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AgSTAR

Project Development Handbook

A Handbook for Developing Anaerobic Digestion/Biogas Systems
on Farms in the United States

3rd Edition

EPA United States
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Agency

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Notice and Disclaimer

The AgSTAR Project Development Handbook provides technical information, processes and concepts to better inform the development of anaerobic digestion/biogas systems. The handbook may not address all information, factors, applicable regulations, or considerations that may be relevant or required for anaerobic digestion/biogas projects. Any references to private entities, products or services are strictly for informational purposes and do not constitute an endorsement of that entity, product or service.

The Handbook provides links to non-EPA websites that provide additional information about anaerobic digestion/biogas systems. EPA cannot attest to the accuracy of non-EPA information provided by these third-party sites or any other linked site. EPA is providing these links for your reference. In doing so, EPA does not endorse any non-government websites, companies or applications.

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Abbreviations and Acronyms

ABC	American Biogas Council
AD	Anaerobic digestion
ADREC	Anaerobic Digester Research and Education Center
AFDC	Alternative Fuels Data Center
AFO	Animal feeding operation
ASBR	Anaerobic sequencing batch reactors
ATA	Anaerobic Toxicity Assays
BMP	Biomethane potential assay
BOD	Biochemical oxygen demand
BSE	Bovine Spongiform Encephalopathy
BTU	British thermal unit
°C	Degrees Celsius
CAA	Clean Air Act
CARB	California Air Resources Board
CAFO	Concentrated animal feeding operation
CFR	Code of Federal Regulations
CH_4	Methane
CHP	Combined heat and power
CI	Carbon intensity
CNG	Compressed natural gas
CNMP	Comprehensive Nutrient Management Plan
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand
CREST	Cost of Renewable Energy Spreadsheet Tool
CSANR	Center for Sustaining Agriculture and Natural Resources
CSTR	Continuous Stirred Tank Reactors
dBA	Actual decibel
DME	Dimethyl ether
DOE	U.S. Department of Energy
DSIRE	Database of State Incentives for Renewables & Efficiency
EPA	U. S. Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
EV	Electric vehicles
°F	Degrees Fahrenheit
FDA	Food and Drug Administration
FERC	Federal Energy Regulatory Commission
FOG	fats, oils, and greases
gCO_2e/MJ	Grams of carbon dioxide equivalent per megajoule
GHG	Greenhouse gas
H_2	Hydrogen
H_2S	Hydrogen sulfide
HAP	Hazardous air pollutants
HRT	Hydraulic retention time
HSAD	High solids anaerobic digestion
IBR	Induced blanket reactor
IRB	Industrial Revenue Bond
ITC	Investment Tax Credit
kW	Kilowatt
kWh	Kilowatt-hour
LCFS	Low Carbon Fuel Standard
LFG	Landfill gas
LMOP	Landfill Methane Outreach Program
LNG	Liquified natural gas
$MMTCO_2e$	Million metric tons of CO_2 equivalent
MSW	Municipal solid waste
MW	Megawatt
MWh	Megawatt-hour
NAAQS	National Ambient Air Quality Standards
NH_3	Ammonia

NH_4	Ammonium
NESHAP	National Emission Standards for Hazardous Air Pollutants
NNSR	Nonattainment New Source Review
NOx	Nitrogen oxides
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NSPS	New Source Performance Standards
NSR	New Source Review
O_2	Atmospheric diatomic oxygen
O&M	Operations and Maintenance
OLR	Organic loading rate
OPEX	Operating Expenses
OSHA	Occupational Safety and Health Administration
PDH	Project Development Handbook
PM	Particulate matter
POTW	Publicly owned treatment works
PPA	Power purchase agreement
ppm	Parts per million
PRE	Pathogen-reducing effect
PSD	Prevention of Significant Deterioration
psi	Pounds per square inch
PTC	Production Tax Credit
R-CNG	Renewable compressed natural gas
RCRA	Resource Conservation and Recovery Act
REAP	Rural Energy for America Program
REC	Renewable Energy Certificate
RFS	Renewable Fuels Standard
R-LNG	Renewable liquid natural gas
RNG	Renewable natural gas
RPS	Renewable Portfolio Standards
SAM	System Advisor Model
SARE	Sustainable Agriculture Research and Education Program
SIP	State Implementation Plan
SOx	Sulfur oxides
SPP	Simple Payback Period
SRT	Solid retention time
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TP	Total phosphorus
tpy	Tons per year
TS	Total solids
TVS	Total volatile solids
UASB	Upflow anaerobic sludge blanket
USDA	U.S. Department of Agriculture
VAPG	Value-Added Producer Grant Program
VS	Volatile solids
VSS	Volatile suspended solids
WARM	Waste Reduction Model
WRRF	Water Resource Recovery Facility
WSU	Washington State University
WWTP	Wastewater Treatment Plant

1.0 Introduction and Considerations

The AgSTAR Project Development Handbook, hereafter referred to as the Handbook or PDH, is intended for agriculture and livestock producers, farm owners, developers, investors, policymakers, implementers, and anyone working in agriculture or renewable energy that is interested in AD/biogas systems as a farm manure management option. This third edition, published in 2020, provides substantial updates from previous versions, including new details about:

- Co-digestion of various feedstocks on farms, as well as for AD in industrial, institutional, and commercial facilities.
- Numerous options for biogas utilization, including transportation fuels and biochemicals.
- Opportunities to combine AD/biogas systems and nutrient recovery for generating alternative, renewable fertilizers.

The PDH outlines necessary development steps and the questions industry professionals must address as part of the project evaluation, development, and implementation process. To increase the chances of project success, many of the considerations that should be addressed when developing, designing, and implementing a farm-based digester project are covered in the PDH, including:

- Technical questions, as well as tips and lessons learned for all project development and deployment stages.
- Information that will help stakeholders make informed decisions to maximize both profits and environmental performance while reducing implementation risk.

AD/biogas systems can be simple or complex depending on numerous factors. This PDH is not intended to address all of the considerations, nor is it designed to serve as a "guidance document" or manual to build an AD/biogas system.

About AgSTAR

AgSTAR is a voluntary outreach program that encourages the implementation of AD projects in the agricultural and livestock sector to reduce methane emissions from agricultural residuals, including livestock waste. The PDH complements other AgSTAR resources for developing biogas technologies at agricultural facilities in the United States. It is designed to be used in combination with the AD/Biogas System Operator Guidebook (under development). These documents were collectively prepared to improve the successful development, implementation, and operation of on-farm AD/biogas systems and are relevant to AD/biogas systems of all types. These documents purposely do *not* provide guidance or details on how to design and construct the necessary infrastructure for AD/biogas systems. Rather, they seek to explain AD processes and concepts, and to provide fundamental information required to make more informed decisions about system development. Learn more by visiting the AgSTAR website.

We can help you do more with your manure

The remainder of the Handbook is organized into the following sections:

2.0	Anaerobic Digestion Overview
3.0	Process Fundamentals
4.0	Digester Feedstocks
5.0	AD/Biogas System Products, Equipment and Uses
6.0	Economic and Financial Factors
7.0	Screening and Feasibility Studies
8.0	Business Relationships
9.0	Permitting
10.0	Public and Community Outreach
11.0	Safety, Operation, and Maintenance Considerations
12.0	Additional Tools and Resources

In many cases, this Handbook provides “rules of thumb” indicating favorable parameters or conditions for project implementation. However, the fact is that market conditions are constantly and often rapidly changing. Thus, “rules of thumb” described herein may decrease in value or applicability as a result of changing market conditions. It is therefore recommended that those interested in pursuing an AD/biogas system project consult with an experienced professional prior to project implementation.

1.1 Keys to a Successful AD/Biogas System

Many factors should be considered to successfully implement and operate an AD/biogas system. The following are 10 key factors that often lead to successful AD/Biogas system implementation.

1. **Plan for success.** During the planning stage, identify and define clear project goals. To establish these goals, site-specific farm information should be collected, including ownership and managerial goals and projections, animal information (e.g., number, types, maturity, bedding type), type(s) of manure recovery, volume of manure, manure analytical information, past and current disposal practices, and operational costs. Working towards project parameters is also crucial in addressing and meeting goals. This includes, often in iterative planning stages, identifying available feedstock, defining the type of digestion system, conversion efficacy of feedstock, economic or financial factors and limitations, and project risks associated with developing an AD/biogas system**.**
2. **Recruit and secure an experienced team.** Seek out and work with an experienced and qualified team to help initiate and successfully implement the project. At project initiation, the “core” team should include: (1) an engineer/permitting specialist who knows the farm history and local regulations, and (2) an engineer or specialist with seasoned experience implementing various AD/biogas systems. Verify the project references, experience, and historical success of the engineers and specialists.

   The “core” team should help identify an applicable system and ensure the development is feasible and planned to meet the owner’s goals and expectations. As the project is further developed, the team may also expand to include technology vendor(s), equipment provider(s), a project developer, investors/bankers/ lender(s), and/or operators to supplement the initial “core” team. The farm owner or operating personnel should also be included in the “core” team early on if the project is not being developed by the farm itself**.** Inclusion of a third-party developer is a critical decision and must be carefully evaluated (this is described in Section 6.4). While considering third-party support, checking references is very helpful in selecting the final team.

3. **Develop a sustainable business model.** A successful AD/biogas system requires a sustainable business model. The project should not only be cost-effective, but it must also meet financial goals. The economic factors include well-defined project costs, expenses, revenue or income, and liabilities, among many others. Personal goals for the project’s liquidity and profitability potential define the financial factors. The business model could consider involving partners, utilizing third party investments, or other traditional ‘cooperative’ models.
4. **Secure suitable feedstock supply.** During the planning and engineering phase, identify suitable feedstocks. This may include evaluating the chemical, biological, and physical characteristics as described in Section 4.1. The digester must be supplied with a consistent quality and type of feedstock (manure and co-substrates) to maintain a productive microbial community. This will result in consistent organic destruction and biogas production and minimize operational issues. It is of high value to ensure that feedstocks are free of toxic and inorganic contaminants that will “upset" the intended microbial and mechanical processes. Sand, gravel, and other inert material should be removed to the degree possible to minimize sediment accumulation in the digester. Feedstocks from outside sources should be routinely characterized to monitor consistency. Projects that focus on co-digestion feedstocks (i.e., feedstock supplementing manure) should include contractual agreements to specify material quantity and quality, testing frequency, revenue received, and duration to ensure the right type and amounts of materials and revenue are provided. Co-digestion feedstocks should be designed for flexibility as external supplies are likely to vary over time. See Section 4.3 and AgSTAR’s Co-digestion Guidelines web page for additional information.
5. **Use the most appropriate technology.** The AD technology needs to be carefully evaluated to match the type and amount of feedstock that is expected to be processed. There is no single AD technology that can be used for all situations or feedstock. Many key factors need to be considered including: (1) the type of manure and co-digestion feedstocks, (2) how the manure is collected, (3) conversion efficiency goals, (4) the climate where the digester is located, (5) bedding type and mass, (6) amount of allocated maintenance, and other factors. AD technology selection should also consider management goals and needs and future plans of the farm. An example of a farm AD/biogas system is shown in Figure 1.1.

Figure 1.1. Illustration of an AD/Biogas System on a Farm

6. **Analyze options for biogas and digestate use.** During the planning stage, considerations should include market availability, capital and operating costs, and potential revenue to determine how the biogas is best monetized (e.g., on-site use or off-site sales). Potential uses include: (1) on-site use of thermal and/or electrical energy, (2) off-site sale of thermal and/or electrical energy, (3) off-site sale of compressed natural gas or liquified natural gas (CNG/LNG) typically used for transportation fuel or other applications, (4) on-site use of RNG, (5) off-site sale of RNG, and/or (6) bio-based material generation. The need for on-site digestate use as fertilizer or bedding should also be determined, and the market for digestate final products should be assessed, including fertilizer, salable compost, or other value-added digestate products. Proper management of digestate, whether recovered for its nutrient value or disposed of in an environmentally correct manner, is critical to the success of a project**.**

RNG can be transported via truck or natural gas pipeline and can be used as a substitute for fossil fuel-based natural gas for thermal applications, electricity production, bio-chemical, and/or transportation vehicle fuel. The value of RNG is discussed in AgSTAR's RNG from Agricultural-Based AD/Biogas System web page.

7. **Develop off-take agreements**. It is critical to execute off-take agreements or legal contracts with users of the AD/biogas products and byproducts (e.g., biogas, electricity, heat, RNG, digestate, fertilizers) early in the development stage. These agreements—including power purchase agreements (PPA), biogas/RNG sale agreements, or digestate sales agreements—define the price and detailed specifications for all materials that a third party will purchase.

8. **Evaluate added benefits.** Consider the added benefits of AD, which may be difficult to quantify, but could be critical reasons for implementing an AD/biogas project. These benefits may include odor control or reduction in greenhouse gas (GHG) emissions. Digesters often are installed to reduce odor problems, particularly on farms where there is public development encroachment.

9. **Conduct community outreach.** Community outreach and education is critical to obtain buy-in and approval from the community, including, but not limited to, regulatory approval and community and neighborhood approval where the project is located.

10. **Plan for operation and maintenance.** Good operation and maintenance practices are key for effective operation of AD/biogas systems. This includes continuous monitoring and management to ensure the biological processes and mechanical equipment are working properly. Often, AD/biogas system operating expenses (OPEX) are underestimated. Analyzing other similar operating systems that have several years of operational history can assist in predicting OPEX accurately. It is also important to consider whether current staff or a third party will be used to perform these functions.

Figure 1.2. 10 Keys to Digester Success

1 **Plan for Success**
2 **Recruit and Secure an Experienced Team**
3 **Develop a Sustainable Business Model**
4 **Secure Suitable Feedstock Supply**
5 **Use the Most Appropriate Technology**
6 **Analyze Options for Biogas and Digestate Use**
7 **Develop Off-Take Agreements**
8 **Evaluate Added Benefits**
9 **Conduct Community Outreach**
10 **Plan for Operation and Maintenance**

1.2 Is an AD/Biogas System Right for You?

Farm-based AD/biogas projects require detailed technical and economic/financial planning. While digesters are simple in concept, there are many sizes, styles, and applications of the technology that need to be carefully evaluated to ensure project success. As a result, implementation can become very complex and thus can be overwhelming to those who are inexperienced. Implementation of a project that meets project goals should be done with the help of an objective, experienced team.

Successful and profitable projects have been implemented on dairy, swine, and poultry farms of varying sizes and types. There are numerous factors that will dictate the likelihood of a profitable project. Changes in input factors, even those that may appear subtle, can have significant impact on the likelihood of project success. Therefore, careful and detailed planning is required.

Manure from dairy and swine operations tends to be best suited for farm-based energy conversion because these manure management systems are often liquid- or slurry-based and have central collection systems in place to collect and recover manure efficiently. Depending on the digester technology selection, this allows for more simplified feedstock conversion compared to materials with higher solids concentrations.

There are many important factors in determining a viable farm size needed for a successful AD/biogas system. One key factor is whether the farm generates and recovers manure from a sufficient number of livestock daily. In addition, candidate facilities should have a relatively constant year-round animal population and a consistent quantity and quality of manure.

While this document provides "rules of thumb" indicating favorable conditions for project implementation (e.g., farm size), market conditions are constantly changing. The current emphasis is on RNG, driven by low carbon fuel standards (LCFS), that has positively impacted AD/biogas project economics (see AgSTAR's RNG from Agricultural-Based AD/Biogas Systems web page). Many small farms have been able to realize the possibility of either direct RNG production or as part of a combined system with other farms. This illustrates that changing market conditions may circumvent the stated "rules of thumb."

Successful farm-based AD/biogas systems typically operate with *at least* 500 cows in dairy operations or *at least* 2,000 hogs in swine operations.[1] As economies of scale yield more favorable conditions (e.g., larger number of animals, larger amount of recovered manure, increased amount of salable products produced) the likelihood of successful application and profitability increases. For example, dairy farms having greater than 1,000 animals or hog farms having greater than 5,000 animals increases the likelihood of project success.

Conversely, many smaller-scale projects (i.e., those with less than the number of animals outlined above) have also successfully implemented AD/biogas systems. Applications on farms of this size require more careful planning and favorable economic and financial conditions to offset the economies of scale. Often, regional market conditions, government incentives (local or state), or other conditions may allow for successful implementation on smaller scale farms.

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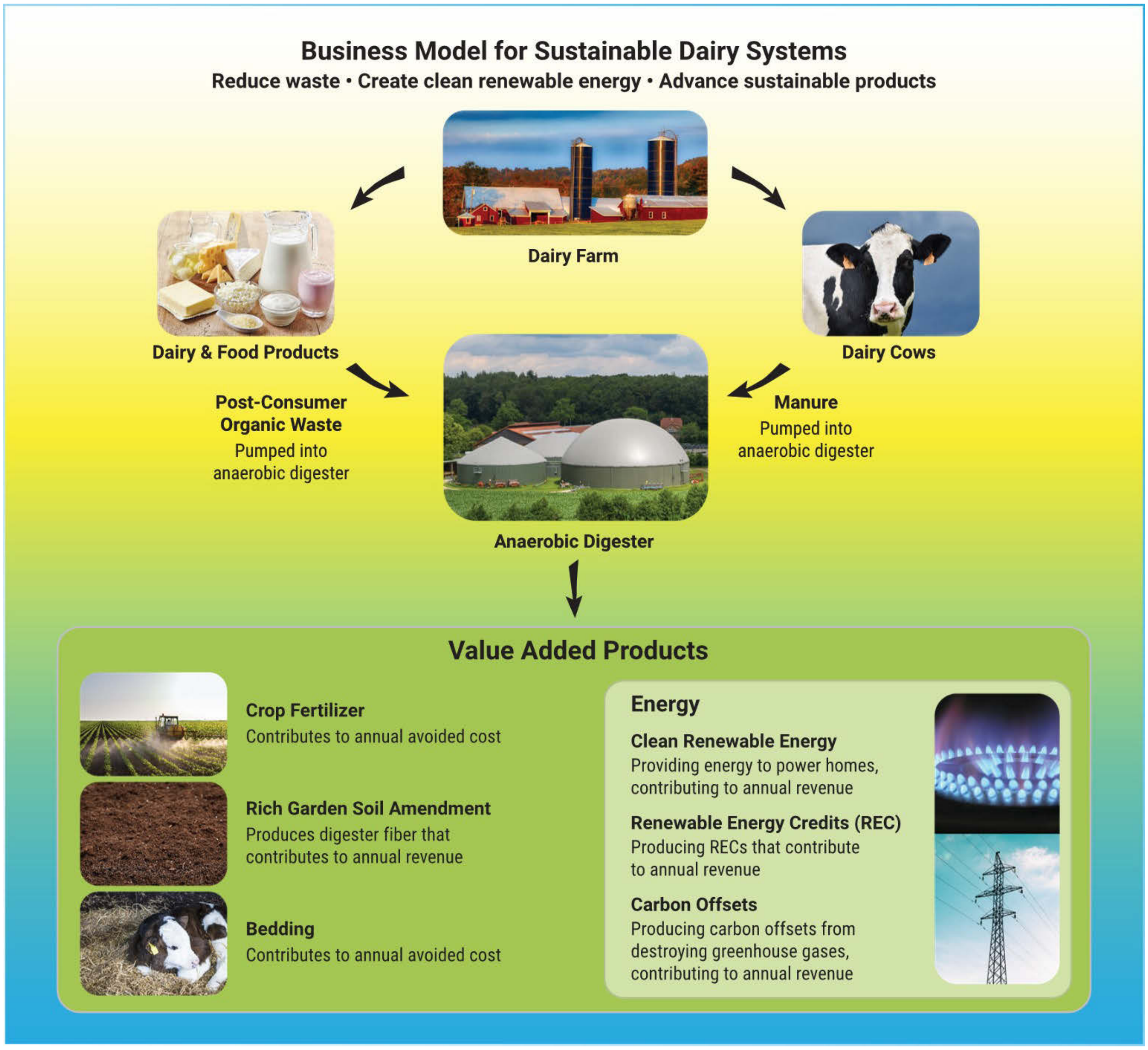
[1] "Market Opportunities for Biogas Recovery Systems at U.S. Livestock Facilities," EPA AgSTAR Program, June 2018, https://www.epa.gov/sites/production/files/2018-06/documents/epa430r18006agstarmarketreport2018.pdf.

Co-digesting viable organic waste streams with manure may make smaller farm-based digester projects more economically feasible. An example could be a dairy farm that is milking 500 cows, but also co-digests other materials (such as organic residuals or food waste) obtained from off-farm sources. Processing certain types of materials to co-digest with animal manures can significantly increase the biogas production to levels that, depending on the material, may equate or exceed a larger dairy farm that digests only manure.

Figure 1.3. Business Model for a Hypothetical AD/Biogas System[2]



As shown in Figure 1.3, AD/biogas systems can include many different components, each of which are interconnected and interrelated. Collectively, the AD/biogas system can generate many beneficial end use products that have high value and can be sold in various market platforms. A “biorefinery” is a term generally used to describe a production facility that converts biomass of various types to usable

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[2] Modified based on the Innovation Center for U.S. Dairy’s “A Business Model for Sustainable Dairy Digester Systems” graphic.

biofuels, biochemicals, and/or biomaterials that are considered alternatives to fossil fuel-based materials. Thus, when an AD/biogas system produces these products, it is often referred to as a "biorefinery." When more saleable products are generated and can be sold, this increases potential revenue, which in turn increases profitability potential, and, therefore, increases the likelihood of project success.

See Section 6.0 for a discussion about business model considerations that may be applicable, and visit EPA AgSTAR's Is Anaerobic Digestion Right for Your Farm web page for additional information about farms that may be a good candidates for AD.

1.3 When is AD Not Applicable?

The use of AD technology is not applicable in all conditions as there are situations when other technologies may be a better choice. Composting, which is also a biological process, can effectively decompose or degrade organics. Composting may be more applicable with certain types of manure that are characterized as "dry," "stackable," or "high solids" material. This feedstock may have been allowed to "dry out" and/or contains considerable amounts of fibrous material, such as straw or hay. Manure with significant amounts of fibrous material is not easily digested when compared to manure in a liquid or slurry. Therefore, these materials may be more appropriately managed through composting. Composting is an aerobic process, meaning it is maintained under oxygen-rich conditions. When properly implemented, methane is not generated from composting. Composting inherently generates low amounts of thermal energy. Additionally, because composting has lower capital and operating costs when compared to an AD/biogas system, it may be a good alternative to AD/biogas systems for some types of drier organic material. Composting is also not effective for wet materials, such as dairy or hog manure; however, it is effective for managing separated solids (e.g., post digestion). Further comparison between AD/biogas systems and composting is illustrated in Figure 1.4.

One of most significant limitations of AD/biogas systems is the inability of those systems to efficiently break down or degrade lignin, a major component of wood. Thus, woody materials (trees, chipped wood, fibrous crop residues, leaves, etc.) cannot be readily biodegraded via AD. In cases in which these materials are to be converted into energy, advanced biological or fermentation processes or thermochemical technologies, such as combustion, pyrolysis, and/or gasification, may be required.

These conversion technologies are not discussed in this document; other sources should be consulted when dealing with these conditions.

Figure 1.4. General Comparison of Anaerobic Digestion and Composting[3]

Anaerobic Digestion	vs.	Composting
No Oxygen = Anaerobic Microorganisms break down organic matter in the absence of oxygen in an enclosed structure.		**With Oxygen = Aerobic** Microorganisms break down organic matter in a controlled, open-air setting.
GREENHOUSE GAS EMISSIONS		
Low Methane (CH_4) in biogas is captured and used to create energy. Carbon dioxide (CO_2) is also released but is a less potent GHG than CH_4.		**Low** Because properly managed composting is aerobic, CH_4 emissions are expected to be low or non-existent. CO_2 is the main byproduct of aerobic decomposition.
SOIL BENEFITS		
Digestate Is Rich in Nutrients Digestate increases nutrient availability for more efficient plant uptake and growth.		**Improves Soil Health** Composed waste can be used to regenerate poor soil and produce healthy microorganisms.
ENERGY PRODUCED		
Large Source Biogas produced from anaerobic digestion is a renewable energy source used to power homes, fuel vehicles, provide heating fuel, and meet other energy needs.		**Not a Source of Energy** There is no usable byproduct from composting that can be converted into an energy source.
ENVIRONMENTAL BENEFITS		
Sustainable Closed Loop Life Cycle Organic wastes are converted to biogas and nutrient rich digestate. For example, on a dairy farm, biogas can be converted to electricity to operate the farm and digestate can be used as bedding for animals or fertilizer.		**Sustainable Waste Reduction** Organic wastes and residuals are converted efficiently to beneficial products.
PROCESSING TIME		
Medium to Fast Depending on the anaerobic digestion technology, the process can occur in as few as several days to two or more months.		**Slow to Medium** Depending on the composting method, the process can take up to three or more months.

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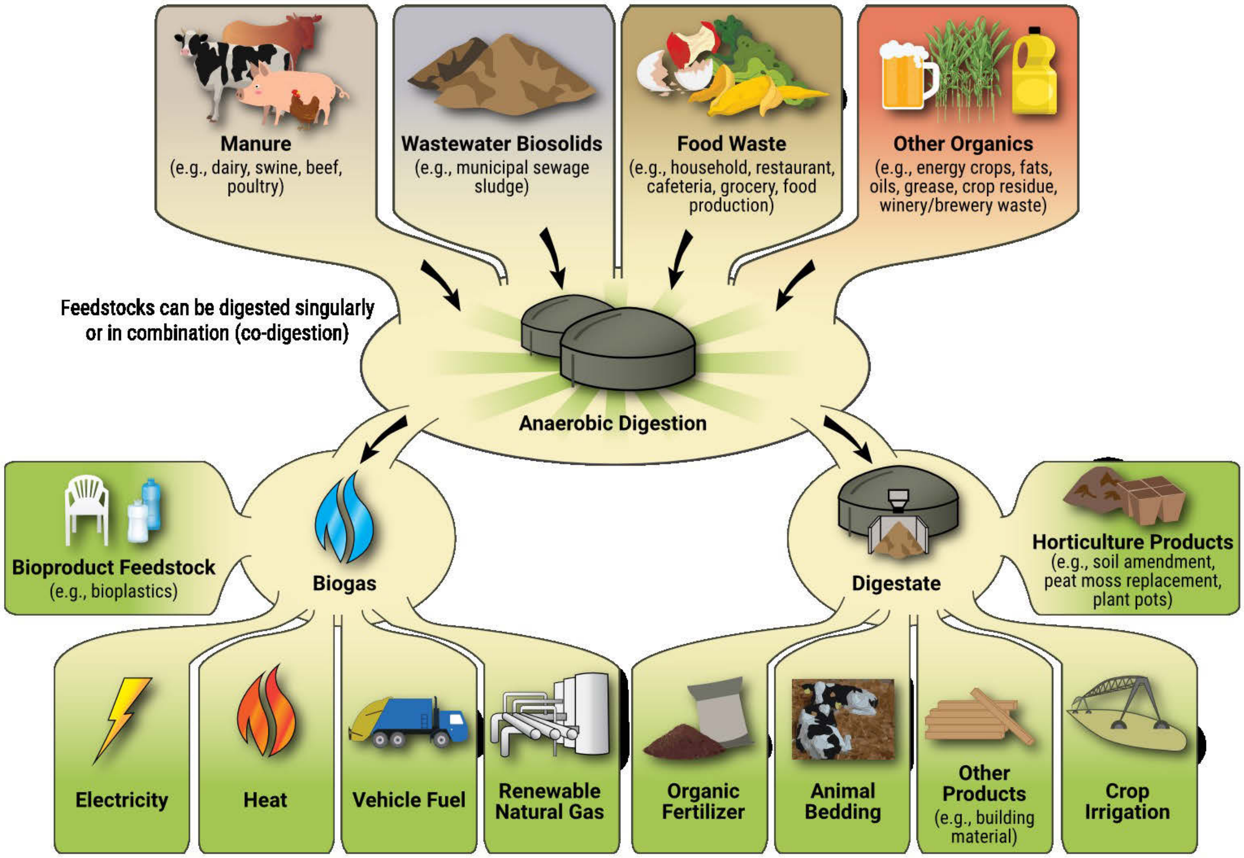
[3] Modified based on RENERGY's "Anaerobic Digestion Versus Composting" graphic.

2.0 Anaerobic Digestion Overview

2.1 What is AD?

The anaerobic digestion process occurs when microorganisms break down organic matter—such as animal manure and food wastes—in the absence of oxygen. Anaerobic digestion for biogas production takes place in a sealed vessel called a reactor, which is designed and constructed in various shapes and sizes specific to the site and feedstock conditions. These reactors contain complex microbial communities that break down (or digest) the waste and produce resultant biogas and digestate (the solid and liquid material end-products of the AD process) which is discharged from the digester. Figure 2.1 illustrates the flow of feedstocks through the AD system to produce biogas and digestate.

Figure 2.1. Basic AD/Biogas System Flow Diagram



2.2 Is AD a New Technology?

Anecdotal evidence suggests that AD/biogas systems have been utilized beginning over 3,000 years ago and operated commercially for more than 100 years. The process of generating methane (CH_4)

from organics was first documented by an Italian physicist, A. Voltas in 1776.[4] Between the 17th and 19th centuries, scientists further refined the relationship between the amount of decaying organic matter and the amount of CH_4 produced. The first commercial AD/biogas plant was built in Bombay, India in 1859. AD was subsequently used in England in 1895 when biogas was recovered from a "carefully designed" sewage treatment facility and used to fuel streetlamps for the first time.[5] More than 150 years later, the use of biogas has expanded significantly. Anecdotal reports suggest that there are more than 5 million operating AD/biogas systems in the world, albeit most on a single family home scale. Germany alone is estimated to have more than 8,000 commercial digesters.

2.3 How does AD Work?

When organic waste is biodegraded inside an anaerobic digester, methane-rich biogas and a stabilized digestate are produced. As shown in Figure 2.1, many organic materials can be used as a feedstock for AD processes.[6] Multiple organic materials can be combined in one digester, a practice called co-digestion. Co-digested materials include manure; food waste (i.e., processing, distribution and consumer generated materials); energy crops; crop residues; and fats, oils, and greases (FOG) from restaurant grease traps, and many other sources. Each organic material has individual chemical and physical properties that impact the digestibility of the material, biogas production, and biogas quality (methane content). The rate and amount of biogas produced from a given organic material is discussed in detail in Sections 3.0 and 4.0.

Biogas is composed of CH_4, which is the primary component of natural gas, at a relatively high percentage (50 to 75 percent), carbon dioxide (CO_2), hydrogen sulfide (H_2S), water vapor, and trace amounts of other gases. The energy in biogas can be used like natural gas to provide heat, generate electricity, and power cooling systems, among other uses. Biogas can also be purified by removing the inert or low-value constituents (CO_2, water, H_2S, etc.) to generate RNG. This can be sold and injected into the natural gas distribution system, compressed and used as vehicle fuel, or processed further to generate alternative transportation fuel, energy products, or other advanced biochemicals and bioproducts.

AD/biogas systems also generate an end-product, called digestate. Digestate is the residual material left after the digestion process. Digestate consists of both undigested inert material and water. As discussed above, some organic materials will not break down under anaerobic digestion. These undigested materials ultimately pass without being reduced and are present in the digestate. Digestible material that is not broken down may be due to a combination of several factors, including temperature, mixing, short circuiting, and/or insufficient retention. Inert material, such as lignin, sand, and grit, pass through the digester unimpacted by the process and are part of the digestate.

Digestate or digester effluent is composed of liquid and solid portions. These are often separated and handled independently, as each have value that can be realized with varying degrees of post

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[4] Bond T, Templeton MR. "History and Future of Domestic Biogas Plants in the Developing World." Energy for Sustainable Development, 2011, 15:347–54.

[5] "A Short History of Anaerobic Digestion," PennState Extension, September 14, 2012, https://extension.psu.edu/a-short-history-of-anaerobic-digestion.

[6] "Biogas: Reducing Emissions, Advancing Recovery and Use," Global Methane Initiative, https://www.globalmethane.org/documents/GMI_Biogoas_Factsheet.pdf (accessed March 2020).

processing. The solid portion is often referred to as fiber on farm-based systems. It can be referred to as “pressate” when derived from a press-type separator (e.g., screw press or belt press). The liquid portion is referred to as “centrate” (referring to liquids derived from a centrifuge). The solid, fiber portion may also include inert material, as discussed above. Much of the fiber is organic and may have a high lignin content, but it may also include undigested material. The portion consisting of lignin is not readily converted via AD/biogas systems, so the digestate may have a high organic content even after exiting the digester. It is for this reason that the fiber or "pressate" may require post processing (stabilizing of the solids), such as composting, prior to their end use.

With appropriate treatment, both the solid and liquid portions of digestate can be used in many beneficial applications, such as animal bedding (solids), nutrient-rich fertilizer (liquids and solids), a foundation material for bio-based products (e.g., bioplastics), organic-rich compost (solids), and/or simply as soil amendment (solids), the latter of which may include the farm spreading the digestate on the field as fertilizer. Digestate products can be a source of revenue or cost savings, and are often pursued to increase the financial and net-environmental benefit of an AD/biogas project. Beneficial digestate uses are discussed in Section 5.0.

2.4 What Are the Best Applications for AD?

Anaerobic digesters can generally be classified by their use in three markets: (1) agricultural or farm-based, (2) municipal systems, or (3) industrial/commercial systems. The following sections describe each of these applications. The benefits derived from each application vary but are generally similar and are summarized in this section.

2.4.1 Farm-Based AD/Biogas Systems

Farms use AD/biogas systems to better manage animal manure and may also co-digest other organic waste streams from off-farm that may be available to increase biogas production. Most AD/biogas systems can destroy pathogens present in manure, as well as reduce odor and GHG emissions. The benefits are described later in the document. Proper management of the solid and liquid digestate can have beneficial environmental effects as well. The amount, quality, and nature of the energy and digestate products will depend on feedstock composition, digestion method, and the extent of the pre- and post-treatment digester management. In comparison to other types of AD/biogas systems (e.g., municipal wastewater treatment plants), farm-based systems are significantly less regulated by EPA and state agencies.

2.4.2 Municipal AD/Biogas Systems

Digestion, either aerobic or anaerobic, is commonly used at municipal water resource recovery facilities (WRRF), which are also called wastewater treatment plants (WWTP).[7] The purpose of digestion in this treatment process is to “stabilize” the activated sludge and thus the resultant biosolids prior to their disposal or subsequent use. The type and temperature of digestion used will impact the degree of pathogen destruction and thus the quality of the treated sludge. As described in

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[7] “Water Resource Recovery Facility” also refers to Wastewater Treatment Facilities (also known as Publicly Owned Treatment Works or POTWs). The term “Water Resources Recovery Facility” acknowledges their ability to produce clean water, recover nutrients (such as phosphorus and nitrogen), and reduce dependence on fossil fuel through the production and use of renewable energy.

Section 3.4, there are three types of digestion as categorized by operating temperature. Note that treated sludge (digestate) from a municipal WRRF or WWTP is referred to as biosolids and is regulated by EPA. Digestate from an agricultural digester used to process manure is not considered biosolids.

There are two classes of biosolids defined by EPA regulations: Class A and Class B.

- Class A biosolids are acknowledged by EPA to contain no detectible levels of fecal coliform and salmonella as an indicator of the lack of pathogens being present in the Class A biosolids. Pathogens elimination, according to Federal regulations, allows for the safe return of the treated organic material to the land (as compost or fertilizer).
- Class B biosolids still contain some pathogens (but less than untreated animal manures, for example) and must be managed at sites with little public contact, in accordance with regulations. Converting biosolids to meet Class A standards may require additional processing beyond AD.

As with agricultural-based AD/biogas systems, co-digesting other organic waste streams that may be available with municipal solids is a viable means to increase biogas production. This is being done more frequently at municipal systems as an opportunity to capitalize on underutilized treatment capacity, create new revenue streams by receiving the material, and/or generating and using more biogas.

2.4.3 Industrial/Commercial AD/Biogas Systems

Organic waste products from industrial/commercial facilities, such as food processing plants or other industrial/commercial operations, can use AD/biogas systems as a primary and dedicated treatment operation. Also, merchant facilities that process organic material from community sources are becoming more common in the United States. These facilities often convert "high strength" organic materials into biogas and energy. Additionally, industrial and commercial operations, such as food processing facilities, may choose to pay a farm-operated digester a tipping fee, sometimes referred to a "tip fee" or "gate fee," to receive and manage its organic residual waste products instead of paying to treat them on site via a privately owned AD/biogas system, in a municipal WWTP, or land-applying it to farmland. In any case, AD/biogas systems are becoming more commonly used in the United States to generate biogas, capture methane, and convert it into energy and other products. Figure 2.2 shows images of commercial AD/biogas systems.

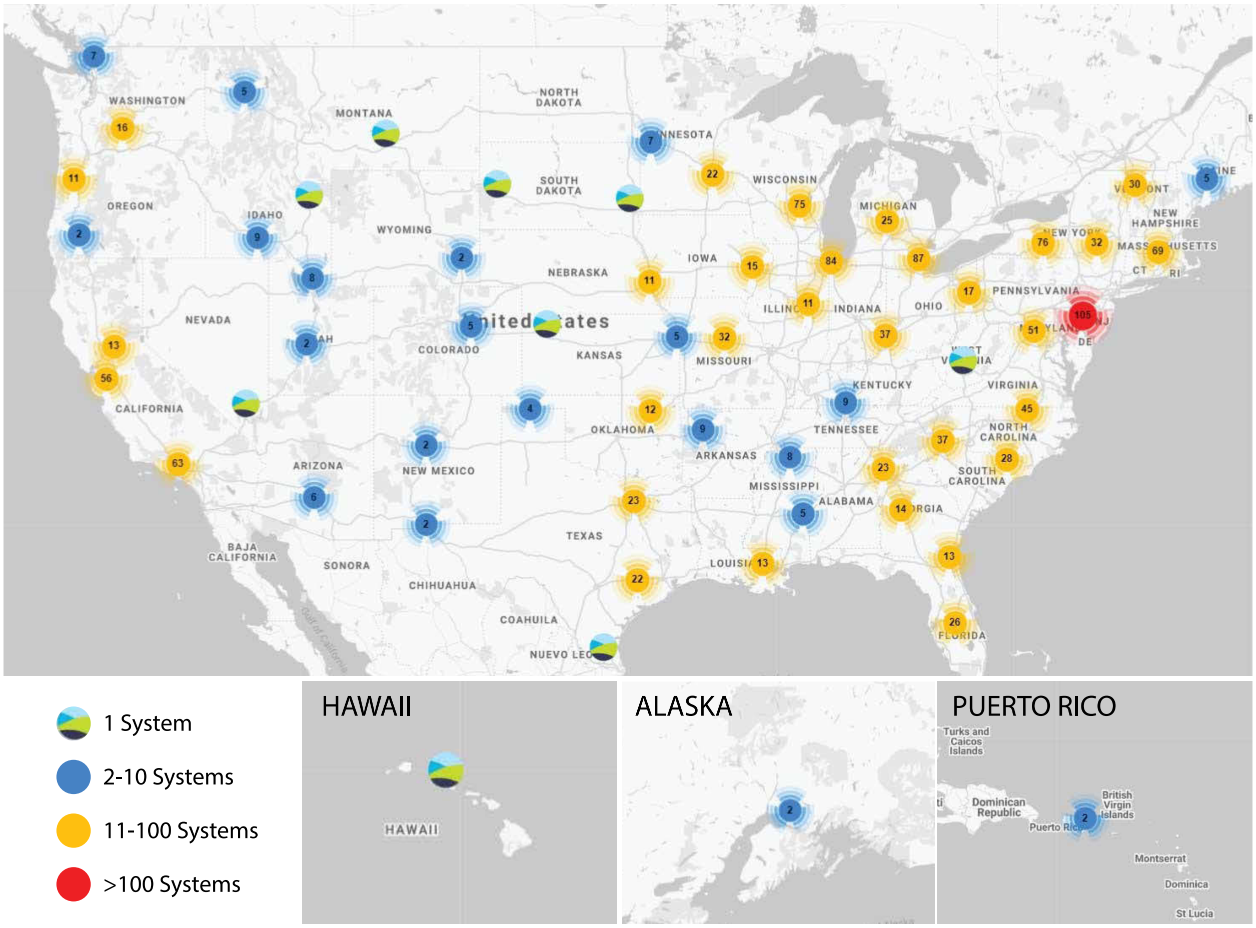
Figure 2.2. Various Commercial AD/Biogas Systems

2.5 Where and How Many Biogas Systems are in the United States?

There is an increasing number of biogas systems in the United States. Statistics and trends are frequently updated and documented on AgSTAR's Data and Trends web page and by the American Biogas Council (ABC). Figure 2.3 shows the locations of biogas systems operating or under construction in the United States.

Figure 2.3 includes landfills as biogas systems. Landfills are contained systems that can produce biogas under limited oxygen concentrations for collection and utilization. EPA defines landfills differently than AD/biogas systems. Landfills have been included here to demonstrate that they present an opportunity. Not all landfills capture methane, which is detrimental to the environment. Diverting organic waste from landfills to AD/biogas systems can have numerous benefits. These include, but are not limited to, more effective conversion of methane for beneficial use, reduction in GHG emissions, more effectively reducing waste by converting it into beneficial products, and creating soil compost and efficiently recycling nutrients.

Figure 2.3. Operational AD/Biogas Systems in the United States[8]



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[8] "Why Biogas?," American Biogas Council, April 26, 2018, https://americanbiogascouncil.org/wp-content/uploads/2019/05/ABC-Handout-2019apr-v4.pdf.

In addition to illustrating where biogas systems are located (as shown in Figure 2.3 above), the following provides a breakdown of how many biogas systems are active, how they are classified, and by whom:

- AgSTAR's Livestock Anaerobic Digester Database tracks farm-based AD systems. As of March 2020, there were approximately 288 documented digesters being used or under construction on livestock farms in the United States. This database is actively managed and is frequently updated. Most AD/biogas systems solely process animal manure, but some co-digest other agricultural residues and co-digestion waste products from off-site sources. Examples of co-digestion feedstocks being used in farm AD/biogas systems include agricultural residues, beverage and distillery wastes, dairy processing wastes, and food processing wastes. FOG feedstocks are also of keen interest because of their high biogas production potential. See Section 4.0 for additional information on digester feedstocks.
- As of 2019, more than 60 stand-alone AD projects are used in the United States to treat the food-based materials produced by food processors, commercial entities such as grocery distribution centers, and institutions like universities.[9] Many more industrial facilities in the United States use an AD system to pretreat their organic wastes prior to discharge. Instead of flaring, some facilities recover biogas for energy purposes. An exact number has not been tabulated; however, it is estimated that more than 600 AD systems may be currently operating at industrial facilities.
- As of 2016, about 1,250 municipal WRRFs in the United States have anaerobic digesters that treat wastewater treatment solids and produce biogas. The Water Environment Federation database tracks these plants. Many of them are exploring co-digestion with other feedstocks to increase biogas production and the amount of renewable energy they create, and therefore, their sustainability execution.
- As of 2019, about 630 municipal solid waste (MSW) landfills have landfill gas (LFG) systems that recover biogas from municipal solid wastes, according to EPA's LMOP. Approximately 10 landfills have also co-located separate AD systems on their sites.

Figure 2.4 shows the number, size, and location of the agricultural AD/biogas systems operating or under construction in the United States as of 2019. Of the systems operating on livestock farms, around 205 are used for the treatment of dairy cow manure.[10] There are approximately 44 digesters operating on swine farms, along with a handful of beef and poultry digesters. A few AD/biogas systems process more than one type of animal manure. The color and size of the circles indicates the type and number of animals that feed the digester at each project.

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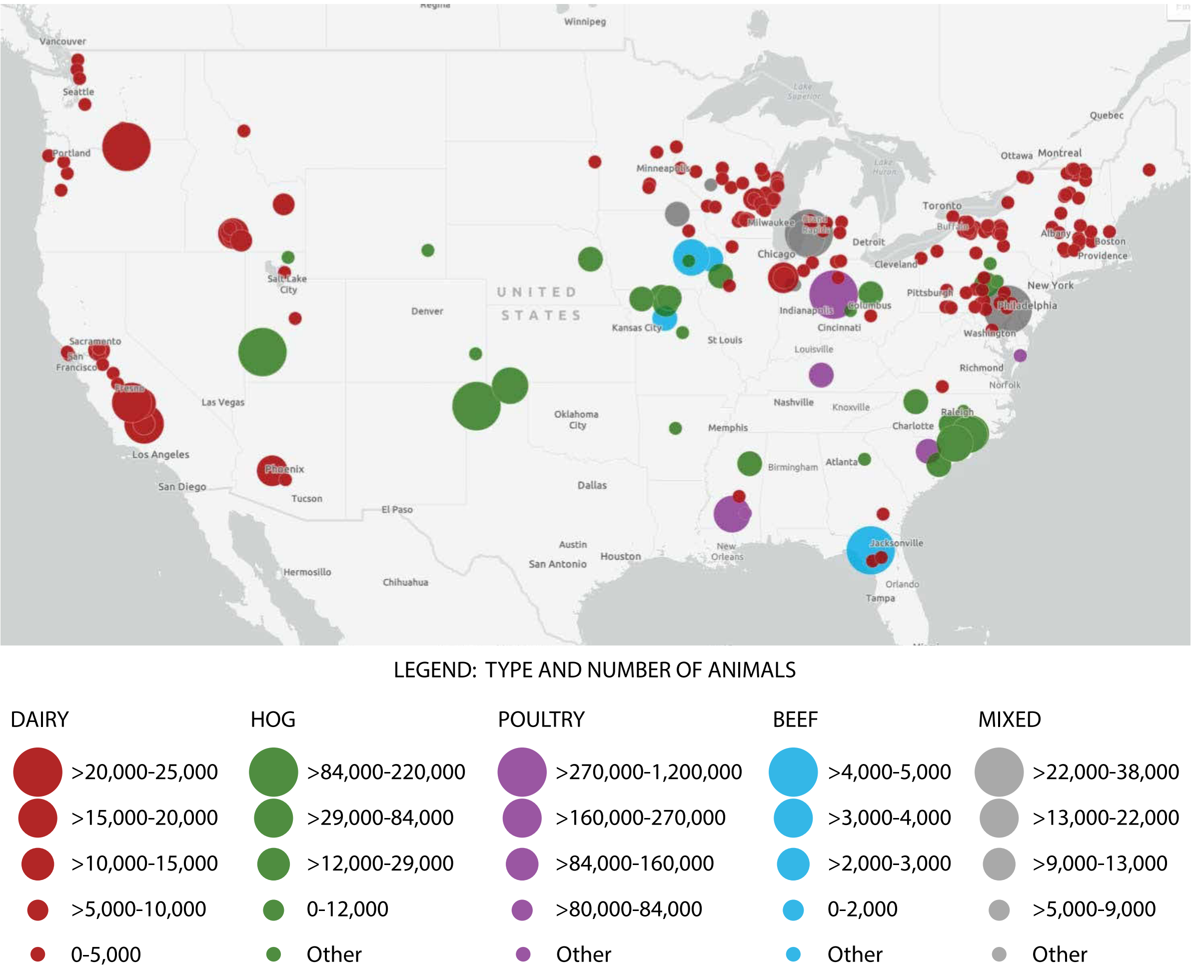
[9] Personal communication with Dennis Totzke, Applied Technologies, Inc., September 2018.

[10] EPA AgSTAR Program, Livestock Anaerobic Digester Database, https://www.epa.gov/agstar/livestock-anaerobic-digester-database (accessed March 2020).

Figure 2.4. Operational Farm-Based AD/Biogas Systems Operating in the U.S.



2.6 What Are the Benefits of AD?

Biogas recovery and utilization from AD systems often creates significant value in new economic, energy, environmental benefits by managing and converting organic waste into energy and beneficial uses of digestate. Unlike traditional organic waste disposal and manure storage systems, modern AD/biogas systems can be designed to increase and optimize the production of biogas and energy generation, among many other benefits. Benefits of AD/biogas systems include, but are not limited to, generation of various types of energy, including baseload renewable energy generation; odor minimization; generation of nutrient rich digestate; improving the environment by minimizing waste; among many others. The benefits of AD systems are summarized in Table 2.1 below.

Table 2.1. Benefits of AD/Biogas Systems[11]

Benefits	Outcome
Economic and Financial	New revenues from AD/biogas systems can significantly diversify farm income.
Environmental and Socio-Economic	Waste products that are considered a liability are converted into a beneficial resource. AD/biogas systems create circular use of materials such that waste products are recycled into beneficial use products.
Energy Generation	Biogas from digestion can be used to provide usable energy, such as thermal energy, electrical power, pipeline-quality natural gas, and/or RNG. Electrical power from biogas can be used as baseload and/or dispatchable power generation (i.e., generation of power at peak periods, as dictated by the utilities). These are two of several significant advantages over wind and solar renewable energy generation, which require energy storage to be added to meet these power demands.
Transportation Fuel	When RNG is used as a vehicle fuel, emissions meet the most stringent GHG pollution laws. For example, as defined by the State of California, RNG is the most carbon negative transportation fuel available.
Stabilized Digestate	Digestate can be used as a nutrient-rich fertilizer and as a soil amendment to improve soil health and crop production, both on farm and off farm.
Climate Change Mitigation	Emissions are reduced by capturing methane (CH_4) that may have been lost to the atmosphere and utilization of that CH_4 as a renewable fuel, offsetting the use of fossil fuels.
Overall General Benefits	The implementation of on farm AD/biogas systems increases overall sustainability, reduces pathogens, and improves overall efficiency of natural resources.
Bio-Products	The primary and secondary products of AD/biogas systems can be the foundation for renewable bio-based products, such as bio-based plastics. This is something no other renewable technology can provide.

2.6.1 Economic and Financial Benefits

There are several economic benefits generated from AD/biogas systems. New revenues can be created for the farm, thereby diversifying the farm business model. Several of these potential revenue streams are summarized below.

- New source of income by selling biogas-based renewable energy and the receipt of tipping fees for co-digestion feedstocks.
- New revenue can be derived from digestate-derived products. For example, new revenues may be created from the sale of treated digestate for use as animal bedding or as a peat moss replacement to increase soil quality. Nutrients present in the manure remain, but nitrogen and phosphorus are transformed from organic forms to inorganic or mineralized forms in the AD process. Inorganic or mineralized nutrients allow for increased plant availability (i.e., more easily absorbed through the roots of the plants for plant growth), which may minimize or offset the use of fertilizers. Further processing of digestate, including concentration of nutrients, allows for the potential of off farm sales. Maximizing co-product value increases farmers' resiliency from the uncertainty of commodity market price fluctuations.

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[11] American Biogas Council, Benefits of Biogas, https://americanbiogascouncil.org/resources/why-biogas/ (accessed March 2020).

- As farmers look to innovative ways to economically and environmentally manage their manure, AD/biogas systems also create new opportunities for rural economic growth. Constructing and operating digesters offers the opportunity to create new local jobs as do new value-added products, which require production and process facilities separate from the AD/biogas facility.

2.6.2 Environmental and Socio-Economic Benefits

There are numerous environmental and quality of life benefits that are summarized below.

1. AD/biogas systems convert waste products that are considered a liability into beneficial resources. This has profound and long-term environmental value. It also creates socio-political goodwill and enhances the foundation of sustainability measures. In addition to the WRRFs and landfills described above, many corporations involved in the food system supply chain utilize AD/biogas systems. For example, livestock and agricultural producers (e.g., Smithfield Foods, Inc., JBS, Inc., and Land O'Lakes, Inc.), and other industries, such as grocers (e.g., Kroger), food and beverage production (e.g., Kraft Heinz Company, Anheuser-Busch, Molson Coors, New Belgium Brewing), pulp and paper production,[12] and several other industries implement the use of AD/biogas systems.
2. Digestate can be post-processed and used as a soil amendment or organic fertilizer to increase crop yield and, through recycling the nutrients, offset heavy use of fossil fuels to manufacture or transport fertilizers from distal locations.
3. Healthy, good quality soil and clean water are important to farmers, their families, and the community. A clear majority of farms in the United States are family-owned and engage in active conservation practices to continue to pass this legacy from one generation to the next. Maintaining the health of the soil and protecting the water generates better products and protects the environment for everyone.
4. Digesters can help protect local land and water resources by reducing pathogen levels via the AD process.
5. In combination with certain post-processing technology, both the solids and liquid portion of the digestate can be used for fertilizer. As described in Section 5, depending on the post-processing and technology selected, nutrients such as nitrogen and phosphorus can be concentrated and used as fertilizer. In some cases, this can be certified as an organic product. Because of the biological processes in an AD/biogas system, the nutrients are in a more biologically available form that allows for improved plant uptake and conversion resulting in more efficient utilization of nutrients.
6. With additional post-processing, removing and transporting nutrients to where they are needed at optimal rates provides substantial environmental benefits.
7. If implemented properly, air quality improvements, including the reduction of methane, a precursor to ground-level ozone (criteria pollutant) and ammonia. Both have health impacts to sensitive populations, including those with asthma. While not regulated, reduction in odor

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[12] Zhang, A., Shen, J., and Ni, Y. “Anaerobic Digestion for use in the pulp and paper industry and other sectors: an introductory mini review." BioResources, 2015, 10(4), 8750-8769. https://bioresources.cnr.ncsu.edu/resources/anaerobic-digestion-for-use-in-the-pulp-and-paper-industry-and-other-sectors-an-introductory-mini-review/.

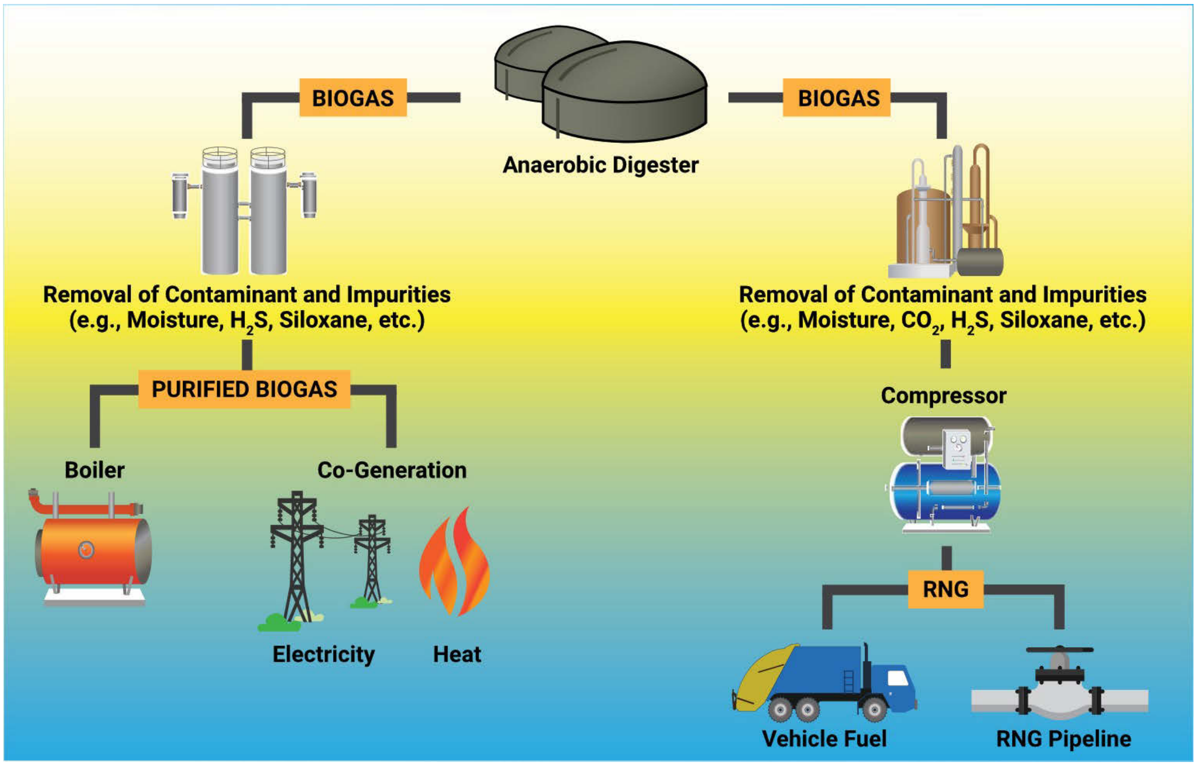
is a perceived benefit to air quality. This is certainly the case when housing or development encroaches on farming operations or fields where manure is spread. Both situations create contentious issues for the farming community. Thus, AD/biogas systems can have direct and indirect benefits to air quality.

2.6.3 Energy Generation Benefits

As summarized below and shown in Figure 2.5, there are several types of energy and resulting benefits that can be generated from biogas.

- Unlike other types of renewable energy generation (e.g., wind, solar), AD/biogas systems can generate many types of energy at “baseload.” These include thermal energy through direct burning, electrical power, a combination of both heat and power (CHP), and/or RNG.
- RNG can also be used for heating, operating engines that can power generators, pumps, and other equipment, and as an ingredient used to make fertilizer, antifreeze, plastics, pharmaceuticals, fabrics and a wide range of chemicals, such as ammonia, methanol, butane, ethane, propane, and acetic acid.
- On-farm energy independence can be achieved as many digesters can provide all on-farm energy needs. Biogas can be used in a variety of ways, and most digesters recover heat that can be used for warming. If electricity is generated, excess power can be provided to the local grid. This can help the local utility meet growing energy demand with locally sourced renewable energy and serves as distributed generation that reduces “line losses” for the entire system.

Figure 2.5. Energy Generation Options from AD/Biogas Systems[13]



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[13] Modified by Tetra Tech as of 2020.

2.6.4 Benefits over Other Forms of Renewable Energy

AD/biogas has benefits over other forms of renewable energy as summarized below.

- Unlike wind and solar, which generates energy only when the wind blows and the sun shines, AD/biogas generates "baseload" renewable energy generation. That means that biogas is generated around the clock ("24/7"). This is because livestock continuously provide feedstock and that feedstock is continuously treated. In winter months, there is less sun and therefore less solar energy is generated. Similarly, wind patterns vary on a daily and seasonable basis, thus solar and wind power generation produce an unpredictable energy supply. Both are challenges for the electricity grid stability. Conversely, biogas is continuously generated and therefore power is continuously generated.
- AD/biogas systems can also produce "dispatchable power," which is power that is generated when it is needed and during the periods when it is of highest value. This so-called "peak power" can be of great monetary value as the energy value can be significantly higher during peak versus off-peak periods based on several factors. When AD/biogas storage is planned, the biogas can be stored in low cost inflatable covers or cells and used when needed. While wind and solar can use batteries to store the energy, batteries of the size required for even small projects are not readily available and are very expensive, so this solution is not often implemented.

2.6.5 Transportation Fuel Benefits

AD/biogas systems are unique because the biogas produced is captured and can be further processed into RNG, which can be used for vehicle fuel in the form of CNG or LNG (see Figure 2.6). RNG is an increasingly common product generated from AD/biogas systems due in part to economic incentives such as the Renewable Fuels Standard (RFS) and LCFS, which is described is Sections 2.6.6, 6.3.4, and 6.3.5 (and in AgSTAR's RNG from Agricultural-Based AD/Biogas System web page). The biogas produced from AD/biogas systems is upgraded to remove most of the contaminants and majority of the carbon dioxide (CO_2) and other trace compounds found in biogas, which results in a biogas-derived, high-BTU (British thermal unit) gas that is predominately CH_4. RNG is sometimes referred to as "biomethane." RNG is biomethane that is upgraded to natural gas pipeline quality standards such that it may blend with, or substitute for, fossil natural gas. RNG is not a fossil fuel; it is a naturally occurring gas generated from decomposition of organic matter. When used as a vehicle fuel, RNG vapor emissions meet the most stringent international GHG pollution laws. Switching from fossil natural gas to RNG is easy and seamless, since no additional capital investment is required for CNG- or LNG-ready fleets.[14] See Sections 5.0 and 6.0 for more information.

RNG is a low-carbon alternative to fossil natural gas, and as such it can be used to also replace gasoline and diesel fuel.

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[14] Coalition for Renewable Gas, http://www.rngcoalition.com/ (accessed March 2020).

Figure 2.6. CNG from RNG Runs This Farm's 42-Rig Truck Fleet[15]

2.6.6 Climate Change Mitigation Benefits

There are numerous climate change benefits realized when biogas is captured and utilized.

- GHG emissions are reduced by capturing CH_4 that may otherwise have been lost to the atmosphere and by displacing fossil fuel energy use. Based on AgSTAR's Data and Trends web page, farm-based AD/biogas systems reduced GHG emissions by 4.63 million metric tons of CO_2 equivalent ($MMTCO_2e$) in 2019 by reducing on-farm direct GHG emissions and the emissions avoided by replacing fossil fuels. This is equivalent to the CO_2 emissions produced by over 1,000,000 passenger cars in one year, according to the EPA's Greenhouse Gas Equivalencies Calculator.[16] These digesters generated the equivalent of 1.28 million megawatt-hours (MWh) of electricity; enough to power more than 104,000 homes annually.
- Biogas derived from dairy and hog manure that is upgraded and used as CNG vehicle fuel has, by far, the lowest carbon footprint or carbon intensity (CI) of any transportation fuel. The CI is a measure of the carbon dioxide emissions per unit of energy produced. The lower the CI, the greater the environmental benefit. Numerous organizations, such as the Energy Information Administration (EIA) and the California Air Resources Board (CARB), quantify and track the CI of specific fuels and sectors; CARB's calculated CI for various fuels are shown in Figure 2.7. As this figure illustrates, the calculated CI range for different types of CNG is quite large due to significant variations in feedstock types, origin, past practices, raw material production processing efficiencies, and transportation distances. CNG vehicle fuel derived from livestock manure represents the lowest CI fuel currently available. In 2019, CARB determined that the CI

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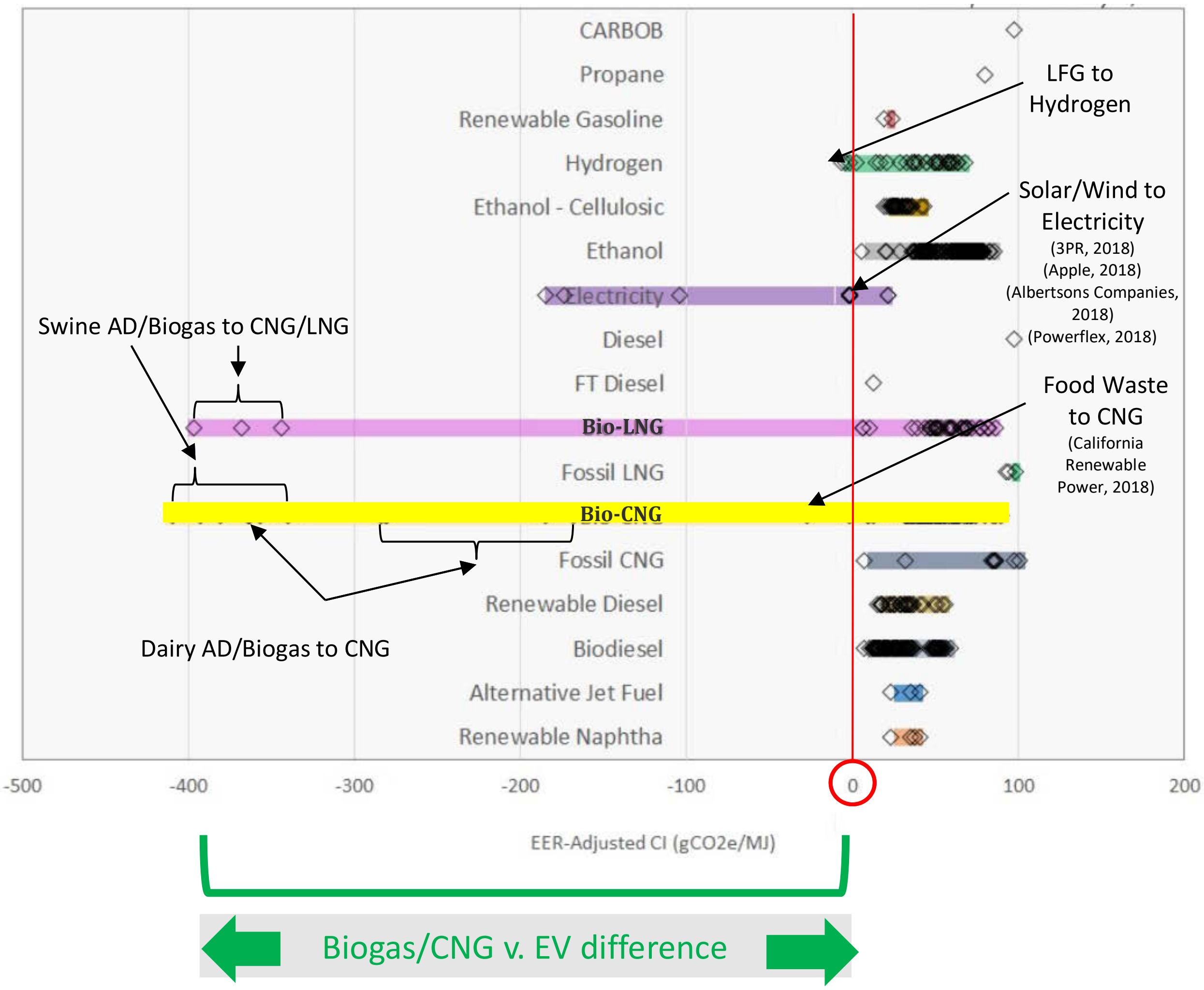
[15] "How A Huge Dairy Is Solving A Major Pollution Problem," Fortune, January 27, 2016, https://fortune.com/2016/01/27/fair-oaks-dairy-farm-manure-fuel/.

[16] EPA, Greenhouse Gas Equivalencies Calculator, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (accessed March 2020).

scores for specific swine AD/biogas system projects could be as low as -372 grams of carbon dioxide equivalent per megajoule (gCO2e/MJ) and for dairy AD/biogas projects as low as -272 gCO2e/MJ as illustrated in Figure 2.7. This figure illustrates several established CI scores. The number of established CI scores (as defined by CARB, shown in the footnote below) are rapidly increasing. CARB, and other State agencies, should be consulted for the most recent information as this is a rapidly changing market.

The CI of various fuels are shown in Figures 2.7 and 2.8. As illustrated in both figures, conventional fuels and nearly all renewable fuels, including ethanol and biodiesel, exhibit a positive CI score. Only AD/biogas derived fuels, and to a limited extent hydrogen-based fuels, have a negative carbon footprint. The negative carbon footprint of AD/biogas is a substantial benefit over most other transportation fuels. Figure 2.7 illustrates the range in difference of CI between AD/biogas-derived transportation fuel and electric vehicles (EV), according to CARB.

Figure 2.7. Relative Carbon Intensity of Transportation Fuels - CARB[17]



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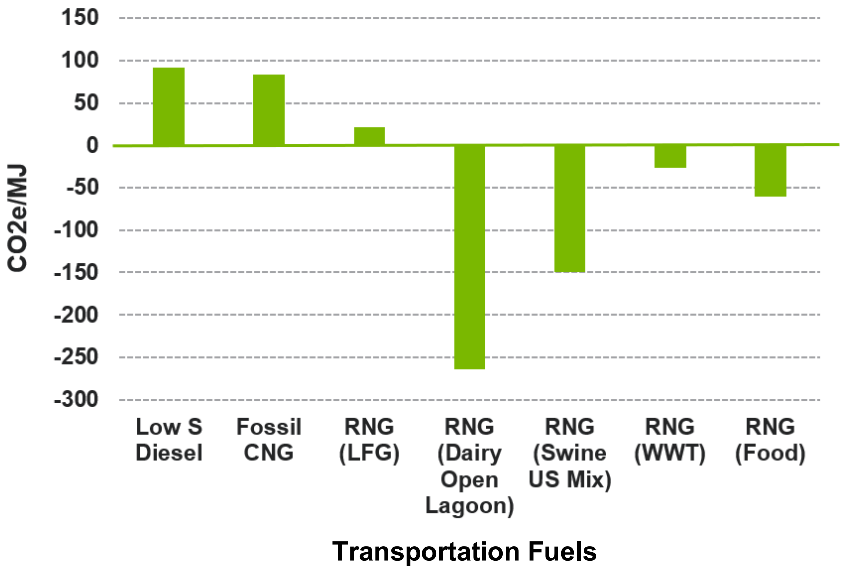
[17] Modified by Tetra Tech as of 2020 based on the California Air Resources Board's "LCFS Pathway Certified Carbon Intensities," https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities (accessed February 2020).

The U.S. Department of Energy (DOE) Argonne National Laboratory also illustrates that many pathways using the GREET Model exhibit negative GHG emissions (Figure 2.8). The CI is particularly low for typically otherwise high GHG-emitting reference cases from livestock waste. Depending on the feedstock source, RNG can dramatically lower GHG emissions.

Figure 2.8. Relative CI of Transportation Fuels – DOE Argonne National Lab[18]



2.7 What is the Potential for Implementing More AD/Biogas Systems?

In addition to the digesters already in operation, AgSTAR estimates that AD/biogas systems are feasible on more than 8,100 dairy and swine farms with characteristics for profitable biogas recovery systems. By using or selling the energy and digester co-products, farms and other facilities can turn organic waste into an opportunity for reducing costs, making profits, and enhancing environmental stewardship.

2.8 What Are Common Challenges of AD/Biogas Systems?

AD/biogas systems can be more complex to operate when compared to other more common renewable energy sources, such as wind and solar. The complexity of AD/biogas systems is dependent upon several factors, but if developed, executed, and operated with experienced professionals, these complexities are mitigated and overcome.

AgSTAR resources such as this PDH and the AD/Biogas System Operator Guidebook (under development) were collectively prepared to address and mitigate many of these challenges and improve the successful development, implementation, and operation of AD/biogas systems.

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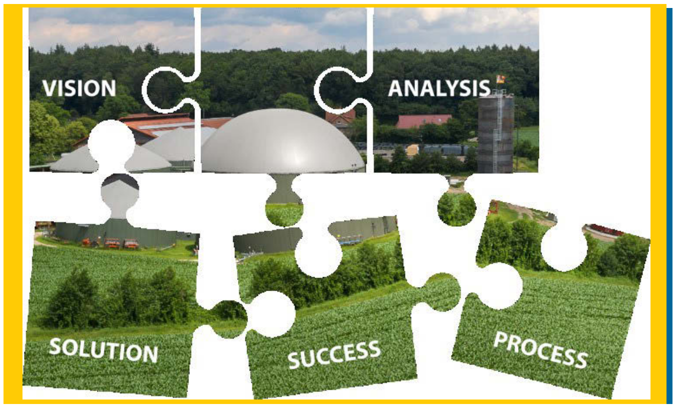
[18] U.S. DOE Argonne National Lab, GREET Model, https://greet.es.anl.gov/greet.models.

Personal communication with Marianne Mintz, U.S. DOE Argonne National Lab, November 2019.



While an AD/biogas project can be complex as compared to wind and solar, the benefits far outweigh those of other sources of renewable energy. If developed, executed, and operated with experienced professionals, these complexities can be mitigated, yielding long-term successful project execution and profitability.

There are several critical project parameters that need to be defined early in the process to ensure a successful project (as outlined in Section 1.1, "Keys to a Successful AD/Biogas System."

While there are around 255 farm-based digesters operating in the United States as of March 2020, many farm-based digesters have failed since the first one was installed in the early-1970's. The reliability of the digesters constructed since 1984 is far better than that of digesters constructed during the period 1972-1984, which is generally due to better controls and simplified digester designs that also help to reduce operating expenses.

While there are no published statistics on the primary reason(s) for digester failure, anecdotally there are several key items that most commonly arise. The list is largely led by inadequate design, inadequate installation, or application of an inappropriate technology at a given project. Failed projects result from many factors, including:

- Inappropriate application of a technology for the feedstocks or end products;
- Inadequate designs;
- Inexperience of the practitioner;
- A lack of understanding of basic process fundamentals;
- Underestimated maintenance requirements;
- Overestimated performance and uptime;
- Inadequate operator training;
- De-prioritization of operation and maintenance activities; and
- Inadequate operations, logistics, and financial planning.

AD/biogas systems represent a significant investment and should be approached in the same manner as one would any other major capital project. Often, however, the implementer or the owner is not properly trained to understand project complexities. This lack of understanding translates to challenges, and often failures.

Some specific challenges faced by AD/biogas system developers or project hosts include:

- High cost – AD/biogas systems are expensive and often cost-prohibitive. Therefore, it is very important to define the full economic benefit of each and all aspects or components of a project.
- Long economic returns compared to conventional generation.
- Long project development periods (i.e., it often takes years from development to operation of AD/biogas systems).
- Relatively over-sophisticated technology application to a very simple project parameter.
- Inappropriate application of a "one-size fits all technology" to a unique problem.
- Inadequate feedstock and off-take agreement negotiation.
- Inadequate estimate of operation and maintenance costs.

2.9 How to Overcome the Common Challenges of AD/Biogas Systems?

The factors common to nearly all successful projects are outlined in the "Keys to a Successful AD/Biogas System" (Section 1.1). To create a foundation for a successful project, it is very important to define realistic project goals, assemble a competent qualified team, adequately match the digester type to the farm's operation and manure management program, define a competent design and installation, and maximize co-product use to enhance economic merit. Overall, working with an on-farm project champion with willingness and leadership to incorporate a new technology into the farm operation is the most important ingredient to overcoming common challenges and achieving a successful project.

Warning:
Avoid Developing an AD/Biogas Project on Assumptions

Never make decisions based on inadequately supported assumptions. Consult an objective professional resource during the decision-making process. Incorrect assumptions can set back projects, leading to technical problems, cost overruns, and even project failure. By making decisions based on an impartial view of the facts, your project will have a better chance of success.

3.0 Process Fundamentals

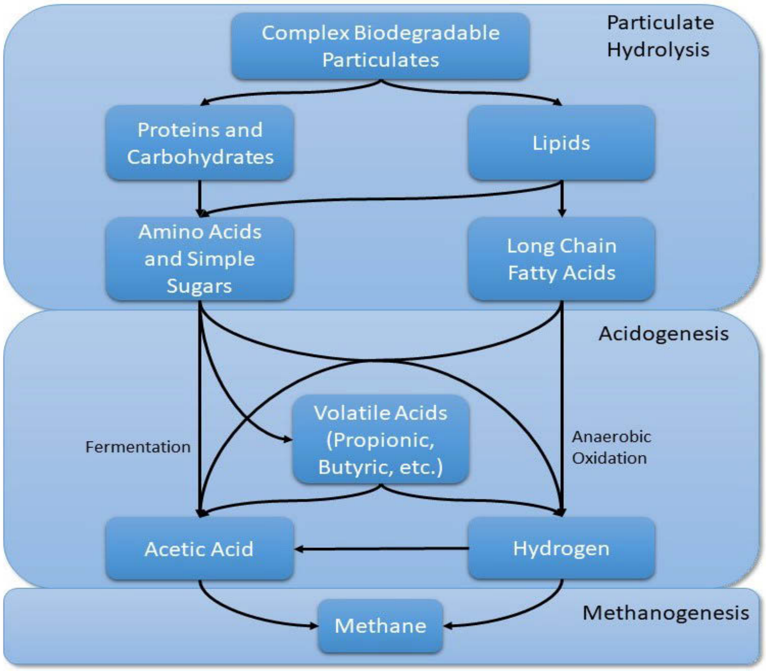
3.1 The AD Process

In nature, microorganisms degrade all organic matter, recycling its elements—including carbon, hydrogen (H_2), oxygen (O_2), and N—for reuse in new growth. There are two primary mechanisms to biologically convert organic matter into more simplistic forms.

- If O_2 is present, matter is degraded by oxidation, leaving CO_2 and water as the main end products. Oxidation reactions occur under what is referred to as aerobic conditions.
- In an O_2-free environment, matter is degraded by reduction, and CH_4 and CO_2 are created as the main end products. Reduction reactions occur under what is referred to as anaerobic conditions.

Anaerobic degradation is a well-documented process where a series of biological processes occur among three groups of microorganisms. Specifically, three stages (hydrolysis/liquefaction, acidogenesis, and methanogenesis) are required for anaerobic degradation to occur. The first group of microorganisms secrete enzymes which hydrolyze polymeric materials to monomers, such as glucose and amino acids (complex carbohydrates are broken down into simpler compounds; for example, starches are converted to simple sugars). These compounds are subsequently converted by a second group of microorganisms, containing acidogenic and acetogenic bacteria, to CO_2, H_2, volatile fatty acids, and ultimately acetic acid. Finally, methanogenic organisms (archaea) convert the H_2, CO_2, and acetic acid into CH_4 and CO_2.

Figure 3.1. The Anaerobic Degradation Process



The anaerobic degradation process includes three fundamental steps as described below and shown in Figure 3.1:

1. **Hydrolysis.** Anaerobic bacteria transform organic matter into less complex soluble compounds. The bacteria break down proteins and carbohydrates into amino acids and simple sugars and reduce lipids to fatty acids.
2. **Acidogenesis.** In a combination of fermentation and anaerobic oxidation reactions, acidogenic bacteria convert amino acids, simple sugars, and lipids to acetic acid, CO_2, and H_2 (fermentation and acidogenesis occur simultaneously, but different microbial populations are involved).
3. **Methanogenesis.** Methanogenic archaea convert acetic acid, CO_2, and H_2 into CH_4 and CO_2; a combination of gases known as biogas.

The following further describes the process of anaerobic digestion.

- For organic wastes to be treated or reduced effectively under anaerobic conditions, the acidogenic and methanogenic microbial populations must be in a state of equilibrium. Methanogenic populations work and grow slower than the remaining microbial community, and if too much food is fed to the digester too quickly, the populations will grow out of proportion and CH_4 formation will slow or cease. If this happens, digester feeding must be stopped until the CH_4 formation returns to a state of equilibrium (i.e., normal or stabilized).
- In organic residues, much of the nitrogen is bound up in proteins and is not readily available to plants without undergoing biological conversion. During the digestion process, organic-bound nitrogen is reduced to ammonium (NH_4) when dissolved in water. Quite simply, during the digestion process, bacterial degradation of organic materials results in the release of ammonia (NH_3). High NH_3 concentrations can inhibit methanogen growth and decrease biogas production. Livestock and poultry manures contain a lot of nitrogen and phosphorus, so ammonium and inorganic phosphorus compounds may accumulate.
- When sulfur-containing organic wastes are anaerobically digested, the sulfur is reduced to hydrogen sulfide (H_2S), which is a gas that smells like rotten eggs and is common in anaerobic waste processes. Hydrogen sulfide is highly toxic and corrosive to many materials, which affects the ways in which biogas can be used (this is discussed further in Section 4.0).
- Anaerobic decomposition occurs at a wide range of temperatures, but occurs most rapidly and efficiently at higher temperatures. Because conversion is quicker at higher temperatures, the digester's reactor can be smaller.
- Biogas is primarily CH_4 and CO_2, but may also contain small amounts of water vapor, H_2S, siloxanes, and other compounds. The ultimate biogas yield and its CH_4 concentration depends on the feedstock's composition and biodegradability. The biogas production rate will depend on the population of microorganisms, their growth conditions, temperature, and the presence of any toxic chemicals or contaminants that will inhibit the process. Depending on the organic wastes, substrates with a lot of highly oxygenated chemical compounds (e.g., sugar) will produce biogas with less CH_4 and more CO_2, due to the need to dispose of excess O_2 in the methanogenic phase.[19]

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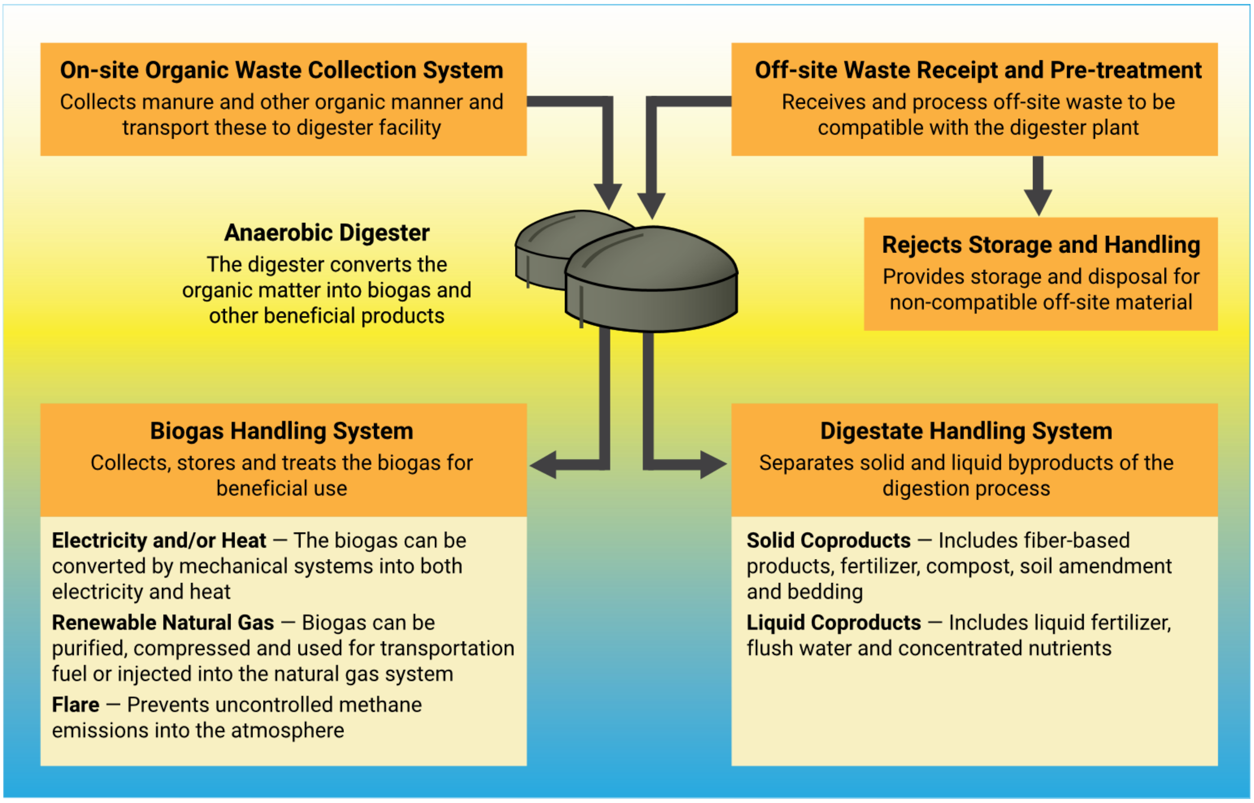
[19] Enzmann, F., Mayer, F., Rother, M., & Holtmann, D. "Methanogens: Biochemical Background and Biotechnological Applications." AMB Express, 2018, 8(1), 1. https://doi.org/10.1186/s13568-017-0531-x.

3.2 AD/Biogas System Process Components

There are several process steps that can be used alone or in combination to treat and manage manure. Figure 3.2 demonstrates a flowchart of the main components of an AD/biogas system.

Figure 3.2. AD and Biogas System Flowchart[20]



On-site Organic Waste Collection System
Collects manure and other organic manner and transport these to digester facility

Off-site Waste Receipt and Pre-treatment
Receives and process off-site waste to be compatible with the digester plant

Anaerobic Digester
The digester converts the organic matter into biogas and other beneficial products

Rejects Storage and Handling
Provides storage and disposal for non-compatible off-site material

Biogas Handling System
Collects, stores and treats the biogas for beneficial use

Electricity and/or Heat — The biogas can be converted by mechanical systems into both electricity and heat

Renewable Natural Gas — Biogas can be purified, compressed and used for transportation fuel or injected into the natural gas system

Flare — Prevents uncontrolled methane emissions into the atmosphere

Digestate Handling System
Separates solid and liquid byproducts of the digestion process

Solid Coproducts — Includes fiber-based products, fertilizer, compost, soil amendment and bedding

Liquid Coproducts — Includes liquid fertilizer, flush water and concentrated nutrients

The AD/biogas system components are described below:

- **Organics collection.** Manure is collected and placed in a centralized location. Co-digestion feedstocks, such as food processing waste and food scraps, are delivered to the facility where it is prepared for processing (this is further discussed in Section 4.3.1).

  The type of manure collection used dictates the physical and chemical manure conditions and generally dictates the type of AD system that is most appropriate for a given farm. Manure collected by flushing the pen or lane with water results in a feedstock having a lower total solids (TS) concentration. Manure collected quickly after excretion using a scrape or vacuum system produces a feedstock having a higher TS and volatile solids (VS) concentration. Volatile solids are the organic fraction of the total solids. If the manure is not collected quickly, the manure rapidly begins to break down aerobically resulting in lower VS. More information on waste collection is available in Chapter 10 of the NRCS Part 651 Agricultural Waste Management Field Handbook.

- **Waste handling.** Depending on the type of feedstock and the type of digester, pretreatment may be required. Pretreatment steps may include:

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[20] Modified based on the EPA AgSTAR Program's "Elements of a Biogas Recovery System" graphic.

  - **Size reduction:** Depending on the type of AD/biogas system, the incoming feedstock may need to undergo size reduction. This is usually the case with continuously mixed low solid systems requiring a homogenized feedstock that is easily pumpable and mixed into the reactor.
  - **Contamination removal:** Depending on the feedstock's source, contaminants such as sand or packaging can show up at the facility**.** Prior to digestion, they need to be removed because they can disrupt the AD system over time. There are many available preprocessing options that can remove sand (sand separators, hydro-cyclones, or sand settling lanes), plastic bags, and other non-digestible materials (trommel screens or hydro-pulpers). Materials separated as contaminants are usually sent for disposal at a landfill.
  - **Equilibration and Storage:** The final blended feedstock is temporarily stored before being introduced into the reactor. Storage prior to digestion equilibrates and homogenizes the material and evens out fluctuations in the amount and other characteristics of the feedstock. Depending on the size and temperature of the equalization and storage vessel, hydrolysis and acidogenesis can begin leading to significant odors.

- **Anaerobic Digester.** Once the feedstock is collected and prepared, it is introduced to the anaerobic digester, which is sometimes referred to as an anaerobic reactor. Given the specific type of manure collection system, the digester is designed to provide the optimal conditions for the anaerobic microorganisms to complete their symbiotic biochemical reactions to convert the organic waste into biogas (see the digester example shown in Figure 3.3 below).

Figure 3.3. Picture of an Anaerobic Digester[21]

The anaerobic digester is designed to capture and recover the biogas. There are numerous digester types, including ambient temperature covered anaerobic lagoons and medium and high temperature digesters which can be steel or concrete tanks. The various types of systems are described in Section 3.4.

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[21] "EPA Gathers Information On Digestion Facilities In U.S." Anaerobic Digest, BioCycle, February 2017, https://www.biocycle.net/2017/02/14/anaerobic-digest-70/.

- **Biogas storage and processing.** As the biogas is recovered, temporary storage may be needed to help balance production with demand, utilization system capacity, and/or end user needs. Often storage is accommodated within the reactor itself in the freeboard space between the material being digested and the reactor's cover, which typically is a flexible membrane. If needed, flexible bladders and storage tanks can be used for medium- to long-term biogas storage. Depending on the digestion process and feedstocks converted, the concentration of CH_4 to biogas may range between 50 and 75 percent. The remaining composition is primarily CO_2, with trace quantities of corrosive H_2S (concentrations up to 15,000 parts per million [ppm], ranging more frequently from 2,000 to 8,000 ppm), water vapor, and other trace compounds. The first biogas processing step is to remove the moisture. Warm biogas cools as it travels through the piping, and the water vapor in the biogas condenses and is removed in a water trap. The next processing step is to remove H_2S. For electricity generation, the biogas may or may not be additionally cleaned or conditioned, depending on the type of energy recovery unit installed. When biogas is going to be used as a vehicle fuel or sold to a natural gas pipeline operator, further processing to remove CO_2 and other impurities is necessary.
- **Biogas use.** Raw biogas has a heating value ranging from approximately 500 to 650 Btu per cubic foot depending on its CO_2 content. The CH_4 in biogas is identical to the CH_4 in fossil natural gas. It can be used for electricity generation, serve as fuel for a boiler, hot air furnace, refrigeration equipment, or be burned directly as a cooking and vehicle fuel (more information on biogas use is presented in Section 5.1). An example of equipment for utilizing biogas from an anaerobic digester is an internal combustion engine and generator. Raw or partially treated biogas is mixed with air and combusted in an engine-generator set to produce mechanical energy, which then generates electricity. This is often combined with waste heat recovery equipment to from a CHP system.
- **Coproduct separation, treatment, and storage.** Digestate, also recovered in addition to the biogas, has several uses. All manures produce recoverable solid fiber that may be used as animal bedding, as a soil amendment, a primary constituent in potting soils, or bio-based products (e.g., bioplastics). Often, solids in the digestate are removed with a mechanical separation system like a screen or a screw press before land application. Depending on the type of system and the type of feedstock, the digestate can be liquid/slurry or less commonly a stackable material that looks like compost. In some regions, the digestate or treated filtrate requires long-term storage because the nutrients cannot be applied to cropland year-round. The digestate requires storage and may need additional processing prior to its use or sale. Solid digestate from dry fermentation digester systems is often composted to make soil amendment products. The material can be sized and formed into dense blocks, pellets, or remain in bulk and shipped easily. There are a lot of uses for this material as a soil amendment, which is commonly desired by agricultural or commercial areas that have nutrient and/or organic deficient soil. After the fiber is removed, a liquid organic effluent remains. This effluent commonly has combined nitrogen, phosphorus, and potassium concentration ranging from 2 to 6 percent (most commonly from 3.0 to 4.5 percent) on a dry matter basis and can be spread directly onto farmland for its fertilizer nutrient value. The liquid portion can be further refined using numerous post processing technologies resulting in a nutrient concentrated fertilizer product.
- Post processing technologies and uses of post digested materials are addressed in greater detail in Section 5.0 and in Newtrient's Technology Catalog.

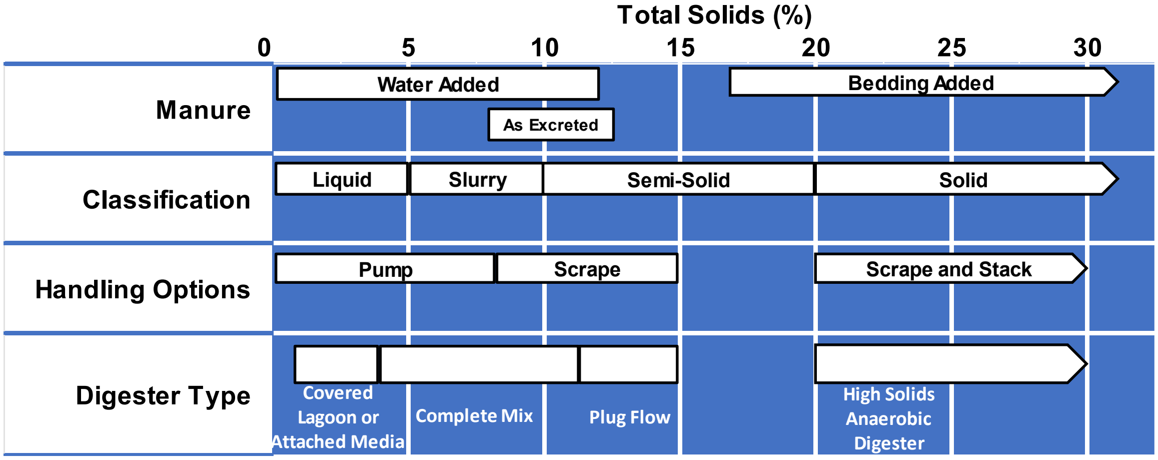
3.3 AD Process Design Parameters

Anaerobic digesters come in a wide range of configurations and sizes—from small household digesters used in developing countries for cooking and heating, to commercial digesters treating the municipal wastewaters of large cities at a WRRF. There are many factors that must be considered when designing an AD/biogas system.

The following section provides a summary of several of key parameters to consider in designing an AD/biogas system. Individual parameters can be impacted and influenced by other parameters and are often highly site-specific. Therefore, ***it is important to note that the values and ranges provided are not absolute or finite***. This section is not intended to take the place of a site-specific design document. An objective, qualified professional should be consulted when designing a site-specific project.

- **Feedstock moisture content or TS.** TS is measured as a percentage and is often referred to as percent TS. Figure 3.4 shows how dairy manure characteristics such as TS relate to the best options for manure handling and the related digester type.
    - ***> 3-5%*** - Feedstocks having a TS content of less than 3 to 5 percent, have traditionally been considered as a general "rule of thumb" to use a covered lagoon as the most suitable type of anaerobic digester system. However, an upflow anaerobic sludge blanket/induced blanket reactor, or a fixed film reactor may also be suitable for treating low TS feedstocks.
    - ***5 to 13%*** - Feedstocks having a TS content of between 5 and 12 percent generally use a complete mix digester.
    - ***12 to 15%*** - Feedstocks with a TS content between 12 and 15 percent generally use a plug-flow digester.
    - ***>20%-*** For feedstocks with a TS content greater than 20 percent, batch digestion in an airtight container is an option. Feedstock with a TS above this value are often referred to as high solids anaerobic digestion (HSAD). Another option is blending in another feedstock with a lower TS concentration for effective digestion in a complete mix system.

Figure 3.4. How Total Solids Impact Technology Choice for Dairy Manure[22]



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[22] Modified from 2004 AgSTAR Handbook. This graphic is for general illustration purposes only and is not intended to provide absolute or finite values or ranges, and it is not intended to take the place of a site-specific design. An objective, qualified professional should be consulted prior to a site-specific implementation.

- **Manure Collection and Recovery**. The method and how quickly manure is collected once generated is directly related to biogas potential. The manure characteristics (e.g., physical characteristics, volume) will change depending on the manure collection and recovery method employed on the farm. There are several types of manure collection. On dairy farms, for example, manure can be moved using water, scraped (either via auto mechanical scraper mechanically or by driven machine), or by vacuum truck. A flush system involves flushing animal pens or lanes with water. In this case, the manure is moved with the pressure of water into a pit or holding tank. Adding water dilutes the manure and increases its volume which, in turn, impacts biogas production and the volume of digester capacity required. Conversely, manure that is recovered using a scrape system or vacuum does so with no added water, and therefore the manure characteristics do not change as significantly. The percentage of manure recovered will furthermore change based on the manure recovery method. As manure sits (e.g., dries in the sun, remains in an open pit/lagoon), VS is emitted. Therefore, it is critical to recover manure as rapidly as reasonably possible to maximize the amount of VS converted to biogas production. It is for this reason that manure from open, dry corral lots has inherently lower VS (hence lower biogas production) than collection of freshly excreted manure from vacuum scrape farms. All of these factors are necessary in order to understand the manure characteristics, and therefore the technology selection and biogas production projection.
- **Operating temperature range**. While methanogenesis is reported to occur over a broad temperature range, there are three operating temperature ranges known for effective AD as defined by Speece (1996).
    - ***Psychrophilic or Ambient temperature*** - digesters operating at the lowest temperatures, generally with only environmental heating (solar) and no external heating, operate at temperatures less than 20 degrees Celsius (°C) (68 degrees Fahrenheit [°F]). Note that the lower effective digestion temperature is about 10 °C (50 °F).
    - ***Mesophilic or Medium temperature*** - digesters heated to operate at a temperature ranging from 30 °C to 40 °C (86 °F to 104 °F). A narrower range from 30 °C to 37 °C (86 °F to 96 ° F) is most common with a desirable economic tradeoff to operate at lower temperatures with longer contact or retention time (Speece, 1996, p 60.), as described further below.
    - ***Thermophilic or High temperature*** - digesters heated to high temperatures often considered to be approximately 50 °C to 65 °C (122 °F to 149 °F) (Speece, 1996, p. 79). A narrower range from 50 °C to 60 °C (122 °F to 140 °F) is most common.

  Overall and within specific operating ranges, higher digester temperatures mean faster waste breakdown, and lower temperatures may mean a longer retention time for effective degradation (see retention time discussed in the section below). Thermophilic digestion produces the greatest pathogen-reducing effect (PRE) as compared to mesophilic digestion. Further, mesophilic digestion has a greater PRE as compared to lower temperature psychrophilic digestion.
- **Hydraulic Retention Time (HRT)**. The HRT is the time needed to digest or stabilize the waste to the degree desired. Usually, an anaerobic digester has an HRT designed to optimize biogas production. Longer HRTs may provide additional biogas and a more stabilized digestate, but the additional digester treatment volume required to retain the material longer increases project cost.

- **Digester volume**. The design digester volume is a function of the daily volume of waste to be digested and the design HRT. For livestock manure, daily manure production can be estimated from estimates published in Chapter 4 of the Agriculture Waste Management Field Handbook published by the NRCS.
- **Number of stages**. Most common is a single-stage AD process where hydrolysis, acidogenesis, and methanogenesis occur simultaneously in a single reactor. In a two-stage AD process, two reactors are used in series to separate hydrolysis and acidogenesis from the methanogenesis step. For some wastes, two-stage anaerobic digestion can increase process stability, although usually at a higher capital and operating cost.
- **Biogas yield**. The biogas yield per unit of digester feedstock for the digester's HRT is important because the biogas yield significantly contributes to the project's ability to generate revenue.

3.4 What Types of Anaerobic Digesters are There?

There are many different digester types and the most common are summarized below. There are many commercial variations of the standard types, and the purpose of this section is to illustrate the different digester types, not to discuss the commercial and proprietary variations. Commercial variations often attempt to take advantage of two general digester types and create a hybrid of both. To learn more about the farm-based digestion systems now being used (location, animal populations feeding the digesters, biogas use, system developers, and more), visit AgSTAR's Livestock Anaerobic Digester Database. Note that the actual operations of each digester type may differ due to regional or site-specific considerations.

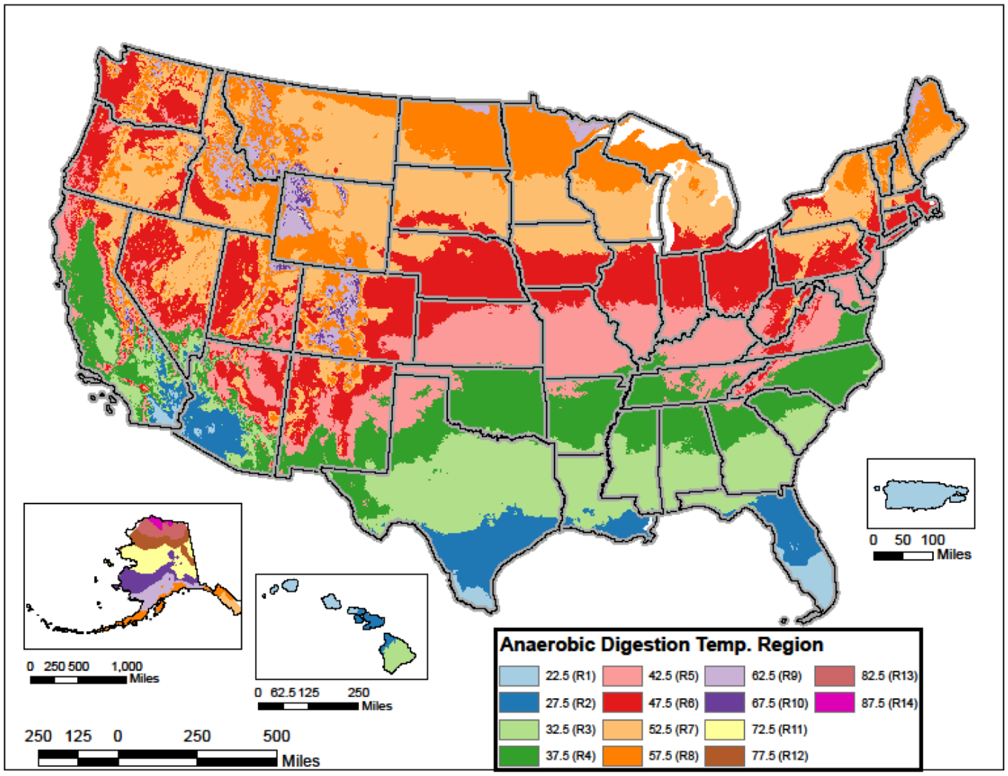
3.4.1 Covered Anaerobic Lagoon Digester

Covered anaerobic lagoons use woven geotextile fabrics to line or cover, and therefore capture, the biogas produced from manures having less than 5 percent TS. Generally, large lagoon volumes are required, preferably with depths greater than 12 feet. The volume required by a covered anaerobic lagoon can be roughly estimated by multiplying the daily manure volume by a desired HRT, which should be at least 60 days.

The areas where lagoon digesters can operate can generally be located south of the 40th parallel or in the green and blue areas shown in Figure 3.5. These so called "ambient temperature digesters" generally operate without added heat and can generate biogas in these warmer climates as lagoon temperature swings are relatively moderate. Covered lagoons with biogas recovery for energy purposes are typically only feasible in these moderate to warm climates.

During the colder months of the year (and for those lagoon digesters located in colder climates), less anaerobic degradation occurs as the digester temperature drops below ideal conditions. In these cases, less biogas is generated and the biogas that is recovered is usually flared to control odor.

Figure 3.5. Anaerobic Digestion Temperature Regions Map for the United States[23]



There are two types of covers for lagoon digesters, bank-to-bank and modular. A bank-to-bank cover is used in regions that have moderate to heavy rainfall. A modular cover is more often used in arid regions. Typically, multiple modules cover the lagoon surface and they can be fabricated from various materials.

Table 3.1 provides a summary of covered anaerobic lagoon digester characteristics. A covered anaerobic lagoon digester illustration is shown in in Figure 3.6, and example applications are shown in Figure 3.7.

Table 3.1. Characteristics of Covered Anaerobic Lagoon Digester

Attribute	Characteristics
Technology Level	Low
Percent Total Solids	0.5% to 5%
HRT	30+ to 60+ days
Best Location	Temperate and warm climates
Co-digestion	Not optimal
Number of U.S. Farm-Based Systems Operating or Under Construction	Approximately 60

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[23] EPA, Organics: Co-Digestion Economic Analysis Tool (CoEAT) User's Guide, https://archive.epa.gov/region9/organics/web/html/index-2.html (accessed March 2020).

Figure 3.6. Covered Anaerobic Lagoon Digester Diagram[24]

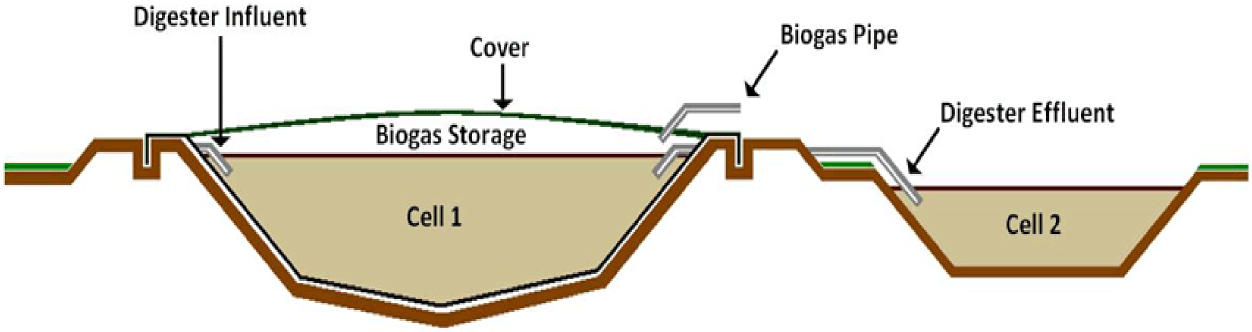

Figure 3.7. Examples of Covered Anaerobic Lagoons[25]

There are a considerable number of lagoon digesters currently operating in those areas that allow operation with ambient heating (e.g., California). Less biogas can be generated from lagoon digesters as compared to those digesters that have fully controlled environments (as discussed below). However, because they are relatively inexpensive (as they require only earth moving and cover applications), many of these digesters are currently under construction in these areas (e.g., California, North Carolina, and Texas).

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[24] EPA AgSTAR Program, How Does Anaerobic Digestion Work, https://www.epa.gov/agstar/how-does-anaerobic-digestion-work (accessed March 2020).

[25] Aligned Digesters, https://aligneddigesters.com/ (accessed March 2020).

California Climate Investments, Profiles, http://www.caclimateinvestments.ca.gov/profiles/2017/3/10/cdfa-verwey-hanford-dairy-digester-project-kings-county (accessed March 2020).

NC Policy Watch, Using Biogas to Clear the Air Near Hog Farms, http://www.ncpolicywatch.com/2017/11/16/using-biogas-clear-air-near-hog-farms (accessed March 2020).

3.4.2 Plug-flow Digester

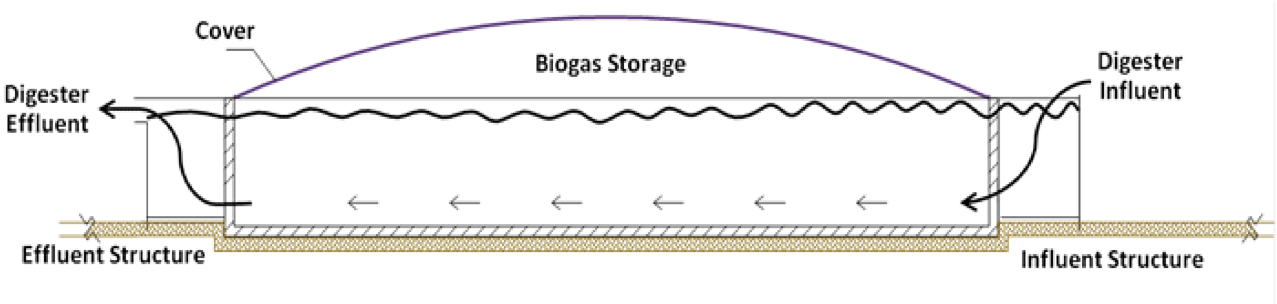
A plug-flow digester is a long, narrow tank recognizable with a roughly 1:5 ratio of width or height to length dimensions. Plug-flow digesters are typically heated and installed below ground for insulation, and have an impermeable gas collecting cover. Plug-flow digestion systems normally do not include mixing. However, this traditional approach has been modified to include horizontal or vertical mixing techniques by proprietary company offerings. These systems work best with dairy manure that is collected by scraping and contains minimal bedding. Swine manure cannot be treated with a plug-flow digester due to its lack of fiber (and therefore has a low TS feedstock content). Plug-flow style digesters are prone to the buildup of solids at the bottom, and eventually it will need to be cleaned out. This can be costly and disruptive to typical farm duties, particularly when the tanks are constructed of concrete.

Table 3.2 provides a summary of plug-flow digester characteristics. A plug-flow diagram is presented in Figure 3.8, and examples of what this digester looks like are shown in Figure 3.9.

Table 3.2. Characteristics of Plug-flow Digesters

Attribute	Characteristics
Technology Level	Low
Percent Total Solids	12 to 15%
HRT	20+ days
Best Location	All climates
Co-digestion	Not optimal
Number of U.S. Farm-Based Systems Operating or Under Construction	About 100

Figure 3.8. Plug-flow Digester Diagram[26]



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[26] EPA AgSTAR Program, How Does Anaerobic Digestion Work, https://www.epa.gov/agstar/how-does-anaerobic-digestion-work (accessed March 2020).

Figure 3.9. Examples of Plug-flow Digesters[27]

3.4.3 Complete Mix Digester

Complete mix digesters, commonly referred to as Continuously Stirred Tank Reactors (CSTR), are engineered tanks above or below ground that treat feedstocks having TS concentrations from 3 to 12 percent. These systems require less land than lagoons and are heated. Contents are mixed mechanically, hydraulically, or both. The tank is topped with an impermeable gas-collecting cover. Complete mix digesters work best when the manure is diluted, usually with wastewater used for sanitary purposes at the milking center. Complete mix digesters are compatible with combinations of livestock manure and work well with most co-digestion feedstocks.

Table 3.3 provides a summary of complete mix digester characteristics. A diagram of a complete mix digester is shown in Figure 3.10, and examples of complete mix digesters are shown in Figure 3.11.

Table 3.3. Characteristics of Complete Mix Digesters

Attribute	Characteristics
Technology Level	Medium
Percent Total Solids	3% to 10%
HRT	15+ days
Best Location	All climates
Co-digestion	Yes
Number of U.S. Farm-Based Systems Operating or Under Construction	Approximately 95

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[27] Manure Manager, AgSTAR Tour Visits Two WI Dairy Digesters, https://www.manuremanager.com/agstar-tour-visits-two-wi-dairy-digesters-3076/ (accessed March 2020).

Figure 3.10. Complete Mix Digester Diagram[28]

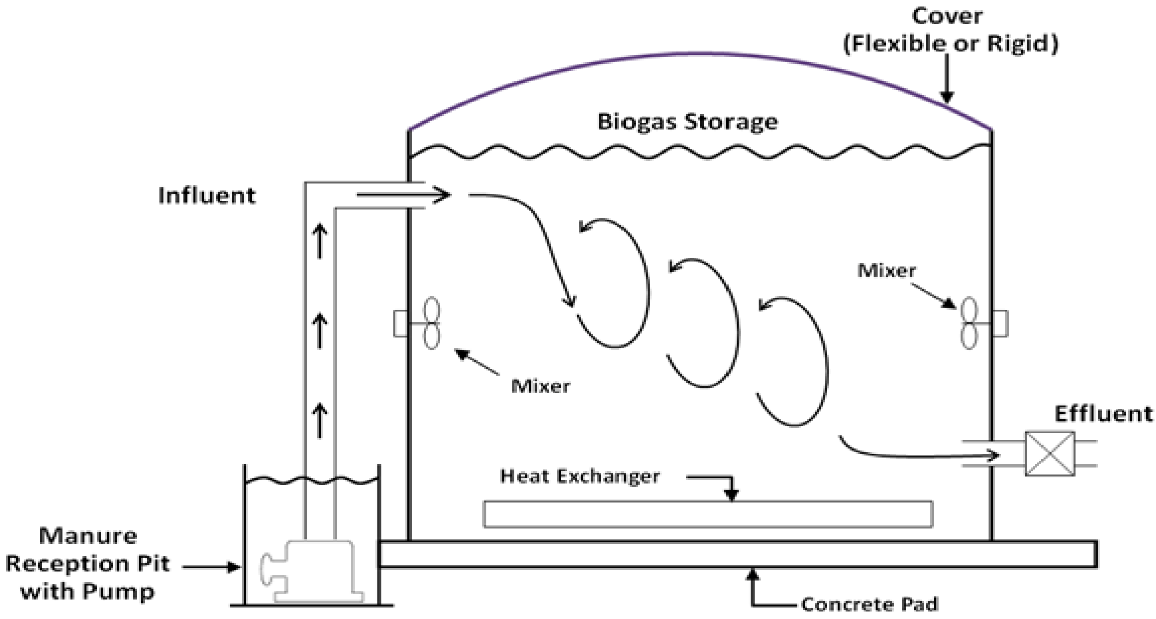

Figure 3.11. Examples of Complete Mix Digesters[29]

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[28] EPA AgSTAR Program, How Does Anaerobic Digestion Work, https://www.epa.gov/agstar/how-does-anaerobic-digestion-work (accessed March 2020).

[29] McMahon Group, Rosendale Dairy Bioferm Bio-Digester, https://mcmgrp.com/portfolio/rosendale-dairy-bioferm-bio-digester/ (accessed March 2020).

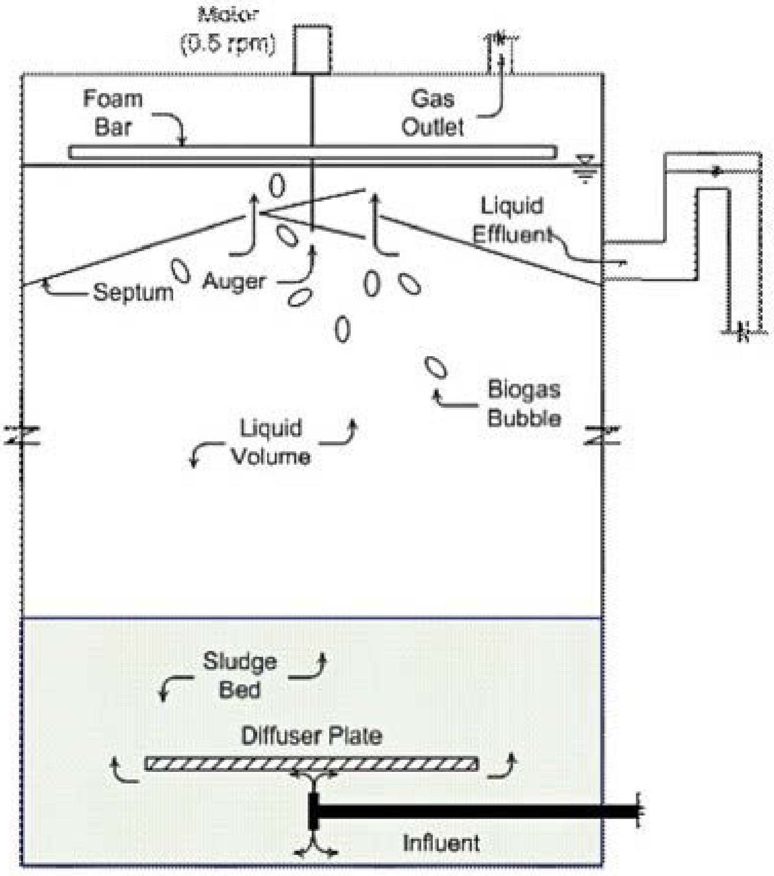
"Anaerobic Digestion of Animal Manures: Types of Digesters," Oklahoma State University Extension, March 2017, https://extension.okstate.edu/fact-sheets/anaerobic-digestion-of-animal-manures-types-of-digesters.html.

3.4.4 Induced Bed Reactor Digester

In this type of digester, microbes are suspended in a constant upward flow of liquid. Flow is adjusted to allow smaller particles to wash out, while allowing larger ones to remain in the reactor. The microorganisms form a slimy growth called a biofilm around the larger particles. As a result, more of the slower-growing methanogens remain in the digester. The digestate is sometimes recycled to provide a steady upward flow of liquid. The advantage of this approach is that it maintains an adequate microbial population with a shorter HRT, which translates into a reduced digester volume. Two types of suspended media digesters can use manure feedstocks, and both can co-digest a wide range of other feedstocks. One type is called the Induced Blanket Reactor (IBR), which is an emerging technology on U.S. farms. The second type of suspended media digester is called an Upflow Anaerobic Sludge Blanket (UASB). The main difference between the two types is that UASB digesters are better suited for dilute feedstocks having less than 3 percent TS. The IBR digester works best using higher feedstock solids concentrations, preferring a range between 6 and 12 percent TS. Both types are best suited for using homogenous waste streams.

An IBR digester diagram is presented below in Figure 3.12. Table 3.4 provides a summary of IBR digester characteristics.

Figure 3.12. Induced Bed Reactor Digester Diagram[30]



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[30] " Types of Anaerobic Digester," Livestock and Poultry Environmental Learning Community, March 5, 2019, https://lpelc.org/types-of-anaerobic-digesters/.

Table 3.4. Characteristics of Induced Bed Reactor Digesters

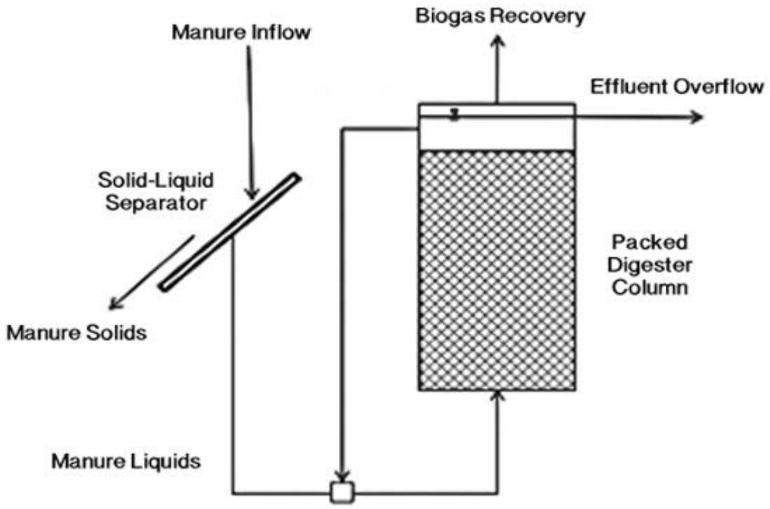
Attribute	Characteristics
Technology Level	High
Percent Total Solids	IBR: 6% to 12% for IBR, UASB: < 3%
HRT	5 days or less
Best Location	All climates
Co-digestion	Yes, using type best suited for feedstock TS
Number of U.S. Farm-Based Systems Operating or Under Construction	About 5, all IBR

3.4.5 Fixed Film Digester

A fixed film digester is essentially a column packed with media. The system is designed to provide surface area to entice methanogenic bacteria to grow a biofilm on the fixed media. The HRT for fixed film digesters can be less than 24 hours, but normally is 2 to 5 days, making for relatively small digesters. Some of the digestate is recycled to maintain a constant upward flow. One drawback to fixed film digesters is that manure solids can plug the media. This system is only appropriate for feedstocks with low TS (mostly utilized for fine or dissolved solids); TS concentrations are usually between 1 and 5 percent. Feedstocks with large particles and higher TS concentrations may require a solid separator to remove some solids to reduce TS concentrations before being fed into the digester. Some potential biogas production is lost due to removing the solids. These types of digesters are also sometimes called “Attached Growth Digesters” or “Anaerobic Filters.”

A diagram of a fixed film digester is shown in Figure 3.13, and illustrations of this operating digester are shown in Figure 3.14. Table 3.5 provides a summary of fixed film digester characteristics.

Figure 3.13. Fixed Film Digester Diagram[31]



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[31] “Types of Anaerobic Digester,” Livestock and Poultry Environmental Learning Community, March 5, 2019, https://lpelc.org/types-of-anaerobic-digesters/.

Figure 3.14. Fixed Film Digester Showing Media and Its Installation

Table 3.5. Characteristics of Fixed Film Digesters

Attribute	Characteristics
Technology Level	Medium
Percent Total Solids	1% to 5%
HRT	5 days or less
Best Location	All climates, if heated
Co-digestion	Yes, only if using low TS feedstocks
Number of U.S. Farm-Based Systems Operating or Under Construction	Fewer than 5

3.4.6 Anaerobic Sequencing Batch Reactor Digester

An Anaerobic Sequencing Batch Reactor (ASBR) digester is a type of system that is mixed intermittently. Typically, these are above-ground heated tanks having an impermeable roof to collect the biogas. Manure is added and removed from the reactor in a cycle of four phases: fill, react, settle, and decant. The methanogenic microorganisms are kept in the digester by settling solids and decanting liquid. The cycle is repeated up to 4 times a day for nearly constant gas production. Liquid retention times can be as short as 5 days. ASBR digesters work in a range of TS concentrations, but they are best suited for treating very dilute feedstock having less than 1 percent TS. Sludge must be removed periodically from the settling tank, along with concentrated nutrients that are harvested during sludge removal.

An ASBR diagram can be found below in Figure 3.15. Table 3.6 provides a summary of ASBR characteristics.

Figure 3.15. Anaerobic Sequencing Batch Reactors Diagram[32]

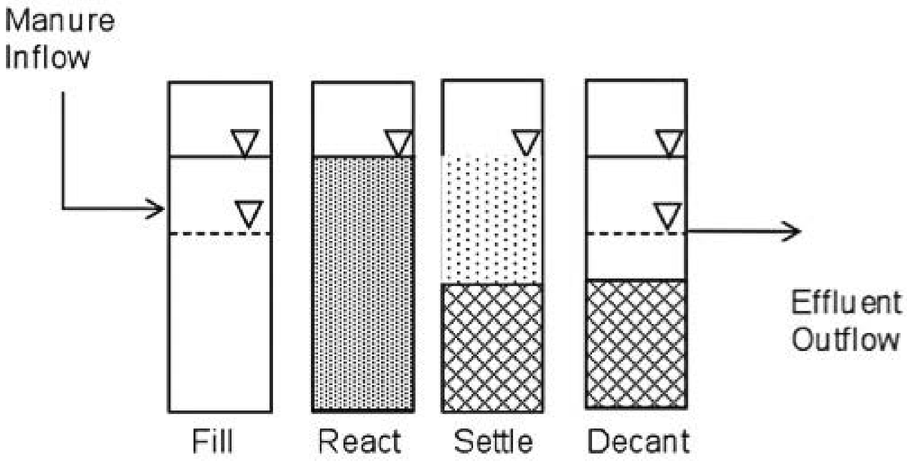

Table 3.6. Characteristics of Anaerobic Sequencing Batch Reactors

Attribute	Characteristics
Technology Level	High
Percent Total Solids	2.5% to 8%
HRT	Typically 5 days or less
Best Location	All climates
Co-digestion	Yes
Number of U.S. Farm-Based Systems Operating or Under Construction	Fewer than 5

3.4.7 High Solids Anaerobic Digester

High Solids Anaerobic Digestion (HSAD), also known as “dry fermentation,” is used to treat “stackable” feedstocks such as drier animal manures, food scraps, yard debris, and the organic fraction of municipal solid wastes. As the name implies, HSAD works with materials having a high solids content that generally include TS concentrations greater than 25 percent. Stackable manure may also be co-digested with other feedstocks in a HSAD.

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[32] “Types of Anaerobic Digester,” Livestock and Poultry Environmental Learning Community, March 5, 2019, https://lpelc.org/types-of-anaerobic-digesters/.

High solids feedstocks are loaded into airtight digestion chambers and heated. These are commonly above ground concrete or steel “vaults” or “tunnels” that normally are horizontal as shown in Figure 3.16. In this case, a door is opened as shown in Figure 3.16 to allow for placement and subsequent removal of material after digestion. Depending on the feedstocks used, a vertical silo may also be used. Leachate is normally drained from the solids, removed with pumps, and handled separately. Some systems recirculate the leachate back to another reactor to enhance biogas production. Some HSAD systems can be operated in either anaerobic or aerobic phases and may be done so sequentially. In this situation, the chamber is kept airtight during the anaerobic phase and air is forced into the chamber during the subsequent aerobic phase. Table 3.7 provides a summary of high solids digester characteristics. An illustration of a portable HSAD reactor system is shown in Figure 3.17.

Table 3.7. Characteristics of High Solids Anaerobic Digesters

Attribute	Characteristics
Technology Level	Low
Percent Total Solids	>25%
HRT	20-30 days
Best Location	All climates
Co-digestion	Yes
Number of U.S. Farm-Based Systems Operating or Under Construction	Fewer than 5

Figure 3.16. Examples of High Solids Anaerobic Digester (HSAD) System[33]

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[33] “High Solids Anaerobic Digestion + Composting In San Jose,” BioCycle, March/April 2014, https://www.biocycle.net/2014/03/28/high-solids-anaerobic-digestion-composting-in-san-jose/. “Facilitating Food Waste Digestion,” BioCycle, May 2018, https://www.biocycle.net/2018/05/01/facilitating-food-waste-digestion/.

Figure 3.17. Example of HSAD System (HSAD)[34]

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[34] Impact Bioenergy, http://impactbioenergy.com/ (accessed March 2020).

4.0 Digester Feedstocks

This section discusses the various AD feedstocks, their potential to produce biogas, and how the various feedstocks can be co-digested to boost biogas production. Feedstock biogas yields vary widely, primarily due to the amount of readily digestible materials the feedstock contains. For example, sugar produces more biogas than dairy manure. Most VS is anaerobically digestible, but some resist digestion and require longer HRT. Many livestock manures contain lignin, the rigid and woody material forming the cell walls of many plants, that breaks down very slowly and inhibits anaerobic activity. The relative CH_4 yield per unit of mass for various feedstocks is shown in Figure 4.1.

Figure 4.1 demonstrates the axiom that not all volatile solids are created equal. The greater biogas yields indicate the relative differences in the quantity of volatile solids converted to biogas between the various feedstocks. It is not simply the presence of volatile solids in a given feedstock, but it is the ability to convert those volatile solids to biogas that is important. This difference accounts for the greater biogas production per unit volume introduced into the digester.

Figure 4.1. Methane Yields from Various Feedstocks

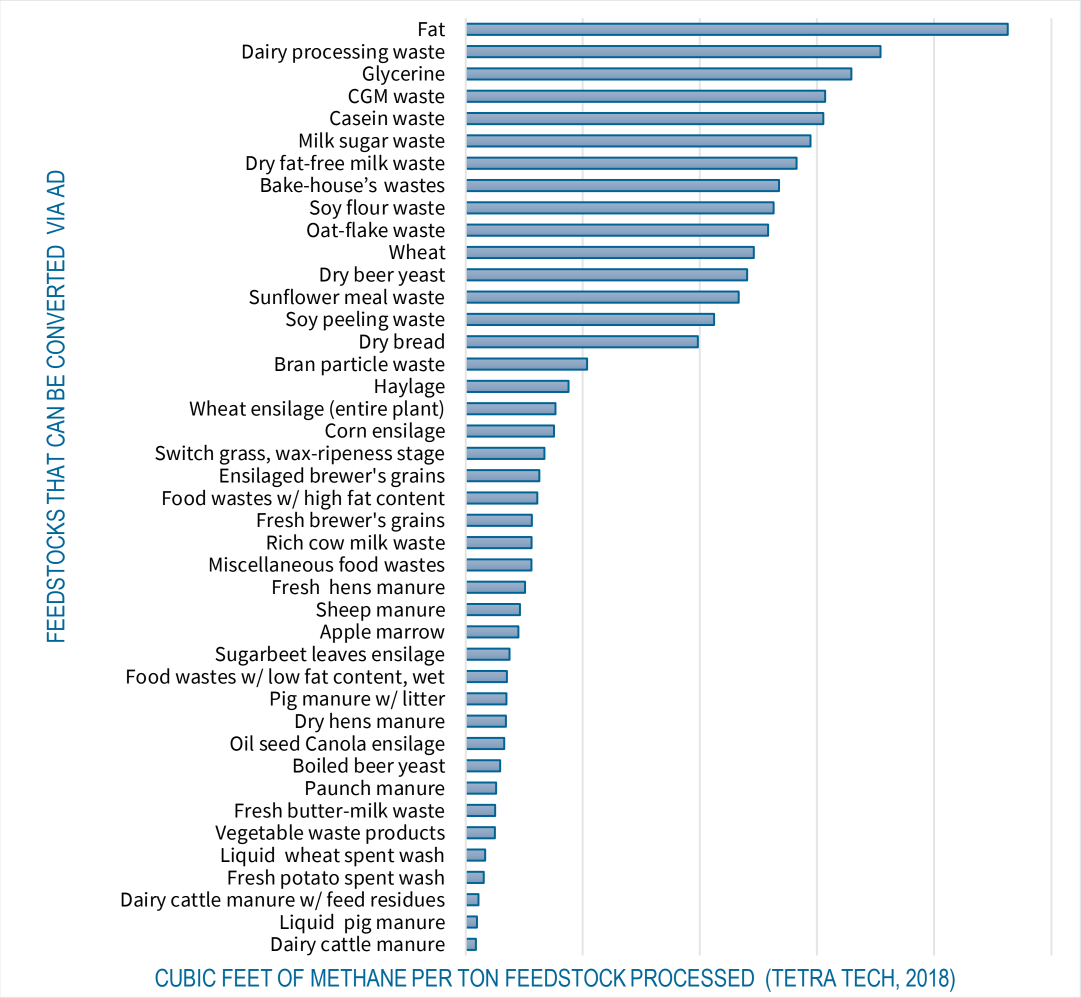


Figure 4.1 is not intended to be used as a precise measure of biogas per unit feedstock, only the relative amount from one feedstock to another (it is for this reason there are no units shown on the X axis).

4.1 Biomethane Testing and Anaerobic Toxicity Assays

Determining the physical and biochemical characteristics of the feedstock is an essential foundation of any AD/biogas system. This analysis typically includes identifying and collecting representative feedstock samples and conducting appropriate laboratory analysis. This analysis is important to determine the value of the feedstock and the type of digester needed to effectively convert that feedstock into biogas. It will also determine compatibility of various types of feedstock and allow avoidance of materials that may inhibit or limit favorable biological activity and methane generation.

AgSTAR's Increasing AD Performance with Codigestion fact sheet provides an overview of the different types of laboratory testing and analyses commonly used to identify TS, VS, and Chemical Oxygen Demand (COD). TS and VS testing is relatively inexpensive and a good baseline for estimating feedstock. These tests are generally performed on the feedstock during the feasibility study phase of a digester and performed regularly throughout operations. Biomethane potential assay (BMP) and anaerobic toxicity assay (ATA) tests are also useful parameters to determine feedstock feasibility. These are more complex and costly, but provide more information about biogas potential. See AgSTAR’s Codigestion Guidelines for additional information.

Most digester technology vendors have lab-scale operating data that is used for a preliminary estimate of biogas potential for specific projects. Additionally, some advanced consultants and universities have databases of feedstock biogas production potentials. These general characteristics are useful to predict any feedstock’s biogas production potential and to serve as a reference base; however, they should be used only as a guide as actual gas production will vary from predicted.

Making a significant financial investment in an AD/biogas system should not solely be based on a feedstock’s general attributes, nor on BMP data extrapolated from other sources and/or feedstocks. For example, HRT requirements vary based on the feedstock’s characteristics and the resultant biogas production can vary significantly. Extrapolation or selection of an arbitrary HRT for the feedstock mixture may result in less than ideal conditions for biogas production, which could lead to underachieving project expectations. It is strongly recommended that the characteristics of site-specific feedstocks be identified and that the AD/biogas system is planned using specific data.

4.1.1 Basic Analyses

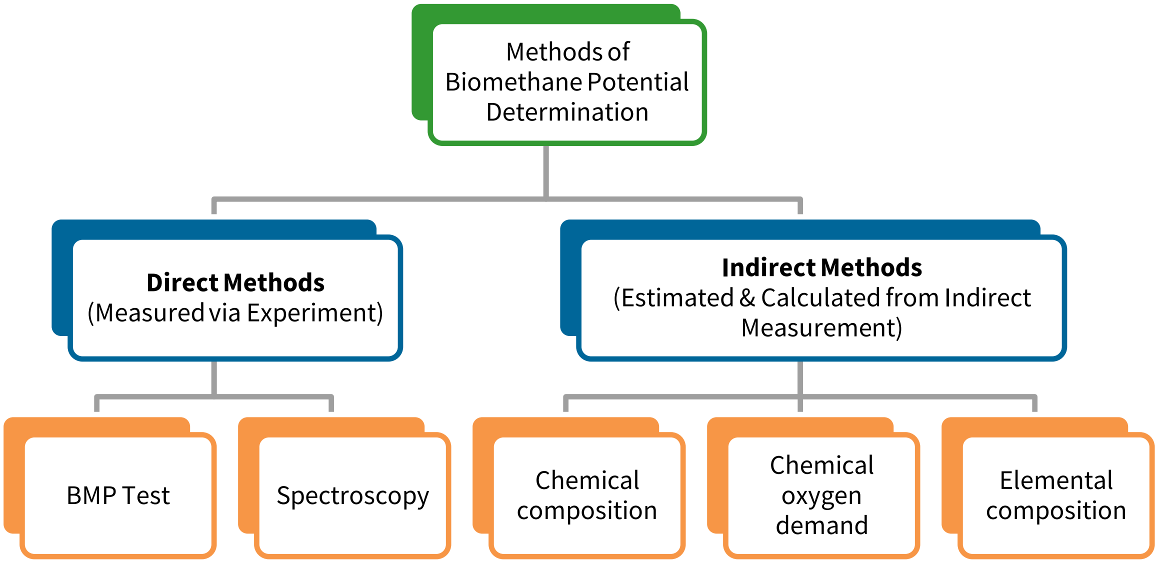
Using livestock manures, biogas production potential is often calculated in the biogas volume units produced per unit mass of VS in the feedstock. The calculation is done using the amounts of VS introduced or the amounts of VS destroyed. An example is that a feedstock yields “six cubic feet of biogas per pound of VS destroyed.” Feedstock biogas potential is also calculated in terms of volume of CH_4 produced per unit of COD introduced or destroyed. Many co-digestion feedstocks measure their biogas production potential using COD, and it is a common measurement unit used by industrial or WRRF digesters. Further information about COD can be found in the AD/Biogas System Operator Guidebook (under development).

4.1.2 Biomethane Potential

Biomethane potential is the measure of how much biogas can be produced when anaerobically digesting organic material under ideal conditions. Because it is determined in a laboratory, a BMP provides a standard basis for comparing the biogas production potential of various feedstocks.

Laboratory testing options include both direct and indirect methods. A diagram illustrating different methods of determining biomethane potential is shown in Figure 4.2. Direct methods measure an actual result in an empirical or experimental environment. These are often regarded as more reliable (if conducted properly), yet are more expensive. Indirect methods include analysis of various "indicator" parameters, including TS, COD, and VS, in combination with subsequent calculations to generate an estimate of biogas production. Indirect methods are relatively quick and can be conducted at lower laboratory cost, but also require assumptions and calculations to determine biomethane potential. Because assumptions are made and they are indirect measurements, they can be less precise as compared to direct measurements.

Figure 4.2. Methods of Biomethane Potential Determination[35]



Practical experience shows the importance of testing feedstocks for their biomethane potential.

A BMP is a laboratory-scale test conducted under ideal conditions. The BMP subjects the feedstocks to an anaerobic environment and empirically measures the material's biogas production. BMP results should determine the optimal biogas production rate, the CH_4 content of the biogas, the H_2S content of the biogas, the total VS that is converted to biogas, and the COD/biochemical oxygen demand (BOD) reduction in the digester. BMP results can also determine the biogas production at varying HRTs. At a minimum, the BMP should establish the concentration of TS, VS, and COD, while ideally the analyses should also include total volatile solids (TVS), volatile suspended solids (VSS), total Kjeldahl

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[35] Modified based on the "Methods for Determination of Biomethane Potential of Feedstocks: A Review." Biofuel Research Journal, June 2017. https://www.biofueljournal.com/article_46479_17fe4ef110d160d592e26ccfe64cfcd8.pdf.

nitrogen (TKN), total nitrogen (TN), total phosphorus (TP), potassium, pH, salinity, and metals (e.g., iron, zinc).

Since BMP assays are conducted under ideal conditions, the results must be adjusted to actual field conditions. Actual biogas production will be less than that measured by a BMP. Some technology providers have small-scale model reactors that supplement a BMP. These reactors are bench scale and are designed to more closely represent pilot conditions. In addition, laboratories can conduct pilot tests using small-scale reactors (these can be larger than bench scale, but are often still conducted in a controlled laboratory environment). BMP results can also be used to compare similar existing operations and provide a reasonable projection for a project under consideration.

Co-digesting numerous feedstocks require a BMP to assess individual and collective biogas production, as well as compatibility. Tests from each individual feedstock cannot accurately determine the BMP for the final, co-digested feedstock blend. Once the feedstock blend has been identified and its relative volumes established, it is best to create a composite sample and perform a composite BMP test. Co-digestion feedstocks should also be periodically tested once the project has become operational. In addition, these results should be helpful in assessing the monetary value when completing supplier agreements. That is, the BMP, the quantity available, the price or revenue on a unit basis, and other factors should drive the feedstock acquisition program.

4.1.3 Anaerobic Toxicity Assays

ATAs are done to establish if any inhibitors or toxic material may impact AD performance. This assay should be routinely conducted when co-digestion of feedstocks from outside sources occurs. Relying only on a BMP to determine capability and biogas production could be a critical error that may result in a fatal error or fatal flaw.

An ATA analysis on a potentially toxic material indicates whether the material stimulates or inhibits biogas production. It also provides a first-level evaluation at determining the maximum loading rate of the material. The ATA test does not indicate the reason why the material is toxic; that requires additional analysis.

For example, typical sources of inhibitory materials in food processing wastes are compounds used for cleaning and sanitation, such as chlorine and quaternary NH_3. Also, rapidly increasing the organic loading rate (ORL) by overfeeding even the best material may also inhibit biogas production. The Oklahoma Cooperative Extension Service's Anaerobic Digestion of Animal Manures: Inhibitory and Toxic Materials fact sheet provides additional information. Toxicity overload from inhibitory materials likely would cause a more rapid system failure than an overfeeding situation.

A standard ATA does not show microorganism acclimation to a toxicant or the effect of toxicant buildup in the biomass. Continuous bench-scale tests may be needed to study acclimation and toxicity due to compound build-up in the biomass. In the event that an ATA identifies an inhibitory material, the next best step is to conduct additional pilot testing to determine whether the toxic effects are temporarily or permanently detrimental to biogas production.

4.2 Livestock Manures

Figure 4.3 provides pictures of different types of livestock. Livestock manures present a readily available source of feedstock for AD/biogas projects. Manures generally contain most of the macro- and micro-nutrients required to support anaerobic digestion. Manure contains VS, which produces biogas as it decomposes. As shown in Figure 4.1, dairy manures have lower biogas yields relative to other digestible organic feedstocks. The livestock manure's lower relative potential to generate biogas is attributed to several factors, the most important of which is the animals' stomach which acts as an initial digester converting feed into energy. The biogas potential represents this fact and the fact that a percentage of the VS are non-digestible under anaerobic conditions.

Figure 4.3. Illustrations of Livestock

While the biogas yield from manure is lower than other feedstocks, there are numerous advantages to utilizing it. Manures from dairy and swine operations tend to be more suitable for farm-based energy conversion because dairy and swine manure management systems are often liquid- or slurry-based, which simplifies the necessary manure movement. Dairy manure also contains anaerobic bacteria, which increases the methanogen bacterial content in the digester, making it less susceptible to upsets.

There are also some things to watch out for with a manure feedstock. It must be free of large amounts of bedding or other materials, such as rocks, stones, and sand. Animal manures containing even small amounts of fine solids can have them quickly fall out of suspension, unless they are continuously agitated. If not kept in suspension, these dropped solids can reduce reactor volume, reactor ability to produce biogas, and damage internal reactor parts. Suspended solids can also drop out of suspension in the piping used for moving manure, which will require an expensive pump-out using a vacuum truck.

The following conditions are *generally* required for biogas digesters using manure feedstocks to be effective:

- Ability to capture significant volume of manure relatively quickly after it is excreted;
- Frequent collection of manure to avoid losing biogas generation potential due to natural decomposition, and to maintain a consistent flow of the feedstock to the digester;

- Manure should be relatively free of foreign materials, such as soil and excessive amounts of bedding, which hamper performance by accumulating in the digester; and
- Manure TS concentration should be known to select the most suitable digester technology type.

4.2.1 Types of Livestock Manure and Collection Practices

Livestock manures vary in their practicality as feedstocks due to differing types of livestock, the materials used for bedding, and the manure collection practices being used.

Dairy Cattle. Dairy cattle manure is quite conducive for the AD process. However, its biogas yield is comparatively low because the cows themselves already act as digesters, and the manure contains lignin that resists digestion. The benefit of using dairy manure is that it already contains anaerobic bacteria. Dairy manure adds to the methanogenic bacteria population, which helps stabilize the digester's operation. An example of a dairy manure alleyway flushing is demonstrated below in Figure 4.4.

Figure 4.4. Dairy Manure Alleyway Flushing[36]

The most common methods for collecting dairy manure is either by flushing or by scraping. Dairy barns using flushing rely on large water volumes to clean the lanes between free stalls and the feed

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[36] JGM Dairy Design Engineers, Manure Management Flush Systems, https://www.dairydesign.com/projects/manure-management-flush-systems/ (accessed March 2020).

lanes. Due to the water volume, the collected manure is dilute (< 3 percent TS). Scraped barn cleaning relies on mechanical scrapers to clean the alleyways. The scraper systems are either mounted on a vehicle such as a tractor or a mechanical alley scraper. As the scraper traverses the lanes, manure is pushed to the end where it is moved to a holding pit. Scraped collection results in manure that is generally >10 percent TS. There are many variations of the two collection methods that are adapted to the barn design and bedding materials. Examples of various types of dairy manure alleyway scraping are shown in Figure 4.5.

Figure 4.5. Various Types of Dairy Manure Alleyway Scraping[37]

The use of manure from dairy operations using sand bedding requires special attention. Separation equipment should be installed to remove the sand before digestion. Ideally, all sand bedding is removed by the separation equipment (in practical terms, not all sand can be removed). However, 4 to 10 percent of the entrained VS will be removed along with the sand, negatively affecting biogas yield. As a result, many AD technology providers traditionally recommend against adding a digester to a

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[37] "15-year-old Freestall Barn Gets a Facelift at Larson Acres," Progressive Dairy, March 31, 2015, https://www.progressivedairy.com/topics/barns-equipment/15-year-old-freestall-barn-gets-a-facelift-at-larson-acres.

John Deere, https://www.deere.com/sub-saharan/en/ (accessed March 2020).

Mensch Manufacturing, https://www.youtube.com/watch?v=WELBac9gjtk (accessed March 2020).

dairy that uses sand bedding. However, due to changing economic conditions (i.e., the value of the biogas with respect to LCFS), this is often viewed differently.

Swine. Swine manure is suitable for AD due to its high degree of readily biodegradable constituents. Most swine in animal feeding operations (AFO) are housed in barns with slotted floors. The pits under the floors are flushed, scraped or pull-plug designed. Flushed pits result in dilute manure with an approximate 2 percent TS, scraped pits yield manure that is approximately 6 percent TS, and pull-plug manure can vary between 3 and 6 percent TS. Examples of common swine manure pull-plug systems are provided in Figure 4.6.

Figure 4.6. Illustrations of Common Swine Manure Pull-Plug Systems

Manure from farrowing barns presents issues for digesters due to the presence of hair from the mature hogs that can easily clog the digester. Because of the hairless nature of smaller pigs, manure used from nursery and finishing operations does not create this problem.

Poultry. Poultry manure has a high TS concentration (~25 percent TS), which makes it impractical to use on an as-excreted basis in lower-solids content digesters typically used on dairy and swine farms. Poultry manures also have high ammonia concentrations that inhibits biogas production and adversely affects the material handling equipment (i.e., it is a highly corrosive environment). Poultry feed contains considerable amounts of grit, which can also settle and accumulate in digesters. For broiler chickens and turkeys, manure is routinely collected on an annual basis, and often contains wood shavings and other bedding material collected from growout houses.

Manure from laying hens is generally collected by a conveyor on a continuous basis. Most use settling chambers to remove the grit from the feed. Poultry manure is then diluted to reduce TS, which also helps solve the issue of high ammonia concentration. This dilution is often done using co-digestion feedstocks. The collected manure also contains feathers that must be considered during handling process, as well in the design of the digester. As of 2019, approximately 10 poultry farms operate an AD system according to the AgSTAR Livestock Anerobic Digester Database.

Beef Cattle. Most beef cattle are raised on the open range where the manure is not collected, or at dirt feedlots where the open lots are scraped only intermittently. Infrequent collection decreases biogas production potential, and the manure that is collected from dirt feedlots often contains significant amounts non-digestible materials such as sand, soil, and rocks. Manure recovered from beef cattle raised at finishing barns having paved surfaces or using slatted floors over a collection pit can be digested, if collected frequently.

Horses. Horse manure is usually combined with bedding materials when collected. This combination degrades slowly due to the high lignin content, rendering horse manure a generally poor candidate for AD. Horse manure can provide a valuable source of organic structure for HSAD. Structure is often a term used to describe the “bulking agent” required with dense material. The bulking agent allows the feedstock to be more porous allowing the permeate to infiltrate and transport through the feedstock, which is how some HSAD systems operate.

Table 4.1 shows the diverse types of livestock manures, the manure collection method, and the anaerobic digestion technology type typically used for each; the table also incorporates suitable climatic conditions.

Table 4.1. Manure Types and Suitability for Digestion[38]

Animal Type	Collection System	Estimated Min. Ratio of Water: Manure	TS %	Digester Type
		Moderate to Warm*		
Dairy	Flush	10:1	< 3%	• Covered Lagoon • Complete Mix • Fixed Film • Plug-flow • High Solids AD
	Scrape & Parlor Wash Water	4:1 - 1.1:1	3% - 13%	
	Scrape - Manure Only	N/A	> 14%	
Swine	Flush	10:1	< 3%	• Covered Lagoon • Complete Mix • Fixed Film
	Scrape	2:1	3% - 6%	
	Pull Plug	5:1	< 2%	
	Managed Pull Plug	3:1	3% - 6%	

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[38] Modified from 2004 AgSTAR Handbook.

Animal Type	Collection System	Estimated Min. Ratio of Water: Manure	TS %	Digester Type
Cold**				
Dairy	Flush	10:1	< 3%	• Limited possibility for Covered Lagoon as Low TS, high volume of water makes heating difficult • Fixed Film • Complete Mix • Plug-flow • High Solids AD
	Scrape & Parlor Wash Water	4:1 - 1.1:1	3% - 13%	
	Scrape - Manure Only	N/A	> 14%	
Swine	Flush	10:1	< 3%	• Limited possibility for Covered Lagoon • Fixed Film • Complete Mix
	Scrape	2:1	3% - 8%	
	Pull Plug	5:1	< 3%	
	Managed Pull Plug	3:1	3% - 6%	

* Moderate to warm generally occurs in the region below the 40th parallel.
** Cold climate occurs above the 40th parallel (see Section 3.4.1 and Figure 3.5).

4.3 Co-Digestion

In addition to manure, other feedstocks may be collected from nearby sources and processed in the AD/biogas system. Co-digestion is the simultaneous digestion of two or more feedstocks. Co-digestion feedstocks should be carefully selected to enhance - not inhibit - CH_4 production. When suitable co-digestion feedstocks are mixed with manure, the volume of biogas produced ideally increases. When evaluating adding feedstocks, consideration should be given to biogas generation per volume of material, impact on the existing digesters HRT and solid retention time (SRT), potential inhibitors, ease of integrating into current AD operation, the fate of the additional liquid volume and nutrients that accompany other feedstocks, and impact on the project's economic/financial performance.

Suitable co-digestion feedstocks may include the following: FOG; pre-consumer (unused and/or expired food from grocery stores or food and beverage processing); post-consumer (including returns, food scraps from restaurants, cafeterias); or biodegradable materials like energy crops or crop residues. The highest value co-digestion feedstocks are those that biodegrade most easily such as sugar, starch, fats, and proteins.

Co-digestion feedstocks can *positively or negatively impact* the economic/financial performance of a farm-based digester. Careful examination should be given to the impact on a project prior to receiving alternative feedstock. For example, fees received for accepting and treating feedstock from organic waste generators and haulers, commonly referred to as "Tip Fees," provide added project revenue. As the biogas production increases from the treatment of these feedstocks, project revenue may also increase. Conversely, the feedstock received could impact the value of the biogas due to how it is classified. In the case of its classification as a renewable fuel, it may alter its "D value" or CI score and, therefore, impact project revenue. See Section 2.6 and AgSTAR's RNG from Agricultural-Based AD/Biogas System web page for more information.

Introduction of alternative feedstock must also be incorporated in the design and operation of the facility, as these feedstocks usually have higher organics concentrations than manure, which can adversely affect the digester's operation if not properly introduced. Moreover, the additional biogas produced must be accounted for in the design of the downstream handling, clean-up, and use. Provisions must also be provided for proper disposal of the resulting digestate, which may contain nutrient concentrations or other constituents not typically present in manure.

The following factors are among those needing consideration to determine if co-digestion is an option:

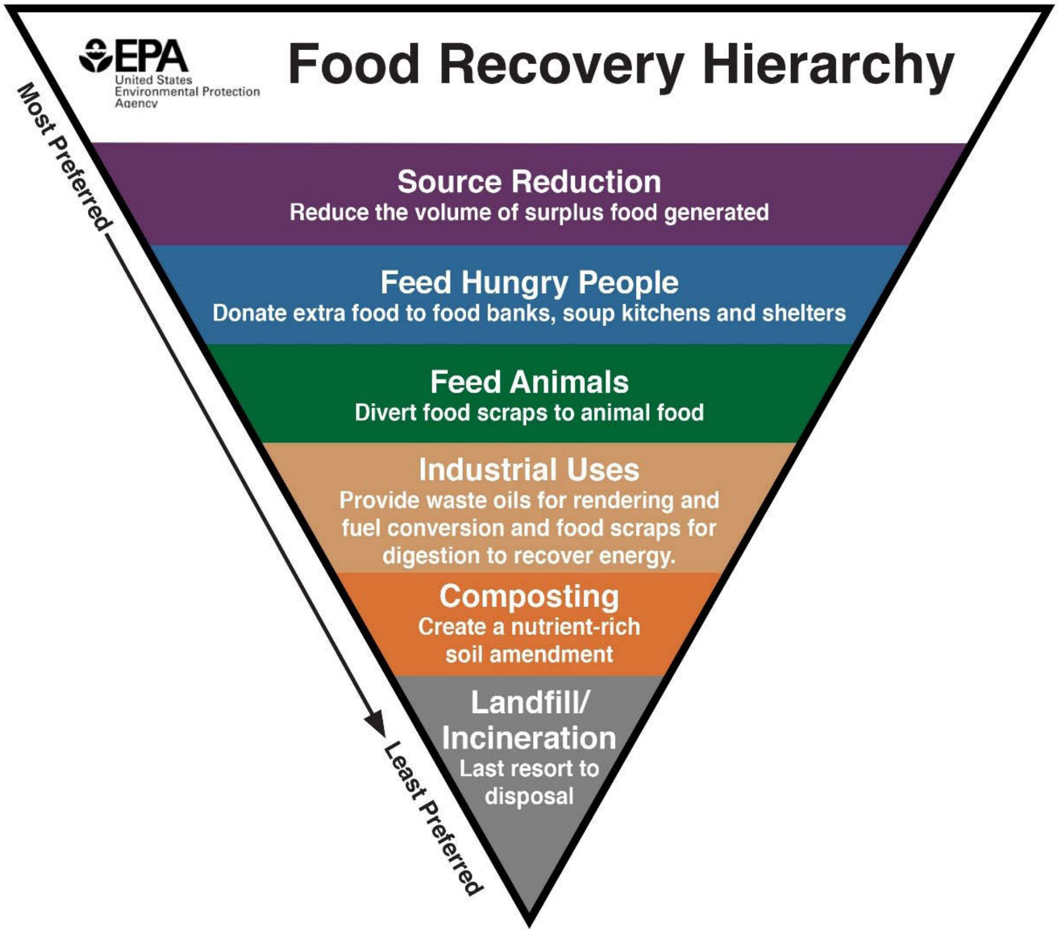
- Does the feedstock volume reduce the digester's HRT below its design value or increase the organic loading rate above that recommended by its vendor?
- Can the biogas storage, conditioning, and use systems handle the increased biogas production?
- Are potentially toxic substances present that may suppress biogas production?
- Do the proposed feedstocks contain components that affect biogas contamination, such as introducing siloxane into the biogas?
- Will digestate disposal requirements change from using the co-digestion feedstock due to added nutrients, such as nitrogen and phosphorus, or contaminants, such as salts?
- Will there be additional regulatory requirements and permitting?
- Can a long-term contract with the supplier guaranteeing the feedstocks' volume and quality specification, and any tipping fee, be secured?
- Will any additions to capital and operating costs be justified by any increase in revenues?
- Will the use or transport of co-products to the AD/biogas system cause any biosecurity concerns?
- Are there short-term feedstock storage and pre-processing requirements? Consider physical storage capacity at a farm, as well as rodent/vector concerns with material storage, additional truck traffic, odor concerns, and neighbor/community relations.
- Are there regulatory concerns with accepting off-site feedstocks? Some off-take revenues are directly impacted by the feedstock; some states allow a certain percent of feedstock to be from off site.
- Are there provisions within the off-take agreements that will allow for increased energy production?

4.3.1 Co-Digestion Feedstocks

Food Wastes. Food waste diversion from municipal solid waste has become an increasing concern due to the shrinkage of available landfill space and concerns about uncontrolled CH_4 emissions. Focus on food waste diversion has resulted in an increased interest in using AD. Many communities and some states require separate collection of this material and its subsequent diversion to AD if facilities exist in proximity to the waste generator.

Examples of pre- and post-consumer food wastes being used as an AD feedstock are found at both farm-based digesters and at municipal WRRFs. EPA has developed a priority hierarchy for food waste disposal, as shown in Figure 4.7 below.

Figure 4.7. Food Recovery Hierarchy[39]



Food Processing Waste. Many food processing plants produce waste streams that were traditionally discharged to a municipal WRRF, treated on site, land applied, or disposed of in a landfill. This material comes from processing wastage, process line cleaning, and from returned products that are generally collected separately. However, not all food processing waste streams are the same. For example, a dairy processing facility may have more liquid and fatty wastes than a fruit processing facility, which may have more high carbohydrate waste. Any food processing wastes containing untreated human wastes should not be accepted by a farm-based digester, as this will bring on regulatory oversight and requirements (see the EPA Biosolids Rule and more details about biosolids below).

Food processing wastes are available as solids, in the case of wastage and returned products, or as a dilute liquid, like streams of wash-water from process line cleaning and by-products like whey. Many food processing wastes have good AD potential because they are readily biodegradable and often have high concentrations of simple sugars and other components like carbohydrates or fats. If product returns are to be accepted, they will need to be de-packaged either at the food processing

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[39] EPA Sustainable Management of Food, Food Recovery Hierarchy, https://www.epa.gov/sustainable-management-food/food-recovery-hierarchy (accessed March 2020).

facility or the farm. This represents a capital and operating expense since the residual packaging will generally require off-site disposal at a landfill. Non-treated paper and cardboard packaging residuals can be beneficial to AD if they are macerated and diluted with liquids before introduction into the digester's reactor. The homogeneity of the feedstock and the consistency of the feedstock delivery are very desirable traits as they allow for more consistent operation and minimizes chances for digester upset due to an overload.

Pre-consumer food waste. This is the organic waste produced by supermarkets, restaurants, and institutions. This material comes from produce and meat trimming prior to sale or cooking, overproduction, spoilage, or from date-of-sale expiration. The presence of packaging or any other inorganic materials must be considered when planning for co-digesting pre-consumer wastes at an AD project. There are companies with innovative food waste recycling systems that can produce a slurry that is stored on site at the pre-consumer waste generator, and then is sent at periodic intervals to an anaerobic digester to produce biogas.

Post-consumer food waste. This waste is the uneaten or spoiled food scraps and leftovers generated by households, dining establishments, and institutions. In the case of households, these wastes are often combined with any trimmings occurring prior to cooking. While cooked food waste has a lower biogas potential than pre-consumer waste, it can still be a significant contributor to biogas production. As a result, alternative methods for disposing of post-consumer food waste is also gaining interest. To be digestible, any coated or treated packaging materials, plastic eating utensils, or other foreign materials should be removed. Maceration may also be required. Regulations governing post-consumer food waste disposal is different than pre-consumer wastes and should be factored into the decision if they are to be co-digested in a farm-based AD/biogas system.

Crop Residues. Significant volumes of crop residues, such as corn stalks and cobs, are left to decay after harvest. These residues have a low biogas production potential because they contain mostly lignin and other complex carbohydrates that are not readily biodegradable. Most of the readily digestible carbohydrates, proteins, and lipids are concentrated in the harvested crops. However, crop residues can provide a valuable source of structural organic material for HSD operations or at digestate composting operations.

Yard Wastes. Other than grass clippings, yard wastes are not good feedstocks for AD. They generally have a low biogas production potential and a high lignin content. Further, the seasonal variation in their supply make composting a more realistic alternative.

Livestock Mortalities. A significant challenge facing livestock producers is the safe disposal of the carcasses of large livestock such as beef and dairy cattle. This is due to regulatory changes regarding landfilling and on-site burial, as well as a substantial contraction in the rendering industry. Livestock mortalities may be regulated by State law, and the USDA should be contacted for further information. AD is a potential method for their safe disposal. Pre-treatment using maceration or alkaline hydrolysis is required prior to co-digesting animal carcasses in most digester systems. Research regarding the anaerobic digestion of dairy cattle carcasses found that the potential for transmission of Bovine Spongiform Encephalopathy (BSE) and Johne's disease via digestate was very unlikely.

Energy Crops. In Europe, there has been great interest in growing crops, primarily corn, specifically to produce biogas in an anaerobic digester. However, to be economically feasible, the value of the biogas generated must be greater than the combined costs of energy crop production, biogas production, and disposal of the digested material. Generally, the value of these products as a food source has been traditionally much higher than the net revenues generated by their use as digester feedstocks. This is due to the relatively low value of energy in the United States compared to Europe, and the comparative lack of incentives to encourage their use in a digester.

Biosolids. WRRFs produce a nutrient-rich sludge known as biosolids. WRRF biosolids are typically dewatered to increase their TS concentration and are commonly land-applied for their nutrient value, but are also composted, incinerated, or landfilled. Because they could be a source of tipping fees, it may be worthwhile to consider co-digesting biosolids in a farm digester. However, WRRF biosolids produced by treating human wastes are highly regulated, and co-digestion should be carefully evaluated and implemented with caution. Many WRRFs have on-site AD, and their biosolids would not be suitable as an additional source of feedstocks.

For additional information on this topic, see AgSTAR's Increasing Anaerobic Digester Performance with Co-digestion fact sheet.

4.4 Boosting Biogas Potential

Biogas is produced by feedstock VS destruction. The volume of biogas produced per unit of VS introduced is primarily dependent on two factors: the feedstock's inherent chemical composition and the efficiency of VS destruction. The chemical composition is a physical attribute of the feedstock and cannot be changed. However, a significant amount of research has been done using alternative methods to increase VS destruction and its subsequent conversion into biogas.

Below are some of the many modifications to traditional digesters that have shown promise in boosting biogas production:

- Digesters operating at medium (mesophilic) or high (thermophilic) temperature convert VS more efficiently than digesters operating at lower temperatures. The increased efficiency means the biogas yield per unit of mass entering the digester is higher. Regardless of any digester's operating temperature, consistently maintaining that desired temperature will increase the production of biogas compared to one with wider temperature ranges.
- Two-phase processes, which separate the acid phase from the methanogenic phase, have shown increasing biogas yield per unit mass entering the digester. This provides near ideal conditions for microbial growth, along with the number of CH_4-producing microbes. The process can result in an increased biogas yield and is generally the only reason to support a two-phase system.
- Another process modification is to create more feedstock surface area, which means more VS is exposed to the microbes, resulting in an increased biogas yield. This modification can be accomplished by reducing particle size during maceration or by a separate hydrolysis phase that breaks down the feedstock's cell structure.

Below are some of biological and/or chemical enhancements that have been implemented to boost biogas production:

- Bioaugmentation or adding specific cultured microorganisms to increase the speed or rate of organic decomposition is well documented. The targeted result of using bioaugmentation is to increase biogas production when compared to using the traditional microbial community. This is an area of interest that has attracted significant research.

- The addition of enzymes in other industrial applications has been shown to increase the rate and yield of AD. It's application in enhancing biogas production is still not used on a large scale, but this area too has attracted significant research and practical application.
- Feedstocks may not contain the sufficient micronutrients needed to sustain the microbes. Metals such as iron and magnesium can be added to control the amount of H_2S production and NH_3 accumulation in the digester. Both factors inhibit biogas production.
- Gas stripping of digestate, a process where biogas is injected into the digestate releasing dissolved biogas, has been shown to be effective in recovering the biogas that is entrained in the digestate. This can be accomplished in either the digester's reactor or at a separate tank designed for this purpose. Storage of digestate with mixing will also release dissolved biogas, increasing the overall biogas capture.
- Research has been conducted on the use of biochar to improve digester performance. The benefits appear to be due to the pH buffering ability of the biochar, as well as the increase in carbon availability. This allows the digester to operate at a more ideal carbon to nitrogen ratio.
- Ammonia stripping integrated into the AD/biogas system may increase biogas production when co-substrates with high nitrogen wastes are digested. Removing ammonia can be of value as the resulting ammonium production can be inhibitory to the microbial community.

5.0 AD/Biogas System Products, Equipment and Uses

An AD/biogas system converts organic matter into two principal components: biogas and digestate. Most projects focus primarily on the biogas fraction, as it provides the most revenue and is readily marketable. In its own way, owning an AD/biogas system is like having a "renewable natural gas well" that will never be depleted as long as the system is fed and maintained.

5.1 Biogas Uses

CH4 produced in the AD process comes from renewable sources, whereas CH4 found in fossil natural gas is not. Because fossil-fuel derived natural gas contains a variety of other hydrocarbons, such as ethane, propane, and butane, it often has higher energy content (e.g., calorie, BTU, or Joule value) than pure CH4.

Depending on the AD process and feedstock, the CH_4 content of biogas is generally between 50 to 75 percent. The remaining amount is comprised of primarily CO_2, H_2S, water vapor, and other trace compounds.

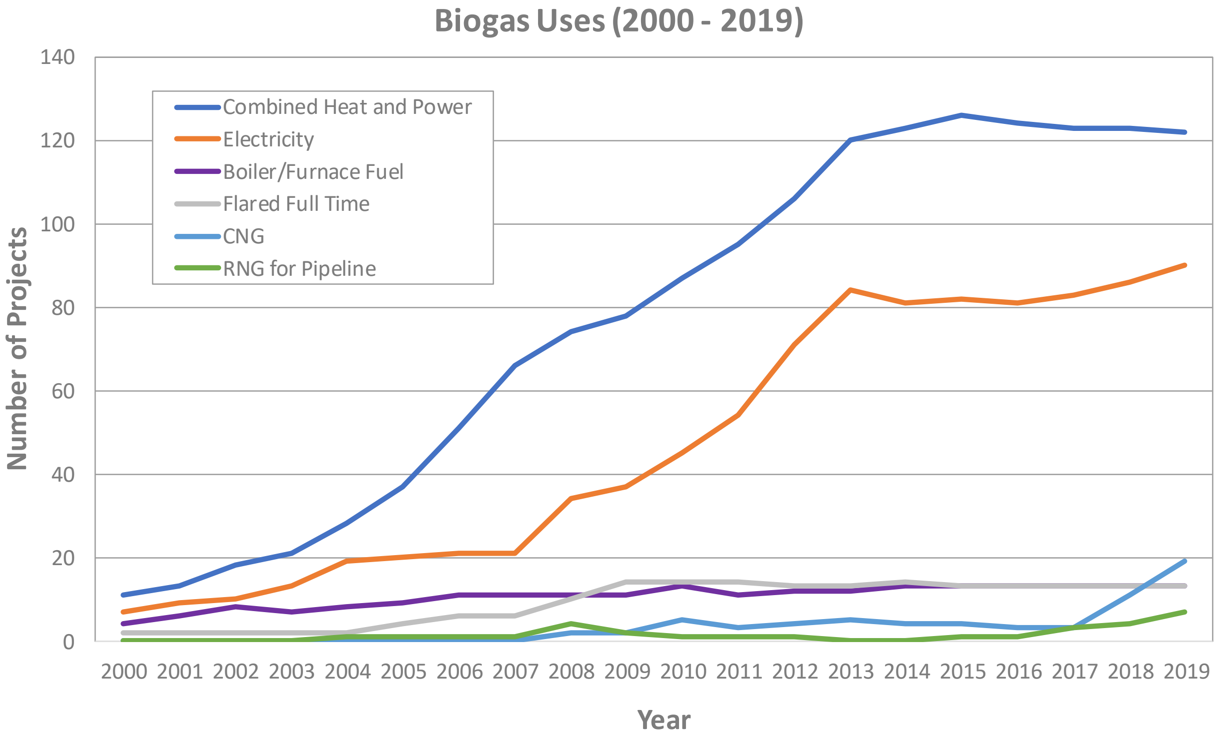
Raw biogas requires upgrading or conditioning to remove these impurities, resulting in CH_4 gas. This gas is similar to natural gas and it can be used in all of the same energy-consuming applications as natural gas (as introduced in Section 2.6). Other potential, but less common uses of biogas and RNG include:

- Renewable liquefied natural gas (R-LNG);
- Methanol;
- Gaseous or liquid hydrogen, conversion at a centralized plant or vehicle refueling station;
- Dimethyl Ether (DME); and
- Renewable diesel fuel via a Fischer-Tropsch process.

Most farm-based AD/biogas systems use the biogas to produce electricity and thermal energy using a CHP engine-generator set. Due to increasing interest and incentives, many current projects are beginning to refine the biogas into RNG for injection into the natural gas distribution grid or compression to produce transportation fuel as CNG.

A line chart showing trends in the end use of biogas from 2000 through 2019 is shown in Figure 5.1. This illustrates that CHP and electricity are the most common uses of biogas from farm-based AD/biogas systems.

Figure 5.1. Biogas End Uses at Farms[40]



As noted previously in Section 2.6, the conversion of biogas into RNG has substantially increased in the number of applications and value. As of October 2019, it is estimated that more than 100 RNG projects are operating in the United States, with more than 40 projects under construction and more than 50 under development.[41] Of these, an estimated 14 RNG projects from manure-based AD/biogas currently operate; more than 20 projects are under construction as documented by The Coalition for Renewable Natural Gas.

The following sections further describe the various uses of biogas.

5.1.1 Electricity Generation

Biogas is readily converted into electricity:

- Using an engine-generator set;
- Combusted by microturbines; and
- Utilized in a boiler to produce steam, which is then used to turn a turbine to produce electrical energy. However, steam turbines tend to be less efficient and more capital intensive.

Combustion-based processes require that the water vapor is separated from the biogas. To prevent corrosion damage, most engines also require some level of H_2S removal. Many state regulatory

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[40] EPA AgSTAR Program, Data and Trends, https://www.epa.gov/agstar/agstar-data-and-trends (accessed March 2020).

[41] The Coalition for RNG, RNG Production Facilities in North America, http://www.rngcoalition.com/rng-production-facilities (accessed March 2020).

agencies also limit sulfur emissions from the engine exhaust, requiring the removal of substantial amounts of H_2S.

Biogas can also be used as the fuel for a Stirling engine. However, Stirling cycle generators are normally used in heat recovery projects. It is also possible to use biogas CH_4 in fuel cells. However, the biogas would require significant purification for this application (similar to RNG).

For projects that plan to interconnect to the electrical grid or natural gas pipeline, it is imperative that the local utility be contacted early in the process to discuss interconnection requirements and fees.

Electricity generation without thermal recovery has a lower initial capital cost and provides the same electrical conversion efficiency as a CHP system (described below). Where there is limited need for thermal energy, engine heat could be simply dispersed into the atmosphere. In these situations, a system designed to produce electricity without thermal recovery may produce a greater return on investment than a CHP system. This approach is often used in low solids AD installations, such as covered lagoons, where heating the water is impractical or not required due to atmospheric heating. If required, digester heating can be provided by a hot water boiler fired with a slipstream of biogas or a limited heat recovery unit adjacent to the generator.

5.1.2 Combined Heat and Power

The most common use for biogas as a fuel is in a CHP system. CHP systems generate electricity and recover heat from the engine cooling system and exhaust that would otherwise be wasted. By recovering this wasted heat, CHP systems typically achieve total system efficiencies of 60 to 80 percent for producing electricity and useful thermal energy. Some systems achieve efficiencies approaching 90 percent. Typical CHP system components include:

- **Power Source.** Converts biogas into mechanical energy.
- **Reciprocating Engine.** Most biogas-fueled engines are modified natural gas engines. These engines have been developed to meet current emission standards and are fuel efficient. In addition to requiring water separation, H_2S must also be removed. Many state regulatory agencies also limit sulfur emissions, requiring the removal of substantial amounts of H_2S.
- **Gas Turbine.** There are two basic types of gas turbines: microturbines and direct-fired gas turbines.
    - Microturbines use a separate combustion chamber, allowing them to operate using a variety of fuels. Gas turbine technology offers lower NO_x emissions and maintenance costs than internal combustion engines; however, turbines have lower efficiency than engines. Microturbines do not need to have H_2S removed to operate. However, as with reciprocating engines, regulatory standards might dictate a similar level of H_2S removal.
    - Direct-fired gas turbines include an integral combustion chamber, which can be operated at higher efficiency than a microturbine. These turbines are typically installed in natural gas fueled power plants. Direct-fired gas turbine generator sets are commercially available for large projects, where power is produced in the 4-6MW range. Because the output of these systems are an order of magnitude larger than a typical farm AD/biogas system project, direct-fired turbines are not often feasible for on-farm applications.

- **Generator.** Converts mechanical energy into electrical energy.
    - Synchronous generators can operate either isolated or in parallel with the local utility grid. A synchronous generator can provide electricity to the operation if the utility grid is shut down, but they require a sophisticated interconnection. This is a more expensive choice, but it is a more commonly used option because it allows power generation to be independent of the grid.
    - Induction generators operate in parallel with the electrical grid. Because they must derive their phase, frequency, and voltage from the grid, induction generators cannot operate independently off the grid.

Figure 5.2 presents images of electricity generation using biogas.

Figure 5.2. Electricity Generation Using Biogas[42]

- **Control System.** Manages the CHP system by coordinating it with the biogas plant and by maintaining synchronous operation with the power grid.
    - The control system protects both the engine and the utility receiving the electricity if there are problems with the utility power source. If the utility power is off or if the project's electricity is out of its specified voltage and frequency range, the control system will disconnect ("trip") the biogas-fueled generator from the grid. In the event

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[42] Capstone Turbine Corporation, Products, https://www.capstoneturbine.com/ (accessed March 2020).

  - of a power trip, the control system could allow the generator to continue to provide electrical energy to the farm when a synchronous generator is used.
  - The control system should also monitor H_2S and CH_4 levels, adjusting or ceasing generation as warranted. Based on air quality permitting requirements, the control system may also monitor other air emissions.

- **Heat Recovery.** Use of a heat exchanger is a means to recover thermal energy (heat) that is generated from electrical production and might otherwise be wasted.
  - Recover heat from the engine cooling system (the heat exchanger is used in lieu of a radiator) and the engine exhaust (by providing water jacketing on the engine block and the engine exhaust), or the exhaust gas stream from a microturbine via directing the exhaust to an air to water heat exchanger.
  - Heat exchangers can recover 60 to 80 percent of the total waste heat produced by the power source, which is transferred to an exchange medium like steam, hot oil, or hot water.
  - Using the exchange medium, the heat can be transferred to maintain the digester's operating temperature or provide space heating and/or hot water for on-farm use.

Table 5.1 provides a summary of CHP technologies applicable for generating electricity from biogas, along with their advantages and disadvantages.

Table 5.1. Summary of Combined Heat and Power Technologies[43]

CHP System	Advantages	Disadvantages	Availability
Reciprocating internal combustion engine	• High power efficiency (40%+), with load-following capabilities • Quick startup • Relatively low investment cost • Can be used in "island mode" or operate on its own and have good load following capability • On-site overhauls • Operates on low-pressure gas	• High maintenance costs • Exchange medium temperatures are low, 180 °F or less • Biogas conditioning required to meet engine specifications for H_2S • Engine must be cooled even if a heat exchanger is not used • High levels of low-frequency noise	Up to 9 MW per unit
Microturbine	• Can operate on multiple fuels • Modular design • Fewer moving parts • Compact size and lightweight • Low air emissions • No cooling required • No H_2S removal required	• Costly • Relatively low mechanical efficiency • Requires pressurized fuel • Need multiple systems installed to use larger biogas flows	30 kW to 350 kW

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[43] "Catalog of CHP Technologies," EPA Combined Heat and Power Partnership, September 2017, https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies.pdf.

CHP System	Advantages	Disadvantages	Availability
Fuel cells	• Low emissions and low noise • High efficiency over load range • Modular design	• Costly • Low durability • Biogas requires extensive conditioning • Not commercially available	200 kW to 250 kW
Gas turbine	• High reliability • Low air emissions • High-grade heat available • No cooling required • Efficient steam generation • Can be used in "island mode" or operate on its own and have load following capability	• Requires high-pressure gas or in-house gas compressor • Poor efficiency at low loads • Output falls as ambient temperature rises	500 kW to 40 MW

While a gas turbine could be used on a very large farm AD/biogas system project, they have generally been used in projects on industrial sites and primarily fueled by natural gas. The overall conversion efficiency of CHP technologies far exceeds that of a comparable gas turbine. Because farms generally do not have a constant thermal energy demand that requires high-grade steam heat, CHP heat exchangers offer sufficient capability to deliver seasonal farm heating requirements. Lastly, CHP engine operations and maintenance (O&M) is similar to farm equipment like a tractor, offering a level of familiarity with O&M best practices. Large AD/biogas systems may find a gas turbine to better fit their needs if they have a constant high-temperature thermal load.

5.1.3 Biogas Storage and Electrical Generation

Short-term biogas storage offers the opportunity to shift the times of day when the electricity is generated, potentially enhancing the value of electricity by taking advantage of electricity rates that are higher on-peak than off-peak (see Tetra Tech's Biogas Storage Farm AD Report). Biogas plants are particularly well suited to serve as on-peak or "peaking" plants because their biogas production is steady, and the incremental cost of a larger generator to the project is relatively modest compared to the overall cost of the facility. Unlike many renewable energy sources such as solar or wind, electricity production from AD facilities can be actively scheduled to meet peak demand periods. AD system owners can potentially utilize this flexibility and negotiate for more favorable PPAs if they are able to assure the utility that they will be available during peak power times.[44]

5.1.4 Direct Use of Biogas

Directly using biogas for space and water heating may not be as financially rewarding as generating electricity or RNG. However, at farms having constant thermal needs and low electricity use, direct use may be a very viable and low-cost option to consider. With minimal conditioning, biogas can be used in modified or biogas-specific boilers, furnaces, and chillers. In addition to energy uses, biogas can be used as a critical feedstock in many bio-based products.

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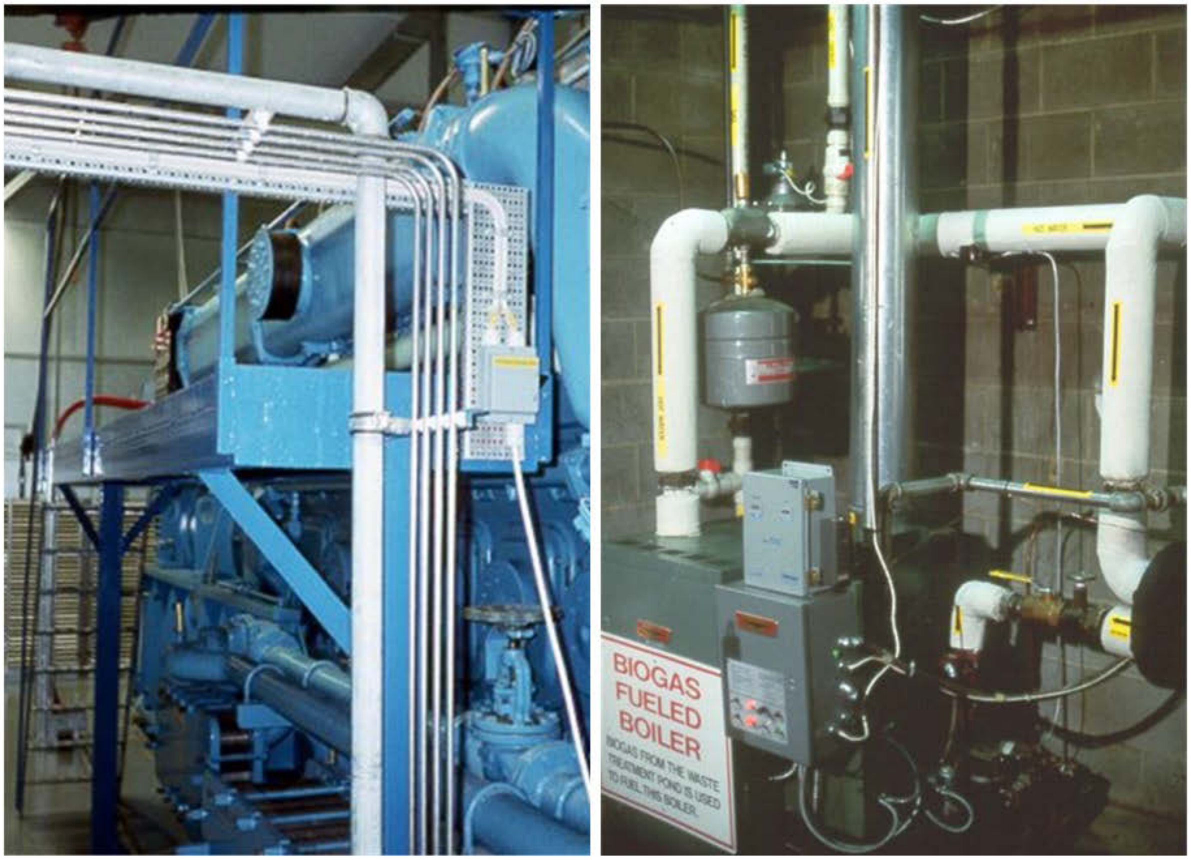
[44] "Biogas Storage Farm AD Report," Tetra Tech, April 30, 2015, https://focusonenergy.com/sites/default/files/2018-06/Biogas%20Storage%20Farm%20AD%20FINAL%20REPORT%2020150430.pdf.

- **Heating.** Boilers and furnaces can be easily fired with biogas for space and water heating, as shown in Figure 5.3. Space heating needs are seasonal in many parts of the United States, while water heating needs tend to be more uniform throughout the year. Dairy farms have a constant need for hot water due to their requirements to maintain sanitary conditions. Forced air furnaces could be used in place of direct-fired room heaters, but they are not typically used on farms. If the thermal needs are consistent year-round and 100 percent of the biogas can be used, direct heating may provide the best return on investment.
- **Chilling/Refrigeration.** Biogas can also be used to provide refrigeration. For example, at dairy farms a large percentage of the farms' electricity is used to cool milk. Many dairies use pre-coolers with well water; however, additional energy resources are needed to fully chill milk and maintain a safe temperature. Gas-fired chillers are commercially available and can be used for this purpose. For some dairies, this may be a profitable option. In addition to refrigeration, biogas can be used to fuel gas-fired air conditioning systems should space cooling be required on a consistent basis in critical areas.

Figure 5.3. Direct-Use of Biogas in Boilers



- **Mechanical Power.** Biogas can be used to operate machinery like feed mixers, blowers, or irrigation water pumps using the same type of reciprocating engine that is used to generate electricity. This is the simplest method of converting biogas to mechanical power, as biogas conditioning is minimal and no electrical generation equipment is involved. However, a continuous demand for mechanical power is needed. A steady duty cycle avoids the factors causing excessive engine wear, as well as maximizing biogas use.

5.1.5 Renewable Natural Gas

RNG is a term used to describe biogas that has been upgraded for use in place of fossil natural gas. What distinguishes RNG from its fossil natural gas is the supply source. Before pipeline injection, biogas must be conditioned to nearly pure CH_4 by removing all water vapor, CO_2, H_2S, and other impurities. Some of the equipment used for upgrading the gas is shown below in Figure 5.4.

- **Pipeline.** RNG has a heating value essentially equal to that of natural gas. Selling RNG to a natural gas distribution utility for pipeline injection requires that biogas meet the specification requirements for fossil natural gas. Natural gas transported through interstate pipelines travels at high pipeline pressure (anywhere from 200 to 1,500 pounds per square inch (psi)). Pipeline injection requires ready access to a natural gas transportation or distribution pipeline, so an AD/biogas system in proximity to a natural gas pipeline is preferred. Costs for laying dedicated RNG pipelines can vary greatly, so when these are necessary, they need to be included as part of the project's total cost. The variable and operating cost to compress RNG to match the pipeline pressure must also be included. Partnerships with natural gas distribution companies having interests in RNG may provide a pathway to reduce capital costs and risk. RNG can be sold directly to commercial or industrial natural gas customers if it can be wheeled through utility gas pipelines.

Figure 5.4. Process Equipment Used to Remove Biogas Impurities When Upgrading[45]

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[45] Bionomic Industries, Series 5000 Packed Tower Fume Scrubber, https://www.bionomicind.com/wet-scrubbers/5000-fume-scrubber.cfm (accessed March 2020).

- **Vehicle Fuel.** RNG also can be used as a vehicle fuel in place of fossil natural gas by being upgraded to R-CNG or R-LNG. Relatively low natural gas prices have provided an incentive for shifting vehicle fuels from gasoline and diesel to natural gas. R-CNG is used to meet requirements of the federal Renewable Fuels Standard (RFS), which is a program that requires the United States' transportation fuel to contain a minimum volume of renewable fuels. The RNG database maintained by the Coalition for Renewable Natural Gas (RNG Coalition) shows that as of 2019, a total of 173 R-CNG/R-LNG projects are underway in the United States: online (91), under construction (40), or under development (42). Figure 5.5 presents images of a centralized digester that is producing R-CNG for a city fleet.

  While the majority of projects are at industrial and WRRF facilities, several are also located on livestock farms. A Report published by Argonne National Laboratory reviews the development and execution of an advanced joint endeavor to create a manure-to-vehicle fuel project between a natural gas refueling infrastructure provider and a dairy cooperative.

Figure 5.5. Centralized Digester Producing R-CNG for City Fleet

5.1.6 Emerging Uses of Biogas

As market conditions rapidly change, the use of biogas for alternative uses presents increasing potential. Below are a few emerging uses of biogas:

- **Biobased Products.** Biobased products are derived from renewable agricultural, marine, and forestry materials. They provide an alternative to conventional petroleum-derived products and include such diverse categories as lubricants, detergents, inks, fertilizers, and bioplastics. Biobased products do not include food, feed, or fuel. RNG might be used as feedstock for some biobased products, but emerging technologies can also combine biogas with CO_2 using an ultra-high yield biocatalyst to produce a naturally-occurring thermoplastic material. This thermoplastic material can be used to make a wide range of biobased products, from furniture to building materials.

- **Alternative uses of the CO_2.** Emerging or alternative uses of CO_2 continue to emerge. Presently, the CO_2 from a CHP system is released to the atmosphere. The CO_2 removed from the biogas in RNG generation is also discharged to the atmosphere. Several projects have been announced in the United States that document that the CO_2 and heat output from a CHP system can be effectively used. Gooch and Shelford (2019)[46,47] have generated a comprehensive computer model of both the energy output of farm-based digesters and the energy required by greenhouses. Stefan Grimberg,[48] from Clarkson University, has linked use of aeroponic greenhouses and AD in a pilot program started in 2012. Other uses of CO_2 have been considered, such as the generation of dry ice.

5.2 Digestate and Its Uses

Digestate is the residual material that remains after the biogas is captured. Typically, it is composed of undigested organic material and inorganic materials contained in the digester feedstock, as well as nutrient-rich water. Figure 5.6 shows the land application of the dairy fiber that is recovered after digestion.

Figure 5.6. Land Application of Digested Dairy Fiber[49]

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[46] "Coupling Dairy Manure Anaerobic Digesters with Commercial Greenhouses – An assessment of Technical and Economic Feasibility," Livestock and Poultry Environmental Learning Community, March 5, 2019, https://lpelc.org/coupling-dairy-manure-anaerobic-digesters-with-commercial-greenhouses-an-assessment-of-technical-and-economic-feasibility/.

[47] "Coupling Dairy Manure Anaerobic Digesters with Commercial Greenhouses – An assessment of Technical and Economic Feasibility," Cornell PRO Dairy, https://ecommons.cornell.edu/bitstream/handle/1813/66973/DigesterGreenhouseProject.pdf?sequence=2&isAllowed=y (accessed March 2020).

[48] "An Aeroponic Greenhouse and Anaerobic Digester: Linking sustainability with research and education on Clarkson University's campus," Clarkson University, https://www.mcgill.ca/tised/files/tised/grimberg_-_an_aeroponic_greenhouse_and_anaerobic_digester.pdf (accessed March 2020).

[49] Recycling Organisher Materialien.

The solid and liquid digestate products should be carefully considered as a source of revenue or cost savings for an AD/biogas system project. Digestate can be used in many beneficial applications, including as a crop fertilizer, animal bedding, or as an amendment used to enhance soil tilth. Biogas commonly comprises about 3 to 4 percent of the digester's output on a mass balance basis, meaning that around 95+ percent of the mass used as feedstocks will remain after going through the AD process. The amount, quality, and nature of these products will depend on feedstock quality, digestion method, and the extent of the post-treatment refinement.

When the digester's ammonium effluent is spread on the ground, bacteria convert it into intermediate nitrite, which is then further converted into plant-usable nitrate. Plants typically convert about 3 percent of the available nitrogen into plant protein as happens with mineral fertilizers. The slow-release forms of bacterial-based protein nitrogen can also be very beneficial; slow-release forms of nitrogen may increase plant nitrogen uptake.

Digestion increases the availability of nitrogen as compared to undigested organic material, including manure, above its usual range of about 30 to 60 percent, depending upon the time of year. The phosphate content is not decreased, and its availability increases as a result of digestion. Potash is usually available at 75 to 100 percent.[50,51]

Thus, using digestate can increase crop productivity and yield. In some cases, this fertilizer can be certified as an organic product, which can have a very high economic value for the growing organic product industry.

During digestion, much of the organic nitrogen is converted to ammonium. This is combined with the ammonium contained in the feedstocks, making the digestate higher in ammonium concentration than the feedstocks. Ammonium is converted into nitrate by microorganisms in soil, which is readily used by plants. However, a sizable portion of the ammonium in the digestate is released as ammonia (NH_3) gas during storage and spray irrigation. A small amount of phosphorus is converted to Ortho-P, a soluble form of phosphorus; however, most of the phosphorus and potassium are retained in the solids of the digestate.

The Food and Drug Administration's (FDA) Food Safety Modernization Act (FSMA) Product Safety Rule placed limitations on using raw manure on crops produced for direct human consumption. The FDA also set microbial standards for composted manure. While digestate is not specifically described in the Act, the microbial standards should be considered when used on crops destined for human consumption.

Digestate should be monitored to ensure that pathogens are reduced and that its hygienic quality meets any sanitation standards required by its intended use. Most mesophilic digesters can achieve a 95 percent PRE, which is virtually free of all common pathogens except for some viruses and helminths. If warranted, digesting feedstocks in a variety of equivalent time and temperature

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[50] Meynell, P-J. "Methane: Planning a Digester." New York: Schocken Books, 1972. pp. 25.

[51] Fontaine, Doline, et al. "Nitrogen and Sulfur Availability in Digestates from Anaerobic Co-digestion of Cover Crops, Straw and Cattle Manure." SpringerLink, December 17, 2019. https://link.springer.com/article/10.1007/s42729-019-00151-7?shared-article-renderer.

relationships can achieve a 4-log (99.99 percent) PRE. This level of sanitation is usually done in a separate tank that is installed either before or after the feedstock is digested.

Due to a lack of trust, consumer acceptance is a potential obstacle to off-site digestate sales. The American Biogas Council has developed a digestate standard that recommends digestate testing and the use of information disclosures similar to those developed for compost-based products.

5.2.1 Unseparated Digestate

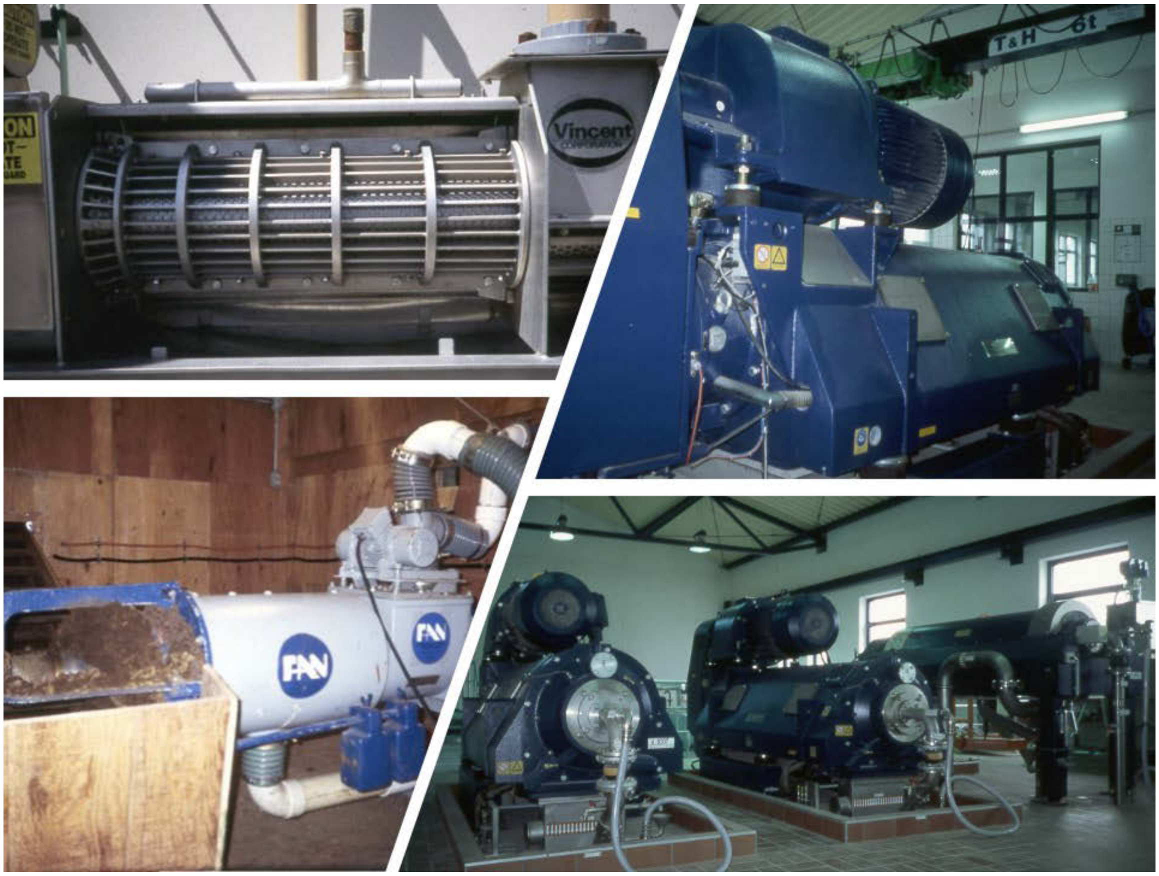
The simplest use of unseparated digestate is land application, where it serves as a source of plant nutrients for crop production. Due to the high concentrations of water in the unseparated digestate, it is most often applied using irrigation pumps. When using co-digestion feedstocks at a farm-based AD/biogas system, the agronomic application rates of the digestate may be different than a manure-only digester. Additionally, the nutrient composition of any co-digestion feedstocks must be accounted for to ensure the blended digestate remains within the current agronomic application rates.

5.2.2 Separated Solids and Liquids

Solids. All manures produce recoverable solid fiber; the exact percentage depends on the feedstock. For example, dairy cow manure produces more fiber than pig manure. As a result, pig manure digestate is rarely separated. As shown in Figure 5.7, the fiber fraction is usually recovered using mechanical solids separation equipment, such as screw presses or vibrating screens. When digested and cured by composting, this fiber has physical attributes similar to those of a moist peat moss. Separated solids have several potential uses:

- **Animal bedding.** Separated fiber from dairy cattle manure is often used as bedding and can offset farm costs or provide a new revenue source. Fiber used as bedding should be dried and must be managed to minimize any bacteria-causing ailments, such as mastitis.
- **Soil amendment.** Separated solids can be further stabilized by composting or mixing with other organic materials to produce a soil amendment or potting soil for horticultural use.
- **Horticulture Products.** Manure fibers have also been used to produce planter pots for use as starting bedding and vegetable plant starts.
- **Fuel pellets.** One method used for compressed biomass is pelletizing. The most common biomass resource that is pelletized and used for a fuel is wood, mainly from sawdust, wood chips, and shavings. High-quality fuel pellets using separated and dried dairy manure fibers could also be produced.

Figure 5.7. Examples of Fiber Separation Equipment



Liquids. After the fiber is removed, the main digestion product is a liquid organic substance. The liquid commonly has combined nitrogen, phosphorus, and potassium percentages ranging from 3 to 4.5 percent on a dry matter basis and can be spread directly onto farmland for its nutrient value. Additionally, liquid can be used on farm as non-potable flush water.

The liquid can be further processed to remove additional solids. This additional step using advanced technologies is often employed when maximum removal of nutrients is desired. This may include removal of solids and potential concentration of nutrients, which may be desired when conveying or transporting nutrients from a watershed to another location (i.e., outside of the watershed where nutrients are less saturated).

The liquid can also be processed using a number of advanced technologies, similar to those used for wastewater treatment at a WRRF. These technologies include membrane separation, ultrafiltration, ion exchange, evaporation, and reverse osmosis. Their use can further refine filtrate to concentrate nutrients and manufacture potable water. While this option requires significant capital and operating costs, it can be applied in arid areas where significant sources of fresh water are unavailable.

Nearly all manure is land applied as demonstrated in Figure 5.8, which means that some of the nutrient value is returned to the soil for plant growth. However, much of the nutrient value contained in manure can be lost before it is recycled or before the nutrients are available or usable for plant use.

Figure 5.8. Filtrate Applied Close to Ground to Prevent Release of Nitrogen as Ammonia[52]

Mineral fertilizers are often preferred by agriculture. Fresh manure tends to suppress or slow plant growth. Fresh manure applied during active growth may "stick" to the plant or its leaves, reducing respiration and plant growth. The less viscous and the more flowable a manure nutrient source, the more the plant will benefit from manure application.

5.2.3 Choosing the Best Digestate Use

When deciding which digestate option is right for your farm consider:

- Land required for applying recovered nutrients at agronomic rates;
- Co-digestion feedstock impact on the Comprehensive Nutrient Management Plan (CNMP);
- Expense of digestate handling and conversion equipment;
- Cost savings from on-site digestate use;
- Revenue potential from digestate product sale;
- Partners (e.g., who will buy products, how will products be distributed,); and
- Time needed to develop and manage new value-added products.

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[52] U.S. Department of Agriculture, https://www.usda.gov/, (accessed March 2020)

Danish Energy Agency, https://ens.dk/en, (accessed March 2020).

6.0 Economic and Financial Factors

So far, the technical aspects of AD/biogas systems have been reviewed in this PDH. Obtaining a basic knowledge of the AD process, the volume and characteristics of the feedstocks to be digested, their expected biogas volume and characteristics, and the possible biogas use options are essential to understanding how this technology can work for you.

The next phase involves the economic and financial factors needed to achieve project success. Not only should a project be cost-effective, it must meet your financial goals. A project's "economics" demonstrates whether it has a good financial foundation by determining if it is, or if it is not, financially viable to implement. The project's financial factors reveal if it can generate sufficient revenue to meet profitability goals. One profitability metric is that the project must not only generate the revenue needed to meet its expenses, but also generate sufficient cash flow after expenses to meet overall financial goals.

A successful AD/biogas system also requires a sustainable business model. The project's economic factors include well-defined capital costs, expenses, revenue, income, and cash flow, among many others. Personal goals for a project's liquidity and profitability potential define the financial factors. The business model could also consider involving partners, using third-party investments, or other traditional "cooperative" models to share project risk and reward.

6.1 Capital Investment

The first step in evaluating financial viability requires establishing the capital investment, which is the funding needed to build the project. As shown in Table 6.1, the investment is the sum of two items: a construction budget and an owner's budget. A farm's "Uses of Funds" statement defines how the money will be spent. A similar type of statement is a required element in any business plan, and it is also essential when borrowing capital. Some of the capital costs associated with building an AD/biogas system may include the following:

- Land acquisition;
- Site development;
- Civil works (earthwork, site work, etc.);
- Structure (buildings, tanks, etc.);
- Equipment (mixers, pumps, generator, relays, etc.);
- Equipment installation;
- Conveyance systems;
- Project controls;
- Interconnection;
- Permitting fees;
- Project management;
- Consulting and legal;
- Contractor overhead and profit; and
- Developer costs for process design and engineering services.

The example shown in Table 6.1 has a turn-key construction budget, a project that is executed as a completed product including all aspects. Some of the items listed above are also included. This is contrasted with a built-to-order project in which the contractor or owner/operator builds an item to the buyer's exact specifications.

Table 6.1. Capital Budget Example

Construction Budget Items	
	Digester Turnkey Cost
+	Engineering and Permits
+	Construction Insurance
+	Interconnection Costs
+	Filtrate Storage System
+	Developer's Fee
=	**Construction Budget Total**

Owner's Budget Items	
	Working Capital
+	Financing Costs
+	Contingency
=	**Owner's Budget Total**

As you might expect, there are many moving parts to consider when developing an AD/biogas system. The more thoroughly defined the project's components are, the less likely that an unpleasant budgetary surprise will happen later. For example, a critical error might occur when "farm-grade" equipment definitions are used, but heavy-duty "industrial-grade" equipment is really needed for the intended work. Codes or operating conditions may dictate equipment and components that would exceed the quality normally utilized by farm operations. These will result in unanticipated cost overruns if they are not initially considered.

Table 6.1 also includes an often overlooked or underestimated capital use element: the owner's budget. Again, many items can be debited against the owner's budget, but a key element in any project is its contingency factor as described below. Placing contingency costs in the owner's budget ensures that the project owner retains control over the distribution of funds should they need to be spent.

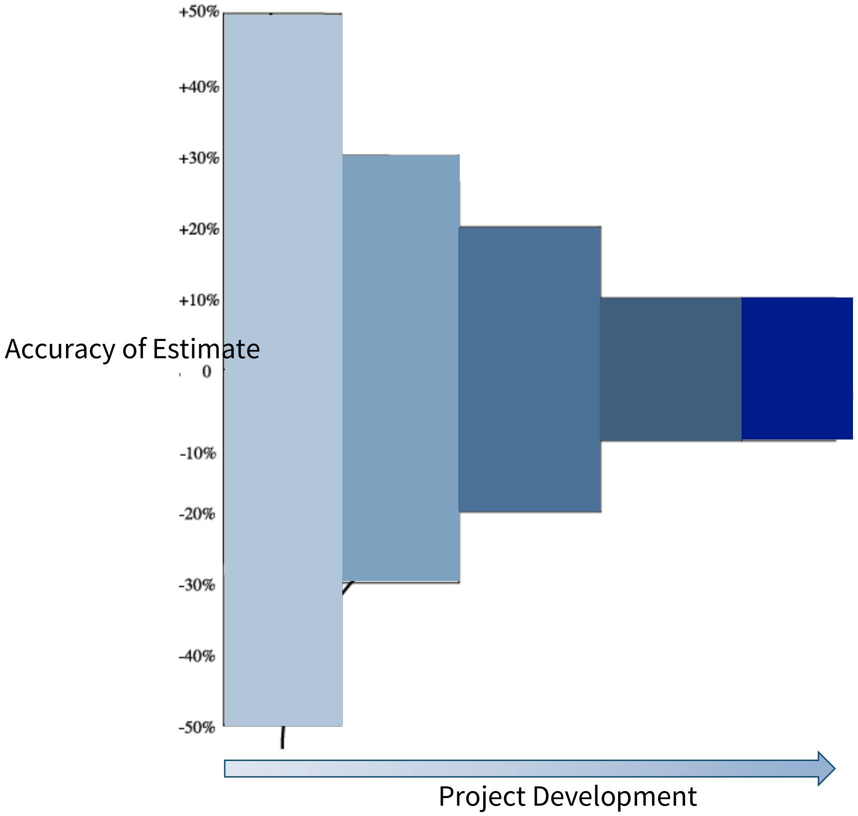
Another key item is working capital, which is the essential up-front money needed for system operation until revenue receivables begin. Other items that may be debited against the owner's budget include owner construction salaries and expenses, and construction interest and related financing costs.

6.1.1 Cost Estimating Accuracy and Contingency

Contingency covers unexpected events that are not accounted for in the planning stages. It may also include other factors such as uncertainty, errors, and omissions. Adding contingency to project cost estimates is a common practice. The amount of contingency included varies based on the degree of project information available and the uncertainly of that information. As project development evolves and more information is gathered about a project, the accuracy of the information increases. Conversely, as the project development evolves, the uncertainty, and therefore the contingency, should decrease.

Project information gathered as development evolves includes an increase in information or details about the site specificity, location, feedstock, technology selected, project design, equipment needed, off-takes and related costs of each of these and many other factors. Figure 6.1 illustrates an example of the "cone of certainty" in technical and cost estimating through a given project cycle. As project development continues (moving left to right on the graph) and more information is collected on a given site-specific project, the resultant accuracy of the project costs should increase.

Figure 6.1. Cone of Certainty in Project Cost Accuracy[53]



As you might expect, the amount of contingency factor can have a range of values depending on the project's level of development. During initial scoping studies, the contingency factor might be plus or minus 50 percent, and it will be lowered at the completion of various project development phases.

6.2 Operating Expenses

The AD/biogas system's O&M costs, which are the ongoing costs for running the system, should be estimated for the following items, as warranted:

- Daily operating labor;
- Purchased utilities;
- Mechanical systems maintenance;

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[53] Modified by Tetra Tech as of 2019 based on the "Estimating the Cost of Capital Projects: an Empirical Study of Accuracy Levels for Municipal Government Projects". Canadian Journal of Civil Engineering, 2002, 29, 653-661.

- Chemicals and consumables;
- Digestate disposal;
- Regulatory compliance;
- Insurance;
- Miscellaneous; and
- Property taxes.

The cost examples shown in Table 6.2 list many of the operating expenses that are applicable to projects and the factor by which they can be estimated. Daily operating labor is commonly assumed to be done by a farm employee to feed the digester and perform the required daily O&M. Operational labor is frequently underestimated, which can significantly damage project economics. Even a farm-based digester generally requires at least one operator close to full time to feed and perform maintenance and service. Lots of factors impact this, but for planning purposes it is recommended that this item be overestimated in budgets.

Table 6.2. Examples of Operating Expenses

Expense	Units
Daily Labor, if needed	\$/hour
Engine O&M	¢/kWh
AD/Biogas System O&M	\$/day
H_2S Removal	\$/year
Insurance	\$/year
Outside Engineering & Other Services	\$/year
Filtrate Management	¢/gallon

A digester is a mechanical system that requires constant attention to maintain its performance. A lack of proper focus on this has caused many AD projects to fail. The owner should be prepared to dedicate the time required to properly perform routine and unscheduled maintenance.

Daily labor includes routine items such as checking mechanical systems, electrical systems, assuring proper control system functions, routine engine maintenance, and checking proper operation of biogas and other meters, digester pH and temperature, and recording the assembled data. Unclogging pumps from obstructions caused by foreign materials may require additional time if the routine inspection indicates there is a problem.

Biogas-fueled engines require routine oil, filter, and sparkplug replacement. Depending on the engine's duty-cycle, oil changes are usually done between 500 to 1,500 hours of operation. After about 20,000 hours, a top end rebuild of the engine may be necessary. Replacing the engine heads normally occurs at intervals of 8,000 to 12,000 hours. Engine O&M is often presented on a cost per kilowatt basis (cents/kWh) basis and includes all of the outside labor and related materials required.

The mechanical parts of an AD/biogas system also require routine O&M and the occasional repair. General O&M costs can be estimated on a daily cost basis (\$/day). To avoid a sudden financial burden due to emergency maintenance, many projects also maintain an O&M reserve fund to cover unexpected major costs.

Depending on the AD/biogas project ownership structure, daily labor may be provided by the farm. Because the farm's primary purpose is to generate a product (and not operate the digester), evidence shows that digester O&M becomes secondary to traditional farm responsibilities. This is to be expected as the laborer is either not trained in digester O&M or it is an additional role that gets overlooked. This can, and often does, lead to the project underperforming expectations or failing outright, and would put the level of financial investment of the project at high risk. The perspective of AD projects as secondary within farm operations must change in order to achieve success in the overall AD project performance. Considering the significant investment to install and operate an AD/biogas system (millions of dollars), this perception requires change.

It is very important to note that a well-trained labor force is essential to a successful AD/ biogas operation.

Typically, farm staff can perform simple O&M tasks and the complex tasks are performed by independent specialists. Some AD/biogas system owners use a third party under a service contract for all the system's O&M. When a farm is operating on a short-handed basis, this might be the preferable option. If used, the cost of this O&M service contract must be included.

If required, removing H_2S from biogas is a cost factor that can be estimated on an annual basis ($/year). When the biogas conversion source is defined and regulatory permitting begins, this cost factor can be better defined using the H_2S emissions that are projected for the air quality permit.

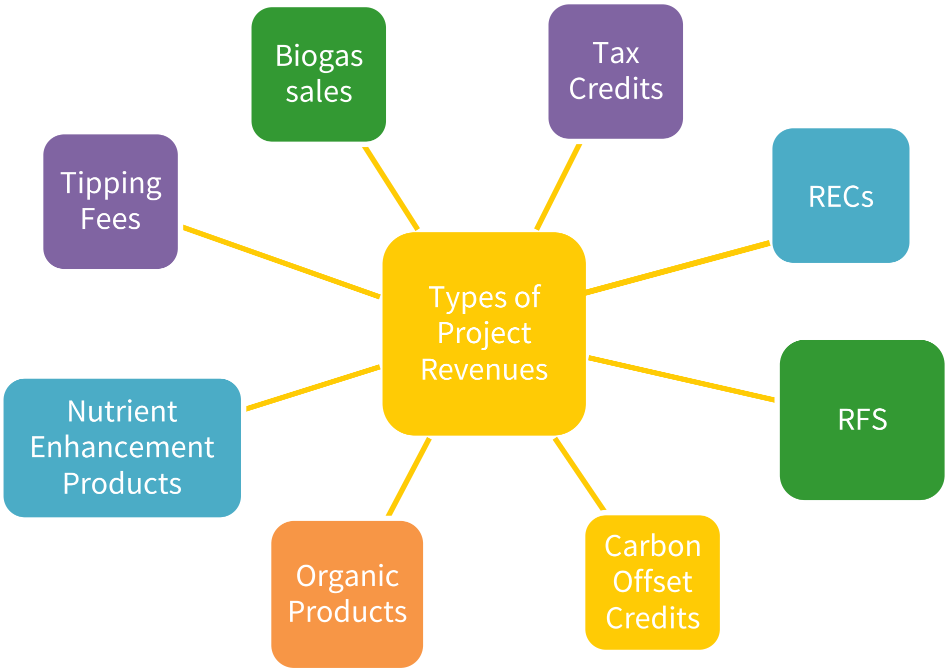
Any project will periodically use outside engineering, as well as accounting, laboratory services, and insurance. These are usually estimated on an annual cost basis ($/year). There are usually no added property taxes, because the AD/biogas system is normally considered agricultural property. However, when certain equipment, such as de-packagers, is installed to process co-digestion feedstocks, there may be added property taxes ($/year).

Co-digesting other organic wastes is attractive from a revenue perspective, but it can affect filtrate disposal costs due to the increased feedstock volume being processed. The magnitude of the increase depends on the individual site's ability, or inability, to absorb any additional nutrients without impacting the farm's CNMP. If needed, filtrate management expenses can be estimated on a cost per gallon basis (¢/gallon). If co-digesting packaged products, cost for packaging disposal should also be included on an annual basis ($/year).

6.3 Project Revenues

As shown in Figure 6.2, a number of revenue sources can be derived from an AD/biogas system. One key focus in the development of a successful project is to optimize the value of the biogas revenues. Also, having a full range of saleable co-products that provide additional revenues can make a significant difference in investment merit. Quite simply, it can be very difficult to justify investing in an AD/biogas system when only considering the revenue received for purchased electricity offsets and selling any surplus electricity in current market conditions. The most profitable operation is one that maximizes revenues from all co-products, especially to use the waste heat from a CHP plant. It is always prudent to assume market prices will change during the project's life, and always be very conservative when estimating potential revenue sources.

Figure 6.2. Types of Project Revenues



Because market conditions are often unpredictable, a conservative means of project revenue should be considered at the initial project development phase. As the project is further developed and project-specific values and detailed proformas are developed, the degree of conservatism is often decreased. This is generally done when project off-takes are secure.

As an example, the nominal percentage growth rates for project expenses (e.g., labor) should initially be assumed to be zero percent and off-takes (e.g., electricity, RNG) at a lower than market level. This dampens the expectations that there will be significant real increases in the value of inputs and outputs. It also presents a more realistic perspective of their value in today's economy, thus avoiding the misleading margins that can result during the project's out-years.

6.3.1 Biogas Sales

The revenue from the sale of biogas will vary with the off-take arrangement, but these can take many different forms. For example, if the farm is using its biogas to operate and run a CHP system, this system can offset the farm's electricity and heating costs, and any excess electricity can be exported off site and sold at wholesale rates. However, some states have incentives to encourage biogas-generated electricity that exceed the farm's retail rate. In these cases, it is better to sell all of the electricity to the grid and use the heat from the CHP system on-farm. In this case, electricity is purchased on a per kWh basis.

Depending on the individual utility, there is a possibility for varying on-peak/off-peak rates. These rates can make a significant difference in the operational plans of the project, with any downtime for maintenance being scheduled for off-peak hours or sizing the generator and storage to use most of the biogas during the on-peak period. Utility contracts and power purchase agreements can have a major influence on project profitability.

If the farm is producing on-site RNG, then the revenue comes from using the RNG on site or injecting it into a pipeline. If the goal is to use RNG as a transportation fuel, compression will take place on site or contracts will be required to collect the revenue from the CNG that is dispensed off-farm. Generally, in the case of RNG, the project will be generating revenue from the sale of the RNG plus the credits for use in the transportation sector.

6.3.2 Federal Electricity Production Credit/Investment Tax Credit

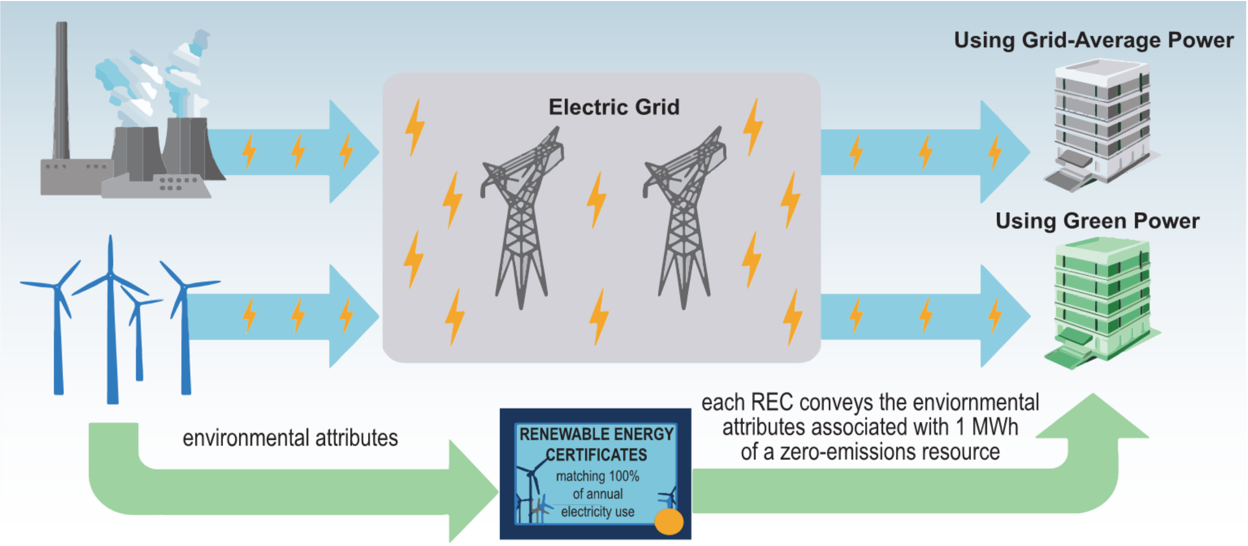
The federal Electricity Production Tax Credit (PTC) is an inflation-adjusted per-kWh (cents/kWh) tax credit for renewable electricity generated by qualified resources and then sold to an unrelated person. The credit's duration is 10 years after the date the facility is placed in service. The current PTC is 2.3 cents/kWh.

AD/biogas systems may elect to claim an Investment Tax Credit (ITC) in lieu of a PTC. The ITC provides a tax credit equal to 10 percent of the eligible property used, and usually is the better of the two federal incentives from a financial perspective. However, pursuing the ITC instead of the PTC requires a tax opinion from a qualified professional. As a result, a project should use a PTC in any initial evaluation. Note: At the time of publication of this Handbook, the PTC and ITC are only available for projects that utilize at least 75 percent of their biogas to generate electricity; there is not an equivalent program for RNG projects.

6.3.3 Renewable Energy Certificates

Many states have some form of a renewable energy portfolio standard and many electric utilities are buying Renewable Energy Certificates (REC) for compliance. RECs are tradable, non-tangible energy commodities representing proof that 1 MWh of electricity was generated from a qualified renewable energy resource. In some cases, electric utilities provide project funding in return for the rights to the RECs generated by an AD/biogas system. Figure 6.3 below demonstrates a summarization of RECs.

Figure 6.3. Illustration of RECs[54]



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[54] "Offsets and RECs: What's the Difference?," EPA Green Power Partnership, February 2018, https://www.epa.gov/sites/production/files/2018-03/documents/gpp_guide_recs_offsets.pdf.

6.3.4 Renewable Fuel Standard/Renewable Identification Number

The RFS, a federal policy established by Congress under the Energy Policy Act of 2005 and later expanded under the Energy Independence and Security Act of 2007, provides financial incentives for RNG that is used as a vehicle fuel that can be much greater than the value of the gas. See Sections 2.4, 2.6, and 5.1.5 for more information about the value of RNG and transportation fuels.

Additional information can be found in AgSTAR's RNG from Agricultural-Based AD/Biogas System web page.

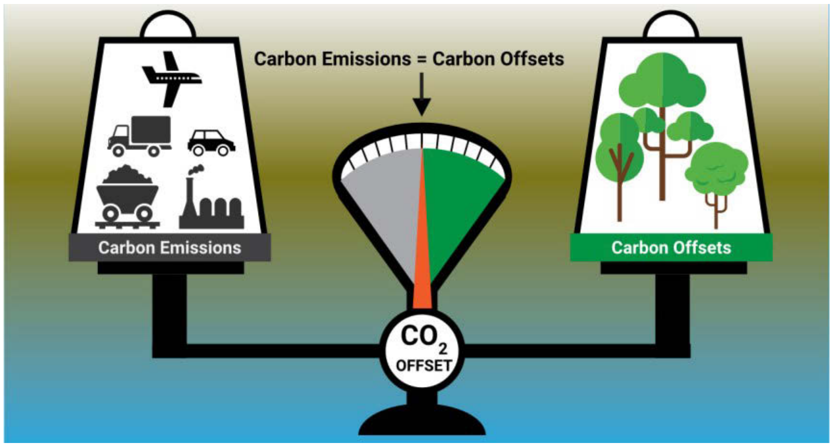
6.3.5 Low Carbon Fuel Standard

Several states have created complementary programs to the federal RFS. These state programs are also focused on the reduction of fossil fuel-based fuel. For example, California and Oregon have LCFS and Clean Fuels incentive programs, respectively. Federal and state incentives are additive, meaning both incentives can be earned for a specific project and provide a substantially greater value of the gas. See Sections 2.4, 2.6, and 5.1.5 for more information on the value of RNG and transportation fuels. At this time, these programs are generally geared toward crediting the value of the RNG based on its CI. This is described in greater detail in Section 2.6.6. Additional information can be found in AgSTAR's RNG from Agricultural-Based AD/Biogas System web page.

6.3.6 Carbon Offset Credits

In some voluntary markets in the United States, carbon offset credits may be earned by reducing GHG emissions, such as the CH_4 recovered from an AD/biogas system. These credits have an economic value and can be bought and sold on commodity exchanges, through private transactions, or through credit aggregators. Besides serving as an additional revenue source, carbon offset credits can also provide incentives for outside parties to provide project funding for AD/biogas systems. These transactions can be based on the volume of CH_4 emissions avoided or produced by the project, or the amount of electric power generated. Additionally, organizations and individuals can purchase carbon offset credits through voluntary offset companies as an opportunity to reduce their environmental impact. Figure 6.4 below demonstrates a summarization of carbon offset credits.

Figure 6.4. Illustration of Offset Credits[55]



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[55] Isaac's Science Blog, Carbon Offsetting, https://isaacscienceblog.com/2019/01/22/carbon-offsetting/ (accessed March 2020).

6.3.7 Separated Fiber

Digested fibrous materials can be used as bedding material, soil amendment product, or to create new products such as CowPots™ and building materials. This material represents a cost offset if used onsite or a revenue source if sold to a third party. Sales are typically arranged per unit of weight or volume at a specified moisture content, and other specifications such as temperature, nutrient content, or particle size distribution may be included. One study[56] found that 30 million cubic yards per year at a likely market value of $217 million could be sold as a peat moss replacement and as on-farm bedding material from dairy farms that are candidates for using an AD/biogas system. It is important to note, however, that these markets are emerging and the sales of these products require market development and contract negotiation.

6.3.8 Fertilizer (Nutrient Recovery and Sale)

Because of its dilute nature, transportation costs of manure are high and limit the potential of generating revenue from liquid filtrate sales. Recovery of nutrients from the manure is of increasing value, as the quality of the nutrients from digested manure can be easily utilized by plants and can be applied directly without burning crops (when compared to undigested manure). Also, because livestock farms have been in operation for many generations and are often in high concentrations geographically, the amount of nutrients in farming communities can be in excess of plant uptake. Thus, recovery and transport of nutrients out of a given watershed has been shown to be of high value from an environmental perspective.

Recovery and selling of nutrients, such as nitrogen and phosphorus, from digested feedstocks is an emerging opportunity. One study sponsored by the Innovation Center for U.S. Dairy found that about 330,000 tons of nitrogen and 110,000 of phosphorus could annually be recovered from dairy farms that are candidates for using an AD/biogas system. The recovered fertilizers were estimated to have an annual value of almost $800 million. Again, it is important to note that these markets are not readily available, and the sales of these products will require significant market development and contract negotiation. In most areas, AD/biogas projects receive little or no revenue from the sale of digestate.

If nutrient recovery and sale is planned, a guaranteed minimum primary plant nutrient analysis should be provided for the most beneficial use of this product, as the product is purchased per unit of weight at a specified nutrient and moisture content. The study results may also be subject to applicable safety standards.

6.3.9 Tipping Fees

Tipping fees received from co-digestion feedstocks are a potential revenue source. Organizations that produce large volumes of waste will often partner with a bidder to off-take their waste. AD/biogas system owners that win these bids can generate significant revenue from the tipping fees associated with accepting these wastes. Depending on its composition, tipping fees are based on a per ton or per gallon basis. The best practice of establishing long-term off-take contracts, with guarantees for quantity and composition, is helpful in securing project financing. See Section 4.3 for more

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[56] Informa Economics. "National Market Value of Anaerobic Digester Products." Prepared for Innovation Center for U.S. Dairy, February 2013.

information about best practices for co-digestion. A lack of standards and specifications for co-digestion feedstocks make accepting off-site wastes a challenge. Co-digestion feedstock quantity guarantees reduce the risk of revenue shortfalls. Significant reductions in waste volume could potentially cripple a project financially, especially one that's heavily dependent on them. Likewise, specifying material composition reduces project risk by ensuring the material is free of potential contaminants.

Figure 6.5. Revenue Examples – Case Study

The table lists some example revenue sources and their unit factor. For example, on-farm retail electric purchases are estimated in units of cents per kWh. An initial revenue estimate can be made by totaling the farm's energy purchases (kWh) and multiplying the result by the farm's retail electric rate. Your electric bill includes cost items such as a basic monthly service charge, and it may have a demand charge if your electric utility bills for the peak amount of current used (kW).

Example Revenue Sources

Source	Units
Retail electricity Offsets	¢/kWh
Wholesale Electricity Sales	¢/kWh
Thermal Energy Offsets	$/unit
Federal Energy Production Credit	¢/kWh
Electricity RECs	¢/kWh
Co-digestion Feedstock Tipping Fee	¢/gallon
Fiber	$/cubic yard

Excess electricity produced above the on-farm requirements is normally assumed to be exported and sold at a wholesale rate in cents per kWh. Including the parasitic electricity used by the AD/biogas system, most farms have wholesale electricity sales potential that significantly exceeds the on-farm annual consumption.

Calculating thermal energy offsets depends on the heating fuel being replaced. Fuel oil and propane are normally measured on a cost per gallon basis ($/gallon); natural gas uses a unit called the therm as the billing factor. A therm is approximately the energy equivalent of 100 cubic feet – often referred to as 1 CCF – of natural gas. Thermal offset revenues can be estimated by multiplying the farm's thermal fuel purchases by the applicable retail rate per unit.

The value of REC sales derived from wholesale electricity vary by region. In active REC markets, they can range between 2.0 and 3.0 cents per kWh. Depending on the waste source, fees received as the tipping fee for waste feedstocks can become the project's main revenue sources and are usually estimated in the fee received to units (cents per gallon). Many waste haulers use rigs having a 6,000-gallon tankage capacity. Tipping fee revenue can be estimated by multiplying truck tankage capacity by the tipping fee. You can multiply this result by the estimated number of waste truckloads per year to derive annual tipping fee revenues.

6.4 Owner and Operator Models

Historically, agricultural AD/biogas systems have been owned and operated by the farm. Today, farm-based AD/biogas system projects have many developmental challenges that require more advanced expertise to navigate. As a result, innovative business models are being deployed to share project risk and reward, diversify project revenue sources, and more efficiently develop systems. There are a number of business models with respect to who owns and operates the AD system. Successful business models:

- Involve partners along the value chain, such as co-ops, customers, suppliers, and processors;
- Draw on strengths, such as marketing, contracting, permitting, energy, design, or operations;
- Search for common goals, such as financial, public relations, or market expansion;
- Evaluate third party investment, ownership, and operation; and
- Look to traditional cooperative models for use with manure solids, nutrients, energy, or fuel.

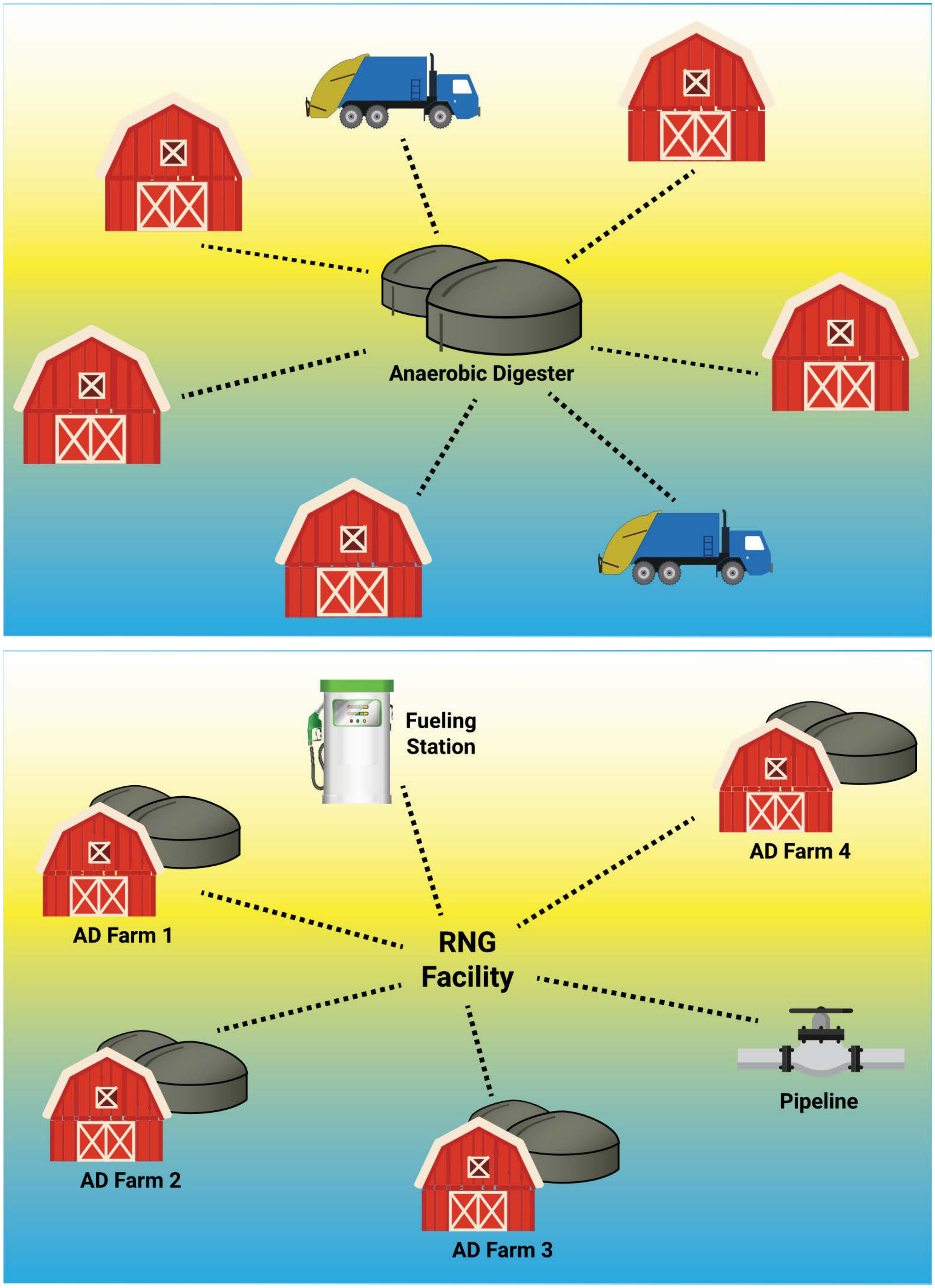
General types of business model ownership structures are presented in table 6.3 below.

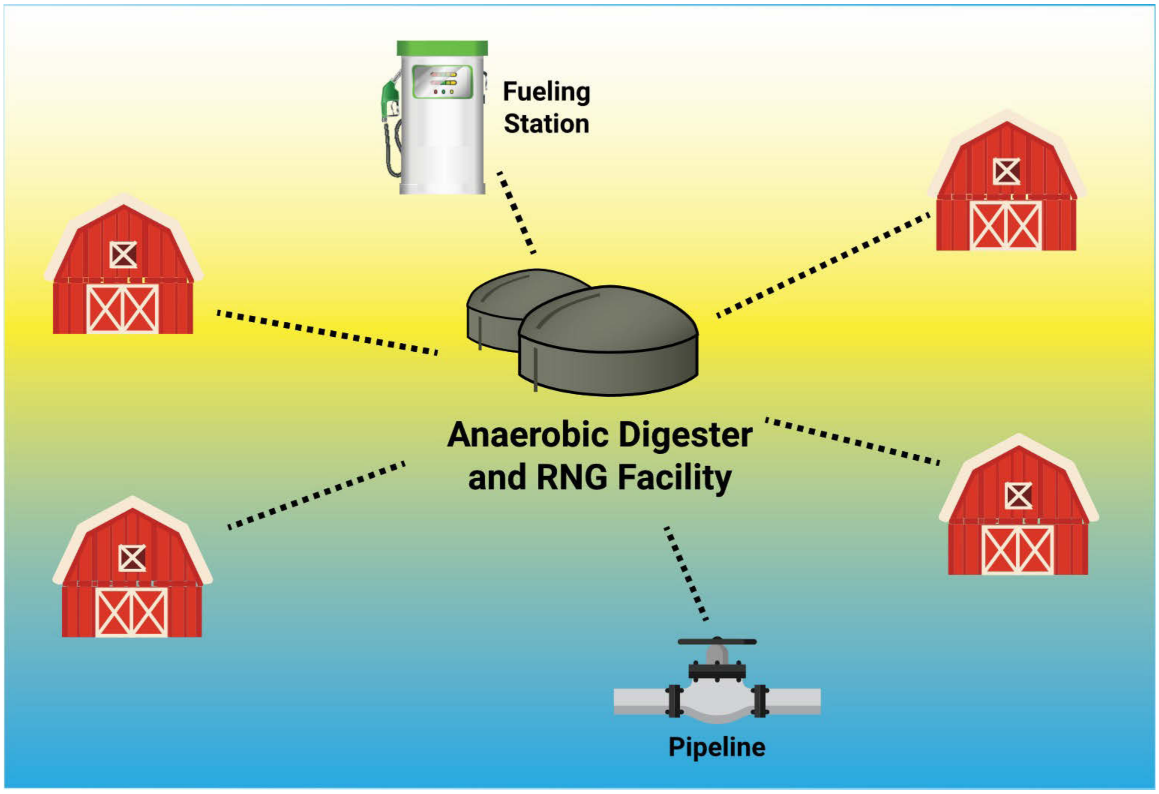
Table 6.3. Types of Business Model Ownership Structures

Model	Ownership Structure
Farmer owned and operated	A farmer typically owns and operates a digester on site and uses manure from the farm, at a minimum, as feedstock. In some cases, the farmer may accept manure or other organics from off site, generally for a tipping fee.
Third party owned and operated	A site owner may receive a rental fee or a share of the project's net income, but the third party owns, operates, and invests in the digester. The third party may be a venture capitalist or an investment group specializing in green energy projects. The third party may also manage the feedstock.
Third party operated	A third party, who does not own the digester, operates the digester, manages feedstock, and manages other aspects of energy and effluent sale. The digester and feedstock can be owned by a single entity or many.
Hub and spoke	This business model can take two general forms: centralized digester or centralized processing, either of which could be owned by the structures mentioned above, or a municipality. It could also be part of a cooperative, which relies on a voluntary partnership of individuals that jointly own and democratically control the project. • Centralized Digester – As shown in Figure 6.5, feedstocks from multiple locations are collected and transported to a centralized anaerobic digester. It can be advantageous for communities to build one digester and distribute the biogas and digestate generated. • Centralized Processing - Digesters at multiple locations send the biogas and/or digestate to a centralized processing facility. Biogas and digestate processing equipment can be expensive and a centralized processing facility provides a cost-sharing opportunity, lowering the financial burden for each entity.

Figure 6-6 demonstrates a hub (central AD plant) and spoke (numerous surrounding farms) model, as well as other types of hub and spoke models.

Figure 6.6. Illustrations of Hub and Spoke Systems and End Uses





6.5 Project Finance

All projects require capital investment, which can be a direct cash equity contribution from the owner, financed with a loan, or both. For projects financed using borrowed money, paying the borrowed principal and interest can be the largest source of the project's expenses until the debt is retired. Therefore, one or preferably more initial financing cost estimates should be obtained to determine the annualized debt cost the project will incur.

6.5.1 Owner Equity Financing

Paying for a project with your own cash saves money since you do not have to pay interest to a bank or share the project's profits with a third party. It is important to repay yourself, with interest, for any owner equity funds invested in the project.

6.5.2 Debt and Equity Financing

Private funding may come in the form of debt financing, equity financing, or a combination of the two. Equity financing raises funds from third parties to provide up-front capital in return for partial ownership or other valuable considerations. Equity financing is most common for larger-scale AD/biogas system projects, which are most likely to attract third party investors, such as energy or technology companies.

Debt financing involves securing capital from banks, credit unions, savings and loans, or other traditional financial institutions. Some more common debt financing methods involve bank loans, lines of credits, and mortgages. This provides project funding, but they require an agreed-upon set of repayment terms and conditions, such as loan period and interest rate. The terms and conditions of debt financing are subject to the borrower's financial status and any previously agreed upon cost-sharing arrangements.

6.6 Financial Assistance for Agricultural Projects

Owners and developers of AD/biogas systems can use several financial assistance methods that include grants, cost-sharing, loan guarantees, and industrial revenue bonds. Many AD/biogas system projects apply for and receive funding from a combination of these. Agricultural Extension agents are usually familiar with these assistance programs and can be a highly useful information source. Also, many project developers, technology suppliers, and consultants maintain a database of the available programs for their client's use.

- **Grants.** Through grants, a federal or state agency provides a cash award to support the installation of an AD/biogas system. Grant funding may be received before the system is constructed and does not require repayment. One grant fund that is often used for AD/biogas system projects is the USDA's Rural Energy for America Program (REAP). In some cases, federal grant money is provided to individual states for administration. For additional information on funding programs, view AgSTAR's Funding On-Farm Anaerobic Digestion fact sheet.
- **Cost-Sharing.** Sometimes referred to as cash reimbursement, cost-sharing lets project owners purchase and construct an AD/biogas system, and then apply for cost-sharing funds after the project is completed. Cost-sharing arrangements do not require repayment. The USDA NRCS Environmental Quality Incentives Program (EQIP) is an example of a cost-sharing program. Note that eligibility requirements vary by program and these criteria should be evaluated during the planning process.
- **Loan Guarantees.** Under a federal or state loan guarantee, a public agency guarantees full repayment of a loan. Loan guarantees typically lower financing costs by lowering a loan's interest rate. A guaranteed loan may allow a project to attract a larger number of potential lenders than a traditional loan. This is because potential lenders are guaranteed full repayment of the loan, even if the owner defaults. In some cases, loan guarantees may require personal guarantees from individual stakeholders in the project. An example of an applicable federal program is the USDA's Section 9003 Biorefinery, Renewable Chemical and Biobased Product Manufacturing Assistance Program.
- **Industrial Revenue Bonds.** Industrial revenue bonds (IRB) raise capital by issuing bonds that are used to build or buy a facility like an AD/biogas system. A bond is a fixed income investment, set for a defined time period using either a variable or fixed interest rate. A state or local public entity issues the bond, but they do not actually fund the loan. The loan's funding source comes from an investor that buys the bond. The public entity owns the facility or some of its equipment for the length of the bond. IRB loans typically have a lower interest rate and a longer term than a simple interest loan provided by a bank. An IRB can sometimes provide property tax relief to the operator because a public entity owns the assets during the loan period. Asset ownership reverts once the IRB is repaid. An operator can re-purchase the IRB when an arbitrage profit margin can take advantage of lower interest rates and longer terms. In general, only larger, centralized AD/biogas system projects rely on IRB bonds.

The AgSTAR website includes resources that can help identify project financing:

- AgSTAR Vendor Directory – Includes listings for financing specialists who provide loans for biogas systems, fund on-farm biogas systems for profit, and broker the sale of carbon offsets and renewable energy certificates.
- Attracting Institutional and Impact Investors – Provides an overview of investor interests and needs, and why biogas systems can be a good fit.

7.0 Screening and Feasibility Studies

Implementing a project requires due diligence and careful analysis. An AD/biogas system is a significant financial commitment, often costing millions of dollars, and effective planning using a logical series of sequenced steps can help lead to project success.

If initial screening warrants further interest, a series of iterative pre-feasibility studies helps refine the analysis to determine if the project remains a good candidate. A go-forward decision from the pre-feasibility studies leads to the planning and conducting of a full feasibility study. The full feasibility study is the final step in deciding if a proposed AD/biogas system should be implemented.

Following initial screening, professionals who are familiar with performing project feasibility studies for AD/biogas systems should be engaged. It may be worthwhile to hire a consultant or project developer to serve as an advisor or project manager from design to completion. Developer costs will vary based on the project type and their involvement level, so it is important to decide the type and amount of expert assistance needed.

Depending on project complexity and the detail level needed, study costs can range between free for an initial pre-feasibility scoping study to upwards of $100,000 for a detailed feasibility study for a complicated project.

While it may seem that conducting these studies may not be necessary before building an AD/biogas system, a lack of effective planning has been the root cause for many failed or poorly performing AD/biogas systems in the United States. It is important to perform rigorous screening and feasibility review up front to ensure the system design meets the owner's needs, expectations, and requirements. Some AD/biogas systems have been sold and installed without the owner engaging a qualified third-party to conduct a due diligence review, and this is a potentially critical error.

Opportunities for Smaller Farm-based AD/Biogas Systems

The success of farm-based systems is usually enhanced with a larger herd size. However, there are exceptions that create opportunities for smaller farms, including:

- Environmental issues
- Odor issues
- Energy production incentives
- Grant funding
- Farm location
- Manure collection practices
- AD/biogas system design
- Farm owner's goals

One exception, for example, is the ability of smaller farms to use co-digestion feedstocks to produce significantly more biogas than a manure-based system alone. Plus, the co-digestion feedstocks also provide new revenues from the tipping fees.

For example, the Bar-Way Farm in Deerfield, MA operates an AD/biogas system using the manure from only 250 dairy cows (see Figure 7.1). The project is successful because it annually co-digests 30,000 tons of food waste in addition to the 9,200 tons of manure produced by the dairy cattle.

Figure 7.1. Co-Digestion Example on 250-Head Dairy Farm[57]

7.1 Screening

An initial set of questions should be considered to determine the potential for project viability. Below is an initial or preliminary list of questions to help start the evaluation process. If the answer to most of the following questions is “Yes,” then your facility may be a suitable candidate for an AD/biogas system, and you may consider conducting a pre-feasibility study.

Figure 7.2. Initial Project Questions

What type of waste does your facility produce?

Do you have dairy, swine or poultry manure available? ___Yes ___No

Do you have access to other co-digestible organic wastes? ___Yes ___No

Is your facility large enough to make AD economically feasible?

500 or more milking cows? ___Yes ___No

2,000 or more finishing hogs?[58] ___Yes ___No

100,000 or more fowl? ___Yes ___No

Any economic or regulatory drivers supporting an AD/biogas system?

Are you paying for disposal of organic wastes? ___Yes ___No

Do you have existing environmental concerns? ___Yes ___No
(e.g., Runoff, fugitive smells)

Do you have a need for heat and/or electricity? ___Yes ___No

Do you have a buyer for the energy? ___Yes ___No

Do you have space for an on-site treatment facility? ___Yes ___No

Do you have wastewater disposal limits or concerns? ___Yes ___No

Do you have nutrient application limits or concerns? ___Yes ___No

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[57] Vanguard Renewables, Jordan Dairy Farms, https://vanguardrenewables.com/jordan-dairy-farm/ (accessed March 2020).

[58] The minimum number is likely 2,000 hogs, as defined in the AgSTAR Market Opportunities Report. However, the minimum number is highly dependent on the site, region, off-take, and revenue. Most projects are not economically viable until greater than 10,000 hogs are incorporated.

The next step in project development is to assemble the information needed to conduct comprehensive assessments for the technical and economic feasibility of implementing an AD/biogas system at your operation.

7.2 Pre-Feasibility Study

Pre-feasibility studies provide the initial estimates (plus or minus 25 percent or greater) of the proposed facility's capital and O&M costs, its biogas production amounts, amounts of energy recoverable based on the conversion technology, the digestate quantity and content, and economic or financial performance evaluations.

Consultants and technology providers use basic questionnaires that define key factors to serve as the pre-feasibility study basis. The first step is usually an initial scoping study that primarily reviews the amount of usable manure available and other co-digestion feedstocks that might be digested.

There are several guidelines available for customers and feasibility study providers interested in conducting a feasibility study for anaerobic pretreatment and AD/biogas systems. In general, an entry-level study will use essential farm information, including:

- Concentrated animal feeding operation (CAFO) status;
- Animal type and number of animals
    - For dairy farms - lactating, dry and heifers, layers
    - For swine farms - sow, nursery, finishing, and the stocking plan for the finishing operation
    - For poultry farms – turkey or chicken, and for chicken layers or broilers;
- Barn type, including for example, free stall, open corral, slatted floor, cross ventilated;
- The amount of time livestock spend in barns as summarized on daily and yearly averages;
- Manure removal practices on the farm, including for example, flush, vacuum, scrape, pit, pull plug, deep pit manure management practices;
- Manure collection frequency;
- Water sources and amounts entering manure stream (e.g., parlor wash, manure flushing, and rainwater management on farm);
- Current manure handling practices (e.g., separation, lagoon, land application practices);
- Current energy uses (e.g., the cost and quantity of electricity, fuel oil, propane, natural gas, electricity service, single- or three-phase);
- Siting available and configuration;
- Co-digestion feedstocks, if any; and
- Environmental considerations, including for example, the impacts to the farm's CNMP.

7.2.1 Manure Feedstocks

The amount of manure that is expected to be collected must be estimated. At initial screening, the questionnaire should note items such as barn cleanliness after manure removal, manure removal method, areas flushed (walkways and feed lanes), livestock population in spaces where frequently removed, the livestock population in open pens, and the frequency of manure removal.

7.2.2 Co-digestion Feedstocks

If co-digestion feedstocks are to be used, their quantity and characteristics must be preliminarily determined. Most nearby waste haulers have some basic information regarding the volume and type of materials that could be directed to the facility. Many websites provide general values for possible co-digestion feedstocks, including fats, oils, and food processing wastes. Be extremely aware that using co-digestion feedstocks can introduce materials that can inhibit the digestion process. Use ATA and BMP testing in a preventative operations program to detect these issues before they can impact digester performance. Depending on the co-digestion feedstock, additional nutrients may be brought to the site that will need to be applied at agronomic rates based on a revised CNMP or sent off site for disposal or sale.

7.2.3 Revenues

The uses of the biogas and digestate, as well as the project's operating expenses and revenue potential, will be evaluated. The easiest revenue source to determine comes from any offset in the farm's electrical and thermal needs when the biogas is used for power generation. Information on selling the electricity produced in excess of farm needs can be obtained from the local electricity provider. If a CHP system is being used, the recovered thermal energy could offset any fuel oil, propane, or natural gas currently used for heating. There could be surplus amounts of recoverable thermal energy that could be used in new applications, such as greenhouse heating. Fertilizer savings, if any, can be estimated. Most farms will not see any decrease in fertilizer cost unless co-products are included in the feedstock, as manure is usually already being used for this purpose. Some savings might accrue to the project if the fiber recovered from a dairy farm project is suitable for use as bedding or off-site sale as a soil conditioner.

7.2.4 Capital and Operating Cost

Many technology providers offer estimates of capital and O&M costs for their systems, and many consultants have databases that can provide scoping-level estimates as well. By seeking out a consulting specialist or engineer that has experience working on farms similar to yours, an independent assessment of the project's capital and operating costs can be estimated. Figure 7.3 provides a basic flow chart of the AD project financial modeling process.

Figure 7.3. Basic AD Project Financial Modeling Process[59]

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[59] EPA AgSTAR Program, Project Financing, https://www.epa.gov/agstar/project-financing (accessed March 2020).

7.2.5 Does the Project Offer Cash flow?

Once the O&M costs and revenue sources have been quantified, the next step is to build a simple accounting ledger. First, add each cost and revenue item into a respective subtotal. Then, subtract the O&M costs from the revenues. This determines what is called the project's "operating income."

If the operating income is greater than zero, the project expects to have a positive cash flow. If the operating income is negative, it is not necessarily bad news, but further refinement is needed.

The project's capital investment is the next item to determine. Initial studies should assume the project is financed using a cash-equity plan. Using your own "out-of-pocket" cash, even if it is only imaginary money, provides a bedrock stress-test of the project's true economic performance. A simple economic stress-test can lead to different conclusions from stress tests performed using the leverage gained with debt financing. If the cash-on-cash rate of return exceeds the cost of borrowing money, then the project is likely financeable. If not, the project is not cost-effective. The initial economics should be performed assuming no grant funds. A critical error in the development of some projects is that they are financed even when they are not cost-effective.

The next step is to divide the capital investment by the operating income. That number represents what's called the Simple Payback Period (SPP). SPP is simply the "break-even" length of time needed to recover the capital investment through positive cash flow. Payback is useful in measuring investment liquidity, but it gives no insight on profitability because the analysis is incomplete. The AgSTAR's Project Financing web page offers several tools to model a project's cash flow.

For example, imagine two different projects that have equal cash flows. If both projects have the same SPP, a project with an infinite lifetime would receive the same financial ranking as a project having a very short lifetime. This is because a factor known as the "time value of money" has not yet been evaluated. Two additional economic statistics are used for the time value of money calculations.

For now, let's consider the SPP a bit more to help identify some of your financial goals. For example, some businesses only undertake investments with an SPP of 2 years or less, and many facilities undertake investments where the SPP ranges from 5 to 10 years. The acceptable SPP depends on the expectations of the owner – some will take a long-term approach to investments, while others will only invest in opportunities that produce short-term, high returns. A farm having an interest in the longer-term may find that an AD/biogas system is an acceptable investment if the SPP is less than the project's anticipated life.

Now, compare the calculated SPP to your financial goal. If that SPP is acceptable, consider taking the project analysis through to the full feasibility study, which is discussed in the next section.

Figure 7.4. Additional Project Questions

Two additional questions to consider before conducting a feasibility study:

Are you capable of basic maintenance? ___Yes ___No

Are sufficient financial resources available for construction, O&M, etc.? ___Yes ___No

7.3 Feasibility Study

The detailed feasibility study is the last step in deciding if an AD/biogas system can be implemented. Further honing the pre-feasibility phase to an even finer analysis, the feasibility study should account for the following:

- Feedstock definition,
- Recoverable products definition,
- Preliminary technology definition,
- Mass and energy balance,
- Capital cost estimate,
- Operating costs estimate,
- Revenues estimate, and
- Economic and financial projections.

7.3.1 Feedstock Definition

Feedstock definition is critical in establishing the standards and specifications for all feedstocks used by the AD/biogas system. Digesters are designed to have a specific OLR that is optimized for the as-fed feedstock volume and its biogas-making characteristics, VS and COD. These parameters are critical in determining the digester's reactor volume with sufficient HRT that allows the microorganisms to do their job.

Barn design, manure removal system and its operating schedule, size of herd, animal weight, and, in the case of dairy cows, the daily milk poundage produced, will all affect the amount of manure collected. Determining actual manure volume and its biogas-making characteristics by conducting a BMP assay are two key tasks necessary during the feasibility study phase. Reference material obtained from the American Society of Agricultural and Biological Engineers can provide general estimates of manure amounts and their characteristics. It is worth noting that actual farm operating conditions may differ from those used to determine the general conditions.

Failing to determine the actual manure and co-digestion feedstock volume and its biogas-making characteristics using ATA and BMP testing is an oversight during the feasibility study phase that could become a critical error. Underestimating feedstock volumes can likely lead to process instability due to overfeeding. Overestimating feedstock volumes will result in reducing the amount of biogas produced, which will negatively impact the project's income statement compared to the financial projections. Figure 7.5 presents sources of AD/biogas system feedstocks.

Figure 7.5. Illustrations of Source of AD/Biogas System Feedstock

If co-digestion feedstocks are to be used, contracts with the provider should include volume for each type of feedstock. Additionally, the chemical composition (TS, VS, COD, etc.) needs to be determined using a BMP. Individual standards and specifications should be considered to help ensure the feedstock's consistency, and a BMP should be performed for the final feedstock blend.

7.3.2 Recoverable Products Definition

The desired outcome for the recoverable products must be defined to assure that the project can fulfill their requirements. For example, if the fiber is to be used for animal bedding, decisions need to be made on separating manure solids before or after digestion. This may be a factor when certain co-digestion feedstocks are used. If the fiber will be used as bedding, additional curing may be needed. Biogas used for export electricity or RNG must define the needed specifications for the utility service upgrades needed by the farm.

7.3.3 Technology Definition

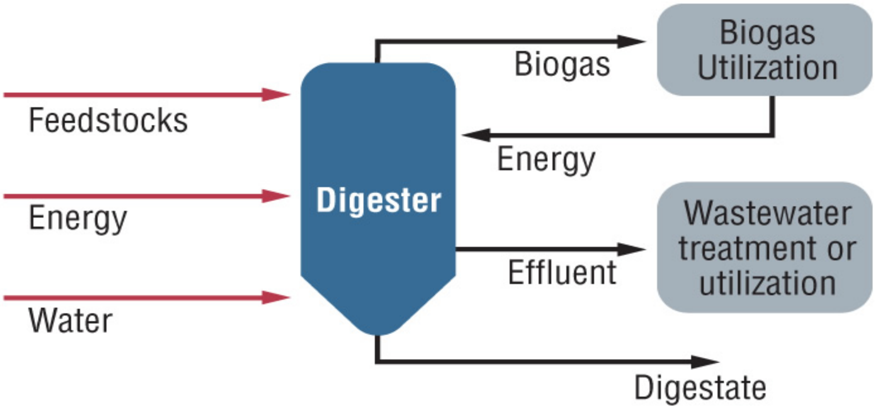
The digester should be defined using the process type best suited for the feedstock's TS concentration. Other important factors that need to be defined include VS and COD loading rates, and other concerns such as odor mitigation, income diversification, and environmental concerns. A preliminary definition should be made on:

- Energy conversion process best suited for the project,
- Feedstock storage and conveyance,
- Feedstock pre-processing requirements, and
- Emission impacts.

7.3.4 Mass and Energy Balance

Once the feedstocks have been quantified and qualified, a simple block diagram should be developed showing the system's mass balance (see the basic illustration shown in Figure 7.6). The mass balance exercise tracks material flows based on the quantities of the inputs provided and outputs received. At the end, the mass of all feedstock inputs must roughly equal the mass of all outputs. Estimating the mass of output is crucial to determining an accurate net revenue of the product. For example, errors resulting from overestimating the mass of the biogas produced can become a critical error, because net revenues would also be overestimated. Under most circumstances, the digestate fraction should represent 95 percent or more of the output mass from a system that is heated at medium temperatures.

Figure 7.6. Example of a Simple Block Diagram[60]



The mass balance exercise should detail manure collection, the introduction of the co-digestion feedstocks to the manure, the pre-processing of the final feedstock blend, digester size, biogas flow, and final energy and digestate recovery. As the project develops, these factors will be used to develop the facility's needed design documents.

In addition to mass and energy balances, air emissions and digestate nutrient balances should also be identified. The parasitic electricity required for running the electric motors used for mixing and pumping materials through the AD/biogas system should be quantified and deducted from gross generation. Only net power generation should be used for estimating the system's potential revenue stream. The mass balance should indicate the volume of digestate and the recovered portion that may generate revenues.

In addition to these physical parameters, the feasibility study should ideally provide a financial prospectus. This prospectus provides a detailed income statement showing all sources of revenue included in the project, a balance sheet, and a statement of cash flows using a standard accounting template. This must be a bankable document, and it is essential for obtaining loans and grants. The three revenue schedules contained in the prospectus demonstrate the project's ability in accordance with any loan agreement.

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[60] "Integrating Anaerobic Digestion With Composting," BioCycle, November 2014, https://www.biocycle.net/2014/11/18/integrating-anaerobic-digestion-with-composting/.

8.0 Business Relationships

To better assure a project's actual revenues and cost assumptions are realized, the owner will likely enter into agreements and contracts for products and services provided by one or more third parties. There are basic difference between an agreement and a contract: an agreement creates a mutual understanding about relative rights and responsibilities, and a contract creates enforceable obligations. Sometimes, a simple hand-shake is the easiest deal. However, when something goes wrong in a business relationship, a written agreement or contract protects the interests of both parties. It is always best to engage an experienced third party when negotiating agreements and contracts. Formal business relations will likely be needed for the following:

- Interconnection with an electric or natural gas grid,
- Sale of energy products like electricity or RNG,
- Digestate use or disposal,
- Trading environmental attributes (RECS, RINS, LCFS credits, Carbon Credits, etc.),
- Co-digestion feedstock supply,
- Financing,
- Facility construction, and
- Facility operation.

8.1 Interconnection Guidelines

An interconnection to an external electric or natural gas grid is necessary for any project that is not operating as an independent microgrid. The AgSTAR Interconnection Guidelines web page provides additional guidance on the steps involved with connecting an AD/biogas system to the power grid of an electric utility. The Database of State Incentives for Renewables and Efficiency (DSIRE) provides more specific information on the Interconnection Guidelines and Standards for 49 states and territories.

Figure 8.1. Connecting to an Electrical Grid

Understanding a utility's interconnection requirements is a key part of any agreement negotiation. Most utilities require that an interconnection study be done prior to providing information on wholesale power purchases. This study evaluates the impacts that the proposed facility may have on the utility power grid, as well as stipulating the requirements needed to harmonize the generated power onto the utility's system. The developer is required to pay for this study, as well as any upgrade requirements identified by the study.

Interconnection costs can be significant and should be included as a line-item in the project's construction budget. Costs are dependent on any needed service upgrade requirements, which are often transformers needing a larger capacity (this can range from a few thousand dollars up to several hundred thousand dollars). Another possibility might be upgrading the farm's power service from single-phase to three-phase power.

Interconnection agreements also specify any additional protective measures that may be required, such as relays. Relays automatically disconnect the farm generator from the utility power grid when there is a service disruption. These relays protect utility personnel, as well as workers at the project site, from electrocution. If an upgrade is needed, a professional familiar with interconnection equipment should negotiate with the utility and supply the required gear for the upgrade when possible.

8.1.1 Elements of Agreements

Many utilities have a standard offer agreement. The entire offered utility agreement should be carefully reviewed by the project developer and legal counsel to ensure that each of the terms is acceptable. If they are not, a more acceptable, revised version of the agreement should be presented to the utility for negotiation. Primary agreement considerations include:

- **Term.** The agreement term should be sufficient to support financing and the life of the project; fifteen years or more is typically satisfactory.
- **Termination.** Grounds for agreement termination should be very limited to protect the long-term interests of all parties.
- **Assignment.** The agreement should consider assignment for purposes such as financing. For example, allowing for agreement assignment to heirs or to partners may be advisable to avoid ownership arrangement difficulties.
- **Force majeure.** Situations that constitute force majeure (e.g., storms, nuclear disasters, acts of war) should be agreed upon; otherwise, this clause could be used to interrupt operations or payment during unusual occurrences.
- **Schedule.** There should be some flexibility allowed for meeting milestone dates and extensions in case unforeseen circumstances cause delays.
- **Price.** The agreement price should ensure the long-term viability of the project, which means accounting for potential cost escalation through the agreement term.

Agreement elements that may be included and must be identified and renegotiated include:

- **Change in Farm Retail Rate.** The utility may mandate a new retail rate for a farm with biogas cogeneration. Rate changes affect project financial performance and must be accounted for in the economic analyses.

- **Standby Charges.** The utility may apply standby charges to the project; utilities levy these charges on customers that purchase power on an intermittent or "as needed" basis, such as those using a farm-scale biogas system under a net-metering arrangement. The monetary impact of these charges should be carefully evaluated in relation to the expected engine-generator performance.
- **Interconnection Requirements.** The Federal Energy Regulatory Commission (FERC) issued the Standard Interconnection Agreements & Procedures for Small Generators grid-connection procedures for smaller generators (<20 MW) such as AD/biogas systems (Final Rule July 21, 2016). These procedures help to standardize the interconnection process across the nation and make it less of a burden for smaller power producers.
- **Insurance Requirements.** Liability insurance is required for any AD/biogas system project. Most operations have adequate insurance added to the AD/biogas system project with a minimal increase in the monthly insurance premium. Some utilities have asked farms to add the utility to the farm's insurance policy, and to increase the insurance limits to levels much higher than any farm insurance carrier would normally underwrite.
- **Monitoring and Reporting.** Some utility companies have clauses that require the generator output and thermal heat use to be recorded. Such requirements are generally not necessary for a farm AD/biogas system and should be renegotiated.
- **Telemetry.** Some agreements can mandate direct control or monitoring of the farm generator from the utility power dispatch center via a dedicated phone or internet connection. This is generally excessive for small power agreements and is an example of applying large-scale power production specifications to small power producers; however, with the increased use of automated controls and sophisticated power management, these systems are used more frequently and at a lower cost than in the past.
- **Interconnection Construction.** Some utilities prohibit co-generators from supplying their own equipment, which can add costs that ultimately affect financial performance. Some utilities can also inhibit a project by applying the specifications applicable to a large-scale power production system to small power producers, such as farm AD/biogas systems.

8.1.2 AD/Biogas System Utility Benefits

Properly executed biogas systems can provide a proverbial "triple-win" because it is beneficial to the owner, the developer, and to the electric utility. Many of the utility benefits are non-monetary, which should be emphasized. For example, during project negotiations, non-monetary benefit considerations should include:

- **Customer Retention.** Using an AD/biogas system to eliminate odor problems with new neighbors may allow the farm to continue operating. Even with an AD/biogas system, a farm will continue purchasing some of its electricity needs from the utility.
- **Demand Reduction.** Most utilities try to manage their peak loads by using demand side management programs. These programs reward customers for not using electricity during peak demand times, which typically happen in the morning and evening hours.

- **Voltage Support.** Where farms are near the end of a loop in utility transmission lines, the farm's generator supports utility line voltage by reducing fluctuations. This saves the utility the cost of providing voltage support or paying for burned out motors.
- **Deferred Capital Expenditures.** In rural areas, electricity generated from biogas provides a distributed generation source. It can delay the need for increasing the utility's system capacity. It may also defer expenditures for transmission lines and substations by supplying electricity at the point of use.
- **Greenhouse Gas Reductions.** Some utilities have goals to reduce GHG emissions, which can be met by purchasing electricity generated by recovering CH_4 from animal manures.
- **Renewable Portfolio Standards.** Renewable Portfolio Standards (RPS) require that a minimum amount of renewable energy is included in the portfolio of electricity resources serving a particular area. Utility purchases of electricity from biogas systems may help meet these RPS requirements.

8.1.3 Energy Contracts

When biogas is used to generate electricity, the contract with the local electric utility is the most crucial factor regarding system profitability. While utilities are legally required to work with small biogas electricity generators, there are no set industry rules or procedures that govern the process for small power producers (less than 250 kW), as most rules were developed for very large independent power producers (greater than 1 MW).

In general, utility rules apply to interconnection requirements, capacity guarantees, payment methods, and purchase rates. Some utilities have developed handbooks of procedures, specifications, options, and draft contracts to provide small power producers with a standard contractual process. In other cases, utilities have dispersed responsibilities across separate groups within their organizational structure. In these cases, the process can become confusing, time consuming, and serve as a potential barrier to project development. Contacting your state Public Utility Commission may be helpful in facilitating the electric interconnection contracting process.

In all cases, contacting the utility early in the project development process is essential, as completing small power contracts takes time. Since contract negotiation is often a complex process, farm owners, operators and developers may want to consult an expert for information and guidance in this area.

To begin the contract development process, the following information is required:

- Avoided cost rate schedules;
- Knowledge of the various contract structures for renewable energy projects;
- Any charges, riders, or rate schedules that may apply to the project (e.g., standby charges); and
- Any incentives that apply to renewable energy in the project area.

8.1.4 Electricity Contract Options

As discussed in Section 6.0, several types of power purchase arrangements can be used for selling biogas-generated electricity to a local utility. However, utilities usually offer one type of contract, with net metering becoming a more common approach with the increase in independent power production.

One key is determining the best value the biogas can provide to its owner or developer. Start by carefully reviewing the utility's rate schedule and the interconnection requirements. The owner or developer must first estimate the project's electric generation potential, and then analyze the farm's historical monthly electric energy use. This analysis will show if the proposed project generates a surplus of electricity to the farm's requirements and needs exporting, or will the farm continue to purchase more electricity than the project produces. Once the potential surplus or shortfall situation is understood, the owner can best determine what type of utility contract to enter in.

8.1.5 Transmission (Wheeling) Arrangements

Another option for biogas-generated electricity is selling it directly to a third party using the local utility's transmission lines. This strategy may be possible if the local utility is required to enter into long-term contracts to deliver or "wheel" electricity from other generators at a reasonable price. Also, farms with more than one site may be able to wheel surplus electricity via the local utility lines to their other locations. Wheeling could produce more revenue than the sale of surplus electricity to the utility or may be an option if an acceptable long-term purchase agreement cannot be negotiated with the utility. Before considering wheeling when your service is provided by an investor-owned utility, contact the state public utility commission to determine if electric utilities under their jurisdiction are required to wheel the electricity generated by small power producers.

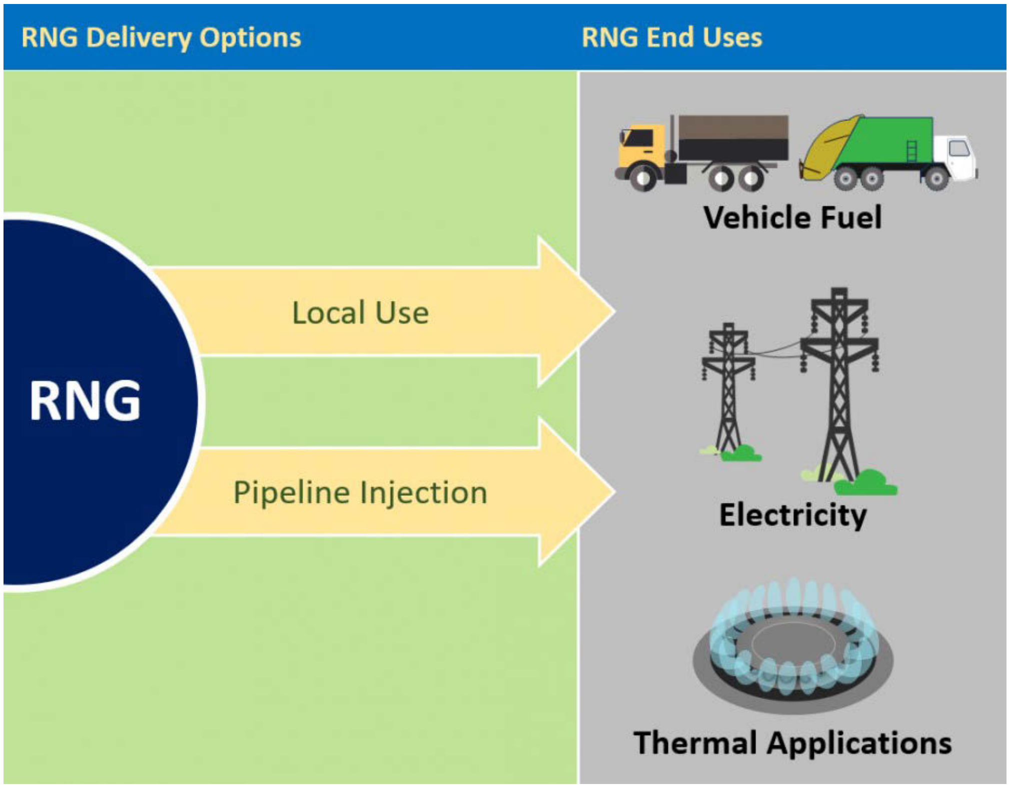
To learn more about electric utility agreements, you can visit the following websites:

- Exploring Power Purchase Agreements: The Basics – An overview of power purchase agreements and their use in financing renewable energy systems. This presentation focuses on solar energy projects, but the information is generally transferable to other technologies (U.S. Department of Energy, 2011).
- The Basics of a Power Purchase Agreement – An overview of power purchase agreement considerations for AD/biogas system projects (Biomass Magazine, 2008).
- Power Purchase Agreement Toolkit – Provides a link to a PPA template (RETScreen International, 2012).

8.2 Renewable Natural Gas

Biogas that has been converted to RNG by purification can be sold and delivered to the natural gas pipeline. The grid must be close enough to the AD facility for direct injection or trucked then injected, provided that local regulations allow for such operating pressure, gas composition, properties, and required safety equipment. Figure 8.2 presents an overview of RNG delivery options and end users.

Figure 8.2. RNG Delivery Options & End Uses[61]



Because of a lack of national quality standards for biogas converted to RNG, requirements for gas quality vary by location and are dependent on the transmission pipeline, local natural gas distribution companies, and state regulators. Methane produced by the AD process is the same as the methane in fossil natural gas. However, fossil natural gas contains a variety of hydrocarbons other than CH_4, such as ethane, propane, and butane. As a result, fossil natural gas will always have a higher calorific value than pure CH_4.

The RNG Coalition provides links to the published tariffs from numerous Major Transmission Pipeline companies. These can be found in the RNG Coalition pipeline database. Within the published tariffs, the criteria thru which upgraded biogas that is subsequently injected into these pipelines are identified. These criteria include, for example, minimum concentrations of CH_4, O_2, N_2, CO_2, heating value, dew point and other pipeline specific criteria.

8.3 Organics Contracts

When a facility co-digests organic feedstock sourced from an outside location, an organics contract should be secured to ensure the volume or weight that the supplier will provide, the waste quality, and the frequency of feedstock delivery. Any applicable tipping fees to be paid to the AD/biogas system owner need to be specified in writing. In addition, the duration of the contract and penalties for failure to perform should be specified.

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[61] EPA Landfill Methane Outreach Program, Renewable Natural Gas, https://www.epa.gov/lmop/renewable-natural-gas (accessed March 2020).

8.4 Project Finance

Most projects will require that long-term financing be secured to enable construction. Terms of the financing agreements can affect the structure of other agreements, as well as the distribution of income to the project's owner. It is always prudent to explore the potential for applicable grants or other public funding that may be available. The capital sources, uses, amounts, and any other terms required for financing need to be finalized prior to other project agreements.

8.5 Construction Contracts

Few developers or owners have the inherent capability to procure the equipment and construct an AD/biogas system by themselves. Contracts with technology providers, engineering companies, and many others will likely be used during project construction and operation. The contents of the agreement are often dictated by the lending institution or other funding sources. The developer will need to determine the value of obtaining performance guarantees for the amounts of biogas produced, as well the system's fitness in digesting the proposed feedstocks. The construction schedule and any other imposed third-party deadlines will also need to be determined.

8.6 Operational Contracts

If a decision has been made to use a third party to operate the AD/biogas system on behalf of the owner, a contract covering their duties, responsibilities, and compensation will be required. The operating agreement will cover the payment of expenses, performance thresholds, and potential bonuses to the operator if performance is higher than the threshold.

9.0 Permitting

Permits are needed to construct and operate an AD/biogas system. The system must meet all local, state, and federal permitting requirements for air, solid waste, water, and construction. The operation of an AD/biogas system may also require ongoing regulatory compliance for many of the issued permits.

Serious consideration should be given to hiring a well-experienced team to assist in the permitting process. These include professionals who have experience securing the range of permits needed for an AD/biogas system, especially those in the project’s local area. Whether it is a do-it-yourself job or someone is hired to help, a complete list of all permits required for project implementation should be compiled. A well-organized schedule for permit submittal and their approvals can then be planned and implemented. Pre-application meetings with the permitting authorities is also a prudent step to introduce the project and to confirm the permit list, application requirements, and timeline.

The type and number of permits required is dependent on factors such as the feedstock source, project site zoning rules, site air quality, digestate use and disposal, and many more location-specific factors. Regulatory conditions may impact project design, so neither construction nor system operation should begin until all of the permits are in place. In some cases, this is a legal requirement. Plan on taking 6 to 18 months to complete the permitting process depending on the project's location. For example, a location requiring no zoning variances or air permits will probably take less time to permit than a project in a location subject to zoning hearings and air permits.

States are generally granted the authority to implement, monitor, and enforce the federal regulations by establishing their own permit programs. As a result, some state permit program requirements are more stringent than those outlined in federal regulations, resulting in a large state-to-state disparity between agencies and standards. For this reason, owners, operators and project developers should determine state and local requirements before seeking project permits. For more information, the AgSTAR Permitting and Guidelines web page contains links to federal and state-specific permitting requirements.

9.1 Permitting Process

Figure 9.1 illustrates potential permitting requirements for AD/biogas systems.

Figure 9.1. AD/Biogas Permitting Requirements

There are typically five key steps in the permitting process; they are outlined in Figure 9.2 and in the following section.

1. **Hold preliminary meetings with key agencies.** Meet as early as possible with regulators to identify all permits that may be required, as well as any other issues needing to be addressed. This also gives an opportunity to educate regulators about the project, because they may be unfamiliar with biogas technologies. Often, contacting the economic development representative for a county or region can be helpful in coordinating a meeting and identifying all of the permits that are required for a project.
2. **Develop the permitting and design plan.** Determine the requirements and assess all agency concerns early on. As a result, permit applications can proactively address those concerns, and delays can be minimized.
3. **Submit permit applications in a timely manner.** Submit completed applications as early as possible to minimize delays.

Figure 9.2. Permitting Process

1. **Contact/meet regulatory authorities and determine requirements**
2. **Develop permitting and design plan, data collection**
3. **Submit permit applications**
4. **Implement any design changes requested**
5. **Application processed and approved**

4. **Implement any design changes requested to meet permit requirements.** A change in a facility's design to meet the applicable permit requirements may occur. Sometimes, the regulatory process provides an opportunity for negotiation. If allowed, negotiations may take technical and economic considerations into account.
5. **Application processed and approved.** This is the last and final step. It may include reiteration of the previous steps as part of negotiations with the regulatory agencies. It may also include sub-steps, such as public meetings and public notifications.

Successful completion of the permitting process relies on a coordinated effort between the project developer and the various agencies reviewing project plans and analyzing project impacts. Developers may periodically have to deal with separate agencies with overlapping jurisdictions, making it important to coordinate efforts to minimize difficulties and delays.

This might be a new process for the officials as well, as they may not have any experience in permitting AD/biogas systems. It may take time to establish a permitting process and plan acceptable to all parties. Involving officials early in the planning stages ensures they will have time to provide meaningful input, decreasing the likelihood for project obstacles. Consider making the permitting process an opportunity to educate permitting authorities by providing useful and targeted information. Local and state USDA NRCS representatives may be of assistance regarding whom to contact.

9.2 Air Quality

When burned in a flare, engine, turbine, or boiler; biogas produces nitrogen oxides (NO_x). When H_2S is present, biogas also produces sulfur oxides (SO_x) when burned. Consequently, exceeding a permitting threshold for either air emission may require an air quality permit.

It might make sense to select a combustion device that provides lower NO_x emissions to minimize regulatory impacts. Burning biogas more cleanly might avoid needing a permit or reduce the permitting requirements. SO_x emissions produced from the H_2S are usually scrubbed from the biogas prior to combustion. Even though H_2S scrubbing includes an O&M cost, removing sulfur before combustion significantly reduces overall O&M system costs.

The air quality permitting program is mainly composed of the New Source Review (NSR) preconstruction permitting program and the Title V operating permits program. These two programs are briefly described in the following subsections.

9.2.1 New Source Review

New Source Review (NSR) is a preconstruction permitting program that requires stationary air pollution sources to get permits before construction starts or the pollution source is modified. NSR normally applies to large industrial facilities, such as power plants, paper mills, and cement plants; but could also apply to smaller facilities like farm-scale AD/biogas systems depending on the particular federal, state, local, or tribal agencies' air permitting requirements. NSR permits are largely issued by state and local agencies, not tribes or the federal government.

The main pollutants regulated under the NSR permitting program are the National Ambient Air Quality Standards (NAAQS). The NAAQS are composed of six pollutants (ozone, particulate matter [PM], carbon monoxide [CO], NO_x, SO_x, and lead). The NSR program regulates the NAAQS under two main parts: Prevention of Significant Deterioration (PSD) and Nonattainment NSR (NNSR) programs.

For each NAAQS, all parts of the country are classified as either in attainment or nonattainment of that NAAQS. Facilities located in an attainment area for a particular NAAQS that have air emissions higher than the applicable threshold for that NAAQS need to meet the permitting requirements of the PSD portion of the NSR program. Facilities located in a nonattainment area for a particular NAAQS that have air emissions higher than the applicable threshold for that NAAQS need to meet the permitting requirements of the NNSR portion of the NSR program. The requirements for the NNSR program are more stringent than the PSD program requirements and a facility might be subject to both portions of the program simultaneously. The NSR program also regulates a few other non-NAAQS pollutants (see 40 *Code of Federal Regulations* (CFR) Part 52.21 for a complete list of the regulated NSR pollutants). Facilities that emit pollutants regulated under the NSR program that are not the NAAQS are usually subject to the PSD program permitting requirements.

The air emission thresholds that determine whether a facility is subject to PSD or NNSR vary, but in general, a facility is subject to either the PSD or NNSR program if it emits or has the potential to emit one or more of the NSR-regulated pollutants at or above 100 or 250 tons per year (tpy).

The minor NSR program applies to facilities with air emissions below the PSD or NNSR thresholds (i.e. in general, facilities with air emissions lower than 100 or 250 tpy) that are located in either attainment or nonattainment areas. Since the Clean Air Act (CAA) and EPA's regulations contain minimum requirements for minor sources, state, local, and tribal minor source programs are very flexible and vary greatly.

NSR may apply to CHP projects generating more than 500 kW and for projects near urban nonattainment areas. NSR may also apply to equivalent-sized projects using biogas-fueled boilers and flares. In most cases, however, farm-scale AD/biogas systems are too small of an air pollution source to trigger major NSR permitting requirements; but could be subject to minor NSR permitting requirements. Minor NSR permitting is an easier permitting process than the major NSR permitting process.

Each state has a permitting program for new or modified minor sources, where a facility may be required to obtain an air permit or just register the air emissions from its operations. Obtaining an NSR permit can be an extensive procedure and can require lead times ranging from a few weeks for minor facilities up to a year from the date the permit application was determined complete by the applicable permitting authority for major facilities. Construction cannot begin until the NSR permit is issued; therefore, you should always check with your local air permitting authority about all permit requirements early in the planning process.

9.2.2 Title V Program

The Title V program is an operating permits program that requires stationary air pollution sources to get permits that contain or consolidate all the applicable requirements of the CAA that apply to the source. These applicable requirements may come from the State Implementation Plans (SIP), from preconstruction permits issued to the source under the NSR program, or from New Source Performance Standards (NSPS) or National Emission Standards for Hazardous Air Pollutants (NESHAP) requirements, among others. Unlike the NSR program, these permits do not establish new requirements for facilities, although in limited circumstances, additional monitoring may be required in the permit if the underlying applicable requirement does not provide sufficient monitoring. Because these permits are required for a source to operate, they are referred to as “operating permits.” They may also be referred to as “Title V permits” or “Part 70” permits referring to the applicable section of the 1990 CAA Amendments, or the section of Title 40 CFR, respectively.

Most Title V permits are issued by state, local, and tribal permitting authorities using regulations developed and approved by EPA as meeting the requirements of 40 CFR Part 70. In general, a facility is subject to the Title V program if it emits or has the potential to emit one or more NAAQS at or above 100 tpy. Lower applicability thresholds apply for certain NAAQS and hazardous air pollutants (HAP). In general, sources with Title V permits that have emissions lower than 100 tpy are usually known as area sources or minor sources.

A facility is required to apply for a Title V permit within 12 months from the date it started operation. Given the complexity of the air permitting regulations, an owner/operator may wish to consult an expert on the NSR and/or Title V permitting process before applying for an air permit.

9.3 Water Quality

If construction activities disturb more than one acre of land, a National Pollutant Discharge Elimination System (NPDES) stormwater discharge permit may be required during project construction. Depending on project location, this permit is issued by each state or by the EPA directly. Good facility design that maintains the site’s predevelopment runoff characteristics allow construction projects to meet stormwater discharge requirements more easily.

There are no national water-related permit requirements solely triggered by the use of an AD/biogas system. However, the addition of an AD/biogas system to an existing WWTP at an industrial facility requires modifying any existing NPDES or sewer discharge permits. States or regions may manage and regulate water discharges, including discharges from an AD/biogas system. Moreover, some states have water permit requirements for farm-based AD/biogas system operations that co-digest other feedstocks with manure.

CAFOs are defined as point sources of water pollution and require permits to limit pollutant discharges. Adding an AD/biogas system does not change these requirements. However, using an AD/biogas system requires a modification of the farm's associated CNMP. In addition, the use of co-digestion feedstocks obtained off site may require updating the farm's CNMP.

9.4 Water Supply

An AD/biogas system can generally recycle the recovered filtrate for any required manure pumping or feedstock dilution. However, there may be exceptions in places such as arid climates where adding groundwater may be necessary. If additional water is needed and use of groundwater is the only or best option, a well drilling permit and a water use permit will likely be required. For surface water withdrawal, the need for a permit needs to be explored on a site-by-site basis, and usually these permits are issued by the applicable state agency.

9.5 Solid Waste

Solid waste processing facilities are required to meet Resource Conservation and Recovery Act (RCRA) Subtitle D requirements covering the landfilling of non-hazardous solid wastes. Solid waste processing facilities are also required to meet 40 CFR Part 258, which covers the criteria to define non-hazardous solid waste. Many states exempt manure-only AD/biogas systems from solid waste permitting requirements. Some states may exempt all or some farm AD/biogas system based on the type and volume of feedstocks they process. For example, farms may require permits if they use certain co-digestion feedstocks, if they accept any off-site waste, or accept off-site waste above a threshold amount.

9.6 Land Use

The first local permitting issue to consider is the project's compatibility with community land use regulations. Projects on existing farms should have few problems, as most communities have a zoning and land use plan that identifies where distinct types of development are allowed (e.g., residential, agricultural, commercial, industrial). The local zoning board determines whether or not a new AD/biogas system project meets existing land use criteria. If not, a zoning variance might be granted.

9.7 Co-Digestion Feedstock Permitting

The permit requirements for using co-digestion feedstocks vary by state and may be subject to change. For example, some states allow a specific percentage of off-farm co-digestion feedstocks to be accepted without triggering the requirement to have a solid waste facility permit. Local and state resources can help you navigate the specifics of the permit process, if applicable.

9.8 Additional Permitting Considerations

Local agencies may have jurisdiction over other parameters that are applicable to an AD/biogas system project or its location. For example, most local zoning ordinances stipulate the maximum allowable levels for noise sources, and these levels vary based on the zoning classifications at the source site. For example, sites located near residential areas will have a lower noise requirement than one located in an isolated area. Even enclosed facilities may be required to meet noise source requirements; therefore, it is important to keep them in mind during the design phase of the project.

Depending on the project's location, other site-specific requirements may be required by permitting agencies. For example, an Environmental Impact Study might be required for a site intending to locate on a site inhabited by endangered or protected plants or wildlife. A site might require a Wetland Delineation Study if it contains a marsh, swamp, bog, or fen, and there may be restrictions to development on this land.

10.0 Public and Community Outreach

It is very important to conduct community outreach and education when a new AD/biogas project is developed. Educating the members of the community who are most likely to be affected contributes to the success of the project. Engage, early and often, with members of the community to educate them about AD/biogas systems; this will help obtain buy-in and approval from the community. This includes, but is not limited to, regulatory approval and the community and neighborhood where the project is located, as well as the surrounding region where the project may have an impact (e.g., truck traffic or odor impacts).

In your outreach efforts, describe the benefits that an AD/biogas system can bring to a community, including improved air quality, odor reduction, economic benefits, diversification of farm income, and pollution prevention. Consider various outreach methods depending upon the specific needs of the community; for example, public meetings, websites, newsletters or social networks. The benefits of AD/biogas should be emphasized during public and community outreach, as obtaining community buy-in can help make the project planning and implementation easier.

The local community needs to understand how the project is designed, especially in communities requiring public participation during project zoning and siting cases. Livestock farms may encounter local opposition due to inaccurate or exaggerated perceptions of project impacts, especially regarding odor or groundwater pollution. It is important to educate the public and to develop an open, working relationship with the local community to build public support for the project.

11.0 Safety, Operation, and Maintenance Considerations

This section outlines some general safety and O&M considerations involved in operating an AD/biogas system. The AD/Biogas System Operator Guidebook (under development) contains considerably more information to foster and increase health and safety considerations on AD/biogas systems.

Biogas contains components that are harmful or deadly to plant operators, and precautions and training should be implemented to focus on the safe operation of biogas systems. Additionally, an AD system contains moving equipment, and proper care must be used to avoid injuries.

A successful operation keeps the digester's microbial population alive by ensuring it is being properly fed as well as by maintaining consistent environmental temperatures. Proper O&M is required for this to happen.

An online AD/biogas system training course is available from America's land-grant universities. Serious practitioners interested in learning more about the "hands-on" aspects of AD/biogas system O&M might find the training that is required for certification as a water operator useful. The American Water Works Association provides the publications, online tools, and other resources needed to become one.

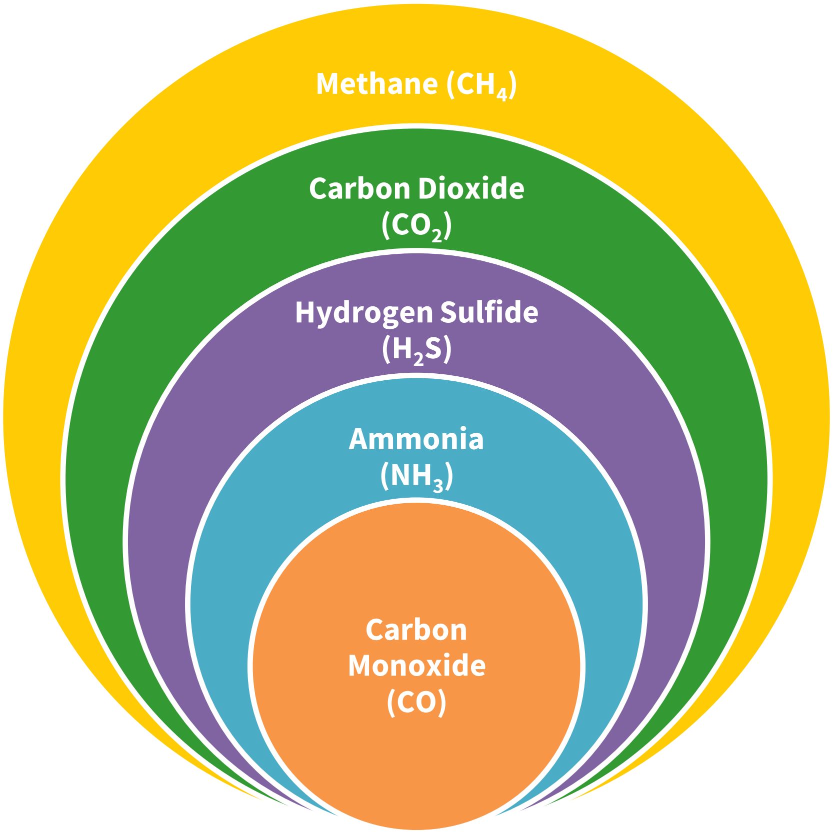
11.1 Safety

While AD/biogas system accidents in the United States rarely occur, producing biogas does result in several potential safety hazards. These hazards include asphyxiation and poisoning from the gaseous compounds that comprise biogas as well as from the gaseous emissions resulting from biogas combustion. Additionally, there is a danger of fire or explosions, potential electrical hazards, along with other risks associated with the management of digestion material. AgSTAR's Common Safety Practices for On-Farm Anaerobic Digestion Systems document identifies the major hazards associated with an AD/biogas system and outlines basic practices to maintain a safe and successful working environment.

11.1.1 Direct Biogas Hazards

Biogas contains five main constituents: CH_4, CO_2, H_2S, NH_3, and water vapor, as presented in Figure 11.1. Each of these gases, except for water vapor, can be dangerous at certain levels of exposure. The greatest risk of exposure to high levels of these compounds can be when an employee is in a confined space, although prolonged exposure or high concentrations can exist in what many would consider a "safe" open space as well. This is also true for CO, which is a product of biogas combustion. Biogas accumulation also presents a fire or explosion risk.

Figure 11.1. Biogas Components



- **Methane.** A colorless and odorless gas can cause asphyxiation, resulting in suffocation and subsequent death. Methane is flammable when it mixes with air. Its upper and lower explosive limits are between 5 and 15 percent by volume of air. The limits provide the range that produces a flash fire when an ignition source is presented. Additional information can be found at https://www.cdc.gov/niosh/index.htm.
- **Carbon Dioxide.** A colorless and odorless gas that also can cause asphyxiation, resulting in suffocation and subsequent death. Additional information can be found at https://www.cdc.gov/niosh/npg/npgd0103.html.
- **Hydrogen Sulfide.** A highly poisonous gas even in low concentrations. Hydrogen sulfide primarily affects the central nervous system, causing loss of consciousness and potential death. While it has a “rotten egg” odor, sensitivity to the odor decreases rapidly with increasing concentrations. Therefore, odor detection by scent alone can be misleading and has too frequently been a cause of death. Additional information can be found at https://www.cdc.gov/niosh/npg/npgd0337.html.
- **Ammonia.** A colorless gas with a strong, pungent odor that serves as a warning. In high concentrations, it can cause lung damage and even death after a prolonged exposure. Biogas has low ammonia concentrations, but higher concentrations of it are typically present in poorly-ventilated manure storage facilities. Additional information can be found at https://www.cdc.gov/niosh/npg/npgd0028.html.
- **Carbon Monoxide.** A colorless and odorless poisonous gas that is produced as one of the exhaust gases resulting from combustion. Any exhaust odor comes from one of the other

gasses. Carbon monoxide combines with blood hemoglobin to prevent oxygen transport, and ultimately causes death through suffocation. Additional information can be found at https://www.cdc.gov/niosh/npg/npgd0105.html.

Accumulations of any of these gases in a confined space or poorly ventilated area can create a danger to both life and health. Areas that are prone to accumulation include the structures housing engine-generator sets or boilers, below-grade pump chambers and manure storage tanks, and any biogas storage device. Installing wall-mounted sensors that are capable of detecting these hazardous gases is a simple, cheap, and convenient way to ensure safety.

Proper confined space entry procedures should be used, including providing proper ventilation, ensuring a second person is present outside any occupied confined space, and using safety harnesses. Additionally, a handheld multi-gas detector should be used to determine if hazardous levels of biogas are present prior to entry into any confined space. Finally, signs and other signals should be used to alert employees and visitors when any confined space entry risk exists.

11.1.2 Electrical System Hazards

Generating electricity with a farm AD/biogas system creates electrical hazards, many of which are found near its generator set, transformer, and electrical panels. Facilities should post signs identifying general electrical hazards near the electrical generation system, and only licensed electricians should service and repair electrical systems. Electrical system hazards include:

- **High voltage.** Transmission lines from the transformer are typical sources of the highest voltage found on farms. When dealing with high voltage sources, physical contact with any exposed wire lead is a major hazard and can prove to be fatal. Enclosed transformers should always remain permanently sealed and locked. Only a licensed electrician should perform any customer-side transformer maintenance.
- **Standard voltage.** Switches, controllers, fuses, breakers, wall outlets, and electrical panels can be considered standard-voltage devices. Arcing, a major hazard, is associated with electrical panels. Arcing occurs when electricity from an energized source jumps a gap and discharges to an adjacent conductive surface. Individuals in the arc's pathway can be seriously burned or killed. Cover plates are used to contain arcing by shielding people from potential harm. Therefore, operators should ensure that proper cover plates are present and intact on panels and outlets. The use of utility-grade fire resistant clothing is always recommended when working with electricity on a farm.
- **Shock, Electrocution, and Fire.** Risks occur anywhere where motors and other equipment are using electricity. Risk is easily minimized by always observing proper installation and repair procedures. These include proper grounding and lockout/tagout before repair.
- **Electrical fires.** Electrical fires are another potential hazard, and they should only be fought using an ABC classified multi-purpose fire extinguisher rather than a water-based fire extinguisher. Using a water-based fire extinguisher could result in electrocution. ABC includes the following classifications:
    - "A" ordinary combustibles, such as TRASH–WOOD–PAPER
    - "B" fires, including all FLAMABLE LIQUIDS
    - "C" fires that are sources from ELECTRICAL GENERATION

11.1.3 Other Safety Concerns

Figure 11.2 presents examples of safety signage that should be observed when present at an AD facility. General safety concerns related to, but not unique at, AD/biogas facilities are:

- **Drowning.** Tanks and ponds used for liquid manure storage pose a drowning risk. Wherever a drowning risk exists, rescue devices like ring buoys, ropes, or ladders should always be readily available. Drowning risk is highest when employees service any equipment near the digester's reactor or biogas storage tanks. Biogas asphyxiants may be present at levels causing unconsciousness and increase the drowning potential.
- **Fall protection.** Serious injuries can result from falls of any height. When possible, employees should perform maintenance work at ground-level. According to the Occupational Safety and Health Administration (OSHA), general industry fall protection standards state: "…any time a worker is at a height of four feet or more, the worker is at risk and needs to be protected." Wherever there is potential for a worker to fall more than four feet, employees should use fall protection measures, such as guardrails, safety harnesses, and self-retracting lifelines.

Figure 11.2. Safety Signage on AD System[62]

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[62] "Cayuga County Manure Digester Virtual Tour," Farm Energy Extension, April 3, 2019, https://farm-energy.extension.org/cayuga-county-manure-digester-virtual-tour/.

- **Burns.** Pipes containing hot fluids or exhaust gases can pose potential burn hazards throughout an AD/biogas system. Other potential burn sources are heat exchangers, boilers, pumps, or engine-generators, where temperatures can exceed 160 °F. Simply rubbing against a heat exchanger or accidently placing a hand on a hot pipe can cause a serious burn. Employees and visitors should be cautioned not to touch any equipment or pipelines.
- **Entanglement.** Pumps, augers, impeller mixers, chains, drive shafts, and other machinery pose entanglement hazards due to various pinch points and other moving parts. In most facilities, unguarded driveshafts are the primary source of an entanglement risk. To reduce entanglement risk, all of the equipment's safety guards should be in place. Individuals should avoid wearing loose-fitting clothing and jewelry, and all hair should be tied back if it is long enough to become entangled.
- **Feedstock and effluent spills.** Plans should be developed to respond to spills by detailing worker safety protocols and containment strategies to isolate a given event from surrounding buildings, surface waters, and sensitive areas. For non-farm co-digestion feedstocks, such as food waste, the spill-reporting agency should identify all records related to the material, including its safety data sheets and manifest logs indicating the date, quantity, and material brought onto the farm. Site cleanup and restoration is essential in any spill response.
- **Ignition sources.** Biogas is highly flammable, and any ignition source can create a fire or explosion. Ignition sources include, but are not limited to, smoking and vaping, open flames, light switches, electric motors, pilot flames, grinding, welding, metal cutting, and cell phones. These should be prohibited in the general vicinity of the digestion system, and a setback distance of 25 to 50 feet is suggested for all possible ignition sources. It is important for each facility to have a "hot work program." Hot work is any work that involves burning, welding, cutting, brazing, soldering, grinding, using fire- or spark-producing tools, or other work that produces a source of ignition.
- **Noise levels.** Exposure to elevated noise level can result in discomfort or short-term hearing loss. In extreme cases, or if the noise exposure occurs over a prolonged period, permanent hearing loss can occur. The main sources of high noise levels at an AD/biogas system come from the engine-generator set or gas upgrading equipment. They can produce levels of between 100-140 Actual decibels (dBA), although each facility will differ due to varying acoustical settings. Pumps, compressors, and blowers also frequently produce noise levels above acceptable dBA ranges. Hearing protection is needed when working in areas with elevated noise. Facilities are required to supply hearing protection devices, such as earplugs, to employees and visitors who are exposed to high noise levels.

11.2 Maintaining Operational Stability

A well-operated AD/biogas system can provide years of reliable performance. However, the microbial populations responsible for the AD process must have a reliable steady-state condition to maximize biogas yield. Like any biological process, the most important thing is to keep the microorganisms fed and warm enough so that they can do their job. This is similar to providing the care and nutrition needs of any farm animal. Many facilities have installed instrumentation that assists the digester operator in monitoring microbiological health.

Instability happens when the four sequences of microbiological reaction within a digester become unbalanced. The result is reduced biogas production (cubic feet per day) and quality (CH_4 percent).

Biogas production rates and composition are excellent indicators of digester health, so it is important to monitor and record both on a regular basis and evaluate long-run trends for digester performance. Always remember that if any of the below instability conditions occur, it could result in digester failure; therefore, immediate action is required. When a digester fails because of unbalanced microbiological conditions, it must be emptied and restarted.

Digester instability usually occurs because of one or all of four basic factors:

- **Hydraulic overload.** Occurs when the digester's HRT is decreased below its design value, as more feedstock is being fed for digestion. This overload causes a reduction of the microbial population. This is particularly true for slower-growing methanogenic microbes, which are necessary for converting organic materials into biogas. This situation is also known as "wash out."
- **Organic overload.** Occurs when the feedstocks load rate (VS or COD) is being fed at a rate exceeding what the microbes can convert into CH_4. This usually happens when a sudden and steady increase in organic matter is being fed for digestion. Overload causes a relative imbalance between the acid-forming and methanogenic microbial populations, which causes an accumulation of volatile acids. An excessive concentration of volatile acids inhibits the activity of the methanogenic microbes. This situation is also known as a "stuck" or "upset" digester."
- **Temperature stress.** Occurs when the digester's operating temperature changes suddenly, significantly, and for an extended period. This could be the result of the failure of one component used in the digester's heating system. An example might be severe engine failure during a blizzard in an extreme weather zone, and a key repair part is not be available for days or weeks. Another cause could be if a blend of manure and recently added co-digestion feedstocks are much colder when fed to the digester than it was when only livestock manure was used. Ensure that input feedstock temperatures do not give the warm microbial population a cold bath. Severe winter temperatures can also be a cause of seasonal temperature stress if the digester's heating system was not properly designed.
- **Toxic overload.** Occurs when the system is stressed by chemical elements or compounds like sulfides, volatile acids, heavy metals, calcium, sodium, potassium, dissolved O_2, NH_3, and chlorinated organic compounds. Typical sources of toxic materials in food processing wastes are compounds used for cleaning, disinfecting, and sanitation (for example, chlorine, copper sulfate, and quaternary NH_3).

11.3 Maintenance of Mechanical Components

The digester operator must monitor and maintain the system. Depending on the digester type, size, and design, the digester operator's job can range from a couple hours to a full day. As stated previously, proper feeding and digester conditions are paramount to success. It is always important to develop procedures that assure constant influent to the digester, both hydraulically and biologically. This will involve monitoring feedstocks, especially if co-digestion feedstocks are utilized. While a co-digestion feedstock may emanate from the same source, there will likely be daily variations on solids content and strength that must be monitored. A procedure for blending these with manure should be a daily operation to avoid under or over feeding the digester. It is important that the effluent side of the AD system is maintained properly since its operation is also crucial to continued operations.

The amount of time required for daily maintenance is dictated by digester type and how the biogas is used. For example, a gravity-fed covered anaerobic lagoon that flares all the biogas will require only a nominal amount of effort to maintain. Increased complexity of the digester type and biogas conversion technology means more time will be required. For example, the maintenance of a complete mix digester that uses biogas to generate electricity will be more complex than for a covered lagoon.

Another issue to consider is the willingness and ability to properly manage an AD/biogas system. While automated control systems may issue warnings about digester health or when stability issues arise, its mechanical equipment still requires daily attention.

Many types of mechanical equipment are used in an AD/biogas system. This includes equipment like the system's pumps, mixers, grinders or macerators, compressors, and electrical generators. The system operator and technology provider should develop a preventative maintenance manual to help avoid mechanical failures at the site.

Ongoing maintenance (e.g., screen cleaning) should become part of a regular routine. Intermittent maintenance (e.g., engine overhauls or pump seal replacement) should follow the manufacturer's recommended maintenance schedule. In the event of a mechanical failure, the applicable vendor's reference manual should be used to help trouble-shoot the issue. Qualified training is essential, and it is important that anyone performing equipment maintenance has the necessary knowledge and skills.

12.0 Additional Tools and Resources

A wide variety of online tools and resources are available for stakeholders who are interested in learning more about the use of AD/biogas systems. Several outreach materials and project development tools, guidance on funding resources, and information on digesters operating within the United States are listed below.

12.1 AD/Biogas System Basics & Overview

Resources that provide a basic overview of AD/biogas systems are included in the table below.

Topic	Description
How AD/Biogas Systems Work	Diagram prepared by the American Biogas Council demonstrating how biogas systems work, from the organic materials to the resulting processed biogas and digested material.
Recovering Value from Waste: AD/Biogas System Basics	Biogas recovery may hold the key to unlocking the financial and environmental benefits of managing manure generated from livestock operations and organic wastes from the agriculture and food production sectors. This AgSTAR fact sheet outlines how an AD/biogas system works and includes factors affecting feasibility and selection of these systems.
Anaerobic Digestion Overview - AgSTAR Stories from the Farm	The AgSTAR website includes “Stories from the Farm” that provide first-hand accounts of the operations, lessons learned, benefits, and challenges associated with AD projects on livestock farms in the United States.
AgSTAR Market Opportunities Report	AgSTAR's *Market Opportunities for Biogas Recovery Systems at U.S. Livestock Facilities* report assesses the market potential for biogas energy projects at swine and dairy farms in the United States, including details on the methodology and sample calculations. For the top ten swine and dairy states, the guide characterizes the sizes and types of operations where biogas projects are technically feasible, along with estimates of potential CH_4 production, electricity generation, and GHG emission reductions.

12.2 AgSTAR Project Profiles

Short profiles of livestock farm AD/biogas systems in the United States, prepared by AgSTAR, are listed below. Visit AgSTAR’s Stories from the Farm web page to find stories by location, animal type and status.

California
- Castelanelli Bros. Dairy
- Cottonwood Dairy

Connecticut
- Freund’s Farm

Idaho
- Big Sky West Dairy

Illinois
- Hillcrest Dairy

Massachusetts
- Barstow's Longview Farm

Minnesota
- Haubenschild Farms

Missouri
- Ruckman Farm

Michigan
- Michigan State University

Nebraska
- Danny Kluthe Farm

North Carolina
- Butler Farms
- Loyd Ray Farms

New York
- AA Dairy
- Emerling Farms
- New Hope View Farm
- Noblehurst Farms
- Patterson Farms
- Ridgeline Farm
- Sunny Knoll Farm
- Twin Birch Dairy

Oregon
- Bernie Faber Dairy (Cal-Gon Dairy)

Ohio
- Ringler Farm
- Quasar Energy
- Ruckman Farm

Pennsylvania
- Mason-Dixon Farms

Vermont
- Blue Spruce Farm, Inc. / Audet's Cow Power
- Foster Brothers Farm

Washington
- Vander Haak Dairy
- WSU (Washington State University) Research Project
- Wisconsin
- Baldwin Dairy
- Clover Hill Dairy, LLC
- Crave Brothers Dairy Farm / Clear Horizons LLC
- Dane County Community Digester
- Five Star Dairy Farm
- Gordondale Farms
- Green Valley Dairy
- Holsum Dairy - Elm Road
- Holsum Dairy - Irish Road
- Norswiss Farms
- Sunrise Dairy (formerly Suring Community Dairy)
- Vir-Clar Farms
- Wild Rose Dairy

12.3 Digester Feedstock Information

Information about digester feedstock considerations for AD/biogas systems are listed below.

Topic	Description
Using Biochemical Methane Potentials and Anaerobic Toxicity Assays	Presentation by Lara Moody, Iowa State University, at the Fifth AgSTAR National Conference, regarding using BMP and ATA.
AD of Animal Manures: Methane Production Potential of Waste Materials	This fact sheet provided by the Oklahoma State University Extension describes how three measurements: Volatile Solids, Oxygen Demand, and BMP are used to narrow the range of methane-producing materials from potential, to possible, to probable.
Anaerobic Digestion on Hog Operations	This AgSTAR fact sheet provides information about how to increase the use of AD on hog operations, featuring current manure management and storage practices and barriers and solutions.
Basics of Energy Production Through AD of Livestock Manure	This Purdue University Extension fact sheet discusses how livestock manure from concentrated livestock operations can be a source of energy production that not only provides an alternative energy source for on-farm use, but mitigates the negative consequences of odor from livestock operations.
Estimating Methane Reductions from Operating AD/Biogas Systems	This AgSTAR fact sheet presents a protocol that can be used as a tool for evaluating the performance of AD systems.

Topic	Description
Increasing Anaerobic Digestion Performance with Co-digestion	This AgSTAR fact sheet discusses the use of co-digestion to increase methane production from low-yielding or difficult to digest feedstocks.
Italian Biogasdoneright® a replicable and exportable model	This article from BE Sustainable discusses the Italian model for agricultural biogas based on the principles of Biogasdoneright®.
Wastewater Creates Energy, Products and More	KQED article that discusses how wastewater technologies can be used to create energy and products.
Massachusetts to Make Big Food Wasters Lose The Landfill	KQED article describes the ban of food waste generators sending discarded food to landfills in Massachusetts.

12.4 Financial Assistance Information for Agricultural Products

Resources related to financial assistance for AD/biogas systems are listed below.

Topic	Description
AgSTAR Webinar: Federal Financing Resources for Anaerobic Digesters	Resources from a webinar conducted by AgSTAR and USDA representatives about funding opportunities and support services available to AD/biogas system operators.
AgSTAR Funding On-Farm Anaerobic Digestion	AgSTAR fact sheet that can help identify grant, loan guarantee, and financial assistance available from federal and state governments, nonprofits, and private companies.
Database of State Incentives for Renewables and Efficiency (DSIRE)	The database contains information about renewable energy incentives and policies, which can influence project economic feasibility.
USDA Energy Matrix	USDA developed this website matrix summarizing USDA's energy-related programs and provides information on alternative and affordable energy solutions, funding for projects, available programs and program information, and research and development.
USDA Natural Resources Conservation Service	The USDA NRCS provides farmers and ranchers in the United States with financial and technical assistance to voluntarily put conservation on the ground, not only helping the environment, but also agricultural operations.
USDA Rural Energy for America Program	The USDA REAP provides guaranteed loan financing and grant funding to agricultural producers and rural small businesses for renewable energy systems or to make energy efficiency improvements. Funds may be used for renewable energy systems, such as AD/biogas systems.
USDA Rural Development Business Programs	USDA's Business Programs provide financial backing and technical assistance to stimulate business creation and growth.
USDA Rural Development Value-Added Producer Grants (VAPG)	USDA's Value-Added Producer Grant (VAPG) program helps agricultural producers enter into value-added activities related to the processing and marketing of new products.
Sustainable Agriculture Research & Education Grants (SARE)	SARE offers competitive grants to fund research and education projects that advance sustainable agricultural practices in the United States.

12.5 Project Screening and Feasibility Study Information

The following resources provide information related to AD project screening and feasibility studies.

Topic	Description	Source
AgSTAR Interviews with AD/Biogas System Operators	During these interviews, operators of AD/biogas systems share first-hand feedback about their projects.	• Dane County, WI • Ideal Family Farms, PA • Reinford Farms Inc, PA • RENERGY, OH • Storms Farm, NC
Case Studies	These links provide a compilation of project case studies, reports, and presentations that provide additional information and details about farm-based AD/biogas systems. Visit AgSTAR's Stories from the Farm web page to learn more about AD projects and case studies (additional case study links are provided on the right).	• Wisconsin • AD at Noblehurst Farms, Inc. • AD in Lamb Farms: Case Study • AD at Swiss Valley Dairy: Case Study • Michigan State University • Peters/USEMCO AD • Joneslan Farm • Dairy Manure AD Feasibility Report
Anaerobic Digestion Ombudsman Case Studies	An AD ombudsman is an independent third-party individual who helps farmers develop and maintain AD/biogas system projects. Learn more about these ombudsman programs and how to implement an ombudsman program in your state (see links on the right).	• AgSTAR • Vermont • New York
AgSTAR Livestock Anaerobic Digester Database	The AgSTAR Livestock Anaerobic Digester Database provides basic information on AD/biogas systems on livestock farms in the United States	
AgSTAR Vendor Directory: Develop AD/Biogas Systems	The AgSTAR Vendor Directory includes organizations that support the livestock AD/biogas system industry.	
Newtrient Technology Catalog	This catalog presents various manure management and nutrient recovery solutions and includes more than 250 technologies that have been rated by third-party experts to meet unique farm needs.	• Introductory video • Complete catalog
Review of Emerging Farm-Based Nutrient Recovery Technologies	Developing additional co-product value requires implementing emerging nutrient recovery technologies. While nutrient recovery technologies for phosphorus and nitrogen exist and are fully commercialized in the municipal and industrial sectors, a moderate amount of continuing research and development is still needed to successfully implement these technologies within the agricultural sector.	

12.6 Online Tools and Software

Additional online tools and software available to inform AD projects are presented below.

Topic	Description
An Economic Evaluation Tool for Farm-Based Anaerobic Digesters	An EXCEL-based model that assesses farm-based AD/biogas systems in Ontario under different scenarios, such as livestock type, farm size, system operation practices system specifications, government policies, and levels of investment certainty (University of Guelph, with funding from the Ontario Ministry of Agriculture Food and Rural Affairs, 2017).
Organics: Co-Digestion Economic Analysis Tool (CoEAT)	An EXCEL-based model using publicly-available data to calculate economic, environmental, and operational parameters using food waste as a co-digestion feedstock at a WRRF (EPA Region 9, Pacific Southwest, 2016).
Cost of Renewable Energy Spreadsheet Tool (CREST)	An EXCEL-based model assessing project economic feasibility; includes a module specific to AD technologies (National Renewable Energy Laboratory, 2013).
System Advisor Model (SAM)	A stand-alone performance and financial model designed to facilitate decision making for renewable energy projects. This model is not specific to AD (National Renewable Energy Laboratory, 2010).
RETScreen Expert	A stand-alone model for determining the technical and economic feasibility of energy efficiency, renewable energy, and co-generation projects. This model is not specific to AD (Natural Resources Canada, 2013).
State Energy Portal Online for Consumers	Provides a United States overview and the state total energy rankings as of 2017.
State Renewable Portfolio Standards and Goals	Provides the Renewable Portfolio Standards (RPS) created by states to diversify their energy resources, promote domestic energy production, and encourage economic development.
Biogas Research Database (ABC)	The ABC research database for biogas and AD digester research projects.
AD Budget Calculator	The AD System Enterprise Budget Calculator is intended for dairy owners, AD system industry experts, and AD researchers to help easily calculate the economic value of investments under a variety of technology and price scenarios for an AD system.
Anaerobic Digestion Financial Decision Tools	This source from Cornell University provides links to a variety of spreadsheet-based financial decision tools.
EPA WARM Tool – Tracking and Reporting of Emission Reductions	EPA created the Waste Reduction Model (WARM) to help solid waste planners and organizations track and voluntarily report GHG emissions reductions from several different waste management practices. WARM calculates and totals the GHG emissions of baseline and alternative waste management practices—source reduction, recycling, AD, combustion, composting and landfilling.

12.7 Business Relationships

The following resources can assist in building business relationships for AD projects.

Topic	Description
US DOE, Exploring Power Purchase Agreements: The Basics	This resource provides information on the basics of PPAs, including risks and unique issues and benefits.
Interconnection Guidelines	AgSTAR's Interconnection Guidelines fact sheet provides general guidance on the steps involved in connecting biogas recovery systems to the utility electrical power grid.
Attracting Institutional and Impact Investors (presentation)	This presentation, available on AgSTAR's website, details the process to attract strong investors in the domestic wastewater market.

12.8 Permitting

Additional information about permitting guidelines is provided on AgSTAR's website.

Topic	Description
EPA Guidelines and Permitting for Livestock Anaerobic Digesters	AgSTAR provides AD guidelines and information about permitting requirements to help in the planning and optimization of AD projects.

12.9 Safety, Operations, and Maintenance Considerations

Resources related to safety and O&M considerations at AD facilities are provided below.

Topic	Description
Farm Energy Anaerobic Digestion and Biogas	This page provides information about AD/biogas systems from the United States' land-grant universities, including Articles and Fact Sheets, Case Studies, and Curriculum and Training Programs.
Common Safety Practices for On-Farm Anaerobic Digestion Systems	This AgSTAR document helps identify the major hazards associated with an AD facility and outlines basic practices that will help maintain a safe and successful working environment.

12.10 AgSTAR Partner Network

Additional websites and resources that support AD projects are provided below.

Topic	Description
USDA Energy Website	The USDA Energy Web includes an interactive map, graphing analysis tools, and the USDA Energy Matrix.
DOE Alternative Fuels Data Center (AFDC)	AFDC provides tools to help fleets and other transportation decision makers find ways to reach their energy and economic goals through the use of alternative and renewable fuels, advanced vehicles, and other fuel-saving measures.

Topic	Description
WSU Center for Sustaining Agriculture and Natural Resources	CSANR has supported research and the development of several farm-based energy resources.
Cornell University Dairy Environmental Systems	Cornell's Dairy Environmental Systems site provides holistic information about facilities housing animals, the cropping practices that provide feed, and the nutrient management practices.
MSU Anaerobic Digestion Research and Education Center (ADREC)	The ADREC provides a platform for multi-disciplinary, multi-institutional, and multi-national collaborations that develop sustainable waste-to-resource solutions to address current and future waste utilization challenges.
Pennsylvania State University Renewable and Alternative Energy	This site includes information and renewable and alternative energy resources from Penn State.
American Biogas Council	Comprehensive library of the American Biogas Council's tools and resources related to biogas, RNG, and policy.
Renewable Natural Gas Coalition	The RNG Coalition advocates for sustainable development, deployment, and utilization of renewable natural gas so that present and future generations will have access to domestic, renewable, clean fuel and energy.
Energy Vision	Energy Vision is a non-profit environmental group that helps to guide the shift from fossil fuels to clean and renewable resources.
Ontario Ministry of Agriculture, Food and Rural Affairs	This page provides links to general information about biogas, such as biogas safety, funding, and training.