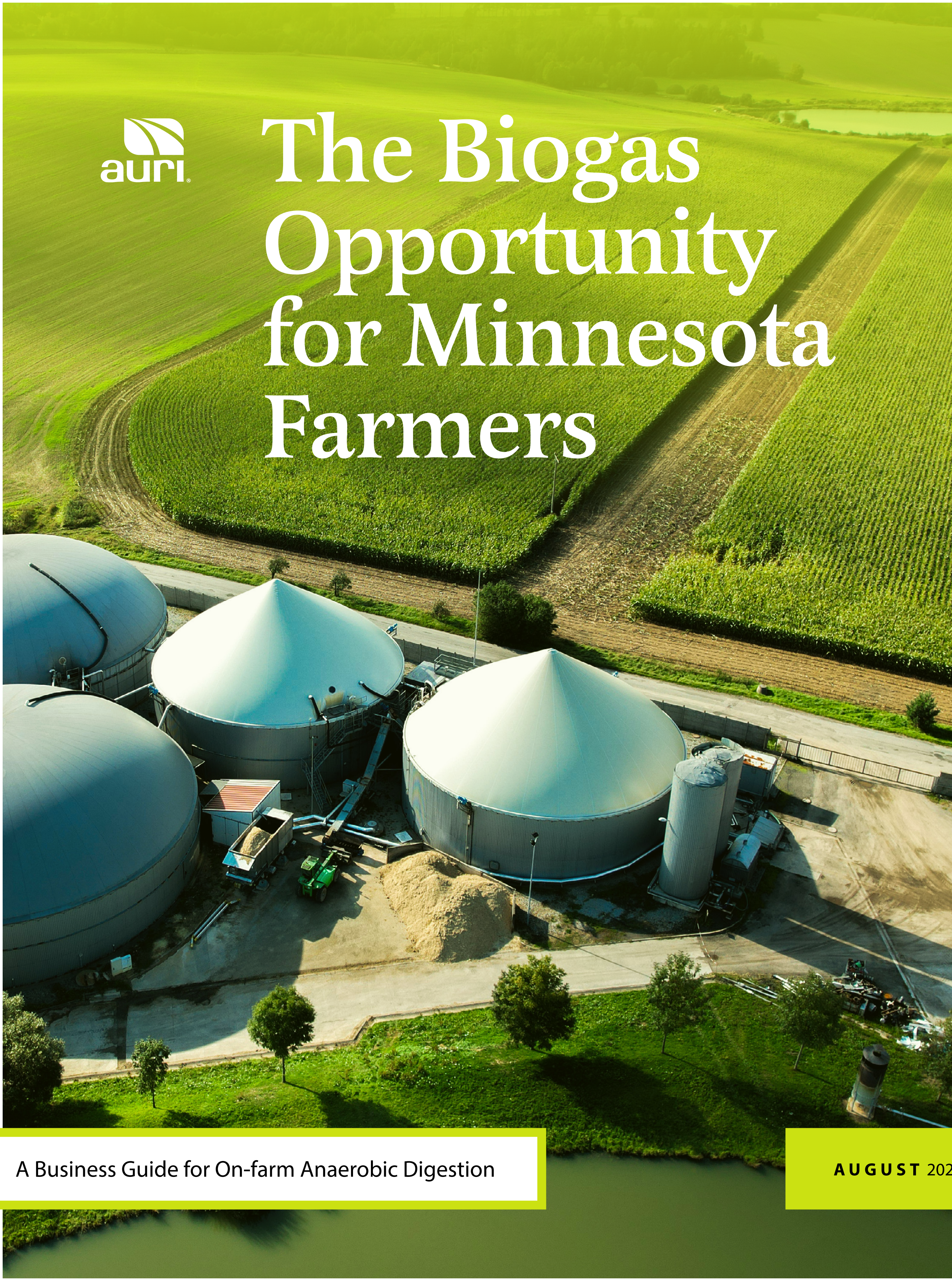

The Biogas Opportunity for Minnesota Farmers

A Business Guide for On-farm Anaerobic Digestion

AUGUST 2025

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Foreword

The Agricultural Utilization Research Institute (AURI) is pleased to present The Biogas Opportunity for Minnesota Farmers: A Business Guide for On-farm Anaerobic Digestion. The objective of this guide is to introduce the concept of on-farm anaerobic digestion (AD) and its specific relevance to Minnesota farmers. This guide will explore the AD opportunity and explain existing and potential on-farm business models and considerations. Installing an on-farm AD can offer numerous benefits, including additional income, improved nutrient recovery and reuse, energy production, water quality enhancement, and odor and greenhouse gas reductions. Despite these benefits, on-farm AD is not without risk. Producers should thoroughly investigate the benefits and risks associated with installing an AD system. This guide is not intended to be comprehensive. While AD is not a new technology, the industry is still emerging in the United States. Producers are encouraged to consult their peers and professionals in the industry to learn as much as they can about the on-farm AD opportunity.

This guide will reference existing resources covering the fundamentals of AD in detail and should be consulted as producers weigh adding an AD system to their operation. Two such resources are the EPA's AgSTAR Program, and A Guide to Anaerobic Digesters for Small Farms.[1,2] However, there are several unique opportunities and challenges associated with the specific conditions of farms in Minnesota, which will be covered in this guide.

[1] EPA AgSTAR Program
[2] Abel, Ebel; Montana State University: A Guide to Anaerobic Digestion for Small Farms

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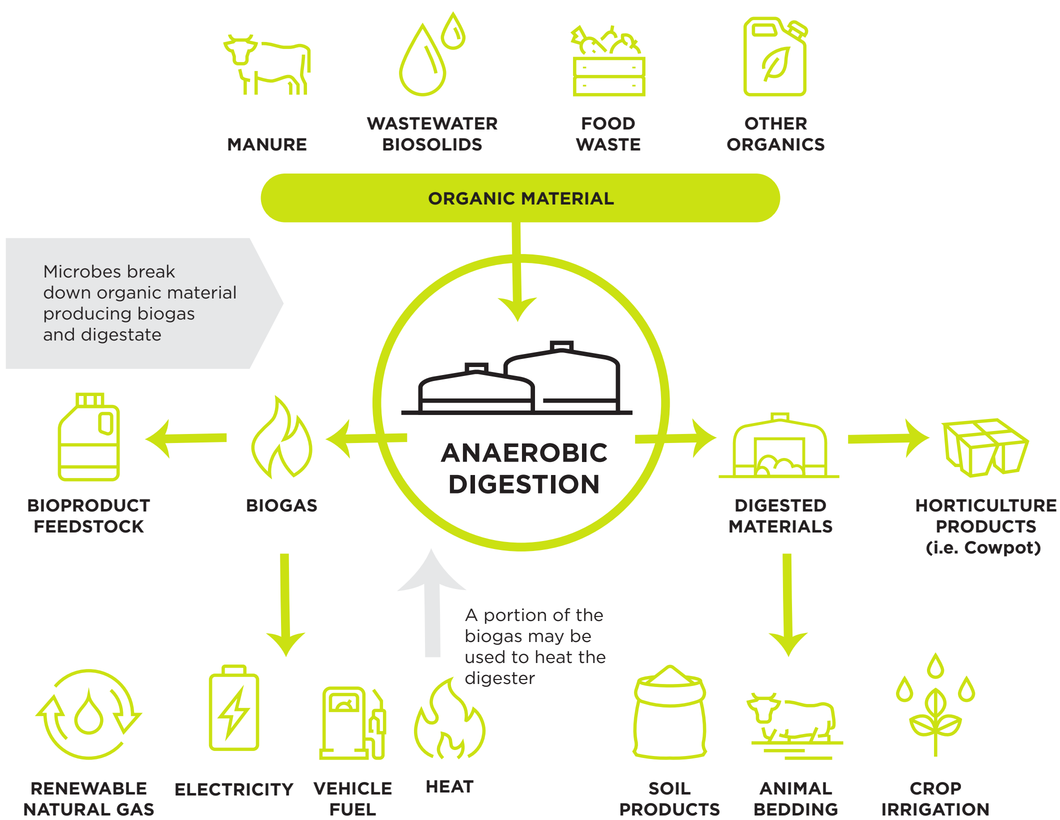
Understanding Anaerobic Digestion

Renewable natural gas (RNG) is an emerging opportunity for Minnesota's livestock producers. As demand continues to grow for clean, renewable energy and more effective waste management approaches, project developers are engaging farmers as they invest in on-farm anaerobic digestion (AD) facilities. The purpose of this guide is to provide producers with an understanding of the many considerations involved with on-farm AD systems, should they be approached by a developer or seek to develop the opportunity themselves.

AD is the natural, biological breakdown of organic waste, like manure and food waste, in the absence of oxygen (See Figure 1). The process produces biogas, a mixture of methane and carbon dioxide, that can be used as a replacement fuel for natural gas, whose main component is also methane, or to produce electricity. The nutrient-rich residual from AD, digestate, can be used as bedding, fertilizer, or further processed into bioproducts.

Figure 1: The flow of feedstocks through AD to produce biogas, digestate, and other value-added products

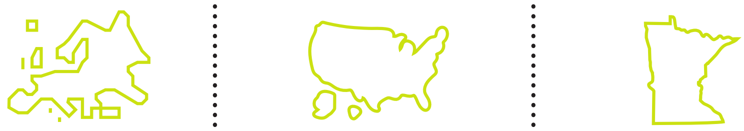


AD has been around for centuries and has been used for energy production since the late 19th century. More recently, it has become a valuable tool in managing organic materials and reducing greenhouse gases. AD biogas can be carbon-neutral when coupled with methane loss mitigation during RNG processing and digestate storage and does not contribute to increased carbon dioxide and methane concentrations in the atmosphere when used as a fuel source.[3]

While Europe has installed over 20,000 facilities to date, the U.S. has approximately 2,500 installations, including 1,189 water resource recovery facilities (i.e., wastewater treatment plants), 583 landfills, 113 stand-alone food waste systems, and 600 farms (See Figure 2).[4] As of 2025, Minnesota has about 26 water resource recovery facilities, 4 landfills, 17 farms, and 2 food waste facilities with AD systems.[5,6] The majority of the facilities in the U.S. and Minnesota were installed (or modified) in the last 10 years, and the number of installations continues to grow. In the U.S., at least 6 new manure-based systems have come online since the beginning of 2024, with another 73 under construction.[7]

[3] University of Florida: Biogas: A Renewable Biofuel
[4] American Biogas Council: Harness the Benefits of Biogas
[5] American Biogas Council: Biogas State Profiles: Minnesota
[6] Minnesota Pollution Control Agency communication
[7] EPA AgSTAR: Anaerobic Digester Facts and Trends

Figure 2: Number of AD facilities in Europe, the United States, and Minnesota



EUROPE	U.S.A.	MINNESOTA
20,000+	2,500	49
	1,189 WRRFs*	26 WRRFs
	583 Landfills	4 Landfills
	600 Farms	17 Farms
	113 Foodwaste	2 Foodwaste

*WRRF = Water Resource Recovery Facility (i.e. wastewater treatment plants)

Until 2013, the traditional AD business model in Minnesota was an on-farm digester producing electricity from manure and generating a nutrient-rich residual. In many cases, the farm owned and operated the digester. The biogas from the digester went to on-site generators producing electricity for use either on-site or distributed to the grid. In the last decade, on-farm digesters began pivoting away from electricity generation and instead began conditioning the biogas to generate RNG.

Beginning in 2014, RNG from manure qualified for renewable identification numbers under the federal Renewable Fuel Standard (RFS), creating another source of revenue. The RNG could be injected into a suitable pipeline and, as a result, be eligible for carbon credit opportunities, such as California's Low Carbon Fuel Standard (LCFS). These environmental incentives effectively increased and drove the installation of more projects. In 2023, farm AD projects reduced greenhouse gas emissions by approximately 14.8 million metric tons of carbon dioxide equivalent.[8]

Interest in RNG has grown not only to satisfy low carbon fuels and other environmental sustainability goals but also due to federal and state programs, and there is ample and growing support for AD from the private sector. For example, the U.S. Dairy Net Zero Initiative has the goal of achieving greenhouse gas neutrality and improved water quality by 2050.[9] And Minnesota-based, Target, is committed to net zero greenhouse gas emissions across its operations and supply chain by 2040.[10]

The U.S. and Minnesota Potential

The historical path of the development of AD systems described above, support from federal and state governments, and support of the private sector have primed the landscape for the growth of AD opportunities. According to the American Biogas Council (See Figure 3), the U.S. has the potential to install more than 17,000 new biogas systems, resulting in significant economic, environmental, and energy benefits.[11] Minnesota has the potential to make more than 63 billion cubic feet of biogas, or more

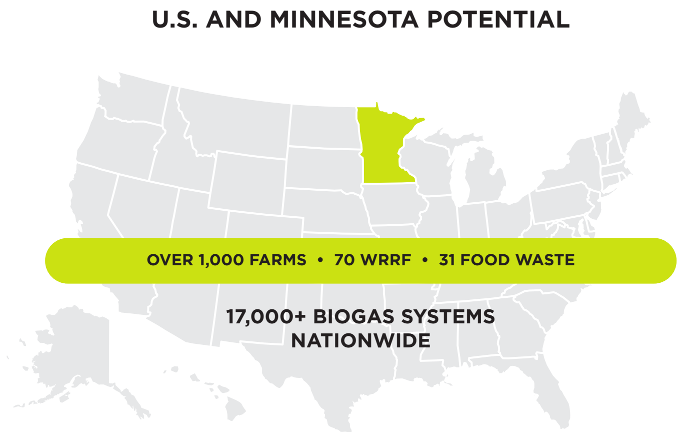
[8] EPA AgSTAR: Environmental Benefits
[9] U.S. Dairy: U.S. Dairy Net Zero Initiative
[10] Target: Climate
[11] American Biogas Council: Harness the Benefits of Biogas

A Quick Look – The California Low Carbon Fuel Standard (LCFS)

The California Low Carbon Fuel Standard (CA LCFS) is a market-based regulatory program designed to reduce the carbon intensity of the state's transportation sector. At the heart of the program is a credit-and-deficit system that assigns economic value to reductions in carbon emissions. Emission reductions are calculated against legislatively established targets, with one LCFS credit representing one metric ton of avoided greenhouse gas emissions. Fuels with lower carbon intensities—such as biodiesel, renewable diesel, ethanol, electricity, hydrogen, and biomethane—generate credits when they displace conventional fossil fuels. Conversely, fuels like gasoline and diesel, which have higher carbon intensities, generate deficits if they exceed the regulatory target. Obligated parties—primarily oil refiners and fuel distributors—must balance these deficits by either lowering their fuel's carbon intensity or purchasing credits from other market participants. Meanwhile, biofuel producers and other clean energy suppliers can sell surplus credits, creating a financial incentive to invest in alternative fuels technologies. Operating under a cap-and-trade structure, the LCFS allows the marketplace to determine the fuel mix while regulatory limits set the overall carbon intensity targets. However, credit prices fluctuate based on supply and demand dynamics. Recently, credit prices have declined due to increased supply—largely driven by increased production and adoption of low-carbon fuels, as well as fuel suppliers improving efficiency and blending more renewable fuels. Furthermore, to participate in the LCFS, fuels must be sold in California. For example, producers of renewable natural gas located outside the state must have the capability to inject their gas into an interstate pipeline connecting to California. Additionally, producers must secure an approved production pathway to certify their fuel's carbon intensity. The California Air Resources Board (CARB) is responsible for establishing the rules for pathway certification and auditing which producers participating in the market need to follow.

Source: Understanding California's Low Carbon Fuel Standards Regulation than 13% of the State's natural gas demand, and is based on the possible production from 31 food waste, 70 wastewater, and over 1,000 on-farm facilities.[12,13,14] In 2022, Minnesota had 2,185 dairy farms and 2,928 swine farms, but at the time of this report, there were fewer than 20 on-farm AD systems.[15] If Minnesota is to reach its potential, more on-farm systems are needed.

Figure 3: The number of potential biogas systems in the U.S. and Minnesota



Farmers who are evaluating the potential for an on-farm AD system should not only consider the questions posed in the sidebar below, *"Is AD Right for Your Farm?"* but also comprehensively examine the overall AD business model, including the business structure, asset ownership, farm infrastructure needs, technical choices, digester economics, operation requirements, regulatory requirements, environmental impact, community acceptance, and risk management. A variety of resources – including AURI – exist to assist producers in these evaluations.

"Is AD right for your farm?"

- *Does AD fit your farm's mission, vision, and strategic plan?*
- *How does AD impact your farm's succession plan?*
- *Does your herd size provide enough manure for a meaningful project?*
- *Do you have plans to increase or decrease your herd size?*
- *Are you open to accepting off-farm feedstocks or hosting a facility that consolidates manure from other farms?*

How much biogas can be produced on a farm?

This is a very common question—and like many questions in the world of anaerobic digestion, the answer is: it depends! It depends on what is being digested, how the feedstock is handled before entering the digester, the size of the digester relative to the feedstock flow, the temperature inside the digester, and many other factors, including the animals' diet.

It is recommended that any feedstock considered for anaerobic digestion undergo a Biomethane Potential (BMP) test. BMP tests are laboratory procedures that estimate the theoretical maximum amount of methane a given feedstock can produce. While BMP results represent an ideal scenario, in practice, around 70% to 75% of that theoretical value is often technically achievable in a full-scale digester. AURI can perform this and other characterizations of feedstock to help assess the potential biogas production of an on-farm AD system.

The EPA AgSTAR Handbook estimates that the manure from a single lactating dairy cow in the U.S. can generate approximately 90 to 100 standard cubic feet per day (SCF/day) of biogas, which typically contains about 60% methane by volume. For planning purposes, heifers and non-lactating cows are typically assumed to produce half of the energy of lactating cows.

So, a farm with 2,000 lactating cows would produce roughly 180,000 SCF/day of biogas, or about 108,000 SCF/day of renewable natural gas (RNG). This equates to approximately 108 MMBTU/day of energy.

To put that into perspective: that's the same amount of energy contained in approximately 790 gallons of diesel fuel per day, or enough to heat seven average Minnesota homes for the entire month of January!

[12] Hoffman, Kurumbail, Rhodes, Anderson, Anex; University of Wisconsin: Renewable Natural Gas: A Case Study of Minnesota
[13] U.S. Energy Information Administration: Natural Gas
[14] American Biogas Council: Biogas State Profiles: Minnesota
[15] USDA: 2022 Census of Agriculture: Minnesota

Herd Size Considerations for Anaerobic Digestion

Both biogas and digestate are essential economic drivers for successful installations and are dependent upon the quantity and type of feedstock(s). In the case of manure, there is a minimum number of animals needed for a cost-effective AD system. In 2018, the EPA AgSTAR program reported that the historical standard has typically been at least 500 dairy cows or 2,000 pigs.[16] AgSTAR estimates tend to focus on minimal techno-economic requirements, but depending on a variety of practical considerations, in particular economic return expectations, many developers are targeting larger projects. Most of the existing on-farm AD facilities in Minnesota have more than 2,500 dairy cows. At the time of this report in 2025, there are no on-farm swine AD systems operating in the state.

As the industry matures, the cost of installations has the potential to decrease due to increased competition, technological advancements, and standardization. As a result, profitable business models for smaller farms will increase as time progresses. In addition to costs decreasing over time, some on-farm AD operations plan to co-digest (See Sidebar) off-farm materials like food waste to increase the amount of biogas created and generate additional revenues. The combination of on-farm and off-farm materials can be a profitable business model for smaller farms because the off-farm materials can generate tipping fee revenue for the owner, aside from improving the cost-effectiveness of the AD equipment. Lastly, there is a "hub and spoke" model featuring a centralized digester accepting manure from multiple smaller farms, which again creates opportunities for operations with fewer animals (See Figure 4). In summary, the on-farm AD opportunity is worth investigating for farms that manage any amount of manure.

What is co-digestion?

Co-digestion in AD involves processing multiple organic substrates, such as manure, food waste, or crop residues, simultaneously within a single system. Combining various substrates enables a more efficient breakdown of organic material and enhances biogas production.

The inclusion of food waste significantly boosts biogas yields, optimizes renewable energy production, and introduces new revenue streams through tipping fees. Facilities accepting food waste can generate additional income while reducing disposal costs for waste generators. Furthermore, diverting food waste from landfills through co-digestion leads to considerable environmental benefits by lowering greenhouse gas emissions from decomposing organic waste, thus enhancing the project's potential to earn environmental credits.

These benefits typically offset the increased complexity associated with co-digestion, such as higher capital and operational costs, more complex digester management, and more intricate permitting processes. Producers considering co-digestion must carefully manage nutrients, as non-manure feedstocks introduce additional nutrients beyond those produced on the farm. Effective nutrient management practices or alternative off-farm disposal solutions become necessary to address this surplus.

Specific Livestock Challenges

Swine Operations

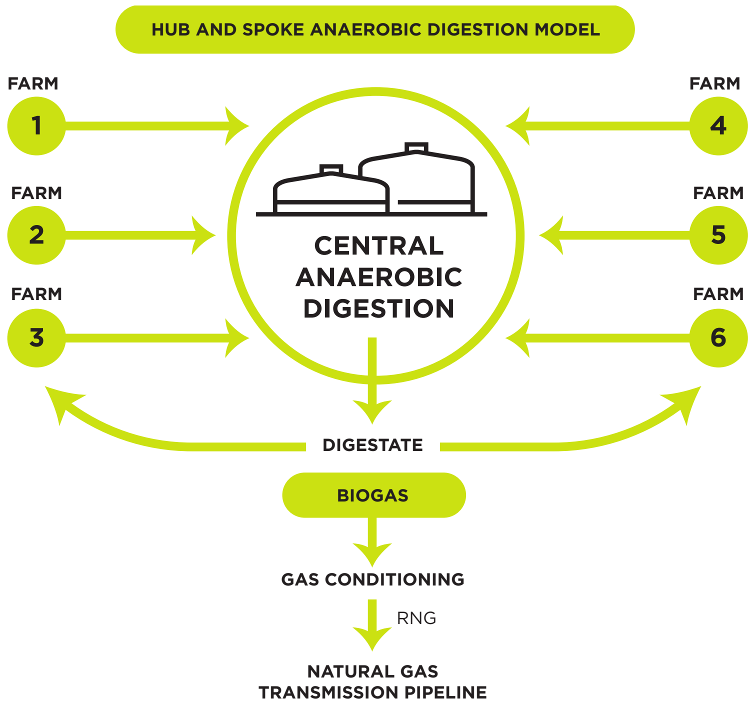
According to a 2024 Minnesota Pork report, Minnesota is the 2nd largest swine-producing state in the U.S., marketing nearly 17 million hogs annually and is home to about 3,000 swine farms. The swine industry is a factor in Minnesota's standing as one of the larger potential biogas producers in the nation, thus making this untapped opportunity critical for Minnesota to reach its biogas potential. Yet, to date, there are no installations on swine farms in Minnesota; although they exist elsewhere in the U.S. There are significant challenges that must be overcome for swine AD systems to be successful. First, most swine operations in Minnesota manage their manure in deep pits that are pumped once or twice a year for land application. Therefore, the environmental impacts of a deep pit model are not as significant as those of a lagoon system. Analysis shows pit-stored manure does not generate as much fugitive methane emissions as lagoon-stored manure.[17] Furthermore, the longer manure sits and decomposes, the less biogas it produces when placed in an anaerobic digester. As a result, pig manure from unmodified pits generates less revenue from environmental attributes since a lower number of emissions is avoided, and less revenue from energy creation as less gas is produced. For a pit to provide an effective AD feedstock, pit modifications and additional equipment such as mixers and pumps are needed. The modification of the pits to allow more frequent removal of manure could have the benefit of improving the swine facility's air quality, leading to improved odor control, better animal and worker welfare, and more community acceptance.[18] Lastly, most swine operations with deep pits will need to add dedicated storage for the digestate. While such storage can be a covered lagoon or pit where the digestate is held until it can be land applied, the additional cost needs to be considered while also noting that open lagoon storage can emit methane and ammonia and can result in public health and environmental risks.

[16] EPA AgSTAR: Market Opportunities Report
[17] Argonne National Laboratory: Waste-to-Wheel Analysis of Anaerobic-Digestion-Based Renewable Natural Gas Pathways with the GREET Model
[18] Jones; Purdue University, Collins; Virginia Tech: Recirculation Systems for Manure Removal

Poultry Operations

According to a 2022 Minnesota Poultry report by the Minnesota Department of Agriculture, Minnesota is 1st in turkey production in the U.S., raising 40 million birds on 666 farms annually. Additionally, Minnesota ranks 12th in overall poultry production (including turkeys, eggs, broilers, and farm chickens) on 6,198 farms. To date, there are no AD installations on poultry farms in Minnesota, and few exist in the U.S. according to EPA's AgSTAR program. Spent poultry litter is a relatively dry mixture of bedding material and manure. The bedding material is typically a poorly digestible woody material such as wood chips or shavings. For litter to be digested, water needs to be added. Poultry litter is also rich in nitrogen, leading to the production of excessive ammonia during digestion, which may prevent biogas production and can increase ammonia emissions causing impairment of local air quality. While these problems can be mitigated and developers are proposing novel approaches to overcome them, their impact on the economic and operational performance of an AD system cannot be ignored. Producers considering a poultry litter AD system should carry out extensive due diligence.

Figure 4: The hub and spoke AD model



What is a community digester?

The concept of a community digester is occasionally presented by developers and frequently referenced in various reports and presentations. Community digesters in Europe—particularly in Denmark—are centralized anaerobic digestion facilities that process manure from multiple farms, sometimes supplemented with organic waste from dairies or food processing plants. These systems are typically co-owned or cooperatively managed by local farmers. While present in other parts of Europe, they have particularly thrived in Denmark due to strong policy support and integration with local energy systems. A notable example is the Lemvig Biogas plant. Established in 1992, this facility cooperates with local farmers and operates as a non-profit organization. The plant processes organic waste from these farms—primarily manure but also crop residues. The resulting biogas is used to generate electricity, with surplus heat captured for district heating, providing residential heating to households in the area. Additionally, the digestate is returned to participating farms to be used as fertilizer.

While this model is conceptually attractive, it has yet to achieve practical implementation in the United States despite several attempts, including by some Danish firms. A key challenge is that U.S. farms—particularly in the Midwest—are significantly larger and more dispersed than their Danish counterparts. This makes the logistics of transporting manure to the digester and returning nutrients to the farms both complex and economically challenging. Although the concept of community digesters remains appealing, these practical limitations must be carefully considered when evaluating feasibility in the U.S. context.

On-farm Anaerobic Digestion Business Ownership Models

There are three primary on-farm anaerobic digestion business ownership models: contractual, joint venture, and self-ownership (See Figure 5).

Figure 5: On-farm AD business models

A producer who does not intend to finance, own, and operate an AD system may enter a contractual relationship with a developer. Typically, the developer is responsible for permitting, financing, owning, and operating the facility, hence the common designation of a "build-own-operate" contract. The formal owner of the facility is often a subsidiary specifically established by the developer's parent company for the project. This type of subsidiary is commonly known as a Special Purpose Vehicle (SPV). A SPV is usually structured as a Limited Liability Corporation (LLC), a preferred entity in project development for various reasons. While the producer might not directly participate in the SPV, it remains essential for the producer to review the arrangement established by the developer to avoid unintended liability due to association with the project. Such liabilities can arise from using the producer’s land, which, like wind and solar energy projects, is leased to the developer or its subsidiary, typically for periods ranging from 10 to 20 years.

Under this contractual model, the developer collects and retains the revenue generated from the sale of gas, environmental attributes, and tipping fees associated with co-digestion. The producer is obligated to provide manure and usually receives the digestate. The primary benefit for the producer includes a modern manure management system at minimal or no cost and revenue from land leasing. Occasionally, but not frequently, a producer may receive additional payments or royalties from the project. To secure such additional benefits, the producer may enter into a joint venture with the developer, acquiring equity in the project's SPV. This joint venture is structured through an operating agreement clearly outlining financial contributions of equity and debt financing, delineation of ownership and operational responsibilities, biogas sales, and digestate utilization. Generally, decision-making authority resides predominantly with the equity holders contributing the most capital, typically the developer. Under the joint venture model, project revenues are distributed directly to the members proportionally to their equity positions, allowing the producer an opportunity to share in the project's profits. The LLC's revenues are reported as income for the owners and are taxed accordingly. This arrangement enables direct producer participation in the project while mitigating some financial and operational risks associated with self-ownership.

A critical consideration for producers is the potential impact of an AD on farm operations. Notable impacts include potential capital investments needed to ensure manure collection systems are compatible with the AD system and necessary adjustments to the farm's nutrient management plan, which may need adaptation due to changes introduced by the digester. This consideration becomes particularly important in cases of co-digestion, where the digestate will contain nutrients not originally present on the farm.

Additionally, the monetization of environmental benefits relies on an auditable life-cycle analysis of the digester operations to ensure the validity of the claimed environmental benefits, which may extend beyond the immediate boundaries of the digester project itself. Any changes in farm operations could influence these environmental benefits and thus affect project revenues. Similar considerations may apply to gas production. Consequently, this could impose significant constraints on farm operational flexibility, a factor producers must carefully evaluate before committing to a project, regardless of the chosen business model. Producers should seek independent expert advice to thoroughly assess these considerations as the digester performance becomes a critical consideration while evaluating the farm operations.

Contractual and Joint Venture Considerations

- *Have you conducted due diligence on the partners you are interested in forming a relationship with? Due diligence could include reviewing financial statements, assessing their financial viability, visiting other installations, engaging with an independent consultant with experience in the sector to review proposed solutions, and connecting with producers with whom they're working.*
- *Did you consult an attorney to advise on the formation of a contractual relationship or joint venture (JV)? While legal costs can be considerable, it is strongly recommended that any term sheet and proposed agreement be subjected to an exhaustive legal review.*
- *How will changes or a potential exit be defined in the JV? This is especially important if the AD system is on your property.*
- *Have you considered the potential exposure to liabilities while participating in a contractual or JV relationship with a developer? While these relationships are often and justifiably seen as protecting the producer from liabilities associated with direct ownership, such protection is often not absolute, and a thorough review with an experienced attorney is always recommended. The producer should be particularly attentive to liabilities and loss of goodwill with the local community in case of environmental mishaps.*
- *How responsive is a developer to the producer's concern? How willing is the developer to negotiate project-specific contracts and deviate from a standard contractual template?*
- *What constraints are imposed on farm operations, if any, once obligations associated with manure delivery and digestate off-take are considered?*

Self-ownership means the producer has complete control of the AD system asset. This requires a good working knowledge of AD systems to manage the financing, regulatory, permitting, installation, and subsequent operation of the system. Undertaking self-ownership of an AD system demands a detailed review of the science, technology, engineering, and operations of on-farm digesters, which is beyond the scope of this guide. Nonetheless, they are well-covered in other documents referenced in this guide. For more information, visit the EPA's AgSTAR program.[19]

"Should I consider self-ownership?"

- *Do you have the expertise and time to manage both the installation and operation of your fully owned AD system, including acting as your own general contractor or managing one during the project planning, permitting, construction, and commissioning?*
- *How will you finance this project? Completely by equity or with debt financing? If the latter, how much credit can you secure, and what is your collateral?*
- *Have you considered all the project costs, not just capital costs, but development costs such as legal, consulting, and administrative costs associated with securing permits and off-take agreements?*
- *How will you negotiate off-take agreements with local utilities or access an injection site into a natural gas pipeline?*
- *Do you have expertise, or access to skilled labor or vendor agreements, to assist with the operation and maintenance of the system?*
- *Do you have a complete picture of the potential liability and how to mitigate risk?*

A common problem with AD systems is not appreciating the financial risks associated with the volatility of the RNG and carbon markets. Like agricultural commodities, market volatility means that an absolute prediction of future revenue is impossible. In fact, being relatively less developed than agricultural commodities, these markets are highly volatile and with fewer risk management options. A producer should be wary of a developer dismissing market risk. Producers should assess their own risk tolerance or aversion before engaging in direct participation in a project and seek expert advice from independent consultants familiar with these markets. A producer who may enter into a contractual relationship may not be completely isolated from these risks, since a failed project on the farmer's land would nonetheless have potentially significant operational consequences for the producer, even if the direct financial exposure is minimal.

Poor communication during project development is a common problem. Regardless of the business model, it is essential to be clear about roles, responsibilities, and expectations. For example, who is responsible for delays in construction, contractual delays, reduced deliveries of gas to buyers, major equipment failures, and environmental mishaps such as spills? Should the joint venture or one of its members default, what liabilities exist and for whom? Is the producer exposed to possible recourse from any affected third party? The importance of the producer to conduct accurate and extensive due diligence to minimize risk cannot be overstated. It is highly recommended to hire an experienced contractual attorney with expertise in capital projects to help review contracts, highlight concerns, support the negotiations of a contract, and identify any necessary risk mitigation measures.

[19] EPA AgSTAR Program

Building and Operating an On-farm Anaerobic Digestion System

A typical AD project includes unique equipment, typically one or more digesters (e.g., enclosed tanks or covered lagoons with mixing systems and temperature control devices), a gas collection and conditioning system, and a gas delivery and utilization system. Associated with this basic equipment are a variety of ancillary pieces of equipment needed to ensure the correct and safe operation of the system, such as feeding and transfer pumps, digestate dewatering equipment, solids separation equipment, gas storage, flares, fire suppression systems, electrical controls, and so forth. The actual type, layout, and specific details of these are project and developer-specific, and it is recommended that the producer engage an experienced technical consultant to ensure that the developer-proposed system can indeed deliver the expected performance before entering a contractual or joint venture relationship. In addition, the installation of these assets may require some farm-level infrastructure changes. For example, changes in the manure handling system, bedding management, changes in solids and liquid storage, access roads, and others. In some cases, the developer may pay fully or in part for these infrastructure changes.

Some critical infrastructure changes that are unique to AD systems relate to manure and digestate handling. While it is typically necessary to adapt the digestion system to whatever manure feedstock is available, at times, efficiency and other preferred technology options may prompt the developer to ask for changes such as adding a sand (See Figure 6) separator before feeding the manure to the AD system. While digestate handling has some similarities with manure handling, the physical nature of digestate compared to manure may impede the unmodified repurposing of raw manure equipment, and existing solids separators or lagoon storage may require modification or upgrading. The producer needs to consider this change carefully and where the financial obligation may reside.

Biogas must be converted to RNG prior to accessing a natural gas pipeline. This requires the installation of what is fundamentally a small chemical plant and represents a unique requirement of the AD system. RNG needs to be delivered to a utility pipeline injection point using a dedicated pipeline, which may cross a significant distance. Besides the cost, one will need to consider the possible need for new easements and rights-of-way. This latter consideration also emerges when other organic waste is co-digested. New or upgraded access roads may be needed to accommodate increased truck traffic. The need for easements, rights of way, and traffic can become a point of contention for permitting and community relationships and should be assessed and addressed as early as possible.

Given each project's specificity, a detailed discussion of all these aspects is beyond the scope of this document, other than to stress the importance of defining, with precision, the developer's scope of work and the producer's assumed commitments – notably the impact on the farm and any needs that may emerge with the associated permitting, financial, and operational obligations. Producers considering an AD project are strongly encouraged to seek expert advice on the AD system's technical requirements and the impact on farm operations.

Farm Infrastructure

- *What structural and equipment changes are needed on the farm, if any? Who pays for it?*
- *Does bedding and manure handling change? If it does, how? Who pays for it?*
- *Do you have adequate storage for the digestate?*
- *Is the current equipment suitable to handle the digestate for land application?*
- *Can you incorporate other bedding waste from your farm into the digester?*
- *Will you use the digester solids as bedding, and what equipment or space is needed to accommodate solids storage and handling?*
- *If using sand bedding, will you need to add or upgrade the sand separation equipment and maintenance of the system?*
- *Do you have a complete picture of the potential liability and how to mitigate risk?*

A Living System

An anaerobic digester is a living system that needs to be cared for like livestock. It requires consistent input of appropriate feedstocks. Input changes are possible but need to be gradual and carried out with proper consideration for the digester's biology. Delayed, insufficient, or inadequate feeding can result in reduced or interrupted biogas production with associated financial penalties. Digesters can be upset by overfeeding, underfeeding, or adding contaminated feedstocks, such as copper sulfate used in footbaths or residual antibiotics, although dilution and large volumes mitigate the immediate impact of these contaminants and provide adequate safety margins if the system is correctly monitored.

Capital and Operating Costs

Digesters are expensive capital assets, and their costs can vary significantly, from a few hundred thousand dollars for a relatively simple digester on a smaller farm with on-site gas utilization, to tens of millions of dollars for large co-digestion projects producing RNG with sophisticated nutrient recovery systems on large farms. The overall cost of an AD project may increase further if farm infrastructure updates or upgrades are required.

Capital costs are also highly location-dependent. Factors as diverse as distance to pipeline connections or local soil conditions can greatly influence total project costs. These considerations are critical because each project is unique; even when using identical technology from the same developer on similarly sized farms, local conditions can cause significant variability in actual capital needs. A large portion of the capital cost for an AD system includes not only the digester itself but also equipment such as gas treatment skids, digestate handling systems, flares, material transfer equipment, and mixers (See Figure 6). However, it should be noted that the installed cost of technical equipment typically ranges between two and three times the purchase price. Additionally, in complex systems, the infrastructure needed to support core equipment can considerably elevate capital costs. Examples of these site-specific infrastructure costs include foundation pads for tank digesters or electrical interconnections to power substations required to operate gas-conditioning compressors.

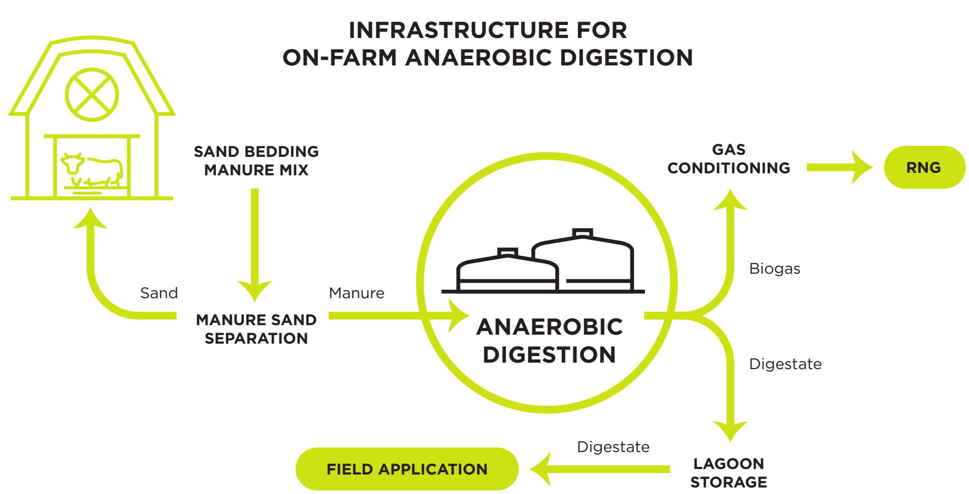
Therefore, it is essential for producers evaluating AD projects—especially when presented with final cost figures from reference projects provided by developers or Engineering, Procurement, and Contracting (EPC) firms—to treat these figures as preliminary budgetary estimates. Producers should not commit to a project without conducting or investigating the results of thorough front-end loading (FEL) engineering studies tailored to the specific location under consideration. At this stage, we strongly recommend that producers seek independent expert advice from engineers or technically qualified consultants to evaluate the quality of the FEL work and estimate uncertainties in capital costs. While references from previous projects provide valuable benchmarks and initial planning tools, they should never replace careful, site-specific FEL analysis before making a commitment.

Operating costs are also highly variable, depending on the type of digester, feedstock handling, and gas utilization. Co-digestion systems generally tend to be more expensive to operate and maintain compared to single-feedstock systems. Running a digester is neither particularly complex nor labor-intensive, provided operations are kept steady and continuously monitored. Sometimes, developers claim that digesters "run by themselves" once stable operations are established. While it is true that a well-operated digester does not require extensive intervention, continuous monitoring and strict adherence to a clearly defined maintenance plan are essential for the long-term success of the project.

Maintenance costs can reach a few percent of the capital cost annually. Equipment with life-limited components, such as gas compressors or electrical generators, requires establishing pro-rata maintenance reserves. This ensures timely maintenance, prevents large, unexpected expenses, and minimizes downtime. Although the party ultimately responsible for system operation and maintenance is dependent upon the chosen business model, producers should always conduct detailed due diligence in these areas. Even if the producers are not directly responsible, poor operational practices and inadequate or delayed maintenance are common causes of digester failure.

Ultimately, a digester and its associated ancillary operations constitute a substantial processing plant. As such, a useful rule of thumb for the annual operating and maintenance cost is approximately 3% to 5% of the installed capital cost, although there is considerable variability with larger systems proportionally costing less to operate.

Figure 6: An infrastructure model for a dairy on-farm AD using sand bedding



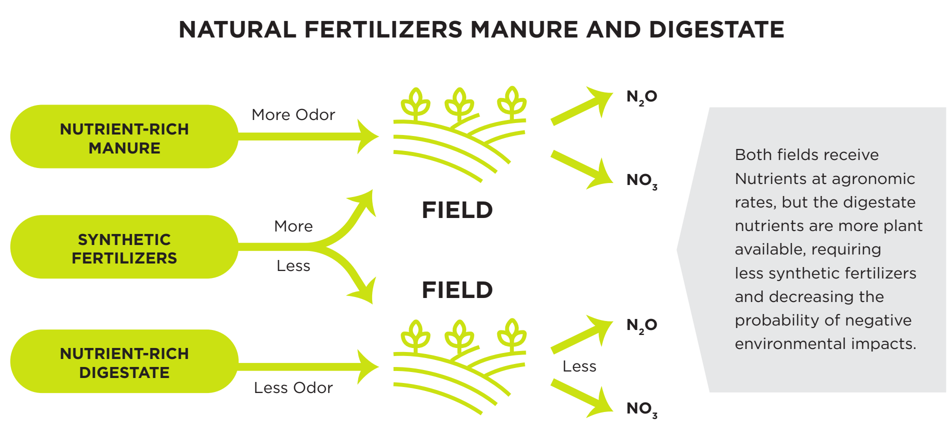
Digestate: A Valuable Soil Amendment

Digestate is the nutrient-rich effluent remaining after the AD process. The physical characteristics of digestate are different from manure prior to going through the AD process. For example, the mass decreases while the moisture increases but the overall volume is similar. In addition, the chemical characteristics are very similar with only a negligible loss of nutrients like nitrogen.[20] Interestingly, the form and availability of nitrogen changes as a result of AD. Most of the nitrogen in raw manure is in an organic form, bound with proteins, fibers, and other organic compounds. The organic compounds are broken down by the AD microbes and the nitrogen changes into ammonium.[21] When land-applied using techniques to minimize volatilization (i.e. direct injection), the ammonium is water-soluble and more readily available for plant use which can reduce the amount of nitrogen needed from synthetic fertilizers compared to raw manure. Further, if land application is timed right before planting, plants will utilize the readily available nitrogen and minimize nitrogen released into surface and groundwater in the form of nitrates. An on-farm AD system can enhance a farm's nutrient management program by creating a pathway for more nitrogen to be utilized by the plant as compared to raw manure (See Figure 7).[22]

Are antibiotics and disinfectants a problem?

Producers are often concerned about the impact of antibiotics, disinfectants, or cleaning agents on anaerobic digesters. While it's true that these substances can act as inhibitors to the digester's microbiology—or simply put, they can harm the microorganisms responsible for producing methane. In practice, they are usually not a significant concern unless used excessively. Digesters are large, buffered systems with considerable biological and hydraulic inertia, allowing for substantial dilution of potential inhibitors. When antibiotics are properly administered and managed, they are not known to cause problems in well-operated digesters. In fact, more worrying challenges for digesters often include sudden changes in feedstock composition, organic overloading, toxic compounds such as heavy metals or industrial waste, and temperature shocks—all of which can significantly disrupt microbial activity. Consistent feedstock quality, stable operating conditions, and regular monitoring are much more critical to the health and performance of a digester than small amounts of well-managed pharmaceuticals or sanitizing products.

Figure 7: Field nutrient management comparison using raw manure, synthetic fertilizers, and digestate



[20] European Biogas Association: Digestate factsheet
[21] IEA Bioenergy: Utilisation of Digestate from Biogas Plants as Biofertiliser
[22] Hoffman, Kurumbail, Rhodes, Anderson, Anex, University of Wisconsin: Renewable Natural Gas: A Case Study of Minnesota

Emissions from Manure Digestate

Livestock manure treated in anaerobic conditions, such as in a lagoon or an above-ground tank, is decomposed into numerous components, most importantly, methane and ammoniacal nitrogen (which consists of soluble ammonium (NH_4+) and ammonia gas (NH_3)). Without gas recovery, methane and ammonia gases are released into the atmosphere. As an enclosed system with an engineered gas recovery system, an anaerobic digester virtually eliminates emissions to the atmosphere and extracts additional value from manure through the collection of biogas, which can be used on the farm or processed into renewable natural gas and injected into natural gas pipelines.

However, anaerobic digesters should be seen as a part of a complete manure management system and are most effective at containing emissions when integrated with upstream and downstream manure and effluent management practices. Digested material, or "digestate", is typically not completely decomposed – doing so, while technically possible, would require an impractical digester size - and contains some small but measurable residual methane potential after leaving the digester. Digesters also change the chemical composition of manure as organic nitrogen is converted into inorganic nitrogen, resulting in a considerably higher ammonium concentration. When digestate is stored in open-air ponds, residual methane and previously contained ammonia gas are emitted. Though the methane emission rate is greatly reduced when compared with open lagoon systems, residual methane potential is not negligible and can be the largest single contributor of fugitive methane emissions from biogas and renewable natural gas supply chains. [23, 24]

Digestate Storage Best Practices

- Anaerobically digested manure can be a potent source of methane and ammonia emissions in storage, unless it is managed well enough to reduce these emissions. Preventing methane and ammonia emissions from digestate can also provide economic benefits for the farm.
- Technologies are available today to reduce these emissions, including digestate pond covers and methane recovery units. Federal and state subsidies are available to help install this infrastructure.
- Pollution from digestate is not commonly discussed or addressed in the U.S. As more digesters are installed, awareness must be developed around the need for improved digestate management.

When prevented from escaping the manure management system, methane and ammonia from digestate can generate additional value for the farm. Methane captured from the digestate can be funneled back to the digester, where it improves the yields of valuable products like renewable electricity or renewable natural gas. If ammonia doesn't escape from a covered digester and the digestate is injected, ammoniacal nitrogen in water is a readily plant-available source of nitrogen, essential for the fertilizer value of the digestate.

Technologies and Funding for Controlling Digestate Emissions

The simplest way to reduce gaseous emissions from digestate is to install a cover on the storage pond. Depending on the management goals of the farm, covers can be non-gastight (permeable) or gastight (non-permeable).

Permeable covers do not control methane loss, but they prevent ammonia loss by shielding the surface of the pond from wind shear.[25] Permeable covers are cheaper, while still delivering the benefit of keeping precipitation out of the storage pond. Permeable covers are most appropriate for farms near population centers, sensitive ecosystems, open water bodies, or those that lack the resources to install a gastight cover. Gastight covers prevent ammonia loss while also presenting an opportunity to recover methane from the digestate.

Several federal and state programs offer funding for farmers and digester operators to install covers on digestate ponds, even though the incentives were designed for covering the storage of raw manure. These include the Environmental Quality Incentives Program (EQIP) and the Regional Conservation Partnership Program (RCPP) through the USDA Natural Resource Conservation Service, and some state-level initiatives.[26, 27]

Prioritizing Improved Digestate Management in the U.S.

Incorporating a covered digestate storage system is the best practice to avoid the emission of residual methane and ammonia, which contribute to degraded local air quality, even without considering greenhouse gas implications.

To protect the environment and climate, the operation and expansion of anaerobic digestion in the U.S. should be paired with effective digestate management processes. These also preserve the digestate fertilizer value. While currently, there are no federal practice standards for digestate management in the US, these best practices are well understood and easily implemented. Proper digestate management can further improve digester sustainability, bolster confidence in and acceptance of digesters as environmentally valuable solutions, and help farmers optimize value extraction from manure.

[23] Maldaner, Wagner-Riddle, VanderZaag, Gordon, Duke, University of Guelph et al: Methane Emissions from Storage of Digestate at a Dairy Manure Biogas Facility
[24] Bakkaloglu, Cooper, Hawkes, Imperial College London: Methane Emissions Along Biomethane and Biogas Supply Chains are Underestimated
[25] Montes, Rotz, Chaoui, American Society of Agricultural and Biological Engineers: Process Modeling of Ammonia Volatilization from Ammonium Solution and Manure Surfaces – A Review with Recommended Models
[26] USDA: Environmental Quality Incentives Program
[27] USDA: Regional Conservation Partnership Program

The Dollar and Cents of an On-farm Anaerobic Digestion System

As described, most on-farm AD projects in recent years have been developer-financed and aim to monetize both energy production and environmental attributes. Some also generate additional revenue through tipping fees. In addition, several government programs currently offer incentives and financing options to producers. Some of these programs support capital project development, while others provide longer-term incentives tied to project performance. At the time of writing, volatility in financial markets and uncertainty in the federal policy landscape may render some of these programs obsolete. For example, the Biden Administration promoted several initiatives to support AD projects through the Inflation Reduction Act (IRA) of 2022, which was designed to promote clean energy, reduce greenhouse gas emissions, and foster a more sustainable energy future. However, as of April 2025, the implementation of the IRA—and other related programs—remains uncertain given the lack of Treasury guidance on tax credit rules and changed Congressional priorities. Additional incentives and financing mechanisms were established by other federal and state agencies. While the details of these programs are beyond the scope of this guide, producers are encouraged to contact AURI for assistance in navigating current and emerging opportunities. The following section provides a core list of key grants, loans, and incentives currently available for biogas projects. AURI can support producers in evaluating these programs and determining their applicability to specific projects.

Government Programs

Federal: Federal Inflation Reduction Act (IRA) – Provides tax credits and incentives to promote AD projects.

- Section 48 Investment Tax Credits (ITC)—AD projects are eligible for one-time tax credits of 6% to 30% of the investment cost. Bonus incentives are also available for domestic material use, certain communities in specific locations, and interconnections to pipelines.
- Section 45 Production Tax Credits (PTC) – AD projects that produce electricity from biogas are eligible for ongoing revenue based on production. The 45Q credit is designed to support carbon capture, utilization, and storage technologies. This also applies to projects capturing carbon dioxide from biogas plants. Unlike capital cost or construction tax credits, this is a credit tied to production, thus potentially available throughout the project's life.

Federal Renewable Fuel Standard (RFS)

AD projects producing RNG for use in transportation can create additional revenue if the fuel meets certain requirements and is assigned a Renewable Identification Number (RIN).[28] A RIN is an environmental credit that tracks the production, use, and trading of renewable fuels in the United States. A project that generates RNG and is assigned a RIN can receive ongoing revenue based on production. RINs are in demand and can be a significant revenue source in addition to the sale of RNG. However, the price of RIN is variable, and the management of RINs requires production auditing.

The USDA Rural Energy for America Program (REAP)[29]

Agricultural producers and small rural businesses can receive financial assistance to support AD projects. One-time grants are available for up to 50% of the total eligible project cost up to $1 million. Also, loan guarantees are available for up to 75% of the total eligible project cost up to $25 million.

EPA's Climate Pollution Reduction Grant

The EPA created a $5 billion fund for states, local governments, and tribal nations to plan and implement reductions in greenhouse gas emissions and other harmful air pollution. The Minnesota Pollution Control Agency is allocating these funds through the Climate-Smart Food Systems program, focused on decarbonizing different aspects of the food system, including production, processing, and transportation.

Database of State Incentives for Renewables & Efficiency (DSIRE)

DSIRE is a comprehensive source of information on incentives and policies that support renewables in the U.S. The database can be searched by state. For example, when searching for "biomass," the state of Minnesota had 132 relevant incentives and policies. It also provides the history and key factors describing the status of clean energy in each state.

The Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP)

EQIP is the NRCS's flagship conservation program. It helps agricultural producers integrate conservation into working lands by providing technical and financial assistance to improve water quality, air quality, soil health, and drought resistance.

[28] Biocycle: 101 For RINs
[29] USDA: Rural Energy for America Program

State Programs: State-Level Low Carbon Fuels Standards (LCFS)

Initiated in California, and now established in Oregon and Washington, the Low Carbon Fuel Standard (LCFS) provides incentives for AD projects that produce RNG for transportation (See California Low Carbon Fuel Standard Sidebars).

Minnesota Methane Digester Loan Program[30]

The Minnesota Department of Agriculture (MDA) provides low-interest loans of up to $250,000 to Minnesota farmers to support AD projects.

Minnesota Forward Fund[31]

The Minnesota Department of Employment and Economic Development (DEED) can provide grants, low-interest loans, or tax incentives for AD projects.

Advanced Biofuel Production Incentive[32]

Advanced biofuels are fuels made from non-food, non-feed, sustainably-grown feedstocks, and agricultural wastes. Advanced biofuels must meet the definition of the national RFS program, including the requirement to improve greenhouse gas emissions by 50% over the petroleum-based fuels they replace. The MDA provides grants to AD projects for up to $2 per MMBtu for advanced fuels produced from cellulosic biomass like corn kernel fiber and $1 per MMBtu for advanced fuels produced from sugar or starch feedstocks like sugar beets or corn starch. For an on-farm AD project to be eligible, the farm would sell the RNG and register with the RFS program for an advanced biofuel pathway.

Minnesota Climate Innovation Finance Authority (MnCIFA – Green Bank)[33]

The Minnesota Department of Commerce operates the Green Bank to accelerate the adoption of proven clean energy technologies and greenhouse gas reduction projects to expand access to untapped markets and to bring benefits to historically underserved communities.

Minnesota's Natural Gas Innovation Act (NGIA)

In 2021, the Minnesota legislature enacted the Natural Gas Innovation Act, establishing a regulatory framework enabling Minnesota's investor-owned natural gas utilities to provide customers with access to renewable energy resources like RNG.[34] As a result, on-farm AD projects can sell RNG to one of these local utilities, bringing a level of familiarity and stability to Minnesota's emerging biogas industry.

Due Diligence

Given the colocation of AD systems on a farm, due diligence on a developer's finances is necessary.

- *Do you understand the financial package underpinning the successful installation and operation of the project? If one source of revenue falls through, will the entire project fail?*
- *What is the wherewithal of the developer? Who are their investors?*
- *What is the recourse for failure to deliver on a successful installation?*

[30] Minnesota Department of Agriculture: Methane Digester Loan Program
[31] Minnesota Employment and Economic Development: Minnesota Forward Fund
[32] Minnesota Department of Agriculture: Advanced Biofuel Production Incentive Program
[33] Minnesota Commerce Department: Minnesota Climate Innovation Finance Authority
[34] CenterPoint Energy: Natural Gas Innovation Act Summary

Sources of Revenue

While each project may have different characteristics, the key sources of revenue for a digester are:

- Sale of energy, either as RNG or electricity
- Sale of digestate and nutrients
- Sale of environmental attributes
- Tipping fees
- Other revenues

Not every project receives all of these, and the amount may change from project to project. If the producer is not the owner and operator, typically, a contractual relationship between the developer and the producer, a Farm Products Agreement, establishes any flow of revenue to the producer for farm products, such as manure. Typically, a producer will also receive payment for the lease of the land, which would be defined through a separate lease agreement, although the lease may be included in a larger Farm Products Agreement. The agreement may stipulate how other payments or non-monetary benefits flow to the farmer as well.

Farm Product Agreements

A farm products agreement – and different developers may use other names for this contract - is a contract between the producer and the developer. This agreement details the terms governing the sale or exchange of goods from the farmer to the project, including obligations related to the delivery of manure and the removal of digestate for farm use. Unless included in a separate ground lease agreement, the farm products agreement will specify terms for land leases, easements allowing access to the digester site, and clearly outline the roles and responsibilities of all involved parties. It is crucial for farmers that the agreement explicitly obligates developers to address any environmental damage that may be caused by accident or careless operation of the digester and indemnify the farmer in case of project default. Similarly, the project's end-of-life provision needs to be stipulated to prevent the producer from distant but possibly considerable liabilities. Furthermore, it is essential that the agreement's terms remain binding in the event of a total or partial sale or transfer of the project, refinancing, or any changes to the corporate structure of the project's owners or operators. The agreement may outline, without exclusion to other provisions not explicitly mentioned:

- Terms for the farm product delivered to the project. This is typically manure, but others are possible. It should include quantity, quality specifications, and terms of delivery. Any accepted variability of the products should also be stated.
- Specification for the digestate (water, solid, etc.) delivered to the farm, including terms of delivery
- Any payment associated with farm products and digestate off-take, if any
- Land lease agreement and payment terms
- Flow of revenues or other payments, such as royalties, to the farmer. These are typically present if the producer is a party in a joint venture with the developer.
- Remedies for the injured party in case of poor performance by any of the parties, including liquidated damages amounts.
- End-of-life provisions, including the responsibility for any environmental remediation and decommissioning of obsolete equipment and infrastructure.

Food Waste Tipping Fees

Revenue from tipping fees typically occurs at co-digestion facilities that accept off-farm feedstocks. In this arrangement, the waste generator pays the producer or developer for the disposal of the waste material. Common feedstocks include food waste from restaurants, institutional food service, food distributors or retail grocery stores, as well as organic waste from food and agricultural commodity processing facilities, such as meat processing plants or dairy processing facilities. These waste products can be expensive to dispose of and may pose challenges for local wastewater treatment plants or landfills. Tipping fees should be competitive with other disposal options available to the generator, and it is essential that the developer accurately accounts for transportation costs within these fees, should they be responsible for collection and delivery to the site.

Land or Ground Lease Agreements

Land lease agreements can be a source of revenue for producers and are typically negotiated as part of the overall AD project and extend throughout the duration of the project. If a land lease is included, its conditions should resemble standard land lease agreements and clearly specify the purpose, duration, payment terms (including any escalation factors), land-use limitations, site maintenance and repairs, approved improvements, utility usage, responsibility for taxes, required insurance, termination conditions (including handling of non-producer-owned assets on the land), dispute resolution mechanisms, assignment terms, environmental responsibilities, regulatory compliance, permitting requirements, rights of entry and easements, indemnification clauses, and any additional protections to safeguard the producer.

Careful consideration of termination and end-of-life provisions is crucial to protect producers from unforeseen liabilities and costs. Expert legal review before finalizing the agreement is strongly advised.

Environmental Attributes

Statutory programs such as the federal Renewable Fuel Standard, the California Low Carbon Fuel Standard (LCFS), or voluntary programs like the Midwest Renewable Energy Tracking System (M-RETS), which serve large energy users aiming to reduce their environmental impact, allow producers to monetize the environmental attributes of their fuel. Typically, the value of these attributes is based on the fuel's carbon intensity, reflecting the fuel's capacity to deliver emission reductions for a given energy service and its renewable content.

A detailed discussion of these programs is beyond the scope of this guide (refer to the sidebar, A Detailed Look- What Is the California Low Carbon Fuel Standard, for an introductory overview). However, all these programs share common features, including the requirement to validate the environmental benefits of fuel production systems through an auditable process. This validation process necessitates detailed engineering data initially, followed by precise record-keeping of system performance, feedstock consumption, and product generation. This significant effort usually involves accredited consultants.

The ultimate value of environmental attributes is determined by market-based mechanisms, resulting in considerable fluctuations. Typically, these attributes provide additional value to the energy sold and are denominated in consistent units, such as dollars per million BTU ($/MMBTU). Although environmental attributes are priced as add-ons to the energy price (See the sidebar, The Calculated Value of RNG, below), they can often be decoupled from the physical sale of gas.

Due to the complexity of these transactions, AD asset owners/operators typically rely on third-party brokers who manage the certification and trading of environmental benefits, although some developers with a broad portfolio of projects may have an in-house trading desk.

A Detailed Look - What Is the California Low Carbon Fuel Standard (LCFS) and How Does it Work?

The Low Carbon Fuel Standard (LCFS) is a regulatory mechanism designed to encourage lower-carbon fuels while discouraging fossil-based options. It attempts to balance technological innovation, market forces, and policy enforcement to reduce greenhouse gas (GHG) emissions in the transportation sector. The California legislation is now a benchmark being considered for similar regulatory frameworks in other States. The LCFS sets a cap on a fuel's "carbon intensity" (CI)—the total lifecycle emissions from producing, transporting, and consuming the fuel—and requires fuel suppliers to progressively lower that CI over time. While the cap itself is established by legislation, the market largely determines the methods of achieving it.

California introduced its LCFS via AB32 (the Global Warming Solutions Act), which grants the California Air Resources Board (CARB) authority to regulate GHG emissions from transportation. Under the LCFS, CARB sets annual CI benchmarks that become increasingly stringent. The state's goal is an 80% reduction in CI from 2010 levels by 2030. In California, the LCFS covers gasoline, diesel, compressed natural gas (CNG), liquefied natural gas (LNG), biofuels such as biodiesel and ethanol, renewable natural gas (RNG) variants of CNG and LNG (bio-CNG and bio-LNG), electricity, and hydrogen used for on-road transportation. Off-road fuels (e.g., for locomotives and ocean-going vessels) are currently exempt.

Regulated Parties

The regulation applies to:

- Producers, importers, and distributors of conventional fossil fuels such as gasoline, diesel, and fossil CNG/LNG in California.
- Biofuel producers and importers (e.g., ethanol, biodiesel, RNG), provided they meet reporting and verification requirements to claim LCFS credits.
- Electric distribution utilities (EDUs), which can opt-in to claim credits for both residential and non-residential electric vehicle (EV) charging. (Electricity rules have unique features not relevant to RNG)

California's LCFS has influenced neighboring jurisdictions. Oregon, Washington, and British Columbia have adopted similar standards, aligning efforts under the Pacific Coast Collaborative to establish a broader low-carbon corridor.

How the LCFS Works: Credits and Deficits

In California's LCFS, each transportation fuel is assigned a CI value measured by the amount of carbon dioxide emitted per unit of energy delivered. These emissions are calculated through a life cycle analysis, covering the entire supply chain from production to final consumption, and the same type of fuel (e.g. RNG) originating from different facilities can have considerably different CI. If a fuel's CI is higher than the annual benchmark, it generates a "deficit." If the CI is lower, it generates a "credit." By the end of the year, regulated parties with deficits must balance them by purchasing credits from parties that have produced surplus low-CI fuels.

The number of credits awarded depends on:

1. The difference in CI between the baseline fossil fuel (e.g., gasoline, diesel, or CNG) and the alternative fuel (e.g., ethanol, biodiesel, or RNG).
2. The volume of the alternative fuel supplied.
3. Fuel-specific factors such as energy density and real-world energy efficiency.
4. Project-specific factors affecting the CI calculation at a given biofuel production site (subject to annual auditing).

One credit represents one metric ton of carbon dioxide-equivalent emissions avoided, which normalizes differences between fuels with varied CIs. While there are multiple avenues to earn LCFS credits, the most common is fuel-based crediting.

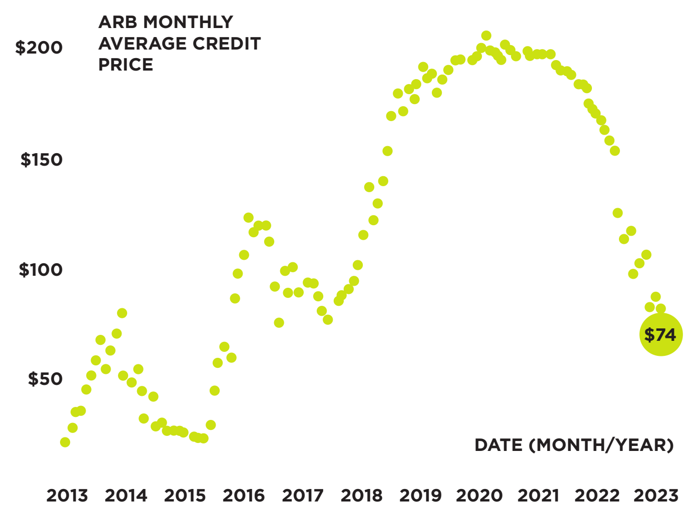
Fuel-Based Crediting: Providers of low-carbon fuels demonstrate that their CI is below the benchmark and then report sales volumes. This process enables RNG producers, for example, to sell credits to obligated parties—possibly directly, but often via brokers or trading platforms. Importantly, the fuels need not be produced in California; however, it must be delivered there. Accordingly, out-of-state RNG producers require access to interstate natural gas pipelines. CARB reported that in 2023, only 18% of the RNG consumed in California was produced in-state.

Credit Prices and Volatility

LCFS credits trade on an open market, where prices fluctuate based on supply and demand. When more low-carbon fuels are supplied (and thus more credits are generated) than needed, prices tend to fall. Conversely, if credits are in short supply, prices rise. CARB set a price ceiling of $200 per credit in 2016 dollars, adjusted annually for inflation; by 2023, this cap had increased to $253.53. Actual market prices can vary widely depending on supply and demand, as shown in the adjacent figure, which illustrates the volatility in credit prices. Any project aiming to sell RNG into California's LCFS—or similar programs elsewhere—faces this risk.

For a more detailed explanation of LCFS, please see [Understanding California's Low Carbon Fuel Standards Regulation - RMI], which informed this section, while quantitative data on the program implementation can be found directly from CARB in [LCFS FAQ and Factsheets | California Air Resources Board]

VOLATILITY OF LCFS CREDIT PRICES



Energy Sales

Biogas is a mixture of methane, carbon dioxide, moisture, and trace gases such as hydrogen sulfide, oxygen, nitrogen, and ammonia. Simple, well-known technologies can easily convert biogas into RNG, which is chemically indistinguishable from fossil natural gas distributed via consumer pipelines. For pipeline injection, an AD site must be located reasonably close to a pipeline. The costs associated with pipeline interconnection can vary significantly depending on local conditions. Consequently, some facilities choose to haul RNG over-the-road to the pipeline injection point (i.e. virtual pipeline).

Although the technology for converting biogas into pipeline-grade RNG is reliable and well-established, failure to meet gas company specifications can result in lost sales, product destruction, and potentially additional financial penalties. Therefore, careful operational management is critically important. RNG pricing typically follows local commercial prices, which are indexed to hub prices.

While becoming less common, power generation remains a viable option, especially where pipeline interconnection is impractical or excessively costly. Unlike RNG, long-term fixed pricing agreements for electricity generation can be negotiated, providing more predictable revenue. However, at the time of this report, power generation remains substantially less profitable than RNG sales, and many projects pursuing electricity generation focus primarily on captive power usage rather than direct utility sales.

A notable advantage of power generation is the potential for waste heat recovery, enabling a combined heat and power (CHP) approach. CHP systems are highly efficient and capable of generating process heat in the form of low to medium-pressure steam, making them ideally suited for integration into industrial processes.

Digestate Sales

In many on-farm AD systems, the solid and liquid portions of the digestate are separated. The solids, which are richer in phosphorus, can be used on-farm as bedding or applied to land. Alternatively, they can be sold as compost or utilized as feedstock for bioproducts, such as Cowpots. The nitrogen-rich liquid portion of the digestate is typically applied to fields for irrigation and fertilization. Unlike raw manure, digestate does not emit offensive odors, thus reducing community impact.

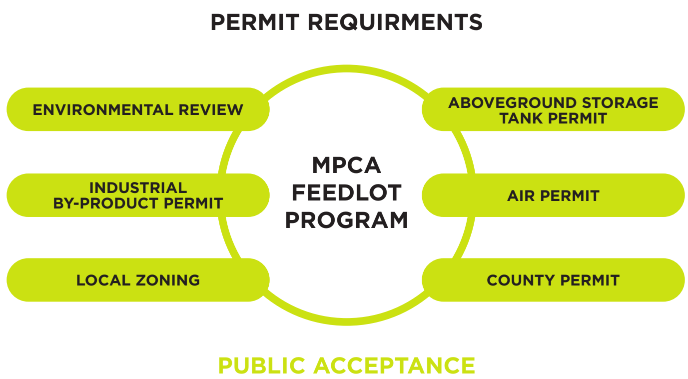
While digestate is often returned to the producer hosting the AD system and managed within the farm's nutrient management plan, selling digestate to third parties is also common. This scenario is particularly relevant for farms engaged in co-digestion systems, as the additional off-farm waste introduces nutrients beyond those contained in the farm's manure. Consequently, managing these extra nutrients becomes more complex. Producers considering an AD project must carefully assess digestate management options and the implications for their existing nutrient management plans.

The Calculated Value of RNG

The value of renewable natural gas (RNG) is determined by the commercial price of natural gas plus, typically, one or more additions that reflect its environmental benefits. These benefits are often monetized through mechanisms such as Renewable Identification Numbers (RINs), as defined under the U.S. Renewable Fuel Standard (RFS), and through carbon intensity (CI) reductions under California's Low Carbon Fuel Standard (LCFS). Additionally, voluntary markets exist in which buyers may pay a premium for RNG that meets specific environmental objectives and possesses certifiable attributes, typically verified by independent entities such as M-RETS. Each market uses different methodologies to assess environmental value. For example, under the RFS, the RIN value is driven by mandated blending requirements for cellulosic or equivalent fuels. In contrast, the LCFS assigns credit value based on the reduction of carbon intensity across a mandated party, such as a fuel distributor, resulting in additions that can range from a few dollars to several tens of dollars per MMBtu. A detailed, project-specific analysis is necessary to determine eligibility and monetization potential, as several project-dependent variables influence value. Like natural gas prices, environmental credit values are not fixed and market conditions influence them, making them subject to significant volatility, which can materially impact project financials. Lastly, because the value of environmental attributes is tied either to regulatory frameworks or, in the case of voluntary markets, to the willingness of private entities to pay for non-mandated benefits, a substantial degree of political and market risk remains.

Regulatory Considerations

Figure 8: Permitting requirements are underscored by public acceptance



The Minnesota Pollution Control Agency (MPCA) is Minnesota's primary regulatory authority for livestock feedlots and is focused on preventing and reducing the pollution of air, land, and water (See Figure 8). The MPCA regulates AD systems based on the type of feedstock used and also regulates the collection, transportation, storage, processing, and disposal of animal manure and other livestock operation wastes as part of its feedlot program.[35] County and township requirements may also apply and often vary from one to the next. Producers interested in an on-farm AD system should contact officials within their township, county, and possibly the MPCA.

The MPCA regulates an estimated 18,000 registered livestock feedlots.[35] An existing or new feedlot can incorporate an AD system that processes a single feedstock (manure) into their permit, and the digestate would be governed by the feedlot rules. Projects using feedstocks regulated by the MPCA's solid waste program (See Sidebar on Source-separated Organics) may require a solid waste permit. The incorporation of any industrial by-products (IBP) (See Sidebar on IBP) would need to align with regulations overseeing the land application of IBP. This also applies to the construction and operation of structures used to store IBP. As a result, on-farm AD facilities co-digesting manure and IBP may be required to follow a combination of rules per the feedlot and IBP programs as follows:

- If the IBP does not exceed 10% of the total feedstocks, the co-digested material is considered manure only.
- If the IBP does not exceed 50% of the total, the digestate is not considered all manure, and the IBP program would have input on the feedlot permit.
- If the IBP exceeds 50% of the total, the digestate is fully regulated under the IBP program.

On-farm storage of IBP exceeding 1 million gallons may also need an above-ground storage tank permit (AST).[36] Finally, an air quality permit may be required. Such a requirement would be reviewed on a case-by-case basis.[37]

[35] Minnesota Pollution Control Agency: Feedlots
[36] Minnesota Pollution Control Agency: Abovegound Storage Tanks
[37] Minnesota Pollution Control Agency: Air Permits

What are source-separated organics (SSO) and industrial by-products (IBP)?

Source-separated organics (SSO) are organic waste separated at the source by waste generators and collected separately from mixed solid waste.

SSO Examples:
- Food waste
- Yard waste
- Vegetative waste from industrial or manufacturing processes that prepare food for human consumption
- Non-recyclable paper

SSO can include the following if specifically permitted by the MPCA Commissioner:
- Animal waste such as manure or carcasses
- Fish waste from industrial or manufacturing processes
- Meat by-products from industrial or manufacturing processes
- Diapers
- Sanitary products

SSO does not include:
- Septage
- Sewage sludge

Minnesota Administrative Rules: 7035.0300

Industrial by-products (IBP) are a residual material resulting from industrial, commercial, mining, and agricultural operations that are not primary products and are not produced separately in the process. IBP Examples:
- Liquid or dewatered wastewater treatment biosolids
- Wash water from food preparation industries
- Livestock truck wash water and solids
- Pretreatment solids settled from wastewater before discharging to a municipal wastewater system
- Whey from cheese processing
- Sweet corn silage
- Sweet corn silage leachate
- Ethanol by-products

Minnesota Pollution Control Agency: Guidelines for Managing Industrial By-products

Permitting Questions

- *Are you interested in digesting manure only, or are you interested in co-digestion opportunities involving a more complex permitting process?*
- *Do you know who is responsible for permitting digesters in your area, and have you spoken with them about your interests?*
- *On-farm AD systems are popping up across the state. Have you observed the process that successful installations went through to understand where there were challenges?*
- *When evaluating a relationship with a developer, it is best practice to understand how they will approach the permitting process and how they would like you to be involved.*
- *Does the permit for the digester influence your farm permits or operations?*
- *Do you understand local community priorities and health and environmental concerns?*

AD systems are considered fuel conversion facilities within Minnesota rules and are subject to environmental review when processing 25,000 dry tons or more per year of manure, which is equivalent to the waste produced by more than 8,000 lactating Holsteins or more than 11,000 lactating Jerseys.[38] The environmental review helps agencies make informed permitting decisions, allows the public access to decision-makers, and ensures public awareness.[39] Smaller installations may also be subject to environmental review. The environmental review includes two levels, starting with the environmental assessment worksheet (EAW) and then moves into a more in-depth environmental impact statement (EIS) if the MPCA Commissioner determines its necessity. The Commissioner will use the results of the EAW, written comments, permit applications, and other relevant documents to determine whether an EIS is needed. It is important to understand that this is a public process in which any person has the right to comment, request changes, or dispute the installation of a facility.

Local zoning can impact the permitting process. Therefore, understanding the activities allowed within a particular zoned area is critical. Most on-farm AD systems processing their own manure are allowed in agriculturally zoned properties across the state. An on-farm AD system co-digesting off-farm feedstocks may not be allowed on agriculturally zoned properties without going through a rezoning process and may be classified as a waste management facility. Rezoning of agricultural land to industrial land requires petitioning the county and can be a complex and lengthy process. However, some counties have conditional uses that allow some types of off-farm materials to be used for AD in areas zoned agricultural. It is important to understand local zoning rules when planning an on-farm AD system. The producer's state or county feedlot officer would be an excellent resource for these issues. It is important to consult them early in the process. The Fire Marshall is another public official who should be contacted earlier in the process, as their input can be crucial to avoid delays later and develop a plan to mitigate safety concerns with the public (See Sidebar on Public Acceptance).

Public Acceptance

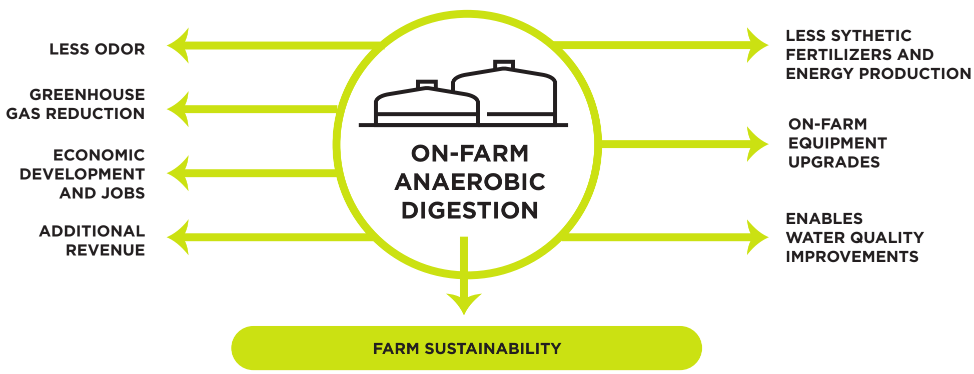
During the permitting process, the public is notified to share comments, express concerns, and provide feedback on the process. There have been cases in which public review leads to challenges to the siting of a facility, renegotiation of the conditions for a permit, or, in some cases, outright permit denial. In other words, a potential project may be technically, economically, and environmentally viable but have too much local concern and opposition to proceed. A producer interested in an on-farm AD project should be transparent on the aims, scopes, benefits, and risks of the project and engage well in advance of the formal public review process with local community stakeholders to gain confidence, maintain positive relations, and effectively address any concerns.

[38] Minnesota Pollution Control Agency: Regulatory Requirements for Anaerobic Digesters
[39] Minnesota Pollution Control Agency: Environmental Review

Benefits and Risks

While additional farm income is increasingly a factor driving more on-farm AD installations, there are equally important positive environmental, operational, and community impacts. Improved nutrient recovery and reuse, odor reduction, local alternative energy production, water quality enhancement, and greenhouse gas reductions are all additional attributes (See Figure 9).

Figure 9: Sustainable benefits of on-farm AD



Nutrient Management and Soil Health

AD converts manure into biogas and digestate. The digestate contains about the same amount of nutrients as raw manure, but in a more stable and plant-available form.[40] As a result, more nutrients are utilized by the plant, and fewer synthetic fertilizers are needed for agricultural crops. Decreased demand for synthetic fertilizers has additional environmental benefits as they require high amounts of energy to produce and generate considerable greenhouse gas emissions, especially since most synthetic fertilizers are produced far from the Midwest. Lastly, digestate application to soils increases the organic matter content, improves plant growth, and alleviates soil compaction.[40]

Odor Reduction

Odors from farms can be a nuisance to the local community. Stored manure can generate volatile organic acids and release odor-bearing volatile compounds, among them hydrogen sulfide, responsible for the "rotten egg" smell associated with manure. The AD process breaks down the volatile organic compounds in raw manure and the odor-bearing compounds are either destroyed or handled in the gas conditioning system without being released into the environment.[40] As a result of reduced storage of raw manure and less odiferous digestate, the local community can benefit.

Water Quality Improvements

On-farm AD systems can improve ground and surface water quality by better managing nutrients that may otherwise be dispersed. An on-farm AD system can enhance a farm's nutrient management program by creating a pathway for more nutrients to be utilized by the plant compared to raw manure. As a result, fewer nutrients may be leached into the ground and surface water.

Disease / Phytosanitary Considerations

AD can reduce the presence of disease-causing organisms that can be a risk to humans and other animals, and digestate has been proven to be less prone to spread weed seed in the fields than manure.[41, 42] However, effectiveness for both pathogen destruction and weed seed control depends on design and operating conditions.[43]

Local Renewable Energy Production

AD produces biogas that can be used as a fuel anywhere fossil natural gas is used, including for space heating, transportation, and power generation. On-farm AD systems can provide local and secure sources of renewable energy. For example, a new single on-farm AD system at a dairy in Southwestern Minnesota is projected to produce up to 480,000 gasoline gallon equivalents per year.[44]

[40] EPA AgSTAR: Market Opportunities Report
[41] Penn State Extension: Fate of Nutrients and Pathogens During Anaerobic Digestion of Dairy Manure
[42] Katovich, Becker; University of Minnesota, Doll; University of Wisconsin: Weed Survival in Anaerobic Digesters
[43] EPA: Pathogens and Vector Attraction in Sewage Sludge
[44] Clean Energy Fuels: Clean Energy's Latest RNG Production Facility at Minnesota Dairy Begins Injecting Into Pipeline

Reduction in Greenhouse Gas Emissions

Traditionally, liquid dairy manure is collected and stored in an open pit or lagoon before land application. During the storage process, manure decomposes and releases odors, noxious compounds, and methane into the atmosphere. Methane is a potent greenhouse gas that has more than 20 times the impact of carbon dioxide over a 100-year timeframe. An on-farm AD system captures methane that would otherwise be released into the atmosphere from the decomposing manure and, by diverting it to valuable use, mitigates its environmental impact.

Nitrous oxide, a pollutant generated in lagoons, while odorless and produced in relatively small amounts, is an extremely potent greenhouse gas, more than 300 times more potent than carbon dioxide, whose elimination has a significant impact on improving the sustainability of the system.

Local Economic Impact

While ground leases and farm product agreements offer farmers a revenue stream insulated from market volatility, the economic benefits go beyond the farm in the form of jobs, capital investment, and increased tax revenue. Temporary jobs include the installation and construction of the AD system, as well as improvements to local roadways and pipelines. The EPA estimates 3-4 skilled employees are needed on-site to operate a typical digester, not to mention the many roles needed to support the system on an ongoing basis, although not directly employed by the facility.

An Ongoing Process

Revisiting the benefits and risks of on-farm AD is not a "one-and-done" exercise. As the system's host, you must regularly revisit your relationships with the developer, regulators, vendors, off-takers, and the community. As the system is built and operated, several issues are worth considering on a regular basis:

- *Has your experience resulted in positive or negative externalities that were not imagined prior to initiation? If so, how would you address them?*
- *Have the conditions on your farm changed or may they change in the future, requiring a possible contract amendment? This discussion is ideally better held before economic or operational necessity imposes strict urgency.*
- *Do you meet regularly with the developer, their employees, and vendors to manage expectations?*
- *Do you keep engaging with the community to build awareness of the benefits and risks of the digester? Have you considered a blog, school visits, social media posts, or signage for passersby (See Figure 10)?*
- *Are you actively gaining feedback and addressing valid stakeholder concerns in a timely fashion and before escalation?*

Figure 10: On-farm sign example

Risks

Only a complete risk assessment, specific to an individual project, can identify potential pitfalls related to technical, financial, operational, environmental, and regulatory risks. Producers are strongly encouraged to hire an attorney to assess legal and contractual risks. An independent engineer can provide a technical risk assessment. Project feasibility studies can highlight challenges and provide solutions prior to the installation of a facility and are typically required for project financing if commercial lenders are involved. In addition, involving the farm's trusted advisors, such as bankers, nutritionists, veterinarians, farm business management instructors, and others, can help uncover concerns and ensure broad support. While the owner/operator of the system is typically the most exposed to risk, a producer should assess their own risk carefully. This also applies if the system is owned and operated by an SPV, since corporate structures do not always provide absolute liability protection to third parties, especially for environmental liabilities. The assessment of many of these risks requires specific domain expertise, and the assistance of competent third parties is often needed. AURI can help a producer assess and navigate risks as they pertain to a specific project and assist in the identification of experienced resources for further assistance.

Technical Risks

AD systems have the potential to produce poor quality and low quantities of biogas due to inadequate design, inappropriate or inconsistent feedstocks, improper operations, and/or equipment failures. To mitigate these risks, producers must adequately vet developers' experience levels and work with proven technologies. Accordingly, producers may hire third-party consultants or engineers to verify design, operational plans, and performance metrics such as gas production and digestate quality that impact the project's financial performance and permit compliance.

Financial Risks

Successfully financing an AD system requires a thorough exploration of incentives, grants, low-interest loan opportunities, and different business structures to minimize risk. While most on-farm AD systems are contractual relationships between the producer and developer, it is important to understand the financial risks assumed by the developer and the possible exposure to liabilities that the producer may incur in case of default. The revenue streams can vary due to market conditions. Diverse income streams like land lease payments, RNG sales, carbon credits, and digestate sales can provide a buffer during poor market conditions. It may be worth considering long-term fixed contracts or Power Purchase Agreements for RNG sales to help stabilize the market lows and highs.

Safety Risks

On-farm AD systems, while not very complex to run on a day-to-day basis, do nonetheless require skilled and adequate personnel. The developer and third-party experts need to ensure adequate training or technical support. The handling of manure, as well as biogas and digestate, can create potential health risks. Biogas is flammable, and while typically remote, the risk of fire and explosion is not absent when a digester is not properly operated. It is important to have adequate safety protocols, regular monitoring, and adherence to operating procedures that were reviewed by process safety experts and vetted by local stakeholders, such as the Fire Marshall.

Operational Risks

It is important to monitor and test feedstock inputs regularly and comply with well-defined and validated operating procedures and maintenance plans. Delayed and improper maintenance is a common cause of a digester's poor performance and, in the worst case, industrial accidents. Preventive maintenance and the availability of a critical spare part inventory will reduce the risk and length of unscheduled downtime and repairs, but a well-run system will have contingencies to handle these unscheduled events. A producer considering a project will need to carefully assess this contingency and be skeptical of any business plan that does not adequately assess operational contingencies.

Environmental Risks

A properly run AD system presents negligible environmental risks. These mostly arise as operational risks from improper operations and maintenance. The most common environmental risks are gas leaks (i.e., methane, ammonia, nitrous oxide, etc.), release of odors, spills caused by improper liquid containment, and, in the worst but less likely scenario, the environmental aftermath of a fire. While these are unlikely events, mitigation plans need to be in place and reviewed with an expert. These mitigation plans are often required for insurance purposes and permitting.

Regulatory Risks

Securing and maintaining the proper permits is essential for the development of a project. Compliance with the terms of the permit is mandatory, and a lack of compliance may result in enforcement action, ranging from fines to mandated shutdown of the system and, in the worst cases, civil or criminal prosecution against owners and operators. Producers and developers should consider engaging with third-party environmental consultants early in the planning process. Subscribing to industry associations can help producers and developers learn about resources and stay current with policy changes. Policy changes create regulatory risk, which, while not having legal risks, affect the financial performance of the digester as incentives may change. For example, California's LCFS rules were recently updated, leading to a modification in the stated carbon intensity of certain projects, while changing guidance from the U.S. Treasury may change the accounting of tax credits relevant to the projects, such as those of the Inflation Reduction Act.

Community and Social Risks

On-farm AD systems can benefit the local community through local energy production, greenhouse gas mitigation, odor reduction, job creation, and infrastructure improvements. Nonetheless, projects may meet resistance due to concerns about odor, traffic, safety, and perceived negative environmental impacts. Community and social risks are typically a consequence of the other risks outlined. Rarely, deliberate spreading of misinformation creates conditions not conducive to a project. As discussed earlier, on-farm AD project developers and producers are encouraged to engage the community to address concerns and to highlight the benefits and risks as transparently as possible and as early as possible. Maintaining good community relations is critical for communicating the benefits and risks of on-farm AD systems that highlight successful projects and address fears and concerns.

Project Development

Often, a technology provider or developer will approach a producer directly. There are dozens of European and U.S.-based technology providers, each with varying levels of experience. Producers are strongly encouraged to conduct thorough due diligence before selecting or engaging with a developer or technology provider. This includes assessing their experience, reputation, and financial stability.

A reputable developer should be able to provide a clear statement of qualifications, including their project portfolio and prior experience. They should also disclose their source of funding. It is not uncommon for developers to seek binding agreements with producers before securing financing. In such cases, the developer is often building a "pipeline" of prospective projects to strengthen their ability to raise capital. While this practice is neither illegal nor inherently problematic, producers should carefully evaluate any binding agreement that is not tied to a guaranteed project execution, especially those with long or open-ended terms.
Producers are also encouraged to tour existing facilities and projects developed by multiple providers. During these visits, having unfettered access to speak openly with the host producers is essential and a positive indicator of the developer's transparency, good faith, and confidence in their work.

If the producer and developer decide to pursue a project, the next step is assessing its feasibility. An early-stage feasibility study will evaluate critical factors influencing the project's potential success, including technical, financial, regulatory, environmental, and community considerations. This study helps minimize risks and determines if the project should proceed.

If the project moves forward, a letter of intent or memorandum of understanding may be created, outlining conditions for subsequent project phases and any restrictions placed on the producer regarding engagement with other developers. Additionally, term sheets or drafts for agreements such as a farm products agreement or ground lease may be introduced, depending on the proposed ownership structure of the AD system. Producers are strongly encouraged to engage an attorney early to assist with the review of these documents and enhance their understanding through all stages, from planning and approvals to construction and commissioning.

AURI Can Help

Right-sizing an on-farm AD system to meet your needs and stay within the limits of your own risk tolerance requires a great deal of due diligence. This guide is a starting point for producers to consider the system and its impacts and interdependencies broadly at the farm level while creating a clear view of the many benefits associated with the on-farm AD opportunity.

AURI can be a resource as producers and developers weigh their options. As a nonprofit organization created by the Minnesota Legislature to support value-added agriculture, AURI is well-positioned to provide unbiased technical and commercialization assistance. AURI's scientists and business development experts are ready to help with the following services:

- AD project feasibility and techno-economic analyses
- Feedstock and digestate characterization
- Biomethane potential assessment and benchtop digestion
- Supply chain and market development
- Assessment and development of off-take agreement
- Assistance with permitting and regulatory assessment
- Validation and due diligence on third-party technologies and developers' claims
- Pilot digestion of complex and multiple feedstocks
- Digestate handling and use, including assessment of its fertilizer value
- Regulatory guidance
- Referrals to resources such as legal, financial, technical experts, financial assistance, and governmental programs.

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