Current Status and Future Potential of Biogas Production from Canada's Agriculture and Agri-Food Sector

Canadian Biogas Association

Agriculture and Agri-Food Canada

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Executive Summary

The purpose of this study is: to quantify the current state of biogas production in Canada's agriculture and agri-food sector, including the end-uses of biogas and digestate; to describe the conditions that led to the establishment of the biogas industry in this sector; to identify the potential for growth as well as the challenges; and to present the broad requirements that could increase the production of biogas between today and 2030.

The study approach involved a combination of primary and secondary research techniques. This included speaking directly to facility operators to capture system information and operational details, seeking input from experts in the sector, and extracting information from industry reports.

According to the findings of the current work, Canada currently has 61 operational anaerobic digestion, or biogas, facilities in the agriculture and agri-food sector, and at least 5 facilities either planned, under construction, or in commissioning. The biogas facilities were organized into four subgroups: (1) livestock operations, accounting for 52 percent of projects, (2) greenhouse operations, accounting for 5 percent of projects, (3) food processing facilities, accounting for 33 percent of projects, and (4) biogas facilities designated as "other", accounting for 10 percent of facilities. The Provinces of Ontario, Quebec and Alberta have the most anaerobic digesters, with Ontario accounting for 64% of the facilities.

There are several end-uses for biogas and digestate. Currently, 64% of the biogas facilities in this sector generate electricity for sale to the grid. The remaining facilities use the biogas for onsite heat and electricity generation and two facilities upgrade their biogas into renewable natural gas (RNG) for injection into natural gas pipelines. To date, almost all biogas produced by the livestock industry is converted into electricity, most of which is sold to a provincial electric utility as green power under a multi-year power purchase agreement[1]. A small portion of the electricity and some of the heat is used directly on farms. The situation is reversed for the food processing industry that has much greater energy needs. Here the majority of the biogas is used internally to generate process steam and heat. A few facilities have installed biogas upgrading systems to produce renewable natural gas (RNG) that is injected into the natural gas distribution system. Renewable natural gas can be compressed or liquefied, and also be used as a fuel for vehicles.

Digestate, the nutrient-rich slurry remaining after anaerobic digestion, that is produced from on-farm digesters is generally applied to the farmer's fields and sometimes to neighbouring farms. In the case of a food processing facility, the digestate can either be sent to the municipal wastewater treatment system or be applied to nearby farms. Half of the operators who responded to the digestate question reported separating the solids from the digestate for use as livestock bedding. Digestate enhancement techniques are being explored to extract more value from the digestate, and improve the profitability of the operation.

[1] A power purchase agreement (PPA) is a contract between the electricity or RNG producer and the entity purchasing the energy, such as an electric utility, that defines the commercial terms of sale such as payment and length of contract.

Poor profitability and the difficulty to obtain project financing and time required to obtain regulatory approval were identified as the greatest hurdles that impede further investments in biogas facilities in this sector. Operators were asked to rate facility expenditures, relative to their expected expenditures, as well as the state of profitability. Most facility operators indicated that the systems were breaking-even, with biogas operations in the livestock subgroup that have a power purchase agreement being most profitable. In general, operating expenditures exceeded projections, indicating that the operating costs were higher than planned for.

To date in Canada, biogas development has been driven by supportive provincial policies and the proponents' interest in managing waste and reducing their environmental impact, recovering nutrients, generating renewable energy, and lowering their greenhouse gas (GHG) emissions. The study provides a deeper dive into provincial policies and programs, and provides some international perspectives. In Canada, provincial energy and waste management policies have been the main drivers influencing the build out of anaerobic digestion systems and how biogas is used (i.e. power or renewable gas). Carbon pricing and climate change policies have resulted in a second wave of development in the EU and US, and have the potential to support the growth of the biogas industry in Canada, depending on how the policies and incentives are designed.

Obtaining regulatory approval was noted as the second largest barrier to development. Typically, there are several regulations that are administered by different departments within the provincial jurisdiction, and regulators are not always familiar with smaller, on farm biogas systems. The length of time to obtain all of the approvals can take as long as 18 months to over 3 years, and in some cases has resulted in a loss of interest of investors. Other hurdles mentioned were: feedstock supply and cleanliness, grid and gas line connection, and community acceptance. These issues are often site-specific, and there was some indication that solutions could be found to address these challenges.

In terms of its future potential, at first glance, feedstock supply and technology do not appear to be constraints to further development. Agriculture and agri-food biogas facilities have access to and can digest a range of agricultural and non-agricultural material. A reliable, high quality supply of suitable feedstocks is the cornerstone of any successful anaerobic digestion (AD) system. Important characteristics of feedstock include: availability, consistency, free of contaminants, good methane yield, and the ability to generate a tipping fee[2]. Looking at provincially-aggregated waste and manure inventory numbers gives the perception that Canada has a very large supply of untapped feedstock. However, in reality, local inventory information is needed to assess feedstock availability within short distances, e.g. 25 km from a central location. By their nature both the digester feedstocks and the digestate are wet; placing limitations on how far the inputs and outputs can be transported. On the other hand, biogas or renewable gases derived from biogas can be stored and transported relatively easily.

System optimization through design, good operation and the adoption of more efficient technologies can be employed to maximize the yield of biogas (in particular methane) from the feedstock. The report mentions ways to verify and improve digester health, as well as technological solutions such as microwave enhanced advanced oxidation process to breakdown dairy manure before it enters the

[2] The fee a landfill charges to dispose of waste.

digester for easier nutrient extraction, adding biochar to increase biogas production, and using designs suited for colder weather operation. While larger systems have a better economy of scale, small-scale package systems have also emerged as lower cost options for small operations.

To date, the development of the biogas industry has been policy-driven with the feed-in-tariff (FIT) program having played a key role in providing a long term and secure source of revenue. The ending of the FIT program in Ontario raises the question of what would be needed to support further development. The banning of organics from landfills combined with climate change mitigation would appear to offer new opportunities for sector growth. From the greenhouse gas perspective, anaerobic digestion of wastes and displacement of fossil fuels is considered to be a double win as landfill GHG emissions are avoided, and fossil fuels use can be partly replaced with renewable energy and recycled nutrients. Identifying new financial models, particularly for farm applications, and the features of an enabling policy and regulatory framework are seen as the key next steps to support new investment in the biogas industry.

Considering how the biogas industry has evolved, the Canadian energy context, and learning from stakeholders in the industry, conditions that would support growth of the biogas industry include: (1) Established markets to provide financial stability and drive investment; (2) Supportive policy and programs; (3) Organics diversion from waste management systems, and support for value-added end products; and (4) Technical support and education related to digester operations and new technologies.

1.0 Introduction

Purpose

The Government of Canada is developing a Clean Fuel Standard (CFS) that is intended to reduce greenhouse gas (GHG) emissions of the transportation, industry, and buildings sectors by 30 Mt CO_2e on an annual basis by 2030 by lowering the respective carbon intensities of liquid, gaseous and solid fuel pools. Biogas is a low carbon intensity fuel that can be used directly for energy or be converted into renewable electricity or clean (i.e. lower carbon) fuels. Clean fuels which can be made from biogas include gaseous fuels such as renewable natural gas (RNG) or hydrogen, as well as liquid fuels such as methanol and dimethyl ether.

The biogas information base in Canada has improved over the last several years, but it is still considered to be incomplete, particularly for smaller sources of biogas produced on farms and in the agri-food industry. Within the agriculture and agri-food sector, wet organic residues and waste streams such as manure and processing effluents can be converted via anaerobic digestion into marketable renewable energy, and more stable digestate products that can partially replace synthetic fertilizers. However, low energy prices, the lack of carbon pricing and small economies of scale have resulted in poor economics, i.e. low return on capital, particularly for biodigesters in the livestock industry, and relatively low uptake.

In order to assess the future opportunities for the biogas generation in the agriculture and agri-food sector to contribute to climate change strategies, additional information is required about the current state of biogas production, the potential for growth, the barriers to development, and what conditions would need to be in place to promote greater production of biogas and renewable gases, such as RNG.

The purpose of this study is: to quantify the current state of biogas production in Canada's agriculture and agri-food sector, including the end-uses of biogas and digestate; to describe the conditions that led to the establishment of the biogas industry in this sector; to identify the potential for growth as well as the challenges; and to present framework conditions that could help the sector to increase its production of biogas between today and 2030.

Methodology

The study approach included a combination of primary and secondary research techniques. To set the baseline for agricultural and agri-food biogas production in Canada, a set of standard questions was developed to capture facility information and operational details. These questions, included in Appendix A, were answered by directly reaching out to biogas facility owners and operators across the country. Where operators could not be reached, information from secondary sources and databases was used. The responses and information were compiled into a searchable spreadsheet database. In most cases, the operators were not comfortable sharing facility information. Therefore, the information has been aggregated at the subsector or provincial level, and the report does not refer to specific facilities unless approval was given to do so.

Additional information on regional biogas development, industry challenges, feedstock supply, new technologies, and opportunities for growth was collected from experts in the sector and industry-specific studies. Members of the federal-provincial-territorial (FPT) Bioproducts Working Group[3] provided access to biogas colleagues within their organizations who shared their internal reports, and the Canadian Biogas Association struck a member advisory committee to review preliminary findings. The list of project contributors can be found in Appendix B.

2.0 Current State of Biogas Production in the Agriculture and Agri-Food Sector

This study found that, as of January 1, 2018, Canada currently had 61 operational anaerobic digestion or biogas facilities in the agriculture and agri-food sector, and at least 5 further facilities are either planned, under construction, or in commissioning. This number does not include municipal anaerobic digesters or landfill gas systems. The biogas facilities in the agriculture and agri-food sector were organized into four subgroups defined as follows:

- Livestock operations: Farms that raise animals to generate a profit, and utilize biogas systems to manage manure, recover nutrients and generate energy for sale.
- Greenhouse operations: Biogas systems integrated into greenhouse operations where some feedstock comes from the greenhouse crop residues and heat from the biogas system is utilized in the greenhouse.
- Food Processing: Facilities that produce food or food ingredients and integrate anaerobic digestion into their operations to treat process wastewater and generate energy for process energy.
- Other: Biogas facilities that process some agricultural and/or agri-food material, and are not located on a farm. These facilities do not fit into any of the previous three subgroups.

As shown in Figure 1 twenty eight biogas facilities, or 46% of facilities in this sector, are associated with livestock operations located in Ontario.

[3] Chaired by Erika Van Neste (AAFC) and Lori-Jo Graham (Alberta Agriculture)

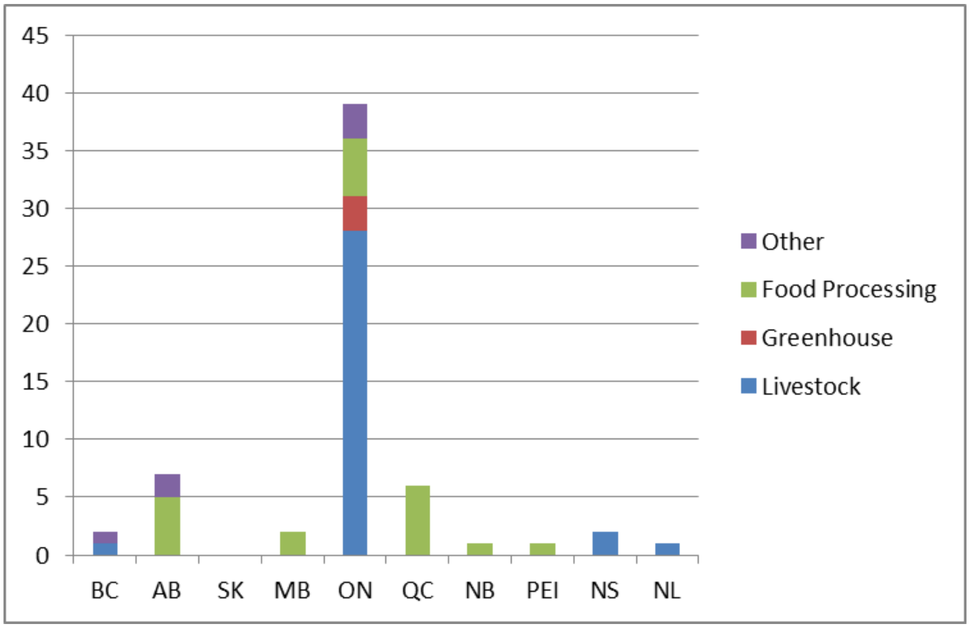

Figure 1. Agriculture and Agri-food Biogas Facilities by Province, with sub-sector breakdown (Jan 2018)

As shown in Figure 2, the Provinces of Ontario, Quebec and Alberta have the most facilities, with Ontario accounting for thirty-nine or 64% of the biogas facilities in the sector.

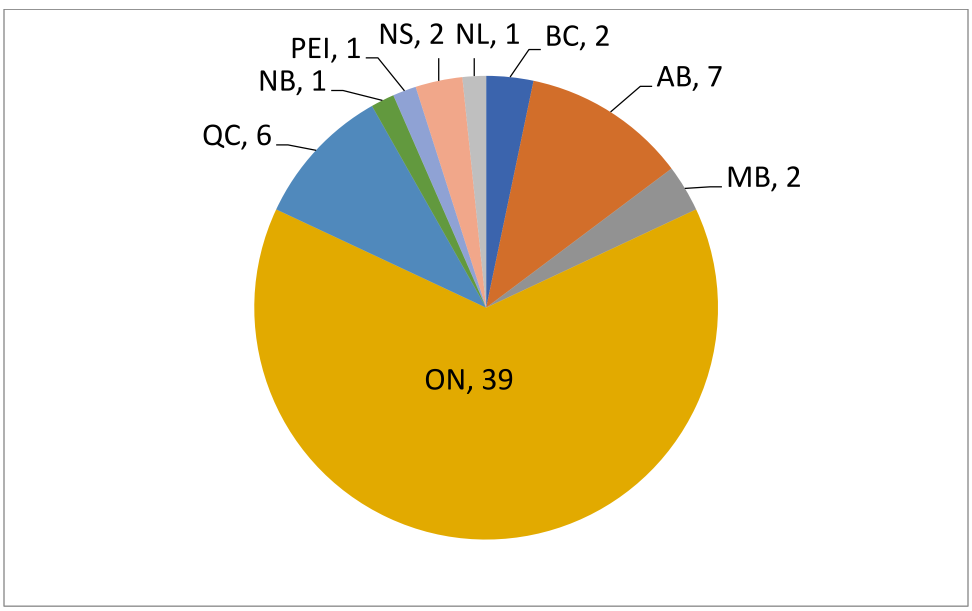

Figure 2. Agriculture and Agri-food Biogas Facilities by Province (Jan 2018)

In terms of biogas use, 64% of the facilities generate electricity for sale to the grid, followed by onsite heat and electricity generation, and renewable natural gas for grid injection. The breakdown, by number of facilities, is as follows:

- Electricity Generation for sale: Thirty-nine facilities mostly livestock operations, ranging in size from 100 kW to 2,852 kW

- Onsite use for heat and power: Nineteen facilities in the agri-food industry, ranging in size from 55 kW to 12.6 MW (thermal capacity)
- Renewable Natural Gas for sale: Two facilities in B.C., producing 40,000 GJ and 90,000 GJ of RNG annually.

Table 1 provides further detail on the biogas production and energy capacity by subgroup and for the sector as a whole. Information could not be collected from all facilities, so the number of reporting facilities is indicated in brackets next to the value. Also, little information was retrieved on the actual biogas production rates. In general, only nameplate capacity was provided by the respondents. Appendix C breaks out this information by province.

Table 1. Canadian Agriculture and Agri-food Biogas Production and Capacity

Subsector	Number of facilities	Biogas Production (Mm^3/year)*	Electricity Capacity (kW)	RNG Production (GJ/year)
Livestock	32	13.624 (9 facilities)	11,490 (30 facilities)	40,000 (1 facility)
Food Processing	20	29.404 (7 facilities)	3,926 (6 facilities)	0
Greenhouse	3	6. 640 (2 facilities)	2,270 (3 facilities)	0
Other	6	30.360 (5 facilities)	7,585 (6 facilities)	90,000 (1 facility)
Total	61	80.028 (23 facilities)	24,771 (45 facilities)	130,000 (2 facilities)

*Assuming 8,000 operating hours per year

Agriculture and Agri-Food Subsectors

The sector generates a variety of wet organic residues and wastes that can be converted into biogas and digestate products via anaerobic digestion. The subsectors include: livestock operations and greenhouses that have on-farm digesters; and food and beverage processing facilities and "other" operations that use some agriculture and/or agri-food waste materials but are not sited on a farm. Each of these subsectors is discussed below as they generate different types and amounts of waste (i.e. feedstock for the digester), and have different on-site energy requirements.

Livestock

Thirty-two biogas facilities in Canada are located at livestock facilities. The majority process dairy manure, and nearly all process a combination of on-farm (manure) and off-farm waste. The allowable proportion of off-farm material that can be used is determined by provincial regulation and varies between provinces. In terms of size, livestock biogas facilities are generally smaller than digester units found in the food processing and "other" industries, with most facilities having a nameplate capacity below 500 kW.

The motivations for constructing these anaerobic digestion (AD) facilities include manure management, nutrient recovery and management, water quality considerations, odour reduction, and destruction of pathogens. Nutrient recovery is particularly important for farms located in areas of high risk for nutrient overloading and leaching into the watershed. The sale of power at higher green premium has been key to their development and ongoing operation. That is, these facilities either had a power purchase agreement[4] (PPA), or market access to sell the electricity or RNG. Not surprisingly the Province of Ontario had the highest FIT rates, and also has the most number of digesters. However, facilities in Alberta do not have PPAs and sell their electricity into the provincial power pool.

The heat produced by a biodigester is used onsite to heat the digester and sometimes also by farm buildings. Dairy operations can make good use of this heat. However in many cases, especially in the summer, heat production is greater than on-farm demand, so not all of this energy is used. With respect to digestate, it is land applied to the farm and sometimes neighbouring farms. The digestate must be stored and can only be land applied at certain times of the year, according to a nutrient management plan. Operations that separate the solids from the liquid digestate, typically use the solids for livestock bedding.

Provincial and federal climate change policies and programs have challenged all sectors of the economy to reduce their emissions. Methane emissions from manure management are an important source of GHG emissions for the livestock subsector. Anaerobic digestion followed by biogas use that displaces fossil fuels can significantly lower the release of methane to the atmosphere, although the size of the GHG reduction depends on what energy the biogas displaces (e.g. electricity from coal, natural gas) and the baseline emissions resulting from typical manure management. Digestate is considered to be more stable than manure and release fewer N_2O and CH_4 emissions.

Greenhouses

Ontario has three biogas facilities operating as part of greenhouse operations. These facilities combine vegetable waste from the greenhouses together with livestock manure from nearby farms to generate biogas. In Ontario, this biogas is turned into electricity that is sold to the grid and the excess heat is supplied to the greenhouses. Traditionally, commercial greenhouse growers have used natural gas as their primary source of fuel to heat the greenhouses. Using surplus heat from biogas facilities can reduce their fuel costs and the corresponding GHG emissions from fossil fuels.

The primary motivations for constructing these AD facilities has been waste management, energy cost savings and energy self-sufficiency. As in the case for the Ontario livestock operations, the sale of power under a long term PPA is key to the financial viability of these operations. Carbon dioxide fertilization is also of interest to some greenhouses, creating some demand for CO_2 that is contained in the biogas. The production of renewable natural gas (RNG) is a potential source of CO_2.

Food Processing

Food and beverage processing is the second largest manufacturing industry in Canada in terms of value of production and it is the largest buyer of Canadian agricultural products. Approximately 6,500 food and beverage processing establishments exist in Canada (AAFC 2016). As they are often located in larger municipalities, they often can discharge their effluents into municipal wastewater treatment systems. However, municipal systems are not always able to manage the additional organic loading and, if so, processing facilities must put in their own treatment system. Anaerobic digestion is a good option for treating wastewater that contains fats, oils and starches that generate a high chemical oxygen demand (COD) and biological oxygen demand (BOD). The digester system serves as an internal wastewater

[4] A PPA is a contract between the electricity or RNG producer and the entity purchasing the energy, such as an electric utility, that defines the commercial terms of sale such as payment and length of contract.

treatment facility for the processing plant, allowing the plant to meet effluent discharge requirements and produce biogas that is combusted in its onsite boilers to generate process steam and heat. In some jurisdictions, the food processor may produce electricity for sale to the grid.

In this study, twenty food processing facilities were identified to have biogas systems. Six of these are cheese manufacturers located in Quebec, while Alberta has five AD facilities at large food processing companies such as McCain Foods, Cargill, Fleischmann's and Archer Daniel Midlands. Three potato processing plants, two in Manitoba and the other in PEI, also have digester systems. One reviewer noted that several facilities were missing from the Ontario list, including several breweries and corn refineries.

The primary motivations for installing AD systems in food processing facilities is for companies to meet their effluent permits in the most cost-effective way, and reduce their purchased energy costs. The potato processing facility owned by Simplot in Manitoba was held up as a "renewable energy poster child," with the digester included in the facility design in such a way that the biogas would provide approximately 10% of the fuel used in the boiler. By using only a 10% blend of biogas in natural gas, the biogas does not require an expensive cleaning stage to remove H_2S and other contaminants prior to combustion. This project was estimated to have saved the company $500,000 in fuel costs in 2002-2003, and the project investment cost has been paid back several times since then. This subsector has significant concentrations of feedstock available to it, providing it with the economy of scale advantage over typical on-farm digesters.

Rendering Plants

One of the subsectors specified in the contract Statement of Work was the rendering industry. It was found that there are no rendering facilities with biogas systems in Canada. Most of this industry's process by-products that have a low or no market value are used internally to produce steam that is needed in the operation. The comment was made that these facilities have an established supply chain and, to date, do not see any economic benefit to diverting the organics to biogas facilities. (Clarke, 2018)

While rendering facilities do play a role in biofuel production by selling some of their processed fats and oils to renewable diesel and biodiesel producers, they produce on very small amounts of organic waste. That is, these facilities send a very small amount of sludge, estimated to account for less than one percent of the rendering facility's output, to nearby biogas facilities. Some rendering companies also collect grease trap waste from restaurants, and some of this material is accepted by agricultural biogas facilities as off-farm feedstock.

There could be some interest within the rendering industry to have an onsite biogas facility to offset energy costs, if energy prices were to increase or carbon prices were sufficiently high. One of the respondents reported that there is a site in Europe that has an AD facility connected to its rendering plant. The rendering plant itself provides only a small amount of feedstock with off-site organic material being the main feedstock supply. The plant is able to use the biogas directly in its operations and offset fossil energy use.

Production and use of digestate

The organic material remaining after anaerobic digestion is known as digestate. This stabilized wet organic stream that leaves the digester contains less odour than pre-digested organic material and retains almost all of the nutrients from the feed material. Based on operators' responses, on average, digestate has 7% solids content and the solids can be separated from the digestate for use as bedding material in livestock operations. Applying the digestate to farm land can partially replace the nutrients in synthetic fertilizers, in particular nitrogen. Land application of digestate must adhere to the farm nutrient management plan that is approved by the provincial agricultural department to avoid no nutrient overloading and water pollution issues. (Government of Alberta, 2011; in-person communications, 2018)

Industry experts report that typically one tonne of feedstock will yield 0.9 tonnes of digestate. From direct communications with biogas operators, an agricultural biogas digester typically produces 30 tonnes per year of digestate per kW of installed capacity, 7,500 tonnes/year for a 250 kW facility or 14,000 tonnes/year for a 500 kW facility. Note these numbers depend on system design and operating efficiency. Biogas operators across Canada reported four main treatments of digestate, namely:

1) No solids separation, land application

   Digestate that does not undergo separation is applied to farmland in compliance with the farm nutrient management plans. Land application of digestate reduces synthetic fertilizer consumption, and farmers have reported cost savings and increased crops yields from using digestate.

2) Solids separation, bedding and land application

   At some facilities, digestate is passed through a screen or a screw press to separate the solids from the liquid portion. The solids are typically used for livestock bedding and the liquid portion is land applied.

3) Solids separation, land application

   In some cases the separated stream and the liquid stream are both land applied. The separated stream is used as a fertilizer with lower moisture content, and the liquid stream is land applied.

4) Fertilizer product, and/or liquid discharge to sewer

   Food processing AD systems (and a few agricultural digesters) are often operated to "polish" wastewater streams prior to discharge into a domestic sewer, or for treatment prior to land application as a biosolid (e.g. Non-Agricultural Source Materials (NASM) in Ontario). A solid or liquid effluent stream may be characterized as a fertilizer under the CFIA Fertilizer Act, and most of the liquid effluent may be discharged to the municipal sewage system.

Figure 3 illustrates the breakdown of the first three digestate treatments, described above. These results represent the responses from 26 facilities - seventeen livestock operations, six facilities that process agricultural and agri-food material, two greenhouses, and one food processing facility.

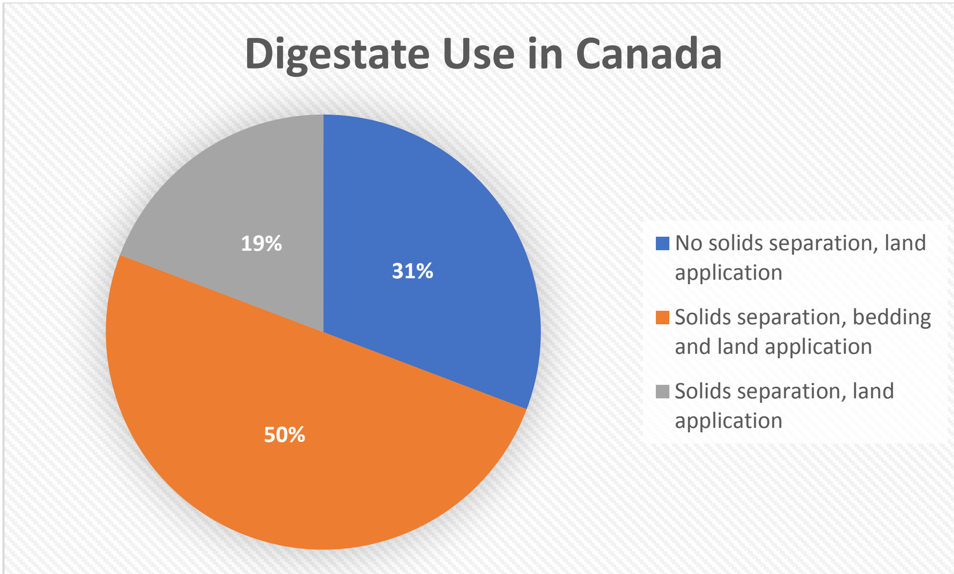

Figure 3. Breakdown of digestate treatment at 26 agricultural and agri-food biogas facilities

Financial values are often not applied to digestate, neither to the liquid and/or solid fractions. Consequently, this high volume co-product of anaerobic digestion makes no quantified contribution to the overall business case even though it can displace a portion of the nutrient demand of the next crop. If the reduction in synthetic fertilizer use can be quantified and/or the solids can be sold as bedding or fertilizer, these could be important contributions to the facility's revenue.

Facility Economics

Financial viability is widely recognized as the major hurdle impeding greater investment in biogas facilities. As facility operators are very reluctant to share details on their facility's financial health, operators were asked to use a rating scale to indicate their facility's profitability and expenditures. Seventeen facilities which included one food processor, two greenhouse operations, eight livestock operations, and six facilities in the "other" category responded to this question. Operators were asked to provide a rating on a scale of 1-5 of the facility's actual expenditures (1 = spent much more than projected, 3 = matched projections, 5 = spent much less than projected) and its state of profitability (1 = operating at a loss, 3 = break even, 5 = very profitable).

The average rating for profitability for seventeen facilities was 3.2 out of 5, indicating that on average facilities are breaking even. Nearly all respondents had market access to sell electricity or RNG, and power purchase agreements (PPA). Most operations charged a tipping fee to suppliers of off-farm material, providing an additional revenue stream. It was assumed that most operations are not currently claiming any revenue from the use or sale of their digestate or its solids. With respect to carbon credits, only two facilities in Alberta indicated this as an income source. It was noted by several respondents who had a PPA that the agreement stipulated that any environmental credits generated by the project belong to the utility, not the digester owner or operator.

Operators with biogas facilities in the livestock sub-sector in Ontario with feed-in tariff (FIT) contracts considered themselves to be either profitable or very profitable. Of the seventeen total surveyed operators, six livestock facilities in Ontario rated their state of profitability at a level of 4 or higher. As shown in Table 2, there is a wide range in the price paid by provincial utilities for electricity or RNG produced from biogas with the highest rates for power being offered by Ontario. Both FIT and microFIT programs have now come to an end in Ontario.

Table 2. Price paid for electricity and RNG from biogas

Province	Power Purchase Agreement - PPA (electricity)	Renewable Natural Gas (RNG)
British Columbia		\$15.28/GJ increased to \$30/GJ
Quebec		\$7-22/GJ has been recommended, it would be based on the production capacity of the project
Saskatchewan	\$0.1082/kWh (in 2017)	
Ontario	\$0.165/kWh to \$0.258/kWh (final round of FIT applications)	
Prince Edward Island	\$0.0775/kWh	
Nova Scotia	\$0.175/kWh	

Also, different forms of renewable energy (e.g. solar, wind, biogas) receive different incentives. As an example, Terryland Farms in Saint-Eugene, Ontario, reported receiving \$0.19/kWh for biogas-generated electricity and, more than double, \$0.52/kWh for electricity generated by its solar panels. (Dupuis, 2013)

In terms of facility expenditures, the average rating for seventeen facilities that compared their actual expenditures to their projections was 2.4 out of 5. This indicates that on average expenditures exceeded projections and the project proponent spent more money operating the facility than expected. The sources of extra costs were not specified by every respondent, but they included repairs, maintenance, and added equipment.

Figure 4 presents the rating of expenditures and profitability for the seventeen facilities that responded to the question. As requested, the identity of the facilities has not been shared.

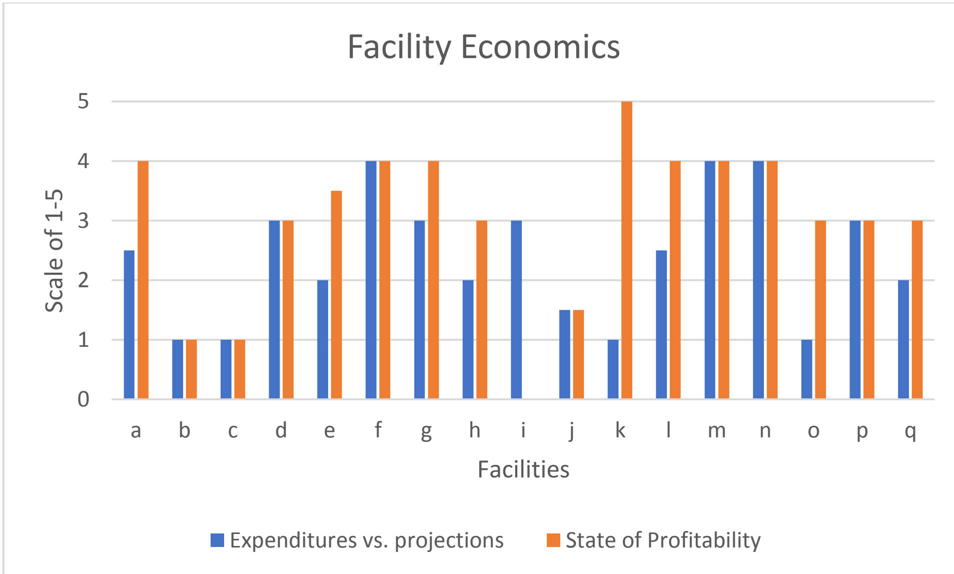

Figure 4. Operator responses on facility financial health

It is also important to acknowledge that some biogas facilities in the livestock sub-sector have shut down because they were not financially viable. Historical information from the Provinces of Quebec and Alberta made reference to the challenge these AD systems have to make a good business case. Also, one facility was identified - the Sweetridge Farms biogas facility in Manitoba – as a facility that was constructed but never operated. (Lagner, 2014) Anecdotal information provided suggested that the existing regulations in Manitoba resulted in a huge overdesign of this biogas facility and substantial cost overruns. What was considered at the start to be a relatively low risk, economical project became uneconomical.

3.0 Evolution of the Agricultural Biogas Sector

Momentum and interest in biogas production and renewable gases is growing nationally in Canada in response to climate change policies, carbon pricing, new renewable natural gas (RNG) targets and waste management. Broadly speaking, Canada has not seen the sustained commitment and support that has been provided in Europe for renewable energy, and as such the biogas industry is still in the early stages of development. (Alcock, 2017) Biogas development to date in Canada has been driven by supportive provincial renewable electricity policies and the proponents' interest in using anaerobic digestion to manage wastes, reduce environmental impacts, recover nutrients, generate renewable energy and, more recently, reduce GHG emissions. The following sections describe the relevant provincial policy framework, and provide some international perspectives.

3.1 Canadian Provinces

British Columbia

British Columbia stands out from the other provinces in that all of its agriculture-related biogas systems produce renewable natural gas (RNG) and not power. That is, the two operating facilities in southwestern BC produce pipeline quality RNG that is injected in the FortisBC natural gas grid. This development is driven by FortisBC's voluntary RNG market. In 2010, the British Columbia Utilities

Commission (BCUC) approved the RNG program at a temporary maximum price of $15.28/GJ which resulted in the first two RNG projects in BC. In 2013, the BCUC made the price permanent and four more projects were approved. In 2017, under the Climate Leadership Plan, the Government of British Columbia took action to support investment by natural gas utilities to increase the use of RNG. Amendments made to the Greenhouse Gas Reduction Regulation enabled utilities to increase the supply and use of RNG. The Renewable Portfolio Allowance (RPA) for RNG allows the gas utility to procure RNG up to 5% by volume per year and pay up to $30/GJ for the RNG supply. At $30/GJ, numerous RNG projects could become viable.

Provincial regulations allow on-farm AD plants to accept up to 49% industrial, commercial and institutional (IC&I) and source separated organic (SSO) feedstocks. This additional feedstock supply helps manure-fed agricultural AD plants because co-digestion of feedstocks is known to increase biogas yields in these systems. (Hallbar, 2017a) Also, tipping fees provide an important source of revenue that in turn makes a business case for the AD system.

The on-farm AD regulatory process involves approval by the Agricultural Land Commission (ALC) for projects within the Agricultural Land Reserve (ALR). Currently, energy production is not yet considered a normal farm practice by the ALC within the ALR, and biogas production may therefore require rezoning of ALR land to industrial land before a new facility can be built.

Alberta

Seven operating biogas facilities were identified in Alberta, five of these being in the agri-food sector and the 2 in the "other" category as they treat a variety of feedstocks are not located on a farm. Currently, these biogas facilities generate electricity and onsite heat, as Alberta has no RNG policy in place at this time. In the absence of long-term power purchase agreements, biogas proponents have relied on various sources of support from the Alberta Government, including climate change regulation, to overcome financial challenges. This support has included:

- **The Bioenergy Producers Program:** The Government of Alberta established the Bioenergy Producers Credit Program (BPCP) in 2007 to provide financial support for bioenergy producers with the expectation that a subsidy program would result in a self-sustaining bioenergy industry in Alberta. This expectation was not realized, and in 2017, the Bioenergy Producer Program (BPP) was extended with a revised scope, for two and a half years. The program will award grants to eligible projects (up to a maximum of $1,000,000 for electricity from combustion projects) and provide producer credit rates of $60/MWh for electricity from combustion of biogas for approved applicants. The production of RNG is not eligible under this program.
- **Carbon Offsets:** A market for Alberta based carbon offsets was created in 2007 with the introduction of the *Climate Change and Emissions Management Act* and the *Specified Gas Emitters Regulation (SGER).* Agricultural AD facilities can claim carbon offsets under the *Quantification Protocol for the Anaerobic Decomposition of Agricultural Materials, September 2007, Version 1.* This protocol is expected to be replaced by the *Quantification Protocol for Biogas Production and Combustion.* The new protocol applies to the combustion of biogas for the purpose of generating electricity, and the production of RNG will not be eligible. The offsets are offered to the market for a little less than $30/t CO_2e.
- **Government Grants:** The Government of Alberta has provided some grant opportunities to projects that reduce greenhouse gas emissions. In 2013, an agricultural biogas facility received a

renewable energy grant from the Climate Change and Emissions Management Corporation (CCEMC) for 50% of eligible project costs including capital costs.

Given the size and importance of the agriculture and agri-food industry in Alberta, it follows that there could be significant biomass feedstock resources available across the province that could support biogas production. The agriculture and agri-food industry is the second largest export industry in Alberta, and the food and beverage processing industry was Alberta's second largest manufacturing sector in 2013. (Alcock, 2017)

However, there are several deterrents to developing biogas facilities in Alberta. Viresco Solutions reported in 2017 that proposed biogas projects in Alberta had issues raising capital, existing facilities ceased operation due to technology failure, and one plant went into receivership due to economic challenges. The Province has a de-regulated electricity market, and at current historically low electricity prices (Alberta power pool prices for electricity generators averaged around $20/MWh in 2016 and 2017) biogas is seen as an expensive energy source when other benefits are ignored. Electricity-producing biogas plants compete with established, low-cost, high-carbon fuel based providers, conventional large-scale electricity generation and subsidized alternative energy technologies in an open de-regulated market where the market share goes to the lowest bidders. Volatility within the market compounds the issue through substantially increasing the risk to investors who cannot establish a confident return on investment. Without longer term policies and programs that can assure a minimum income, investors are unlikely to finance a biogas project.

In addition, developing a biogas facility in Alberta is not a straightforward process. There is no clear regulatory pathway for developers to follow regarding the permitting process for biogas projects. Proponents have to deal with multiple agencies that operate on different timelines. The multi-faceted value proposition of biogas to provide agricultural, environmental and energy related benefits has been shown to complicate interaction with the provincial government. Coordinating leadership among the various departments involved and driving a common biogas agenda continues to present a challenge to new development.

Saskatchewan

Biogas development in Saskatchewan has been limited. Currently, Saskatchewan has one biogas capture system tied to a municipal waste landfill. In 2014 the City of Saskatoon began operating its Landfill Gas Collection & Power Generation System which generates electricity from biogas that is produced through the decomposition of municipal waste. The system collects gas in vertical wells, drilled into the landfilled waste, with a vacuum compressor. The landfill gas is piped to the Power Generation Facility where the gas is combusted to generate electricity. This electricity is sold to SaskPower, generating revenue of about $1.3 million annually and a 9 year pay-back.

On the agriculture side, demonstration projects have been well received but have not led to further commercialization so far. In 2007 the Prairie Agricultural Machinery Institute (PAMI) established the Applied BioEnergy Centre with funding from the provincial government to undertake research projects on biomass and biogas. According to PAMI: "If all the feedlot manure in Saskatchewan could be digested, there would be 6.2 million GJ of energy in the biogas produced." By 2013, PAMI had established two pilot reactors utilizing a liquid and solid mix feedstock. Each reactor had a capacity to treat ten tonnes of a manure-straw mix which produced 50 m^3 of biogas (25 m^3 of methane) per wet tonne of feedstock. The research project demonstrated that this feedstock mixture could be used and does not require the solids to be separated from the liquid. (Rieger, 2018)

In 2014, the Saskatchewan Research Council (SRC) built a demonstration biodigester for the Canadian Agriculture and Food Museum in Ottawa. According to SRC:

> "The digester is designed to produce about five cubic meters (25 full bath tubs or 2 large garbage bags per hour) per day of biogas (60% methane, 39% carbon dioxide), at full capacity with good organic material. The biogas produced over one week is equivalent to 23 litres of gasoline."

No commercial biogas systems were identified using agriculture and/or agri-food feedstock in Saskatchewan. Livestock operations are smaller than those in Alberta, and manure is typically applied to the surrounding farm land. In general, food processing waste is sent to a municipal landfill and/or treated in a municipal wastewater treatment system. The availability of land and low population density has not created a waste management need that exists in more populated parts of the country.

SaskPower has introduced a Small Power Producer Program for generators that have a total nameplate capacity not exceeding 100 kW. While biogas facilities are listed as eligible facilities, on-farm digesters are not specifically mentioned in the criteria:

- "The addition of a biomass or a biogas generating facility must not result in a net increase in greenhouse gas (GHG) emissions.
- Biogas must be a gaseous fuel (primarily methane and carbon dioxide) produced by the anaerobic decomposition of organic wastes such as landfill sites, sewage treatment plants and anaerobic digestion organic waste processing facilities."

Manitoba

Three demo-scale anaerobic digesters were built in the late 1990 to early 2000 time period in Manitoba. Together they covered the three operating temperature ranges (low temperature, mesophilic and thermophilic) of anaerobic digestion. However, none of these operations continued due to poor financials.

In 2010, the federal Clean Energy Fund supported a biogas demonstration project that was part of Manitoba Hydro's Bioenergy Optimization Program Demonstration. A 50 kW AD facility was constructed at Sweetridge Farms (a 200 head dairy farm) to generate electricity and heat for on-farm use. The project was anticipated to have a high probability of success. However, this did not turn out to be the case and the plant was built but never fully commissioned. The idle status of the facility is attributed to overly-onerous regulatory requirements. In its final report to the Clean Energy Fund, Manitoba Hydro stated that if the regulatory impediments were not addressed in the future, they would act as a major deterrent and "to a large extent technical and economic barrier to the adoption of on-farm biogas technology in Manitoba". (Lagner, 2014)

However, in the food processing sector, Manitoba does have biodigesters installed at Simplot and McCain's operations.

Ontario

Sixty four percent of AD facilities in the agriculture and agri-food sector are located in the Province of Ontario, and this is attributed to the support of the provincial government for the development of renewable energy, including biogas.

Ontario provided early incentives for biogas production with the Renewable Energy Standard Offer Program that was introduced in November 2006 and ran until it was replaced by the feed-in tariff (FIT) Program in October 2009. Modeled after Germany's program, Ontario's FIT Program was introduced under the *Green Energy and Economy Act* and it has proven to be the most successful program in Canada for encouraging rapid investment in renewable electricity generation. The FIT Program offered a range of prices for electricity from different sources and included incentives for power produced during peak times. FIT contract prices were established by incorporating the cost of purchasing, financing, building and maintaining a project as well as a reasonable rate of return on investment over the contract period. The FIT Program ended in 2016.

At the same time as the FIT program, the Province of Ontario also offered the Ontario Biogas Systems Financial Assistance Program (OBSFAP). OBSFAP offered grants of up to $400,000 for capital costs, and $35,000 for feasibilities studies. This $11.2M program provided capital support to 25 agricultural and food-based digester construction projects, and feasibility and design studies. OBSFAP also provided financial support for the establishment and first operating years of the AgriEnergy Producers' Association (APAO), the precursor to the Canadian Biogas Association.

During the final round of FIT applications, the FIT pricing schedule offered $0.165/kWh to $0.258/kWh for electricity produced from biogas, i.e. a fixed rate over 20 years. Smaller systems were provided with higher tariffs to allow more development across a range of farm and system sizes. In the final year of the FIT program, 75 agri-food facilities applied for FIT contracts. However FIT prioritized projects that included municipal, community co-op or indigenous community ownership, and only 6 FIT contracts were offered to agri-food AD facilities.

Figure 5 shows the positive impact the FIT Program had on the growth of the biogas industry in Ontario since 2009.

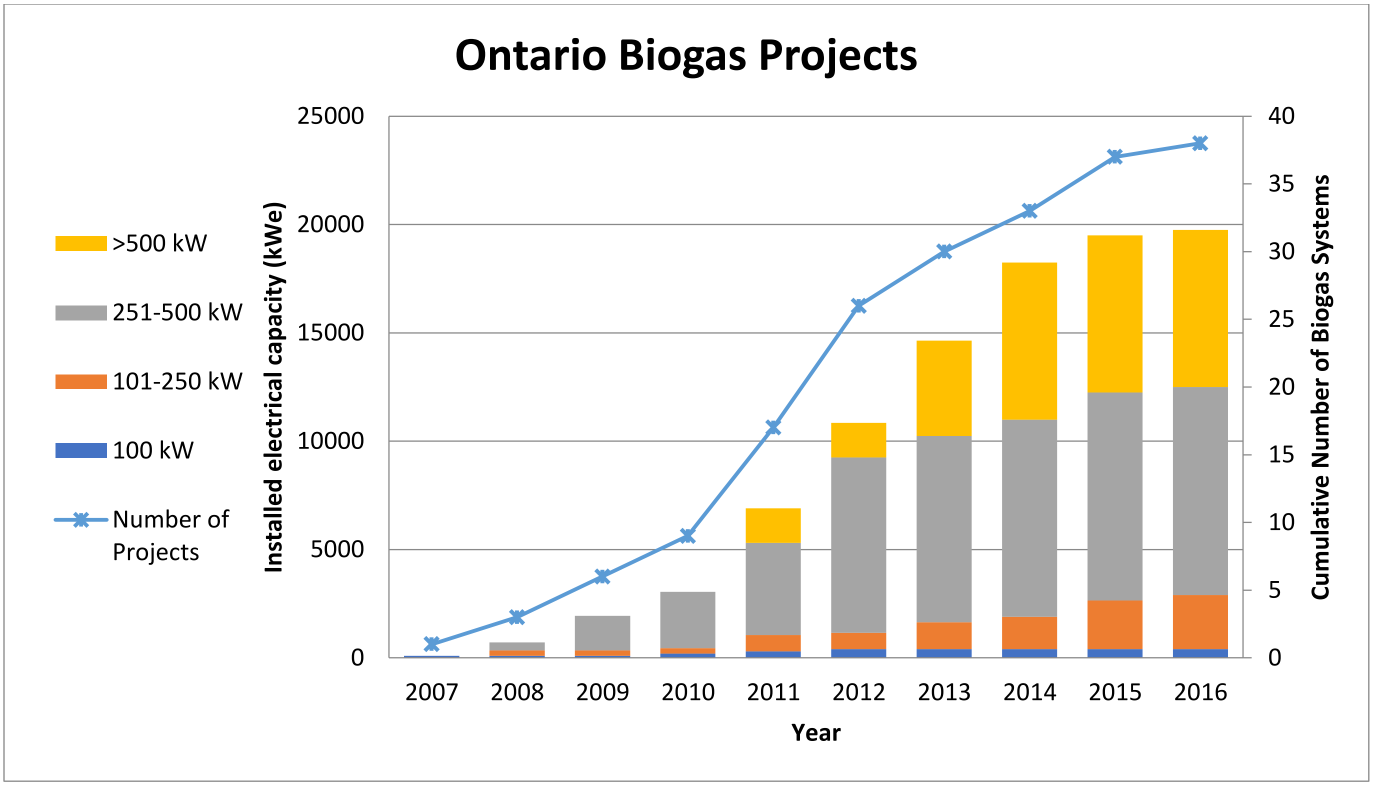

Figure 5. FIT biogas projects in Ontario 2007-2016

The Province of Ontario also has regulations in place that allow the addition of off-farm materials to agricultural anaerobic digestions facilities. The regulations permit up to 50% off-farm materials to be digested in on-farm biogas systems in accordance with specific regulations and procedures. In addition to allowing co-digestion of off-farm materials, the digestate from these mixed feedstock digesters is still considered to be an agricultural source material. That is digestate from these mixed feedstock operations can be land-applied, following regulations similar to manure application.

Quebec

The initial driver for on-farm AD systems in Quebec was the need for environmental mitigation, i.e. addressing phosphorus loading issues associated with manure management. Two on-farm digesters were built in the early 2000s, and while they did reduce phosphorus loading and produce heat energy for farm buildings, there was no market for biogas-generated electricity in a province with abundant, low cost hydroelectricity. The two facilities subsequently shut down due to financial reasons. Long approval time was identified as a second factor that has contributed to the slow rate of development in Quebec. Three AD projects that had adequate financing were dropped by investors because it took in the order of 18 months to obtain the necessary approvals. (Hince, 2018)

There are a number of AD facilities operating in the food processing industry, in particular, cheese manufacturing. Little additional information was retrieved on these facilities, other than what is published on public websites. For the most part these are small facilities that treat their process waste streams using AD and use the generated biogas for their own heat and process needs. Together, these facilities are reported to have a total installed capacity of 2.5 MW. (Whitmore, 2016)

To date, there have not been any incentive programs similar to FIT or renewable energy premiums for biogas in Quebec. The natural gas utility in Quebec, Énergir, has been actively involved in facilitating the development of RNG projects and, in July 2017, submitted a package of measures to the Régie de l'énergie that would make it possible to further increase the competitiveness of RNG production and the development of RNG projects in Québec. Recommended measures for purchasing parameters for RNG include the introduction of a feed-in tariff ranging from $7/GJ to $22/GJ depending on the production capacity of the project, and contract terms ranging from 5 to 20 years to facilitate the financial planning of RNG projects.

New Brunswick

The New Brunswick Climate Action Fund supported the construction of a farm-based biogas facility in 2010. Currently the province does not have incentives in place to support biogas or biomethane development. New Brunswick released its climate change action plan "Transitioning to a Low Carbon Economy" in December 2016 which included plans to invest in renewable electricity, price on carbon, and caps on GHG emissions. (BioNB, 2017) This could lead to measures that promote biogas production.

Newfoundland and Labrador

In October 2016, the Government of Newfoundland and Labrador published two policy documents on climate change: *Greening Government* and *Market Transformation Framework.* These aim to create a culture of environmental sustainability, and to green buildings, transportation, and products and services through energy efficiency, net metering, and preferred procurement of green products. (BioNB, 2017) There is one dairy farm biodigester operating in the Province, and several other potential AD projects have been identified. There is potential to develop more projects provided an energy price is established.

Nova Scotia

The Government of Nova Scotia operated a Community Feed-in-Tariff (COMFIT) program from 2011-2015 where CHP biomass renewable electricity projects that met the criteria could apply for connection to the grid and receive a premium rate of $0.175/kWh over a 20-year period. The increased cost generated by the COMFIT rate is passed on to the consumer via their electricity bill. In August 2015, the Government stopped accepting new applications to the Program. There is currently one operating on-farm biogas facility, and two facilities are nearing the end of their construction. All three facilities will benefit from the COMFIT program. As of the time of this writing, the COMFIT program has been replaced with "Renewable to Retail" framework, which includes new and amended tariffs intended to facilitate the sale and purchase of renewable low-impact energy.

With *Taking Action on Climate Change, Nova Scotia Electricity Plan,* and *Nova Scotia's Proposed Cap and Trade Program* there is significant commitment to reduce GHG emissions, including a major shift in the electricity sector, and a review of cap and trade policy. (BioNB, 2017)

Prince Edward Island

Canada's largest agri-food anaerobic digester is located at Cavendish Farms in New Annan, Prince Edward Island (PEI). It has a thermal capacity of 12.6 MW.

The Province of PEI has an equivalent to a feed-in tariff called the Minimum Purchase Price (MPP) which is regulated by the *Renewable Energy Act*. The MPP established for the purchase of electric energy by a public utility from a medium capacity renewable energy generator under the REA is $0.0775/kWh. The

MPP treats all sources of renewable electricity in the same way, unlike Ontario where the power purchase agreement differed for each type of renewable energy. (PEI, 2016)

The current policy framework in PEI does not provide a suitable environment for the viable development of AD systems at the farm scale. However, impending carbon pricing, GHG mitigation strategies and enhanced nutrient management planning could improve the feasibility for biodigesters in the future. It is conservatively estimated that there are about a dozen farms, including dairy, hog, beef, and crop farms in PEI that may have the scale to consider incorporating an AD system and creating revenue. However, a reasonable purchase price and contract length is required to make the projects viable. (PEI, 2016)

3.2 International Perspectives

Europe and Germany

The growth of the European biogas industry can be attributed to a number of regulatory, market, and economic factors. The European Commission developed several directives, targets and programs related to energy, waste management and climate change, that have initiated thriving biogas industries in a number of countries. Most of these systems have targeted renewable electricity, and currently biogas contributes approximately 6-7% of the renewable electricity produced in the EU. Biogas production is expected to continue to grow with interest increasing in the conversion of biogas into biomethane and other renewable gases. The successes of the tools and measures in Europe show that common barriers of capital investment, feedstock supply and technology scale can be overcome when appropriate frameworks and financial incentives are provided.

Germany is by far the largest biogas producer in Europe at 36,775 GWh of electrical and 18,851 GWh thermal energy per year, accounting for 5% of the total electricity demand. In 2015, there were a total of 9,772 biogas plants in Germany, firmly placing them at the top of the international biogas production rankings. (Liebetrau et al., 2017) The Renewable Energy Act has played the key role in developing the biogas industry in Germany; however there are a number of other Acts and Regulations in the areas of waste management, fertilizer use, manure management, GHG emissions and the energy market that have been deemed as necessary complements to the Renewable Energy Act.

The majority of German biogas plants are smaller plants (<75 kW) that are owned by individual farmers or small businesses who utilise both electricity and heat produced by CHP. It is estimated that approximately 8,000 biogas facilities in Germany are agriculture-based, and more than 50% of German biogas is produced from energy crops - corn silage that is grown specifically for anaerobic digestion. Corn silage is an expensive feedstock for biogas operators; however feed-in-tariffs (FITs) have made these energy crops economically attractive. The FITs differentiated between the technology used, production capacity, and feedstock, and were available for a 20-year period. This guaranteed power purchase mechanism created a framework for secure investments from the private sector. (Alcock et al. 2017, PEI 2016)

Over time, different tools have been used by the government to support the biogas industry in different stages of development (e.g. initiation, market build up, etc.). The German biogas industry has moved from the “industry consolidation” phase to “market integration”. To support the industry’s evolution, the Renewable Energy Act was significantly amended in 2014 bringing an end to the FIT program and introducing a system of full market exposure through auctions. The shift in policy, or perhaps more importantly, the speed at which it occurred created a lot of uncertainty within the industry.

Pursuing very ambitious renewable energy targets has significantly increased the cost of electricity for the average consumer in Germany. Combined with the landscape changes that accompanied the large increase in silage corn production, public support for biogas-to-power has declined. (Funke, 2017) With facilities starting to reach the age of twenty years, decisions need to be made regarding reinvestment. Germany, along with most countries in the EU, is now shifting some of their biogas into renewable natural gas – a storable, flexible energy carrier and vehicle fuel.

United States

There are over 247 farm-based biogas producing sites in the United States (US). The agricultural sector is a significant source of growth potential for biogas in the US, where it is estimated over 8,000 dairy and hog farms could include biogas production in their operations. (Alcock et al. 2017)

The US Biogas Opportunities Roadmap (2014) lists the main barriers to realizing the full potential of the biogas industry as follows: lack of awareness of biogas benefits; unpredictable biogas market conditions; lack of market maturity (i.e. carbon markets, non-energy products); lack of full valuation; inconsistencies across federal, state and local governments; lack of adequate environmental, technical and economic performance data, and; the need for applied R&D to increase biodigester yields.

Biogas developments in the US are currently shifting the industry away from biogas-for-electricity projects to projects that are focused on upgrading biogas to RNG mostly for vehicle fuel. This is due to the much higher revenues that can be generated through the Renewable Fuel Standard (RFS) compared to what most electric utilities will pay for renewable electricity from biogas. The RFS is a federal program that is designed to increase the amount of renewable fuel of all kinds produced in the US. With it, producers can sell fuel and credits called Renewable Identification Numbers (RINs) generated by the programme. Since 2014, the biogas sector has been a key component of the non-corn ethanol biofuels section of the RFS. (Serfass, 2018)

Nearly all of the other significant US market factors are at the state and local level. Favourable policies and market conditions exist across the US that are helping develop biogas projects. For example, Vermont has a program that will pay more for electricity from biogas than nearly any other state, Massachusetts has passed a landfill ban and has very clear regulations for anaerobic digestion and electricity sales, and Florida recently passed regulation to allow RNG into their natural gas pipelines. (Serfass, 2018)

4.0 Future Potential

The potential for further production of biogas and renewable gases from the agriculture and agri-food sector can be addressed from at least four different perspectives, namely:

- Feedstock supply;
- Optimization of Anaerobic Digestion systems;
- Other Uses of Biogas and Digestate; and
- Carbon Credits.

4.1 Feedstock

A reliable, high quality supply of suitable feedstock is the cornerstone of any successful AD system. Feedstocks are the source of biogas, the consistency and quality of supply strong effect system stability and operational functionality. Over the last decade, there has been a trend to move from single feedstock AD systems to multiple feedstock systems to improve digester yields and methane production.

Current Amount of Feedstock Processed with Anaerobic Digestion

Summarized in Tables 3 and 4 is the information received[5] from 24 (out of 60) facilities. They included 7 food processing plants, 2 greenhouses, 10 livestock operations, and 5 facilities in the "other" category. Although there was not complete coverage of all operating facilities, these tables provide an overview of the types and volumes of different feedstocks used by biodigesters in the agriculture and agri-food sector. In the case of on-farm digesters, manure is the dominant feedstock. As shown in Table 4, a wide variety of feedstocks are treated via anaerobic digestion.

Table 3. On-farm feedstocks

Type of Feedstock	Quantity (tonnes/year)	Number of biogas facilities
Dairy manure	124,735	11
Beef manure	22,500	1
Hog manure	14,000	1
Poultry manure	1,085	1
Manure (unspecified)	50,416	5
Crop and vegetable waste	2,763 tonnes and 570 m^3	4
Energy Crop – Sugar beets	1,000	1
Corn Silage	1,200	1
Tulips	1,045	1

[5] from the respondents or retrieved from a website or other source

Table 4. Off-farm feedstocks: Agri-food processing and municipal/industrial wastes

Type of Feedstock	Quantity (tonnes/year, unless indicated otherwise)	Number of biogas facilities
Cheese processing waste	1,800 tonnes and 5.9M liters of processing waste	4
Brewery Waste	300	1
Candy processing waste	520	1
Dissolved Air Flotation Sludge	34,062	3
Fats, Oils, and Grease (FOG)	25,306	8
Food processing waste	76,300	3
Food processing waste water	not quantified	3
Food Waste	50,085	2
Grape Pumice	7,725	2
Grocery Waste	23,950	3
Livestock Processing Waste	12,015	3
Meat processing wash water	4,700,000 gallons	1
Pet Food	955	2
Potato Waste	98,065	2
Rendering Sludge	2,000	1
Source Separated Organics (SSO)	30,500	3
Starch	4,495	1
Whey	925	1
WWTP Sludge	6,583	1

Estimated Feedstock Available for Anaerobic Digestion

The total Canadian production of agricultural residues or waste ranges in the order of millions of tonnes per year. Table 5 summarizes feedstock available in the agriculture and agri-food sector in each province. Aquaculture residues have also been included for the Atlantic Provinces. When compared with the feedstock volumes presentedin Tables 3 and 4, the values in Table 5 suggest that there are significant volumes of biomass available for anaerobic digestion across the country.

Table 5. Feedstock availability across Canada

Province	Manure	Food Processing	Aquaculture	Crop Residues
	tonnes/year	tonnes/year	tonnes/year	tonnes/year
Canada	16,006,926	> 1,100,000 - 5,400,000	187,374	49,153,113
BC	1,139,000	no data	no data	no data
AB	2,560,000	500,000	no data	2,654,585
SK	1,871,000	no data	no data	no data
MB	1,394,000	no data	no data	no data
ON	3,108,000	600,000 - 4,900,000	no data	6,299,000
QC	2,615,000	no data	no data	no data
NB	1,024,167	no data	24,331	96,684
NS	1,237,313	no data	7,167	73,346
PEI	832,753	no data	22,640	323,130
NL	225,693	no data	22,814	941

Sources: Alberta Innovates 2011; Alberta Research Council, 2010; Bell, 2015; BioNB, 2017; Government of Alberta

The viability of converting agriculture and agri-food feedstocks into biogas will depend on the availability, cost, and competing uses the feedstock within a certain geographic distance. While thematerials listed in Table 5 would all be expected to be amenable to anaerobic digestion, only a portion of these volumes should be assumed to be available for biogas production. Some of these residues, particularly in the food processing industry, have other uses. Also the geographical concentration of these materials and their location will greatly influence the viability and cost of transporting them to a digestion facility. In general, biodigester operators consider important characteristics of feedstock to include: availability, frequency, degree of contamination, methane yield, and ability to generate a tipping fee.

Off-farm feedstocks can increase biogas generation and the size of an on-farm digester, and may also provide an opportunity for livestock AD owners to generate additional revenue through tipping fees. However, this will require a dedicated reception/storage system for off-farm feedstocks that should be odour-tight, and sized to meet the operational needs of the AD system, as well as all regulatory requirements. (CH-Four Biogas, 2010) Also the addition of off-farm feedstocks needs to meet stringent criteria with respect to contamination, and it could place limitations on where the digestate can be land applied. For example, in Denmark, digestate from digester fed with source separated organics cannot be applied to organic farms.

Additional Information by Province

Pyecombe (2004) determined manure production intensity for different livestock groups in British Columbia. This information, on regional concentrations of manure, would have to be updated as livestock production patterns have changed over the last 15 years. As manure is generally co-digested with other organic material, this inventory work should include all sources of digestible material.

A study performed by Hallbar Consulting in 2017 found that the long term potential for RNG in British Columbia is estimated to be up to 11.9 PJ/year – a significant increase when compared to achievable short-term RNG production potential of 4.4 PJ/year. This was based on a projected increase in feedstock availability (from agricultural, commercial, municipal, wastewater, landfill and forestry sources) but it did not assume significant technology advancement. Approximately 20 to 35 dairy farms in B.C. have more than 200 milk cows, and these farms could be well suited to the production of RNG. (Stanners, 2018)

Another potential opportunity for biogas production that is being explored in the Lower Fraser Valley of B.C. is the combination of feedstocks from municipal and agricultural operations, such as organic portion of MSW with poultry waste (i.e. the easiest manure to transport) and crops (e.g. silage corn and possibly a winter cover crop) that are grown on underutilized farm land. It is proposed that the digestate could be applied to the farmland that is used to grow the silage corn. While the ideal proportions of each type of biomass still need to be determined, energy crops (in this case silage corn) are not expected to be the first nor the second feedstock. (Bittman, 2017)

A study performed by Alberta Agriculture and Forestry (Bell, 2015) determined available organic waste by sector, and found that the potential feedstock resource in Alberta is large and varied, indicating that there is an opportunity for Albertans to explore options to convert waste streams into higher value products. As discussed further in the next section, the Province also faces several barriers to expansion of biogas.

In Ontario, Geomatrix estimated the quantity of food processing industry waste that could be available for biogas production in 2008. Four different approaches were used to estimate a wide range of potential residues. If 50% of the total residues were available for biogas production, the volumes could range from 0.6 to 4.9 million tonnes of residues, and generate 53 to 697 GWh per year of biogas generated electrical power (or 0.64 to 8.4 million GJ/year of natural gas equivalence). Factors that would influence the availability of food processing industry waste included: the demand for residue by the different sectors that currently use the residue; the location of the residues relative to potential users; the transportation costs; the costs for current treatment and disposal; the costs for traditional and emerging forms of energy; and the residue to energy conversion efficiency of AD, biodiesel and methanol. (Geomatrix, 2008)

The BioEconomy Now report led by BioNB (2017) identified potential feedstocks for bioenergy production in Atlantic Canada, including agricultural crop residues and livestock waste. The study tabulated the total manure production from livestock animals including cows, sheep, boars, pigs, and poultry, and volumes are included in Table 5.

At a national perspective, livestock production is expected to grow at a modest rate for the next decade. As shown in Table 6, milk, cheese and meat production are expected to increase at a slightly stronger rate than animal production. This information helps to show that manure volumes are expected to slowly grow over the next decade.

Table 6. Forecasted Growth in Animal, Meat and Dairy Production (AAFC, 2017)

Domestic Production	2015 Value	2016 Estimation	Average growth rate (2016-2026)
Animal Production, no. of head			
• **Dairy cows**	959,000	966,000	- 0.2%
• **Dairy heifers**	448,000	449,000	+ 0.1%
• **Beef cows and bulls**	4,040,000	4,045,000	+ 0.5%
• **Beef heifers**	1,457,000	1,488,000	+ 0.3%
• **Steers**	1,173,000	1,135,000	+ 0.6%
• **Calves**	3,914,000	3,941,000	+ 0.4%
• **Hogs**	13,240,000	13,310,000	+ 0.2%
Food Production			
• **Milk Production**	94.1 Std. Mhl	97.0 Std. Mhl	+ 1.3%
• **Cheddar Cheese Production**	148.6 kt	144.5 kt	+ 1.5%
• **Specialty Cheese Production**	277.3 kt	290.3 kt	+ 1.1%
• **Beef Production**	1,026 kt	1,073 kt	+ 0.5%
• **Pork Production**	2,065 kt	2,105 kt	+ 0.4%
• **Chicken Production**	1,112 kt	1,160 kt	+ 2.0%
• **Turkey Production**	172 kt	173 kt	+ 1.0%
• **Mutton and Lamb Production**	16.8 kt	16.5 kt	- 0.2%

As a final point, it is important to note that not all livestock groups have the same potential for biogas production. There are significant differences in yield (shown in Table 7), and some types of manure contain inhibiting substances. Poultry manure, for example, is known for its high ammonia content requiring that this manure be blended with other feedstocks or pretreated.

Table 7. Yield and Energy Content of Biogas from Different Animal Groups (Pyecombe, 2004)

	Swine	Dairy Cattle	Beef Cattle	Poultry (layers)
Yield (per ft^3 digester volume)	1	1	1	1
Yield (ft^3/head/day)	4	46	28	0.29
Gross energy content (Btu/head/day)	2,300	27,800	16,600	180
Net energy content (Btu/head/day)*	1,500	18,000	10,700	110

*35% of gross energy is used by the digester

New Energy Crops

The production of energy crops for use in anaerobic digestion is taking place in Europe, and has grown dramatically in Germany. An International Energy Association Bioenergy study carried out in 2011 outlined the opportunity of biogas from energy crop digestion. Many varieties of grass, clover, cereals and maize, including whole plants, as well as canola or sunflower proved feasible for methane production. Hemp, flax, nettle, miscanthus, potatoes, beets, kale, turnip, rhubarb and artichoke were also tested successfully. However, the study found crop digestion not to be economically feasible. (IEA Bioenergy, 2011)

To date, there are no energy crops being grown on a commercial scale in Canada for use in anaerobic digestion. Some agricultural operators are interested in growing corn silage to provide feedstock security for on-farm digester systems. One biogas project in Ontario is planning to test the addition of miscanthus as a supplemental feed. Although the economics may not justify growing a dedicated crop strictly for this purpose, AD systems could provide a secondary market for perennial grasses and corn silage.

4.2 Anaerobic Digestion System Optimization

Design and Operation

Anaerobic digestion systems are designed to convert the available feedstocks into biogas and digestate streams that can have a variety of end-uses. The targeted end-uses will dictate both the design and operating conditions. In general, systems are optimized to maximize the yield of methane for a given feedstock. Those systems that target energy end-uses seek to recover as much usable energy as possible, in the desired forms – electrical or thermal energy. The required degree of biogas cleaning will also depend on the end-use of the gas. This can range from removal of hydrogen sulphide and moisture from the biogas to purification to 99% methane content. Digestate streams can be applied directly to farmland “as is”, or undergo solid-liquid separation or a more complex nutrient recovery process to separate out valuable components.

An overview of the design considerations and common operational issues, provided by industry experts, is described below. They point to areas where further efficiencies could be made.

Design Considerations

Optimizing the design of AD facilities can significantly improve operation and reduce downtime. Design considerations include:

- **Digester Heating:** Design that accounts for the Canadian climate and cold winter temperatures will ensure the digester maintains operating temperature and increase operational time and biogas production.
- **Mixing:** Designs that allow for easy maintenance of mixers outside of the vessel will reduce downtime by avoiding the need to perform repairs inside the digester.
- **Dome design:** Adding a weather cover to the dome protects it from the elements and prevents the dome from getting loose and catching in the wind and tearing.
- **Back-up heat:** Having a back-up source of heat for the digester in addition to process heat is a design feature that will ensure the digester can get back online in a timely manner after an outage. A robust design is needed that will recover upsets with the ability to heat the digester. Some operators have back-up heating from wood boilers or propane, however a number do not have any back-up heating ability.

Regular Monitoring and Preventive Maintenance

As with most mechanical systems, regular monitoring and maintenance can reduce facility downtime. In the case of biogas systems, this may require additional technical with specialized expertise and accessing replacement parts from outside of Canada. For example:

- **Replacement Parts Availability:** It can be difficult for operators to access spare parts for systems supplied from outside of Canada, as the technology providers often do not stock spare parts. This means they have to source replacement parts from third-party providers or wait for weeks for parts to arrive by plane, resulting in unnecessary downtime. Easier access to replacement parts will expedite repairs and bring the plant back into operation sooner.
- **Preventative Maintenance:** Digesters are integrated systems that require many mechanical and electrical parts to operate concurrently, causing downtime if one part isn't working. Preventative maintenance is recommended to reduce downtime caused by weak links in the chain and increase biogas production.
- **Monitoring System Leaks:** At various points throughout the system, biogas can escape from the system resulting in efficiency losses and odour issues. Regular monitoring and maintenance is required to minimize these losses.

Digester Health

Awareness of digester health is key to preventing upsets and achieving optimal biogas production. Many parameters act in concert to influence the health, and in turn affect the efficiency and productivity of the digester. The most important digester health parameters include:

- **Feedstock Mixtures:** A balanced feedstock mixture is essential for optimal biogas production. Co-digestion refers to the process of simultaneously digesting two or more input feedstocks to achieve optimal system operation and maximize biogas yield. While manure-only AD systems typically have stable biology, co-digestion can increase biogas yield and generate tipping fees for some offsite feedstocks. There is significant experience with on-farm AD systems co-digesting to achieve more favourable economics. However, the unregulated introduction of non-agricultural feedstock can be detrimental to both this biology and biogas yields. (CH-Four Biogas Inc., 2010) For example, high fat or protein feedstocks can have a high energy yield, but they can also make the system susceptible to digester upsets by creating fat toxicity or high ammonia toxicity, both of which do not appear in normal process control procedures and result in low gas production.
- **Process Monitoring:** Monitoring process control parameters such as biogas concentration and volatile fatty acid to alkalinity ratios should increase system control and operating efficiency. Periodic monitoring of the process' key parameters is recommended for resolution of digester upsets and prevention of system failure. (Labatut and Gooch, 2012)
- **Foaming:** Foaming issues are often caused by a build-up of fats in the digester. Fats at a high pH can create a saponification reaction, i.e. produce soap bubbles that build up in the digester to a level that they produce a reactor upset. Both reactive and preventative measures are needed to manage digester foaming. Commercial additives will reduce foaming for a few days. It is important to ensure the products are silicone-free so they don't form siloxanes that will damage the engine. Preventative measures involve ensuring the nutrient balancing of the system and avoiding fat build up.

- **Micro-nutrients and additives:** Biogas plant performance and gas production can be improved by stimulating the microbial activities using various biological and chemical additives under different operating conditions. Additives can provide the ideal nutrient conditions for microbes, and the optimal concentration depends on the biological ecosystem and requires close observation. (Prasad et al., 2017) Some digesters can benefit from adding micro-nutrients, but not all digesters need these additives. For example, digesters that do not have a well-rounded nutrient profile, such as receiving off-farm material that is mostly fats, can increase their biogas production by adding micro-nutrients to balance the system. As another example, receiving a load of feedstock that is high in sulfur can upset the digester operation. The high sulfur input will result in high hydrogen sulfide concentrations for a few days, and while the gas concentrations will return back to normal, the system will experience poor operation for a few weeks because the sulfide binds irreversibly with trace elements, affecting their bioavailability. Adding chelated micro-nutrients can help to stabilize the system.

New technologies and processes

Technological progress, in a wide range of areas, can further improve biogas, and most importantly, methane yields. Some examples include:

- Microwave Enhanced Advanced Oxidation Process (MW-AOP)

Boost Environmental Systems Inc., a University of British Columbia (UBC) spin-off has exclusive licencing rights to the patented microwave enhanced oxidation process (MW-AOP) developed at the University. The MW-AOP process can break down solids and release nutrients from the liquid fraction of dairy manure, making the resulting solution suitable for production and recovery of struvite (magnesium ammonium phosphate), a slow release fertilizer. The breakdown of manure particulates also results in readily biodegradable products in the form of volatile fatty acids suitable for high-rate methane production via anaerobic digestion. Using the MW-AOP treated feedstock, an advanced anaerobic digester can be created that has a high rate of methane production. Consequently, the digester footprint can be substantially reduced to less than a third of a conventional anaerobic digester.

- Adding Biochar to Increase Biogas Production

New research by Texas A&M AgriLife Research scientists shows that biochar addition has the potential to make anaerobic digestion of animal manure more efficient. The researchers note that adding biochar to digesters decreased the lag phase, which is the time that elapses before production starts, and cut the biogas production time in half each time they added more biochar. Reducing the retention time and footprint of the digesters would mean lower initial investment cost, water consumption, utility costs, operating costs, and land requirements. (Jang et al, 2017)

- Conversion of Food Waste into Biogas in a Cold Environment

In a study published in Process Safety and Environmental Protection, researchers from Concordia University's Department of Building, Civil, and Environmental Engineering demonstrated the viability of using anaerobic digestion in a low-temperature (20°C) environment to convert solid food waste into renewable energy and organic fertilizer. The researchers employed psychrophilic bacteria - which thrive in relatively low temperatures - to break down food waste in a specially designed bioreactor. In doing so, they produced a specific methane yield comparable to that of more energy-intensive anaerobic digestion processes. (Rajagopal et al. 2017)

- Low Temperature Anaerobic Digestion Systems

Bio-terre Systems (bioterre.com) originally developed their anaerobic treatment technology at AAFC as a technology that could operate in colder climates in North America. Compared with higher temperature systems, the Bio-terre system is more stable and requires less energy. Several livestock operations have installed these facilities.

- Small-scale biogas systems

Recently, small scale, manure only digesters have been introduced in Canada. These could be suitable for the 12,000 to 15,000 small scale dairy farms across the country. These operations could use the system as an onsite energy system with the additional benefits of GHG reduction, bedding supply and pathogen destruction. In Ontario, these small-scale systems now rely on a net metered or islanded installation since the FIT and MicroFIT programs have concluded.

The value proposition of these small-scale systems includes:

- The use of combined heat and power (CHP) generation means the system is operating at a ratio of over 85 % fuel to usable energy, compared to 45% with the conventional method of producing usable heat and power separately.
- Pathogen destruction is very beneficial to the farmer and community.
- The avoidance of fossil fuel use for heating and for electrical supply is the equivalent of taking 200 cars off the road for each 20 kW system installed, according to mini-digester manufacturer Bioelectric.
- The automated system for manure management improves farm productivity and still permits land application of digestate with better nitrogen-to-plant availability than raw manure.

4.3 Biogas End-Uses and Digestate Enhancement

Biogas can be converted directly into heat and power in a combined heat and power (CHP) system. It can also be blended with natural gas in boiler applications, as done at several food processing facilities, or be used within the agriculture industry to dry wet grain for storage or distillers' grains in ethanol plants. The end-use and blending rate will dictate the tolerance for contaminants in the biogas and the type and cost of gas cleaning technology.

More recently, projects have been undertaken to clean biogas to produce renewable natural gas that can be directly injected into a natural gas pipeline. These applications take advantage of the energy storage capability and transportability of RNG, lower the carbon intensity of the natural gas system and provide a way to "future proof" the natural gas supply system.

Generating Electricity and Heat from Biogas

Many biogas facilities that are producing electricity employ efficient combined heat and power (CHP) systems. CHP systems produce electrical and total (electrical and thermal) efficiencies up to 45 percent and 95 percent, respectively. (General Electric, 2018) Thermal energy is released in the combustion process and can be used for preheating, digester heating and providing building heat, for example.

The following CHP technologies can run on biogas. (EPA, 2015) They have technology readiness level (TRL) values of at least 8 and are suited to different sized applications:

- Steam turbines: TRL 10
    - Electrical efficiency of 5-30%
    - Suitable for 50kW to 250 MW
    - Extensive field experience, widely available
- Gas (combustion) turbines: TRL 10, including microturbines: TRL 9
    - Gas turbines are often the technology of choice for electric generation due to their low capital cost, low maintenance and low emissions.
    - Electrical efficiency of 22-36%
    - Suitable for 500 kW to 40 MW, microturbines 30 kW to 250 kW
    - Extensive field experience, widely available
    - Limited models of microturbines available
- Reciprocating internal combustions engines: TRL 10
    - Reciprocating internal combustion engines are a widespread ad well-known technology used for a diverse set of power generation applications including automobiles, construction and mining equipment, and stationary engine products.
    - Technology has improved dramatically over the past three decades, driven by economic and environmental pressures for increased fuel efficiency and reduced emissions.
    - Electrical efficiency of 22-45%
    - Suitable for smaller than 5 MW
    - Extensive field experience, widely available
- Fuel cells: TRL 8-9
    - Fuel systems are an emerging small-scale power generation technology with high electrical efficiency and very low emissions.
    - Electrical efficiency of 30-63%
    - Suitable for smaller than 1 MW
    - Some field experience
    - Undergoing commercial introduction and demonstration
- Stirling engines: TRL 8-9
    - The Stirling engine is a reciprocating engine that is externally heated with the fuel burned in a continuous manner outside of the Stirling engine’s cylinders. The external combustion allows for more complete burning of the fuels, which results in lower emissions, and reduced noise and vibration compared to internal combustion engines.
    - Stirling engines are not commercially available today for stationary power applications.
    - Electrical efficiency of 5-45%
    - Suitable for smaller than 200 kW
    - Limited field experience

    - Undergoing commercial introduction and demonstration

Generating Renewable Natural Gas from Biogas

Biogas can be upgraded into pipeline quality RNG by removing carbon dioxide and various impurities, including hydrogen sulfide (H_2S). Renewable natural gas can substitute for natural gas and be used in similar applications, such as injection into the natural gas network or use as a fuel for heavy duty vehicles and ships. Several different biogas upgrading techniques are on the market today (Hoyer et al. 2016):

- Pressure swing adsorption: TRL 10
    - Dry method used to separate gases via their physical properties
    - Compressed biogas is fed into tan adsorption column which retains the CO_2 and not the methane
    - Hydrogen sulfide and water need to be remove upstream
- Water scrubbing: TRL 10
    - Water is used to separate carbon dioxide from biogas
    - Carbon dioxide is desorbed from the water in and air stripper
    - Compounds such as hydrogen sulfide, ammonia and VOCs are present in the air stripper stream and further processing is required to meet environmental legislation
- Amine scrubbing: TRL 9-10
    - Uses a reagent, typically a water solution of amines, that chemically binds to the CO_2 molecule, removing it from the gas
    - Can handle gas impurities, the CO_2 rich stream may require further processing similar to water scrubbing
    - Lower demand for electricity in this process than other upgrading techniques
    - Needs external heat for regeneration
    - Works at low pressure (100-200 mbar) compared to the other techniques
    - Four major operating issues: failure to meet specifications, foaming, amine loss and corrosion.
- Organic physical scrubbing: TRL 9-10
    - Uses a solvent, mixture of dimethyl ethers and polyethylene glycol, that absorbs the CO_2
    - Process flow and operating resembles waste or amine scrubbing
    - No corrosion as experienced with amine scrubbing because the solvent is anti-corroding
    - Robust technology able to handle various impurities similar to the water scrubber
- Membrane separation: TRL 10
    - Hollow filter membranes separate CO_2 and methane using the fact that the gases have different permeability through the filters
    - Membranes are sensitive to liquid water, oil, and particles
    - Few consumables are used in the membrane upgrading plant
- Cryogenic upgrading: TRL 6-7
    - Biogas is cooled under pressure and CO_2 is turned into a liquid state while methane remains in a gaseous state
    - Requires elevated pressure
    - Not used commercially for biogas upgrading in any large scale

Generating and Using Carbon Dioxide from Biogas

Carbon dioxide (CO_2) is the second largest constituent of biogas, accounting for 30-50% of the total volume. The production of RNG results in the separation of CO_2, and exhaust CO_2 is also produced from the biogas system engines. In addition to CO_2 fertilization in greenhouses, the agriculture and agri-food sector has a number of uses for CO_2 including industrial uses in the beverage industry, and emerging applications such as serving as a feedstock for algae production. As an example, Blue Ocean Nutrasciences has patented a CO_2 gas infusion technology that can significantly increase plant growth. CO_2 foliar spray trials are being conducted in Ontario, and connecting this project to a biogas plant is considered as a next step. (Kanes, 2018)

Deriving value from the CO_2 would help to improve the overall economics of an AD system, but it could increase system complexity.

More recently, CO_2 methanation projects have emerged in which CO_2 in biogas is reacted with renewably-derived hydrogen to form CH_4, thereby significantly increasing the production of methane from an AD facility. This additional CH_4 is also referred to as an "electro fuel" or egas. For example, at the biogas plant in Werlte, Germany, an electrohydrolysis unit uses excess electricity from wind energy to convert CO_2 from biogas into methane. The process, referred to as Power-to-gas (P2G or PtG), produces more storable renewable energy, and is a way to capture excess wind power. (Beez, 2018) The project information is outlined in the chart below.

	
Commissioned in	2002, 2012 (egas portion)
Capacity (gas/electricity)	900 m^3/h (raw w 65%CH_4) /600 kW (most fed into gas grid)
Commercial Products	Biogas, biomethane, electricity, heat, CO_2, fertilizer
Feedstocks	Food waste, slaughterhouse, water treatment plant sludge (all material is pumpable). Feedstocks are stored in separate tanks (high energy value in one, lower energy value in another) to allow mixing of optimal digestion feedstock.
Utilization	internal
Notes	Biogas upgraded to biomethane (via amine scrubbing) and fed into national gas grid. Waste CO_2 from biogas cleaning process is used as raw material in co-sited electrohydrolysis plant, which converts excess electricity from wind plants and CO_2 into additional CH_4. Waste heat from CHP is used in gas cleaning and upgrading process. O_2 produced is vented. Cost of €8.4million. Digestate is all land applied within a ~25km radius. Digestate is stored both onsite and at farms where it is applied.

Biogas and Renewable Natural Gas in Transportation

The use of upgraded biogas as a transportation fuel has been successfully tested in a number of applications, including dairy operations. In early 2018, the Province of Ontario announced a new demonstration pilot program called Agrifood Renewable Natural Gas for Transportation. This program is intended to support the demonstration of business models for the production and use of RNG using agricultural and food waste based materials for use as a transportation fuel.

Potential Applications for biogas and RNG as transportation fuels include:

- Compressed Renewable Natural Gas as a Transportation Fuel: TRL 10

A recent study released by Energy Vision and the U.S. Department of Energy's Argonne National Laboratory evaluated a dairy cooperative in Indiana, with 36,000 cows, that converted its cow manure into compressed RNG that it uses to fuel 42 heavy-duty milk tanker trucks. The fleet uses 9-liter Cummins Westport ISL G engines rated at 320 horsepower, and a fuel storage capacity of 130 DGSs via two back of cab and two saddle tanks.

The resulting reduction in lifecycle GHG emissions is 80% or more compared to gasoline or diesel fuel. The use of manure-derived compressed RNG not only reduced the fueling cost of the fleet, it also generated additional revenue through the sale of environmental credits through the U.S. Environmental Protection Agency. (Argonne National Laboratory, 2017)

- Bi-Fuel and Dual Fuel Vehicles: TRL 8-9

Bi-fuel vehicles can run on gasoline and diesel, and operate on compressed RNG when it is available. A Bi-fuel conversion allows the vehicle to start on gasoline or diesel and then switch to running on RNG when the engine reached a certain temperature. Dual fuel vehicles allow a vehicle to run on a RNG/diesel bench (e.g. 90% RNG, 10% diesel) using a modified diesel engine. These systems have been demonstrated at farm-based biogas systems. (OMAFRA, 2015)

- Bio-methanol for Transportation: TRL 4-5

Methanol is being increasingly investigated as a clean-burning transportation fuel. The application of methanol in the transport sector has risen from 4% of global production in 2005 to 23% in 2010. Biogas can replace natural gas in current methanol production process, although the biogas-to-methanol route has not yet been commercialized. While the production process is largely similar, some technical changes are needed because biogas typically contains a larger share of CO_2 than natural gas. (IRENA, 2013)

Biogas to Chemicals (non-Fuel Applications)

- Bio-methanol in Biodiesel Production and Chemical Manufacturing: TRL 4-5

Methanol is an important basic chemical, typically produced from fossil fuels such as natural gas, coal and oil products. Methanol is used in the production of biodiesel and other chemicals in Canada. Biogas-derived methanol would reduce the carbon footprint of these fuel and chemical products.

- Renewable Hydrogen from Biogas in Petroleum Refining: TRL 5-6

The Ottawa-based company Iogen has developed a technology where petroleum refineries can incorporate biogas-derived renewable hydrogen as "renewable content" in conventional gasoline and diesel fuels. (Iogen, 2018) This in turn reduces the respective carbon intensity values of the fuels produced from such a refinery. Renewable hydrogen could be used in other applications, such as ammonia production, reducing the carbon intensity of synthetic fertilizers, for example.

- Microbial conversion of Methane

The methane in biogas can also be converted biologically, via methanotrophs, into biochemicals such as carotenoids, isoprene, 1,4 butanediol, farnesene, lactic acid, isobutanol and 2,3 butanediol, and intermediate microbial liquids that can be converted into renewable diesel. Unibio and Calysta are two companies that produce concentrated protein products for animal and fish feed using methanotrophs. With the abundance of natural gas, the bioengineering of methanotrophs is receiving significant attention. All sources of methane, including biogas, could potentially benefit from these scientific advances to produce higher value products.

Digestate Enhancement

Assigning a financial value to the digestate, its nutrient components and its other attributes, such as odour reduction or pathogen destruction, is very often missing in the typical anaerobic digestion business case. Finding ways to fully valorize digestate and create markets for all of its attributes could improve the profitability of AD systems.

Land spreading of digestate is generally considered to be a good use of the nutrients that are contained in the manure and other digester feedstocks. The AD process converts the nutrients into a more readily available form, and digestate application releases fewer undesirable air emissions, when compared with manure. Unlike manure and compost where nutrients are tied up in organic matter and have less predictable release rates, digestate nutrients are better separated from the organic matter and more closely aligned to chemical fertilizer.

However, as with manure application, the opportunities for digestate application can be limited by the amount of land within a local area that is available to accept these nutrients. That is, in some parts of the country, the soil and adjacent water bodies already have high nitrogen and phosphorus concentrations so digestate would have to be applied to a larger area, incurring higher transport costs. Also, digestate generally does not have the same nutrient content as synthetic fertilizer, or relative concentrations. For example, digestate has a higher phosphorus to nitrogen ratio than what is required by a corn silage crop, meaning that application to meet crop nitrogen requirements would result in an over application of phosphorus. The specific soil type, location, crop needs and nutrient management regulations will dictate where digestate application can provide the most benefits, and the associated transport costs.

As with biogas, digestate can be "upgraded" by separating out its solids and/or nutrients. In one study, Hallbar (2017b) estimated the following revenues for the separated components of digestate: $30/tonne for bedding, $10/tonne for nutrient rich cake and $400/tonne for ammonium sulphate. While they could be considered as optimistic values, they provide useful starting points for analysis. Digestate enhancement techniques can be employed to increase the value of the digestate, create new markets for digestate products, reduce dependence on land application, ensure more secure and sustainable outlets for digestate products, and potentially reduce the operating cost of the facility.

Depending on local site conditions and requirements, the treatment process can vary considerably, and the available outlet must be considered along with demand for digestate products.

There are numerous physical, thermal, biological and chemical post-digestion enhancement techniques available today (WRAP, 2012). Some examples are:

- Physical: Used to separate the solid and liquid fractions of the digestate
    - Thickening: Belt, centrifuge
    - Dewatering: Belt press, centrifuge, hydrocell, bucher press, electrokintetics
    - Purification: Ultrafiltration and reverse osmosis
- Thermal: Uses thermal energy to either remove water from the digestate to increase solids and nutrient concentration or to recover energy from the digestate
    - Drying: Rotary drying, belt drier, solar
    - Evaporation: scraped surface heat exchangers
    - Conversion: incineration, gasification, wet air oxidation, pyrolysis
        - TRL 7: A Canadian company, CHAR Technologies, has developed a technology that transforms solid digestate into biochar using pyrolysis. The biochar, called SulfaCHAR is used to remove corrosive hydrogen sulfide from biogas prior to combustion using the same configuration as an activated carbon filter. The adsorbed hydrogen sulfide is converted into a beneficial form of sulfur and the used SulfaCHAR can be applied to fields as a fertilizer. (Zhang et al., 2016) CHAR Technologies currently has a demonstration system at University of Guelph – Ridgetown anaerobic digester.
- Biological: Uses naturally occurring micro-organisms to convert organic matter within the digestate to reduce organic load or produce novel products such as biofuels
    - Composting
    - Reed beds
    - Biological oxidation
    - Biofuel production: Algae, hydrolysis of fibre to bioethanol
- Chemical: Utilise chemical reactions to recover nutrient from the digestate or modify its properties
    - Struvite precipitation
    - Ammonia recovery: stripping and scrubbing, membrane contactor, ion exchange
    - Acidification
    - Alkaline stabilisation

Digestate Enhancement Example – Trident Nutrient Recovery Technology: TRL 9-10

A nutrient recovery system offered by Trident enhances digestate at Seabreeze Farm in Delta, British Columbia. The automated system has been in operation for more than two years. The treatment process includes:

- Rotary screen conditioner that conditions and extracts the fibre
- Screw press recovers fiber for reuse and bedding
- Dissolved Air Flotation (DAF) tank coagulates the solids creating effluent sludge with NPK (nitrogen, phosphorous, and potassium) nutrients
- A press processes the sludge into a nutrient rich cake that is easy to land apply, transport, and store or ready for granulation. (Trident, 2017)

In their evaluation of Nutrient Recovery Technologies (NRTs) for dairy manure and digestate, Hallbar Consultants found that centrifuges were a good fit for most B.C. dairy farms that have, on average, 140 milking cows. If many off-farm feedstocks were mixed with the manure, then other technologies such as membranes and flocculation should be considered. However, the study found that none of the nutrient recovery technologies would be economically feasible for single dairy farm operations in BC. A mobile NRT facility that could be shared by several farms might be a more viable option as a system twice the size is much less than twice the price.

At the time of this writing (February 2018), Foresight Cleantech Accelerator Centre and BC Bioenergy Network (BCBN) are searching for new value-added digestate treatment technologies. They announced an ARCTIC Innovation Challenge to find technologies that will convert the by-products associated with producing RNG into commercially viable products, such as organic fertilizer, to improve the RNG business case. (Stanners, 2017) The technologies eligible for consideration in the ARCTIC Challenge include Nutrient Recovery Technologies (NRT), which can extract the nutrients from digestate, as well as those that can convert the nutrient by-products into a marketable end-product (e.g., improve the ability to transport the product at lower cost).

4.4 Carbon Credits

Government commitments to reduce GHG emissions, clean technology programs and the pricing of carbon emissions are intended to create a signal and provide a financial value to making GHG emission reductions. Anaerobic digestion of manure and waste materials, and use of the biogas and digestate to substitute for fossil fuels or synthetic chemicals, can be a lower GHG emitting alternative than landfilling or land application. Organizations, such as the California Air Resources Board, assign large reduction credits to the displacement of fossil fuels by biogas. As an example of the order of magnitude, the use of biogas from manure and co-digestion for CHP could reduce the GHG emissions between 129% and 286% over a natural gas CHP system. (Offsetters, 2011)

This additional revenue stream has the potential to improve the financial viability of biogas systems. The net GHG benefit will depend on factors such as the GHG accounting protocol, the baseline emissions associated with conventional feedstock disposal, the value of the carbon credit, and the cost of credit verification.

5.0 Challenges Facing Agricultural Biogas and RNG Development

Biogas and RNG producers converting agriculture and agri-food-based feedstocks have faced numerous financial, regulatory, operational, and technical challenges. Some of the challenges described below were identified during the interviews with facility operators, while others are issues that are known to the Canadian Biogas Association based on previous feedback from biogas operators and system developers.

The primary challenge is economic. This is a universal challenge that is not only experienced in Canada which historically has had low energy prices, but is also experiencedin other countries that have very ambitious renewable energy goals and tight restrictions on the use of landfills. If waste treatment is not required, the facility does not have a high energy demand, fossil fuel energy prices are low and there is no price on carbon, it is very difficult for an ADsystem to become profitable in a short period of time. This is particularly so for smaller livestock farms with a low energy demand. To date, on-farm biogas facilities in Canada have required their electricity production to be sold for a significant premium in a long term contract in order to raise the capital investment and break even or become profitable in an acceptable number of years.

In 2008, Geomatrix listed the following as factors that would influence the economics of an AD facility in the food processing industry:

- Capital cost of the AD system;
- Operating cost of the AD systems;
- Interest rates;
- Market value of natural gas;
- Market value of electricity;
- Cost of fuel for transporting residues to digester;
- Storage costs for digestate;
- Costs for fuel to transport digestate to agricultural land;
- Availability of land for utilizing digestate;
- Availability of alternative uses for digestate;
- Ability to economically process digestate into other value added products;
- Tipping fees that the food industry can bear;
- Demand for food processing residues for biogas production;
- Demand for food processing residues for animal food production;
- Value of food processing residues for animal food production; and
- Energy potential of residues.

Today, the market value of digestate products and the price of carbon could be added to this list.

The agri-food industry differs from the agriculture or farm community in the following ways: it has a larger, more concentrated feedstock supply; there is a regulatory requirement to treat process effluents and solid wastes; and it has a substantial process energy requirementthat is typically met through purchased energy. The challenges described below are particularly relevant to the agriculture/on-farm biogas systems.

Raising Investment

In a 2017 study, Viresco Solutions reported that the chief hurdle to AD facility development – on a global scale - is financing and costs, both capital and operating costs, when compared to conventional fossil fuel industries. The availability of capital investment and the economic feasibility of a project are often related to energy policy, regulation and related markets. The lack of economic value assigned to environmental benefits and non-energy products of anaerobic digestion does not allow biogas operators to achieve the full economic potential of their operation. To date, renewable energy policies have focused on electricity production and liquid biofuels, providing little incentive for renewable heat and renewable gases.

Raising investment can be very difficult without a guaranteed revenue stream, especially in jurisdictions without power purchase agreements that have to operate in a context of fluctuating electricity prices. One respondent stated that a net metering contract is not considered sufficient for banks to extend a loan.

Economics of Small Scale Operations

While smaller operations have to raise less capital, they do not benefit from economies of scale. It is a more difficult business case for them to make. The relatively high capital cost of AD systems makes it difficult for smaller-sized farms, unless they are able to make a contract for a stable supply of suitable off-site organic material where the supplier of the waste material is willing to pay tipping fees for its disposal. (BioNB, 2017)

Regulatory Pathways and Approvals

In some provinces, the uncoordinated and lengthy regulatory pathway has discouraged new development, added to investor uncertainty, and unnecessarily increased budgets for the development of projects. The multi-faceted aspect of AD systems to provide agricultural, environmental and energy-related benefits has proven to complicate action and delay the approval process. Project developers have identified the need for governments to better coordinate leadership and drive a common biogas agenda.

Three provinces – Alberta, Manitoba, and Quebec - provided specific examples of these challenges.

In the case of Alberta, TEC Edmonton reported that the regulatory process to establish a new biogas facility in Alberta involves four different government departments – municipal/county and 3 provincial departments: Alberta Agriculture and Forestry, Alberta Environment and Parks, and Alberta Energy. Based on discussions with the biogas industry, the "regulatory process from start to issuance of the required permits (4 in total) will take a minimum of three years, up to seven or eight years." Developing a biogas facility in Alberta is not a straightforward process. There is no clear pathway for developers to follow regarding the permitting process for biogas projects and proponents have to deal with multiple agencies that operate on different timelines. (TEC Edmonton, 2015)

In Manitoba, biogas project proponents must comply with additional regulations that are not required in other provinces. The challenges encountered with the Sweetridge Farms project and impacts on the project success were articulated by Manitoba Hydro in its report[6] to Natural Resources Canada:

> "Construction and commissioning of the PlanET system at Sweetridge Farms faced significant regulatory barriers. Strict application of the CSA B149.6 Code for Digester and Landfill Gas, requirements for biogas flares, modifications to accommodate manure, and mortalities regulations, along with a lack of capacity of equipment suppliers to provide engineering support in order to address regulatory issues, increased the cost and complexity of the project. Major changes to the design of the system were therefore required, which lead to a delay in the construction and commissioning of the system."

In the end, this project was constructed but the facility was never operated as it was too expensive to run due to overdesign that was required to meet provincial regulations.

Similarly, in Quebec, waiting 18 months to obtain regulatory approvals was cited as the reason three projects did not proceed. The investors could not wait any longer.

In some jurisdictions, proponents found they spent a considerable amount of time building the regulators' understanding of the technology, of on-farm businesses, etc.

Feedstock Supply

The low operating capacities of AD systems are most often caused by a problem with feedstock supply quality or quantities, or poor feedstock management by the system operator. (CH-Four Biogas Inc., 2010)

Agricultural biogas facilities process farm waste and require off-farm feedstocks to increase biogas production. Consistent off-farm feedstock supply is a challenge and an initial concern and consideration for operators. This has led some farmers to explore the use of crop residues or perennials such as switchgrass or miscanthus to provide a more secure feedstock supply. In addition to quantity, feedstock needs to be of a certain quality and free of stones. Agricultural facilities that accept off-farm feedstocks have dealt with contamination issues such as plastics, and some have implemented quality assurance programs to ensure the feedstock quality of offsite organics. Contaminants can build up in the digester, requiring maintenance and resulting in downtime.

Also feedstock storage, particularly of off-site materials, can be the main source of odour issues from the AD systems..

Connections to the Grid and Gas Network

Most of the on-farm biogas facilities included in this study are connected to the grid to sell electricity or to a natural gas pipeline. Operators noted that the process for interconnection was quite extensive and foundthere to be too many requirements for small systems. Grid connection, whether to electricity or

[6] Source: https://www.nrcan.gc.ca/energy/funding/current-funding-programs/cef/4959#a4

gas pipeline, will vary depending on the distance to the grid, and the capacity and constraints on the grid.

Historically in Ontario, grid connection for electricity was difficult and the cost to do so varied significantly. Improvements have been made over time. For example, one facility in Ontario had to delay its operation by two years due to capacity issues with the electricity grid. The utility had brought on a higher than anticipated load of renewable energy and needed to halt connections to build more capacity into the grid. Consequently, the timeline for the facility was pushed back two years, impacting the date when the facility could begin producing and selling electricity.

TEC Edmonton (2015) reported that the Alberta Electric System Operator has a seven-stage process for getting connected to the Alberta Interconnected Electric System, which consists al all energy transmission facilities and distribution systems in the Province. According to this 2015 report, it takes approximately 96 weeks (1 year and 10 months) to navigate through this process.

Operator Training and Technical Support

Operator training was not identified as a specific hurdle to development in the interviews. However, maintaining good digester health is known to be an ongoing challenge for biogas systems. Ideally, operators should be invested in ensuring the process is stable, and determining which feed mixtures and rates result in the best biogas production. They should seek to avoid operational upsets which result in downtime and low biogas production. This requires dedicated and trained operators, that can be challenging for smaller farms.

Lack of operational efficiency can result in significant lost revenue. For instance, for a 500 kW biogas system receiving $0.16/kWh, a 10% efficiency reduction (e.g. the equivalent loss of approximately 800 hours per year of production) could result in $64,000 of missed revenue.

Many operators reported a hurdle being unexpected maintenance, or that their equipment degraded sooner than projected. This resulted in unplanned downtime and costs for repairs.

When reflecting on their systems, operators have reported the desire to have easier, local access to technical support and service providers. It can be difficult to get replacement parts and maintenance that are cost competitive. Also, there is some loss in efficiency when new equipment is installed as there is a learning curve.

One respondent remarked that the small size and lack of sufficient experienced staff of renewable energy firms was an impediment to finding efficient design solutions. Unlike large engineering firms where there is an extensive pool of expertise to draw on, small renewable energy firms can be challenged to come up with solutions. However, as interest in clean energy has risen in recent years, this situation could be improving.

Community Resistance

Some projects have experienced community resistance, particularly when they are located closer to more populated areas. Concerns about odours, transport, waste handling, pollution, safety, emissions and pathogen risks can impact the permitting process during project development. (Alcock et al., 2017)

One example from southern Ontario was the community's opposition to build a biogas facility for Bick's Pickle operation in Norfolk County. While project proponents are expected to consult with affected municipalities, only provincial approval is needed for a green energy project. In this case, local residents protested by putting up hand-made signs on their property. Their concerns included odour, depreciated property values, potential impacts on Big Creek and ground water, and potential health impacts for their children.

In 2006/2007, the proposed biogas facility in Lethbridge also met with community opposition. The 3.2 MW co-gen plant was to use biogas derived from agricultural waste products (manures, food processing waste, and animal by-products). The Alberta Energy and Utilities Board initiated an Alternative Dispute Resolution process that addressed the main issue of location and interveners' concerns related to increased traffic, odours, and water and air pollution.

Land Application of digestate

Digestate management, in particular land application of digestate on farmland, has been a challenge for getting projects off the ground in certain provinces. Most of the concern relates to nutrient management and the potential for nutrient overloading, for example, resulting from the import of off-farm organics. All provinces now require the approval a nutrient management plan. As organic waste diversion policies continue to grow, pressure for farms to co-digest off-farm materials could increase. This will require careful controls to avoid introducing new contaminants to farmland.

6.0 Conditions to Support Growth

Conventional anaerobic digestion and biogas to power systems use proven technologies. There are interesting emerging technologies that could further develop the industry, increase the financial viability of AD systems, and contribute to a more circular economy. Degradable feedstocks are available, within the agriculture, agri-food sector and municipalities, to develop more biogas facilities. The industry continues to struggle with poor economics, and needs new business models that monetize all of its products and provide a better return on capital. Industry growth will increase the production of renewable energy, improve waste and nutrient management, reduce GHG emissions and foster a circular economy.

Multiple government agencies, biogas operators, equipment suppliers and industry associations were contacted as part of the study. Obtaining specific information on biogas facilities operating in the agriculture and agri-food sector proved to be very challenging. Good information was collected from the Provinces of Ontario, Alberta and British Columbia, where the industry is most developed. Having this baseline information is critical to assess its true potential and justify further industry investment and support. There is a need to continue to gather and update information on the biogas facilities across the country, including facility contacts, feedstock consumption, actual biogas and power production, details on digestate handling, and data needed to determine GHG impacts. An industry-government biogas working group could be considered to collectively address the data gaps.

Considering how the industry evolved to where it is today, and learning from stakeholders in the industry, the following recommendations can be made on the conditions to support growth the sector:

Established Markets to Provide Financial Stability and Drive Investment

For Canada to benefit from biogas, a multi-faceted solution that directly reduces methane emissions, the economics need to make sense and the financial viability of projects needs to be certain, paired with an established market that creates a demand for low carbon intensity fuel.

A policy or mechanism to ensure long-term guaranteed off-take and pricing for RNG and electricity from biogas ensures sufficient and reliable revenue to justify investments and is required to accelerate project development and achieve near-term GHG reductions. A sustainable, long-term energy price offers a level of certainty that will accelerate access to investors and financing required to build projects. Successful operating plants already rely on predictable revenue from PPAs, however the opportunity to enter into PPAs currently does not or no longer exists in many provinces.

Markets for renewable heat, renewable gases, digestate and its components, digester solids and nutrients, and the valuation of all environmental benefits (e.g. reduced water pollution) could complement such a policy.

Policy and Programs

Supportive government policy has resulted in the build-out of agricultural and agri-food biogas facilities. These policies recognized environmental benefits and focused on increasing the shared value of renewable energy and reducing GHG emissions. Given the cross-sectoral nature of biogas systems, they are generally jointly developed by departments responsible for environment, energy, agriculture and industry.

Canada has set ambitious GHG reduction targets both on the provincial and federal level, however specific support would serve to further develop the biogas industry, including:

- Long-term policies and programs to support this vision and the business case for each plant;
- Clarity on accounting for biogas GHG emissions reductions;
- A regulatory environment that facilitates biogas development with clearly defined requirements;
- Strong leadership on the biogas file from all levels of government, especially environment and agricultural departments;
- Policies focused on GHG reductions that recognize biogas such as: renewable content requirements, renewable fuel standards that include gaseous fuels, carbon pricing, and renewable energy premiums; and
- Innovation funding and support.

Agriculture and agri-food biogas and RNG facilities would benefit from the ability to monetize environmental benefits from AD facility operation, including methane capture, offsetting fossil fuel use, and lowering the carbon intensity of fuels. Eligibility to generate and sell credits under the Clean Fuel Standard, provincial fuel standards, and cap and trade as policies and regulations are implemented would also support growth.

Support Organics Diversion and Value-added End Products

Consistent quantity and quality of digestible feedstock is essential for every AD system, and lack of access can be a challenge to development and successful operation. Moving towards a circular economy and encouraging the diversion of organics from landfills to beneficial uses such as AD will support growth in the industry and generate new revenue streams through tipping fees and value-added end products such as soil amendments.

Tipping fees need to be sufficiently high to discourage landfilling and make AD more financially attractive. With respect to digestate or its solid or nutrient constituents, they need to be developed into marketable products with known characteristics, and which have proven environmental benefits.

Technical Support and Education

Findings from this study have indicated that having access to technical support and expertise can be a challenge for smaller facilities, leading to lower operating efficiencies and less methane production. This underlines the importance of supporting education and outreach in the sector to build the collective knowledge base and supportive services to ensure optimal operation of AD systems for increased renewable energy production and GHG emissions reductions.

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http://www.biogas-info.co.uk/about/incentives/

8.0 Appendices

Appendix A – Questions on Anaerobic Digestion Facility Operations

Facility Information

- Facility Name/Business Name:
- Location (Town/County; GPS coordinates)
- Project subsector: (livestock, Greenhouse operations, rendering, food processing, other)

Feedstock (for latest calendar year – 2017 or 2016)

- Feedstock type (Manure/FOG/Pet food/Local Glycerin/Crop Waste)
- Amount of each feedstock type (tonnes/year)
- Moisture content "as is/green" or dry
- Feedstock pretreatment (hydrolysis, pasteurization, other)

System information

- Type of operating approval (NMA, ECA, REA, or other provincial approvals)
- Nameplate Capacity (kWh)
- Digester Volume (m^3)
- Digester Type (complete mix, etc.)
- Recorded runtime during the last 6 months (e.g. 24 hours/day, 7 days/week)
- % of FIT Contract Fulfilled (Ontario)
- Average biogas production (m^3/hour - STP) ; *conversion to annual units assumed 8,000 operational hours per year*
- Biogas Quality (v/v %CH_4)
- Biogas Quality (v/v %CO_2)
- Biogas Quality (v/v %H_2S)

End Products

- Biogas End-Use (electricity, heat, RNG, other)
- Heat application (Y/N)
- Energy Market (who buys the electricity/RNG)
- Do you have market access? (Y/N)
- Do you have a defined power purchase agreement? (Y/N)
- Digestate (tonnes/year)
- Digestate quality (% solids)
- Do you separate solids from the digestate? (Y/N)
- Digestate end-use (Land application, bedding, etc.)
- Regulatory regime the digestate is managed (CFIA, nutrient management)

Facility Economics (confidential, information will be aggregated)

- What are your sources of revenue, in addition to gas and power sales? (e.g. charge tipping fee, renewable energy premium, carbon credit, etc.)
- Have your expenditures matched your projections? Scale 1-5, 1 being much more than projections, 3 being matched projections, and 5 being much less than projections
- On a scale of 1 to 5, how profitable is your AD Facility? Scale 1-5, 1 being operating at a loss, and 5 being very profitable
- Have there been any unanticipated additional expenses (e.g. added scrubbers, etc.)

Operational Issues

- Have you experienced any operational issues? E.g. raising investment, consistent feedstock supply etc.

Additional Notes

- Are you considering new feedstocks (e.g. corn silage, miscanthus, fish oil, etc.,)
- What is your proximity to natural gas pipeline?
- Are you considering RNG?
- Are you participating in carbon market? Selling offsets?
- Have you made significant modifications to your biogas system since it first began operation?
- If you were to build again, is there anything you would have done differently?

Appendix B – Project Contributors

The Canadian Biogas Association wishes to thank the AAFC Bioeconomy Policy project lead, Maria Wellisch, the FTP Bioproducts Working Group and the CBA Advisory Committee who assisted in the development and review of this study. We appreciate the AD facility operators from across Canada who contributed verified system information for the database and provided real-world insight for the study.

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Appendix C – Summary of Survey Results

The tables in this section contain aggregated data from the interviews conducted by the Canadian Biogas Association from December 2017 to February 2018.

Table C-1. Current Status of Operational Biogas Facilities in Canada's Agriculture and Agri-Food Sector (Jan 2018)

Province	Biodigesters/ AD facilities	Electricity Capacity (kW)	RNG Production (GJ/year)	Biogas Production* (m^3/year)
British Columbia	2	N/A	130,000	6,200,000
Alberta	7	3,483 (2 facilities)	N/A	16,400,000 (2 facilities)
Saskatchewan	0	N/A	N/A	N/A
Manitoba	2	No data	N/A	2,184,000
Ontario	39	17,062 (34 facilities)	N/A	27,680,000 (12 facilities)
Quebec	6	1,926 (5 facilities)	N/A	132,000 (3 facilities)
New Brunswick	1	2,000	N/A	8,000,000
Prince Edward Island	1	12.6 MW *(thermal)*	N/A	18,768,000
Nova Scotia	2	800	N/A	664,000 (1 facility)
Newfoundland	1	No data	N/A	No data
Total	61	24,771 (44 facilities) + 12,600 thermal	130,000 (2 facilities)	80,028,000 (23 facilities)

- Assuming 8,000 operational hours

Tables C-2 through C-5 summarize the number of biogas facilities, the total electricity capacity, RNG production, and biogas production (assuming 8,000 operational hours annually) by province for four subsectors: 1) livestock industry; 2) food processing: 3) greenhouse industry; and 4) other off-farm biogas facilities that process agricultural or agri-food materials.

Table C-2. Current Status of Operational Biogas Facilities in the Livestock Subsector (Jan 2018)

Province	Number of facilities	Electricity Capacity (kW)	RNG Production (GJ/year)	Biogas Production (m^3/year)
British Columbia	1	N/A	40,000	1,600,000
Alberta	0	N/A	N/A	N/A
Saskatchewan	0	N/A	N/A	N/A
Manitoba	0	N/A	N/A	N/A
Ontario	28	10,690 (28 facilities)	N/A	11,360,000 (7 facilities)
Quebec	0	N/A	N/A	N/A
Newfoundland	1	No data	N/A	No data
Nova Scotia	2	800	N/A	664,000 (1 facility)
Total	32	11,490	40,000	13,624,000 (9 facilities)

Table C-3. Current Status of Known Biogas Facilities in the Food Processing Sector (Jan 2018)

Province	Number of facilities	Electricity Capacity (kW)	RNG Production (GJ/year)	Biogas Production (m^3/year)
British Columbia	0	N/A	N/A	N/A
Alberta	5	No data	N/A	No data
Saskatchewan	0	N/A	N/A	N/A
Manitoba	2	N/A	N/A	2,184,000 (1 facility)
Ontario	5	No data	N/A	320,000 (1 facility)
Quebec	6	1,926 (5 facilities)	N/A	132,000 (3 facilities)
New Brunswick	1	2,000	N/A	8,000,000
Prince Edward Island	1	12,600 *(thermal capacity)*	N/A	18,768,000
Nova Scotia	0	N/A	N/A	N/A
Newfoundland	0	N/A	N/A	N/A
Total	20	3,926 + 12,600 *(thermal)*	N/A	29,404,000 (7 facilities)

Table C-4. Current Status of Operational Biogas Facilities in the Greenhouse Subsector (Jan 2018)

Province	Number of facilities	Electricity Capacity (kW)	RNG Production (GJ/year)	Biogas Production (m^3/year)
British Columbia	0	N/A	N/A	N/A
Alberta	0	N/A	N/A	N/A
Saskatchewan	0	N/A	N/A	N/A
Manitoba	0	N/A	N/A	N/A
Ontario	3	2,270	N/A	6,640,000 (2 facilities)
Quebec	0	N/A	N/A	N/A
Atlantic Canada	0	N/A	N/A	N/A
Total	3	2,270	N/A	6,640,000 (2 facilities)

Table C-5. Current Status of Operational Biogas Facilities that accept agricultural and agri-food waste ("Other" Subsector, Jan 2018)

Province	Number of facilities	Electricity Capacity (kW)	RNG Production (GJ/year)	Biogas Production (m^3/year)
British Columbia	1	N/A	90,000	4,600,000
Alberta	2	3,483	N/A	16,400,000
Saskatchewan	0	N/A	N/A	N/A
Manitoba	0	N/A	N/A	N/A
Ontario	3	4,102	N/A	9,360,000 (2 facilities)
Quebec	0	N/A	N/A	N/A
Atlantic Canada	0	N/A	N/A	N/A
Total	6	7,585	90,000	30,360,000 (5 facilities)