Factsheet

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Anaerobic Digestion Basics

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INTRODUCTION

Anaerobic digestion (AD) of manure and agri-food byproducts is becoming more common in Ontario. There are a number of reasons farmers and developers consider building AD systems, including:

- production of renewable energy
- reduced odour and pathogen levels in the manure
- reduced greenhouse gas production from the farmstead
- improved fertilizer value of the manure
- use of existing or purpose-grown crops for energy production

AD systems also provide benefits to others, including creating new destinations for managing food waste and creating economic opportunities in rural areas.

This factsheet discusses some of the factors to consider when deciding to build an anaerobic digester for a farming or food processing operation.

What Is Anaerobic Digestion?

Anaerobic digestion is the process by which organic materials in an enclosed vessel are broken down by micro-organisms, in the absence of oxygen (Figure 1). Anaerobic digestion produces biogas, which consists primarily of methane and carbon dioxide. AD systems are often referred to as "biogas systems."

Figure 1. A manure-based anaerobic digestion system on a dairy farm.

Depending on the system design, biogas is combusted to run a generator producing electricity and heat (called a co-generation system), burned as a fuel in a boiler or furnace, or cleaned (called "upgrading") and used as a natural gas replacement. Pipeline-quality upgraded biogas is often referred to as renewable natural gas (RNG) or biomethane.

The AD process also produces a liquid effluent (called digestate) that contains all the water, nutrients and minerals, and approximately half of the carbon from the incoming materials. A solid-liquid separator is commonly used to produce a solid digestate component, which is used as livestock bedding or as a solid nutrient for land application.

In Ontario, the main ingredient in a farm-based AD system is manure. AD systems are attractive as manure treatment systems because they offer multiple benefits while providing a good economic return from energy production. AD systems can handle both liquid and solid inputs, thereby providing a good solution to liquid agri-food wastes such as food-processing byproducts.

Common AD System Configurations in Ontario

Ontario has a growing biogas marketplace, with anaerobic digestion systems located on farms and in urban areas. While most farm-based AD systems are located on large dairy farms, a number of systems have been built at other livestock farms and at greenhouses. In addition, several large non-manure digesters have been built in urban areas to handle primarily food processing waste and some post-consumer food waste. Most Ontario AD systems produce electricity for sale to the electrical grid. Most agricultural AD systems return their digested nutrients to the land as an agricultural nutrient.

Operational Characteristics

Completely Mixed

Farm-based AD systems in Ontario are all completely mixed or continuously stirred tank reactor (CSTR) systems. Completely mixed systems consist of a large tank where fresh material is mixed with partially digested material. These systems are suitable for manure or other agri-food inputs with a lower dry matter content (4%–12%). Material with higher dry matter content can also be added to a completely mixed system since the anaerobic bacteria consume the carbon, liquefying the input material. Very watery materials can also be added to a completely mixed AD system, although there are other digester configurations better suited for wastewater treatment.

Temperature Ranges

There are three main temperature ranges for AD systems:

- **Mesophylic (35°C–40°C) —** Mesophylic systems are most common in Ontario. Depending on the input material characteristics, mesophylic systems need several weeks of average treatment time to effectively treat the organic matter and convert it to biogas. Systems operating at this temperature are stable and relatively easy to operate. Some AD systems are specifically designed to concentrate the solids content, reducing the average retention time needed to treat materials in a mesophylic system.
- **Thermophylic (50°C–55°C) —** Thermophylic systems operate at a high temperature. The micro-organisms rapidly break down organic matter and produce large volumes of biogas. The quick breakdown means that the digester volume can be smaller than in other systems (average retention times in the range of 3–5 days). Greater insulation is necessary to maintain the optimum temperature range, and more energy is consumed in heating the system. These systems are more sensitive to nitrogen levels or other inhibiting ingredients in the incoming materials and to temperature variations. Thermophylic systems are most effective for pathogen removal in manure.
- **Psychrophylic (15°C–25°C) —** AD systems operating in Quebec and Oregon are designed to operate in this lower temperature range. These systems are very stable and easy to manage, however, longer solids retention times are required to achieve equivalent gas production and pathogen removal.

Figure 2. A load of vegetable byproducts is received at a farm-based anaerobic digestion system.

Scale and Location of AD Systems

There are three options for the scale of the AD system:

- **Farm-Based Systems —** Farm-based systems are designed for farm manure, for the manure from several nearby farms or for the use of energy crops from local fields. In Ontario, most farm-based systems will rely on off-farm feedstocks such as food processing byproducts to boost biogas production and increase operational effectiveness (Figure 2). Farm-based systems have the advantage of a local source of inputs and the ability to handle digestate nutrients locally. When compared to the management of raw manure, farm-based systems experience the additional benefits of odour reduction, pathogen treatment and improved manure handling.
- **Food-Processing Systems —** AD systems located at a food-processing site are designed for removing organic matter from wastewater. They do not receive materials from other sites and will only handle their own byproducts. These facilities have the advantage of using co-generation to produce electricity as well as heat, reducing on-site energy costs.
- **Centralized Systems —** Centralized or non-farm AD systems are becoming more common in North America. In Europe, centralized AD systems often receive material from many farms and food-processing plants. The digestate is transferred to agricultural fields where the nutrients are needed (away from the original livestock farm sources). In North America, the current trend is for centralized AD systems to only handle food-processing waste and urban source-separated organics. In some cases, the treated liquid digestate is discharged into municipal sewers for further treatment at the municipal wastewater treatment plant. Centralized systems are often located on the edge of urban areas where there may be opportunities for heat from the centralized AD system to be used at other nearby commercial or industrial facilities.

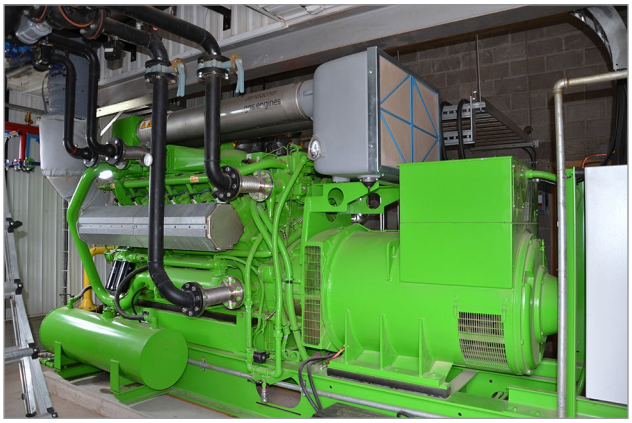

Figure 3. Most biogas systems produce electricity by burning biogas in a co-generation system.

Planning an AD System

When planning to build an anaerobic digestion system, consider the following:

- Get permission to accept materials: A new AD system that accepts off-farm material may need to hold a Renewable Energy Approval or Environmental Compliance Approval under the *Environmental Protection Act, 1990,* or an approved nutrient management strategy (NMS) under the *Nutrient Management Act, 2002*. Allow sufficient time to develop the documents and acquire the approvals.
- Secure agreements to sell the energy produced (Figure 3).
- Even though an AD system is totally enclosed, and the produced biogas is contained, stored and used, locate the facility site at acceptable distances from conflicting uses. There may be some odours from feedstocks and digestate effluent, and during scheduled maintenance. These odours are more evident if the biogas system is constructed in an area not used for livestock production. Because the AD system reduces the odour in the effluent compared

to the raw inputs, the net effect for livestock facilities is anticipated to be a reduction in odour. Some AD facilities in the U.S. are built for the main purpose of effective odour reduction.
- Retain a professional to ensure the construction of a safe and effective system, and to help navigate the various necessary approvals.

Anaerobic Digestion of Manure

Although the fundamentals of AD systems are simple, the operation and control can be complex. Design and management considerations include:

- securing approvals, ensuring that there is capacity in the local electrical or gas grid
- developing and financing a project when the final recipe and source of inputs may be uncertain
- maintaining operating conditions (temperature, mixing, materials) suitable for digestion
- installing and managing an interrelated group of systems to safely handle heating, material flow, hydrogen sulphide reduction, methane transfer, electrical and heat production, and interconnection with the electrical grid
- developing and maintaining a good "recipe" to generate enough and consistent biogas production to make the economics work. This works best with a regular supply of uniform inputs, which may be challenging with intermittent supplies of food-based off-farm feedstocks. Manure works well, especially if it is fresh, warm and nearby.

Economics

For agri-food AD systems to be economical, there are several key considerations. The biggest is the sale of energy from the AD system. Other benefits, including revenue from tipping fees or sales of byproducts, will vary, depending on each project's specific conditions.

Interconnection to the Electricity Grid

AD systems designed for electrical production usually generate more energy than is used at the site. Even in cases where energy production matches on-site energy needs, an interconnection with the grid is useful. Energy demands at most facilities are not static or linear. Under normal conditions, there are peaks in energy demand that the AD co-generation system may not be responsive enough to supply. Instead, the grid acts as a large battery, with the AD system putting energy in and the local facility drawing energy out. When farms add non-agricultural materials to the AD system, the result is significantly more energy than the farmstead can use.

Net Metering

Net metering is an agreement where the energy generator (the AD operator) pays the electricity distributor only for the net amount of electricity consumed. This allows the AD facility to generate electricity at any time, send it to the grid and then use electricity at any other time. The net billing or reconciliation is within a specified period of time (1 year in Ontario). The electricity distributor bills the facility for the net amount used. Generally, offsetting the farm's energy use will provide insufficient savings to cover the capital and operating costs of an AD system, meaning other revenue streams are needed. Contact the local electrical distribution company for more details on net metering.

Sale of Electricity

Ontario has some of the best rates in North America for renewable electricity from biogas. The former Renewable Energy Standard Offer Program (RESOP) and the Feed-In Tariff (FIT) Program have provided AD operators a guaranteed revenue stream. They ensure the long-term economic stability needed for a project of this nature. The Independent Electricity System Operator (IESO) provides more details on the sale of electricity.

Sale of Renewable Natural Gas

Currently, economical pathways for renewable natural gas (RNG) sales still have to be clearly demonstrated. RNG from biogas is more expensive than conventional natural gas, meaning a premium price is required for good project economics. Some of the factors that influence the economics of an RNG project include:

- finding gas buyers who will pay a premium for "greener" gas
- advances in carbon markets
- alignment with other financial incentive programs to reduce the overall project cost

Like renewable electricity, RNG is attractive because it fully integrates into the existing natural gas system without impact on the end user.

Use of Surplus Heat

While some manure AD systems are designed exclusively to combust biogas for heat, the system cost and the availability of low cost conventional fuels means that biogas for heat alone is not economically viable. However, with an electrical co-generation system, there is often significant excess heat available, even after heating the digester vessel. In addition to heating the digester, buildings and farmstead hot water, finding other users for hot water nearby can improve project economics. In Ontario, several greenhouses operate biogas systems and use the surplus co-generation heat to reduce their fuel use for hot water heating.

Tipping Fees

Off-farm feedstocks are added to farm-based AD systems to boost biogas production. Ontario allows the mixing of up to 50% off-farm feedstocks while still maintaining the agricultural designation of the digested materials that are produced. If off-farm source feedstocks are added to the system, AD operators may benefit from tipping fees for those materials.

Several factors influence tipping fees, including:

- the quality of material for digestion
- how difficult the material is to dispose of with alternative techniques such as land application, composting or landfilling
- the geographic location of the material in relation to the AD system

Tipping fees make up a small portion of the revenue stream of an on-farm AD system relative to energy production.

Figure 4. Digestate solids are commonly reused as dairy bedding.

Sale of Nutrient Byproducts

Sometimes project developers include the sale of the digestate nutrient end product in their budget. Niche marketing of nutrient products is possible. As more systems come into operation, this economic stream may diminish. Also, the cost of processing the end product to a point where it is a marketable product (e.g., solid-liquid separation, evaporation, composting, nutrient blending, etc.) is another budget item to account for. Several dairy farms in Ontario use their digested solids as bedding on their own farms. In the U.S., there are examples of farms selling their dried digestate solids to neighbouring dairy farms for use as bedding (Figure 4).

Pathogen and Odour Reduction Benefits

Agri-food AD systems remove pathogens and odour from the input materials. In the case of farm-based AD systems, the removal of pathogens and/or odour from manure may result in a digestate that's more acceptable to neighbours than conventional, untreated manure. It is difficult to assign a dollar value to these intangible benefits.

Changes in Nutrient Availability

Due to the removal of readily available carbon through the breakdown of organic compounds, the digestate contains nutrients that are more readily available for crop uptake (similar to commercial fertilizer). This means that the effluent is more predictable in nutrient release, allowing the operator to reduce commercial fertilizer use more than they would have using raw manure. Conversely, the increased nutrient availability may increase nutrient

loss if crops are not available for uptake. When spreading digestate in autumn, it is best to take up the ammonium-N with a standing crop or cover crop to prevent the nitrogen from leaching below the root zone. Longer digestate storage is required to ensure proper nutrient application timing compared to conventional manure.

Reduction in Weed Seeds and Improvement in Effluent Handling

European farmers claim a high reduction in weed seeds compared to raw manure. The reduction of weed seeds is of special importance to organic farming systems but also contributes to reduced herbicide costs on conventional farms. The digested material is easier to agitate, pump and move through small distribution pipes used in a liquid application system because of the breakdown of organic matter in the digester.

Reduction of Inputs

A digester will remove approximately 1.1 kg mass/m^3 of gas produced. This results in a significant reduction in volume if primarily dry input materials are used. However, since most digesters bring in off-farm feedstocks, the total digestate volume and total nutrients handled on the farm are higher compared to the original manure quantities.

SUITABLE INPUT MATERIALS

Many organic materials can be digested, particularly feed for animals, food waste or byproducts from that feed.

Manure

Manure is animal feed that was not fully digested, plus additional water and bedding. It contains energy that can be harvested in an anaerobic digester. Consider the following:

- Digestion of dairy and cattle manure is a proven approach with a strong track record of success.
- Digestion of only poultry or swine manure may present more challenges because of their higher nitrogen levels. Add other materials to optimize the blend.
- Sand or other inorganic materials will settle out in the digester vessel, taking up digestion space. Many digesters require shutdown and removal of built-up materials after 5–10 years of use.
- AD systems work best with fresh manure — manure stored under a barn is not as suitable.
- AD systems are not effective with highly diluted manure. Consider processes to bypass milkhouse washwater.
- AD systems may be adversely affected by materials mixed with inputs (such as cleaning agents). Keeping these materials out of the manure system and anaerobic digester is important.

Food Byproducts

Food byproducts and unmarketed food products are used as feedstock for the digester at little cost or for a tipping fee. Mixing of off-farm feedstocks with manure in an “on-farm mixed anaerobic digester” may increase biogas production and make the economics more attractive. A variety of off-farm source feedstocks are received at farm-based AD systems in Ontario, including fats, oils and greases, pre- and post-consumer food wastes, grease trap waste and other food-processing products or byproducts. There are a variety of considerations that influence the suitability of off-farm feedstocks:

- Most food byproducts break down rapidly in the digester.
- When introducing different food byproducts, it is important to make changes to the recipe slowly to allow the micro-organisms to adapt to the new menu.
- When food byproducts come from a variety of sources (a blend of processing facilities, restaurants and retail food store materials), there may be less certainty about the consistency or quality of material compared to material from one consistent source. Agreements with reputable material handling companies are key to success.
- Regulations enable off-farm feedstocks to be received and to ensure safe and appropriate management. These regulations include the Nutrient Management Regulation Approval (O.Reg. 267/03), the Renewable Energy Approval (O.Reg. 359/09) and the Environmental Compliance Approval (O.Reg. 347).

Energy Crops

For some farms, feeding energy crops makes sense:

- Energy crops such as corn silage, haylage and grasses require on-site storage (conventional ensiling systems).
- The addition of solid energy crops to liquid systems requires specially designed solid input devices that prevent gas or liquids from escaping.
- Unlike manure or many food byproducts, energy crops are valuable, and the cost of crop production has to be covered by energy production. A higher energy sale price is needed for AD systems using energy crops compared to similar systems using manure and food byproducts.
- Using energy crops is attractive because it reduces the dependency on uncertain supplies of food waste.

SAFETY

AD systems present a variety of potential safety risks that must be considered in the design and operation of these systems. While combustibility of the methane in the biogas is the obvious risk, another key risk is the production of dangerous gases that can lead to serious health impacts or death. If materials are mishandled, there are also risks to air, water and land from spills or discharges.

A number of design and construction standards must be followed, including regulatory requirements from the municipal and provincial governments, technical standards from the Technical Standards and Safety Authority and Electrical Safety Authority, and workplace health and safety rules. In addition, an online biogas safety awareness e-learning package for biogas workers provides awareness about risk management at an AD system.

As with all farming systems, proper design and training are key to minimizing risks. and the Canadian Biogas Association provides information on the various rules.

SUMMARY

Anaerobic digestion systems are becoming more common in Ontario. AD systems provide a viable option for manure treatment, with real economic returns and a variety of other societal benefits.

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