

Aguirre-Villegas, Horacio A., Rebecca A. Larson, and Douglas J. Reinemann. "From waste-to-worth: Energy, emissions, and nutrient implications of manure processing pathways." Biofuels Bioproducts and Biorefining 8 (2014): 770–93.

Aguirre-Villegas, Horacio A., Thaís H. Passos-Fonseca, Douglas J. Reinemann, Louis E. Armentano, Michel A. Wattiaux, Victor E. Cabrera, John M. Norman, and Rebecca A. Larson. "Green cheese: Partial life cycle assessment of greenhouse gas emissions and energy intensity of integrated dairy production and bioenergy systems." Journal of Dairy Science 98 (2015): 1571-92.

AgSTAR. A manual for developing biogas systems at commercial farms in the United States. Handbook, 2nd edition, edited by Kurt F. Roos, John Martin, and Mark A. Moser. Washington, DC: USEPA Office of Air and Radiation, 2004. https://www.epa.gov/sites/production/files/2014-12/documents/agstar-handbook.pdf.

AgSTAR. Livestock anaerobic digester database. Washington, DC: USEPA, 2016. https://www.epa.gov/agstar/livestock-anaerobic-digester-database.

Appels, Lise, Joost Lauwers, Jan Degrève, Lieve Helsen, Bart Lievens, Kris Willems, Jan Van Impe, and Raf Dewil. "Anaerobic digestion in global bio-energy production: Potential and research challenges." Renewable and Sustainable Energy Reviews 15, no. 9 (2011): 4295–301.

Burkholder, JoAnn, Bob Libra, Peter Weyer, Susan Heathcote, Dana Kolpin, Peter S. Thorne, and Michael Wichman. "Impacts of waste from concentrated animal feeding operations on water quality." Environmental Health Perspective 115, no. 2 (2007): 308–12.

Chadwick, Dave, Sven Sommer, Rachel Thorman, David Fangueiro, Laura Cardenas, Barbara Amon, and Tom Misselbrook. "Manure management: Implications for greenhouse gas emissions." Animal Feed Science and Technology 166-167 (2011): 514-31.

Ileleji, Klein E., Chad Martin, and Don Jones. Basics of energy production through anaerobic digestion of livestock manure. West Lafayette, IN: Purdue University Extension, 2004. http://www.extension.purdue.edu/extmedia/ID/ID-406-W.pdf.

Moody, Lara B., Robert T. Burns, G. Bishop, Steven T. Sell, and R. Spajic. "Using biochemical methane potential assays to aid in co-substrate selection for co-digestion." Applied Engineering in Agriculture 27, no. 3 (2011): 433-9.

Myhre, Gunnar, Drew Shindell, Francois-Marie Bréon, William Collins, Jan Fuglestvedt, Jianping Huang, Dorothy Koch, Jean-François Lamarque, David Lee, Blanca Mendoza, Teruyuki Nakajima, Alan Robock, Graeme Stephens, Toshihiko Takemura, and Hua Zhang. "2013: Anthropogenic and Natural Radiative Forcing Supplementary Material." Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, edited by Thomas F. Stocker, Dahe Qin, Gian-Kasper Plattner, Melinda M.B. Tignor, Simon K. Allen, Judith Boschung, Alexander Nauels, Yu Xia, Vincent Bex, and Pauline M. Midgley. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2013. http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf.

Rotz, C. Alan, M.S. Corson, D.S. Chianese, F. Montes, S.D. Hafner, R. Jarvis, and C.U. Coiner. The integrated farm system model (IFSM): Reference manual, v. 4.2. University Park, PA: Pasture Systems and Watershed Management Research Unit, Agricultural Research Service, United States Department of Agriculture (USDA), 2015. https://www.ars.usda.gov/northeast-area/up-pa/pswmru/docs/integrated-farm-system-model

Acknowledgement

This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2013-68002-20525. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

Authors: Horacio Aguirre-Villegas, assistant scientist, Rebecca A. Larson, assistant professor, and Matthew D. Ruark, associate professor, University of Wisconsin-Madison.

Reviewers: Mahmoud Sharara, Biological Systems Engineering, University of Wisconsin-Madison; Brian Langolf, Biogas Systems, University of Wisconsin-Oshkosh; and Ted Bay, Grant County, University of Wisconsin-Extension.

Graphic design: Elizabeth Rossi, University of Wisconsin Environmental Resources Center.

University of Wisconsin-Extension, Cooperative Extension, in cooperation with the U.S. Department of Agriculture and Wisconsin counties, publishes this information to further the purpose of the May 8 and June 30, 1914, Acts of Congress. An EEO/AA employer, the University of Wisconsin-Extension, Cooperative Extension provides equal opportunities in employment and programming, including Title VI, Title IX, and ADA requirements. If you have a disability and require this information in an alternative format, please contact Cooperative Extension Publishing at 432 N. Lake St., Rm. 227, Madison, WI 53706; pubs@uwex.edu; or (608) 263-2770 (711 for Relay).

This publication is available from your county University of Wisconsin-Extension office (counties.uwex.edu) or from Cooperative Extension Publishing. To order, call toll-free 1-877-947-7827 or visit our website at learningstore.uwex.edu.

USDA United States Department of Agriculture National Institute of Food and Agriculture

Publication Numbers: UWEX A4131-02
GWQ 074