Best Practices for Reducing Costs of Anaerobic Digestion of Organic Waste and Increasing the Valorization of Biogas and Digestate

March 2022

BIOGAS WORLD

CONNECTING THE BIOGAS INDUSTRY

DISCLAMER NOTICE

This report has been prepared for and funded by Environment and Climate Change Canada (ECCC).

The content of this report is based on information gathered in good faith from both primary and secondary sources and is believed to be correct. BiogasWorld has taken all reasonable care to ensure that the information presented in this report is fair and accurate. Considering that this report is based on the information provided by different industry stakeholders, BiogasWorld cannot guarantee its accuracy. Any decisions made based upon any information contained in this document are the sole responsibility of the reader.

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EXECUTIVE SUMMARY

The main target of the current report prepared for Environment and Climate Change Canada (ECCC) was to research the best practices for reducing costs of anaerobic digestion (AD) of organic waste and increasing the valorization of biogas and digestate. The research concentrated on the three most common types of AD systems, namely on-farm digesters, stand-alone digesters that process municipal organic waste and co-digestion systems for municipal organic waste treatment at WWTPs.

The data collected through the literature search, analysis of interviews and questionnaire responses of more than 90 biogas and RNG industry stakeholders allowed to list the current industry barriers, highlight the major Canadian particularities that influence CAPEX and OPEX, enumerate best practices that can reduce costs and discuss ways to valorize end products. Additionally, the study highlights opportunities for future research.

Biogas and RNG Industry Barriers

Several groups of barriers have been identified, namely, economic, technical, institutional, market and socio-cultural. The first two, economic and technical, have been the ones mentioned the most frequently by the study participants. The economic barriers include high capital costs, lack of guaranteed long-term project revenues and lack of funding. The technical barriers include difficulty to ensure stable feedstock procurement, lack of technologies available in Canada, lack of knowledge and infrastructural barrier.

Canadian Particularities that Influence CAPEX and OPEX of Biogas Projects

The major particularities that influence CAPEX and OPEX of biogas plants in Canada can be divided into market, regulatory, economic and other groups.

Canadian market is characterized by the presence of smaller projects and slower biogas and RNG industry development as compared to other countries. Additionally, all major equipment is imported which as well has significantly impacted the costs due to Covid-19-related changes. From regulatory perspective, the factors that influence CAPEX, OPEX and revenues include the complex and lengthy decision-making process, the need to obtain Canadian certifications for equipment and specific project requirements. Moreover, municipal projects (e.g., WWTPs) have strict compliance regulations and typically low risk tolerance. Cost of labour, equipment price increases, particularities of quotes by utilities and desire to save on CAPEX in earlier biogas projects in Canada represent economic category of particularities.

Additionally, some particularities on the provincial level have been identified. For example, in British Columbia, current FortisBC RNG program and some local organics regulations contribute positively to the biogas and RNG market development. The major project challenges that influence costs include the need of more complex digestate treatment systems due to limited land availability in some regions. In Quebec, major particularities include strict RNG standards, high labour costs and AD design regulations. Alberta is different from all other provinces as its energy market is deregulated that has the influence on OPEX.

Methods and Best Practices for Reducing Costs

Based on the research results, BiogasWorld prepared the list of best practices to reduce the costs and improve the valorization of end products from AD systems. The best practices are categorized by the main actor involved in implementing the best practice to differentiate among three groups of industry stakeholders (e.g., facility, industry associations and other groups and government).

On project level, the main best practices to reduce costs and increase the revenue include:

- Economies of scale – plant sizing
- Use of benchmarking as a tool to reduce costs
- Process optimization through use of efficient equipment, feedstock review to boost biogas production, etc. preventative maintenance and AI
- Use of collective negotiating power and sharing professional resources between plants

On industry level, the best practices to optimize project economics include:

- Equipment/project standardization and creation of local industrial fabrication capabilities
- Involvement of industry associations (consulting services, training, guidelines)
- Long-term agreements with waste haulers or municipalities

On government level, the highlighted best practices to reduce costs and increase revenues are as follows:

- Introduction of biogas/RNG offtake subsidy and use of CI score or GHG emissions reduction
- Establishing a carbon credit market and offset protocols
- Recognition of U.S. or European standards for equipment used in Canada
- Training and education for operators

Valorization of End-products

The end-products of the AD process are biogas, digestate and CO_2. While biogas is being actively valorized as electricity, heat or RNG, digestate use options do not allow for efficient revenue generation yet as many processes of valorization are in development. As for the CO_2, projects with its use are yet to be developed in Canada.

Opportunities for Further Research

It is suggested that further research focuses on feedstock and local energy, life-cycle analysis, measurement of fugitive emissions, small-scale solutions and digestate end use . Additionally, the development of resources for training, benchmarking and industry interaction will help the industry develop. Other research themes include synergies by integrating different renewable methane production methods, fate of plastics and the use of energy crops.

Target Audience and Disclaimer

The present document targets the project developers, project owners and operators and all other industry stakeholders that work on Canadian biogas and RNG market. The results presented in this report have a certain degree of uncertainty; thus, the document should not be considered as definitive. Complexity of the biogas and RNG market, lack of publicly available information, reluctance of numerous industry stakeholders to share confidential information and the lack of time to participate in the initiative contributed to the uncertainty of the results.

TABLE OF CONTENTS

ABBREVIATIONS

AD	Anaerobic digestion
CAPEX	Capital expenditures
CHP	Combined heat and power
CI	Carbon intensity
ECCC	Environment and Climate Change Canada
EPC	Engineering, procurement, construction company
FOG	Fats, oil, grease
ICI	Industrial, commercial and institutional sector
LCOE	Levelized cost of energy
MAC	Marginal abatement cost
OPEX	Operational expenditures
RNG	Renewable natural gas
SSO	Source-separated organics
TS	Total solids
WWTP	Wastewater treatment plant

CURRENT STUDY IN CONTEXT

BiogasWorld was contacted by Environment and Climate Change Canada (ECCC) in spring 2021 to research the best practices for reducing costs of anaerobic digestion (AD) of organic waste and increasing the valorization of biogas and digestate.

Although the biogas and renewable natural gas (RNG) industry in Canada has seen a steady development in recent years, growing from 180 to almost 280 installations within last decade, the potential for the industry is far from being used. While there are many reasons why the adoption of AD processes is slower in Canada than in other countries, costs associated with installing and operating a biogas plant and the lack of revenues remain major drawbacks. With the upcoming Clean Fuels Regulation and global recognition that net zero goals cannot be met without addressing methane emissions, it is important to offer the biogas and RNG industry ways to boost its development via guideline document that Environment and Climate Change Canada is developing.

This initiative aligns closely with the main mission of Environment and Climate Change Canada to inform Canadians about protecting and conserving our natural heritage, and ensuring a clean, safe and sustainable environment for present and future generations.

Current Information Gaps

To the knowledge of BiogasWorld, there was no extensive research done on the topic of AD project revenues and expenses in Canada. Some effort has been put by the Canadian Biogas Association, QUEST Canada, Canadian Agricultural Partnership and the Ontario Ministry of Agriculture and Rural Affairs to provide guidelines for the industry, including specifics of project economics. However, there is a need to investigate this further.

The analysis of existing literature and knowledge base shows the lack of well-documented experience or cost information sharing not only by biogas plant operators but also by other industry stakeholders that include turn-key providers, suppliers, companies providing engineering, procurement and construction services (EPCs), utilities, government bodies, etc. Additionally, no research has been done on how the current best practices to improve economics in biogas industry in other countries can be applied in Canada. The main gaps in information come from the lack of common AD system or uniqueness of plant designs and the desire of most projects owners to keep their data confidential.

Project Execution

Over the period of four months, BiogasWorld conducted interviews, data collection using questionnaires and analysis of existing research and documentation to ensure that the information presented in the current document is correct and relevant to the Canadian biogas industry.

It was initially decided to concentrate the analysis on the three most common types of AD systems:

- On-farm digesters
- Stand-alone digesters that process municipal organic waste
- Co-digestion of municipal organic waste at WWTPs

Overall, BiogasWorld reached out to 230 biogas industry stakeholders from Canada and abroad, including owners and operators of biogas and RNG plants, turn-key providers, suppliers, EPCs, utilities, associations, government bodies, consultants, researchers, etc.

BiogasWorld conducted 43 interviews and received 50 submissions of the questionnaires from the following stakeholders:

- Biogas facilities: 37
- Supplier/service provider: 23
- Government: 5
- Researcher: 6
- Utilities: 7
- Associations and other stakeholders: 15

Approximately 95% of the participants were the professionals that are currently involved in the Canadian biogas and RNG industry.

Issues of Scope

It is important to mention the following issues of scope:

1. The reader of the document is assumed to have prior knowledge and understanding of AD systems/biogas generation technology.
2. The results presented in this report have a certain degree of uncertainty; thus, the document should not be considered as definitive. Complexity of the biogas and RNG market, lack of publicly available information, reluctance of numerous industry stakeholders to share confidential information and the lack of time to participate in the initiative contributed to the uncertainty of the results.
3. Although an extensive effort has been put to acquire biogas facilities information on costs within the framework of this study, the financial information is scarce and cannot be fully presented due to confidentiality requirements.

Report Organization

The current document consists of four sections that are organized as follows:

Section 1 provides an overview of the Canadian biogas industry and discusses the current barriers to biogas and RNG industry development

Section 2 provides an analysis of the financial information retrieved from Canadian biogas facilities, including capital and operational expenditures and revenues. The section presents general information as well as discusses the specifics of each type of biogas plant. It provides the analysis of CAPEX and OPEX data collected for this research and the reference data for selected European countries. The information on revenues is also presented in Section 2 and includes the general revenue streams and specifics of the Canadian biogas industry. Section 2 ends with a discussion of factors that influence the CAPEX, OPEX and revenues in Canada on pan-Canadian and provincial levels.

Section 3 provides information on best practices to reduce the costs and improve the valorization of end-products from AD systems. The best practices are categorized by the main actor involved in implementing the best practice to differentiate among three groups of industry stakeholders (e.g., facility, industry associations and other groups and government). Marginal Abatement Cost and Levelized Cost of Energy for analyzed biogas projects are presented in this section. Additionally, this section presents other suggestions that can be used to develop the biogas and clean energy / RNG industry in Canada.

Section 4 focuses on the valorization of end products of biogas facilities, namely biogas, digestate and CO2. The section discusses the major developments in the area and provides particularities of the Canadian biogas and RNG markets.

Section 5 identifies further research that could be done to help the industry develop.

STUDY BACKGROUND

Recent Changes in Canadian Biogas Industry

The Canadian biogas and RNG industry has seen a steady development in recent years (CBA, 2021), growing from 180 to almost 280 AD installations within the last decade to a production capacity of 196 MW of clean electricity and six million gigajoules (GJ) of renewable natural gas (RNG). As of October 2021, BiogasWorld is aware of at least 50 new biogas projects in Canada at different stages of development, with the majority of plants planning to upgrade the biogas to RNG for pipeline injection.

Focus on RNG production has been one of the major changes that the Canadian biogas industry has been going through in the last couple of years. The switch from electrical application to RNG is driven by the end of Feed-in Tariffs (FIT) programs in most provinces, emergence of lower cost renewable electricity, and by the current RNG mandates of British Columbia and Quebec. Another important driver of new biogas projects is actual or planned adoption of organics diversion policies on municipal and provincial levels.

Overall, with the discussion of more aggressive GHG emissions reductions, the introduction of GHG accounting and carbon intensity (CI) scoring and the emerging ways to monetize carbon, the renewable energy industry gets more visibility. However, the general interest in favour of electrification and hydrogen, raises the question of where the biogas and RNG industry is positioned in the Canada's clean energy future.

While the market drivers such as provincial mandates and RNG premiums are pushing the industry forward, biogas and RNG projects encounter numerous challenges. As the present study's initial assumption is that the economic barrier plays an important role in the development of AD sector in Canada, research was undertaken to confirm this assumption and to list other existing barriers.

Biogas Industry Development Barriers

The barriers to biogas development can be divided into several groups including technical, economic, market, institutional, socio-cultural and environmental barriers (Nevzorova, T., Kutcherov, V., 2019).

Information collected during this study shows that the most frequently mentioned barriers for the development of the biogas and RNG industry are of economic, technical and institutional character.

The results of the survey of 90 biogas industry stakeholders are shown in Figure 1.

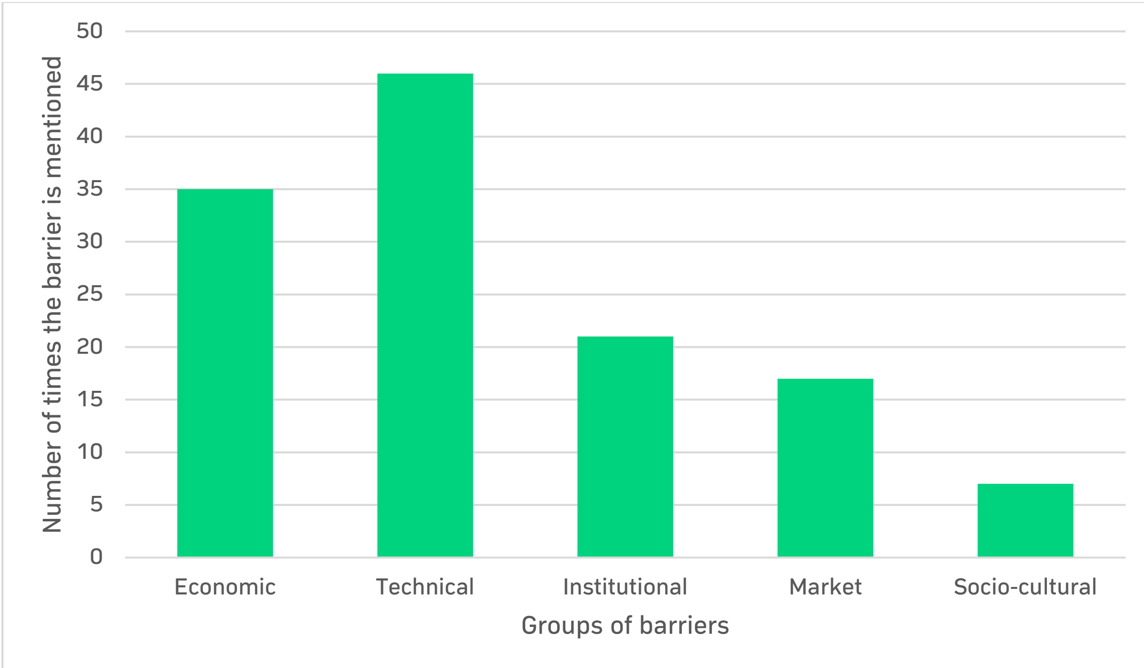


Figure 1. Barriers and Challenges of Biogas Industry in Canada, Results of Survey

The **economic barriers** were always mentioned first in the responses and include mainly:

1. Challenges connected to high and increasing capital costs.
    - Particularities of Canada as for the project economics are discussed further in the report. For example, the RNG production must be large enough or combined with a number of other sources of RNG to justify the cost of interconnection and injection station.
2. Lack of guaranteed long-term project revenues.
    - Currently, several utilities in Canada offer long-term contracts but there is no option to sell electricity or heat. Existing RNG offtake revenues are considered low by the industry stakeholders
3. Lack of funding and financial support for pre-feasibility studies, project development and capital expenditures.

The **technical barriers** include:

1. Difficulty to ensure the stable procurement of high-quality feedstock.
    - Numerous survey participants mentioned the challenges to find acceptable feedstock. Another connected challenge is the competition for the organic waste, for example, in Quebec there is feedstock competition between municipal projects funded under *Programme de traitement des matières organiques par biométhanisation et compostage* (PTMOBC, Program to treat organic materials via anaerobic digestion and composting) and private farm projects.
2. Lack of available technologies that will work in Canada for either biogas production or upgrading to RNG.
    - The majority of technologies are not adjusted to colder weather or are not economically viable for smaller-size projects. For example, RNG upgrading systems tend to target larger

biogas facilities to attain the economies of scale, thus leaving smaller units to look for other solutions.

3. Lack of knowledge.
    - Running a biogas plant cannot be considered as a side job. Additionally, it requires experience and knowledge to operate it efficiently, avoid leaks and prevent downtime. Major industry stakeholders such as financial institutions, municipal decision makers and permitting agencies lack knowledge and experience with biogas projects.
4. Infrastructural barrier.
    - Location of the suitable natural gas infrastructure in close proximity of the project that is able to accept the RNG is important as the cost of new pipeline construction is very high. A new solution to compress RNG and transport it via truck to the injection site is used in one of the BC projects and can potentially be replicated.

The **institutional barriers** include many challenges as follows:

1. Lack of common equipment standards. The interpretation of some federal standards may vary on provincial level, the standards may differ between the provinces, out-of-Canada standards are not recognized.
2. RNG quality requirements can be too strict leading to higher CAPEX and OPEX for the biogas upgrading
3. Permitting process in most provinces is lengthy and complex. The nature of biogas projects being the potential solution for waste management, energy production and GHG emission reduction adds up to the complexity of the regulatory process as it requires the approvals and implication of energy, waste management, environmental, transportation and other agencies.
4. Ownership and delivery models for wastewater treatment plants are challenging to develop projects
5. Policies and support mechanisms of provincial and federal governments do not target the growth of biogas and RNG industry
6. Lack of established processes that help monetize environmental attributes (carbon pricing, carbon tax, offsets, clean energy credits, carbon footprint or carbon intensity).
7. Existing government priorities (climate change, renewable energy, circular economy, waste management, nutrient management, innovation, etc.) do not have an integrated strategy to support AD plant development.

Lack of offtake markets for RNG, electricity and heat generated from biogas is included in the **market barriers.** Another market barrier mentioned is the comparison of biogas with other forms of renewable energy such as solar and wind energy that does not consider the non-energy and other environmental attributes of the anaerobic digestion of organic waste.

The small number of industry players and the lack of reliable partners that understand the benefits and challenges of biogas and RNG production are still a barrier. While there is an emerging interest of new larger players in the market (for example, financial and investment companies), the market is still uncertain for smaller farm biogas projects, projects located far from gas pipeline and municipal installations.

The last group of barriers identified in this survey is **socio-cultural.** It includes the lack of public understanding of biogas technology and NIMBY approach that threatens project development. BiogasWorld is aware of several projects that did not go through as planned due to social acceptability concerns. Additionally, low risk tolerance in the public domain that comes into play when planning RNG projects at municipal WWTPs and facilities that treat municipal organic waste.

ECONOMICS OF BIOGAS PROJECT

Capital and Operational Expenditures of Biogas Systems

The current study concentrated on the three most common types of AD systems, namely on-farm digesters, stand-alone digesters that process municipal organic waste and co-digestion of municipal organic waste and other organic waste at wastewater treatment plants.

Overall, the types of capital and operational expenses of AD projects are very similar and will include the expenses mentioned in Tables 1 and 2 below.

Table 1. Capital Expenses of Biogas Plants

CAPEX – Biogas Plants	
EQUIPMENT - Turn-key solution (total project cost) - Feedstock pretreatment system - Anaerobic digester (tanks, mixing, heating, etc.) - Digestate system (separation, post-treatment) - Instrumentation and controls - Biogas cleaning system (water, H_2S, etc.) - Biogas compression system - Co-generation unit (CHP unit) - Flare - Biogas upgrading unit - Grid connection (electricity or natural gas) - Injection site/skid (RNG) - Transport - Storage - Building and landscaping	**SERVICES** - Project development - Design and procurement - Construction (civil and installation) - Commissioning - Site management + insurance - Project management **DOCUMENTS AND PERMITS** - Legal and other professional expenses (incorporation, accounting, etc.) - Permits - Environmental and other compliance documents - Risk management

The capital expenditures of biogas plants include three groups of expenditures: equipment, services and documents/permits.

Table 2. Operational Expenses of Biogas Plants

OPEX – Biogas Plants	
• Labour • Operation (lab, consumables) • Maintenance, repairs, wear • Utilities (electricity, natural gas, water, wastewater) • Injection costs • Feedstock transport • Digestate transport	• Disposal fees (landfill) • Land lease • Taxes • Compliance • Debt service • Overhead expenses (management salaries, insurance, accounting)

Due to the particularities of each system the information on project economics will be presented separately for each type of system.

On-farm and Food-industry Digesters

System Particularities

On-farm and food industry digester particularities that affect capital and operational expenditures include the following:

1. On-farm digesters are typically installed and operated by a farmer that uses liquid manure (e.g., dairy, swine). To boost biogas production, the digesters accept off-farm organic material such as food processing waste or other waste coming from industrial, commercial and institutional (ICI) sector.
2. Off-farm feedstock is delivered by a waste hauler or another service company and does not require the procurement of transport vehicles by the biogas plant.
3. Typically, only off-farm organic feedstock and deadstock needs pretreatment to destroy pathogens.
4. Farms use already existing farm equipment for transport of feedstock or digestate, storage, etc., thus decreasing capital expenditures.
5. Depending on the location and the ways to use the digestate, digestate treatment or advanced nutrient extraction from digestate – beyond solid/liquid separation by a screw press - is rarely installed.
6. Food-industry digesters are installed at food manufacturing facilities and treat production wastewater or other organic waste. Existing food-industry digesters in Canada can be either farm-based (e.g., cheese production) or industry-based (e.g., meat processing facility or brewery).
7. All farm facilities that participated in this study used a wet digestion process.

CAPEX of Agricultural and Agri-food Biogas Plants

The standardized approach to capital costs distribution in Canada as well as in other countries is challenging due to the different plant designs and conditions that are specific to the project. Additionally, some of the costs that may be associated with AD systems are accounted for as a farm cost.

CAPEX per tonne of treated waste

The analysis of capital costs of 16 operating agricultural and agri-food digesters that produce electricity using generated biogas in Canada shows that the capital costs per tonne of treated organic waste (based on design capacity per year) ranges from CAD$76 to CAD$923 per tonne after CAPEX adjustment to 2021 dollar value. In actual numbers, without adjustment, the range is CAD$67 to CAD$833 per tonne.

The amount of treated organic waste is in wet tonnes and presents the actual amount of waste accepted into the digester.

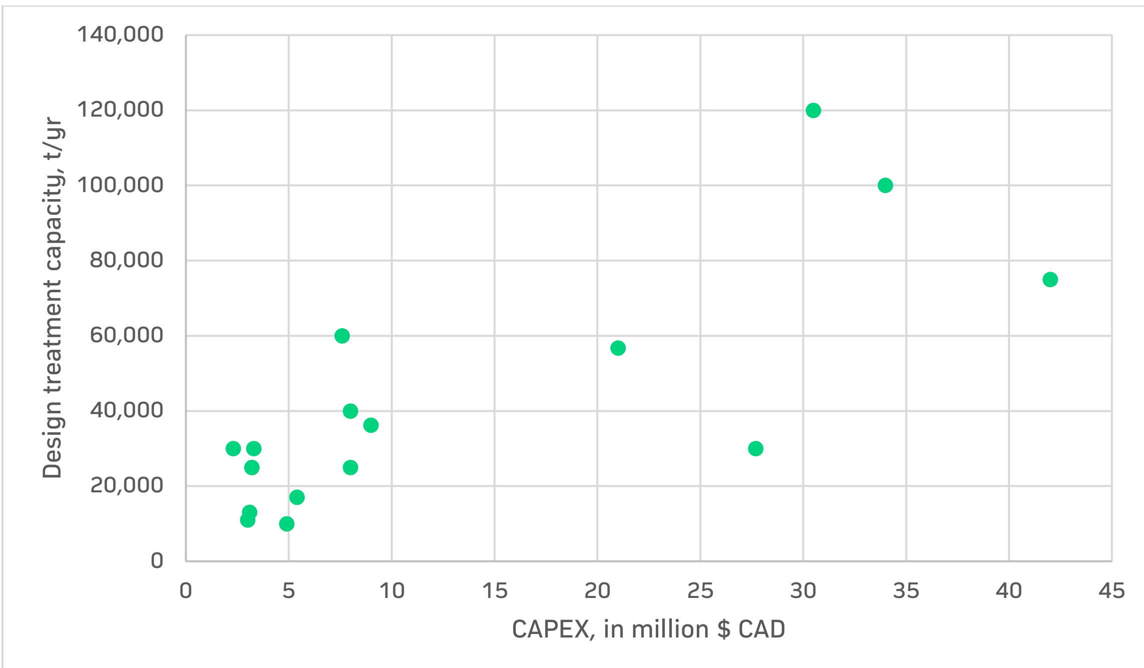


Figure 2. CAPEX of Operating Agricultural and Agri-food Biogas Plants, CHP, $ CAD/tonne, Adjusted to 2021 Dollar Value

The majority of the facilities in the above figure treat dairy manure with a portion of off-farm waste that includes FOG, corn silage and commercial production waste. The price per tonne for these facilities ranges from CAD$76 to CAD$490 (CAPEX adjusted to 2021 dollar value). Other facilities are food-processing plants treating industrial waste. Their CAPEX (adjusted to 2021 dollar value) ranges from CAD$126 up to CAD$923 per tonne of organic waste (based on annual plant tonnage).

The analysis of plants in construction and development stages, all of them upgrading biogas to RNG (Figure 3), shows that the planned cost per tonne of treated waste varies from CAD$305 up to CAD$622.

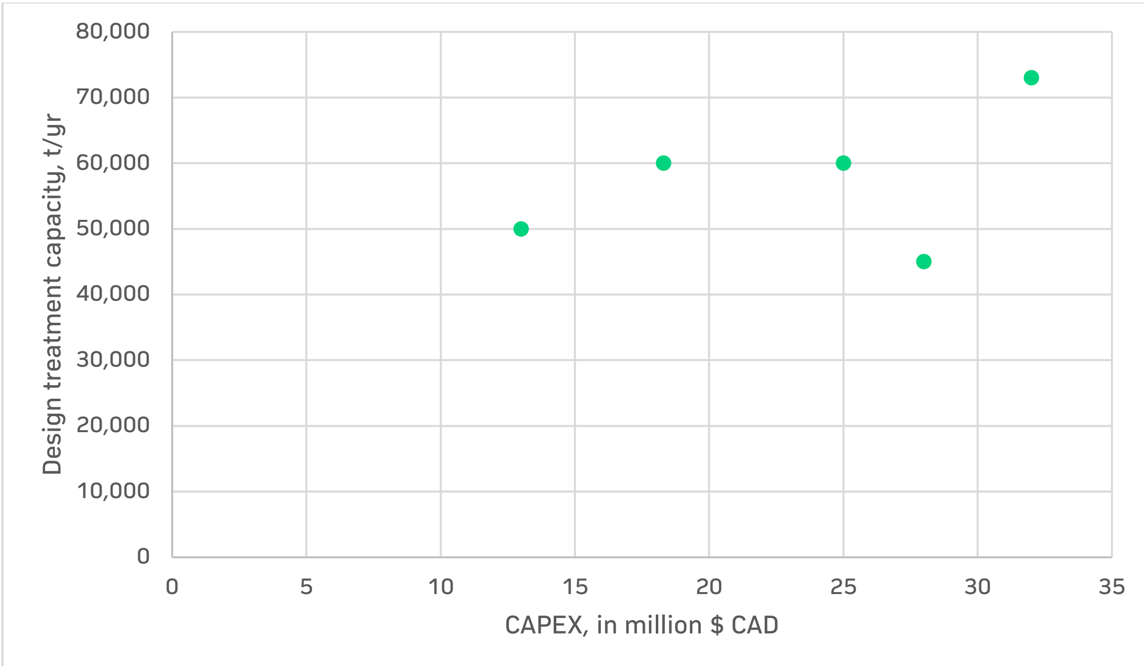


Figure 3. CAPEX of Upcoming Agricultural and Agri-food Biogas Plants, RNG, $ CAD/tonne, adjusted to 2021 Dollar Value

Figure 4 presents the AD facilities based on the year of the start of operations. Projects in development are plants that are currently under construction or in substantial development phase. The CAPEX has been adjusted to 2021 dollar value.

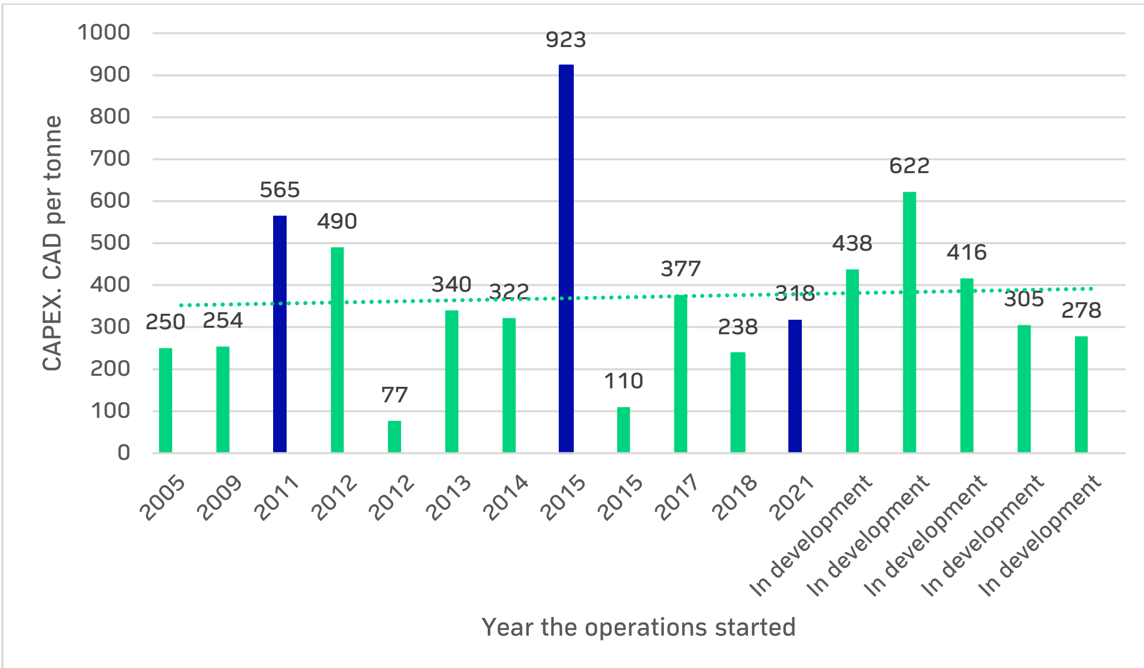


Figure 4. Average CAPEX for Agricultural and Agri-food Biogas Plants Using CHP and RNG, $ CAD/tonne, Adjusted to 2021 Dollar Value

Figure 4 shows the cost per tonne for biogas plants with on-farm units in green and food-processing facilities in dark blue. The operating projects with available CAPEX use the biogas either for heat or electricity production. The projects in development are planning to upgrade the biogas to RNG.

The collected data shows a slight upward trend in the capital expenses of biogas plants. Additionally, the comments of industry stakeholders clearly support this observation. Feedback recorded during interviews as well include the information that the first AD units in Canada were not very durable. Many changes had to be made in subsequent years to either change or replace major pieces of equipment. This approach in initial CAPEX can partly explain lower cost per tonne. Replacement parts and facility upgrades are not included in the CAPEX presented and affect mostly the OPEX.

Additionally, the recent projects are using or planning to use biogas upgrading systems that add up to the capital expenditures, as upgrading equipment capital cost is roughly five times higher than the cost of CHP. The grid connection for RNG compared to electricity is also significantly higher. It can reach 10 to 20% of the CAPEX to extend the natural gas pipeline (<5 km) and place an injection site.

CAPEX per kW

As the majority of AD systems analyzed in this section use CHP, it is possible to calculate the CAPEX based on expenses per kW. The CAPEX of analyzed biogas plants ranges between CAD$2,400 and CAD$30,250 per kW after each facility CAPEX has been adjusted to 2021 dollar value.

The information is presented in Figure 5.

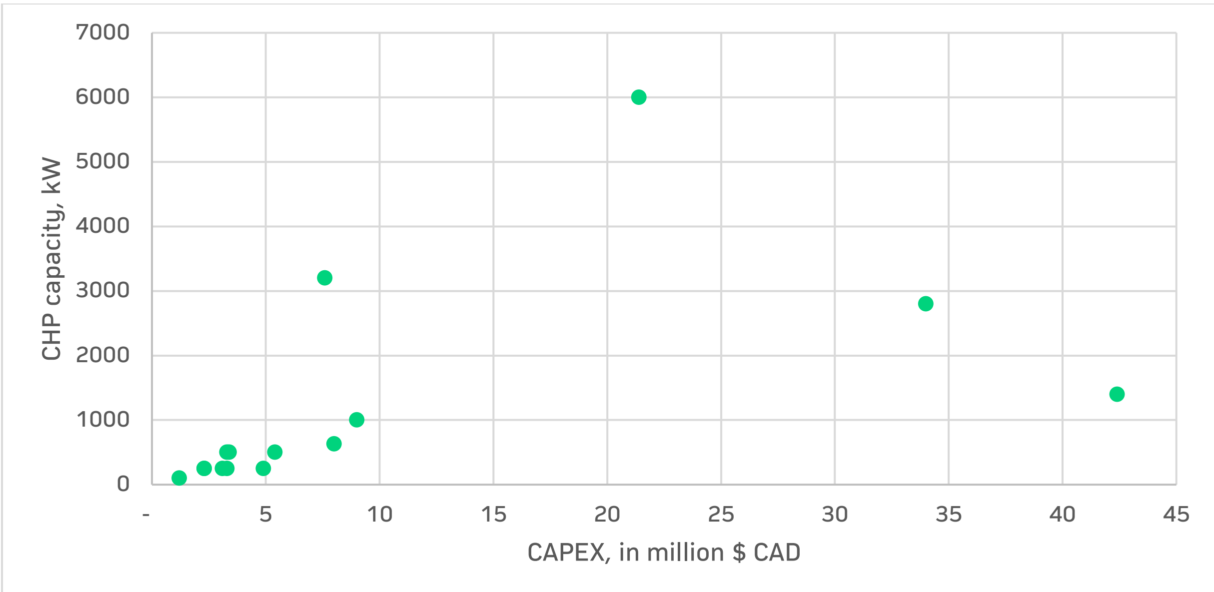


Figure 5. CAPEX for Agricultural and Agri-food Biogas Plants, $ CAD/kW, Adjusted to 2021 Dollar Value

Available information for RNG projects under construction or at a substantial development stage shows that the planned CAPEX ranges from CAD$260 to CAD$622 per GJ/year.

The information on CAPEX of farm biogas plants is presented in Appendix 1.

CAPEX Distribution

The most important capital expenses of agricultural and agri-food biogas plants are plant equipment, construction, development costs, biogas upgrading and interconnection.

The main challenge encountered when analyzing the cost information is that project costs may include different categories (e.g., development costs may include part of the equipment).

CAPEX in more detail was provided by several plants for this research and the information of four AD systems is presented below. The cost distribution by component shows substantial variability. A better understanding of CAPEX in Canada requires more data.

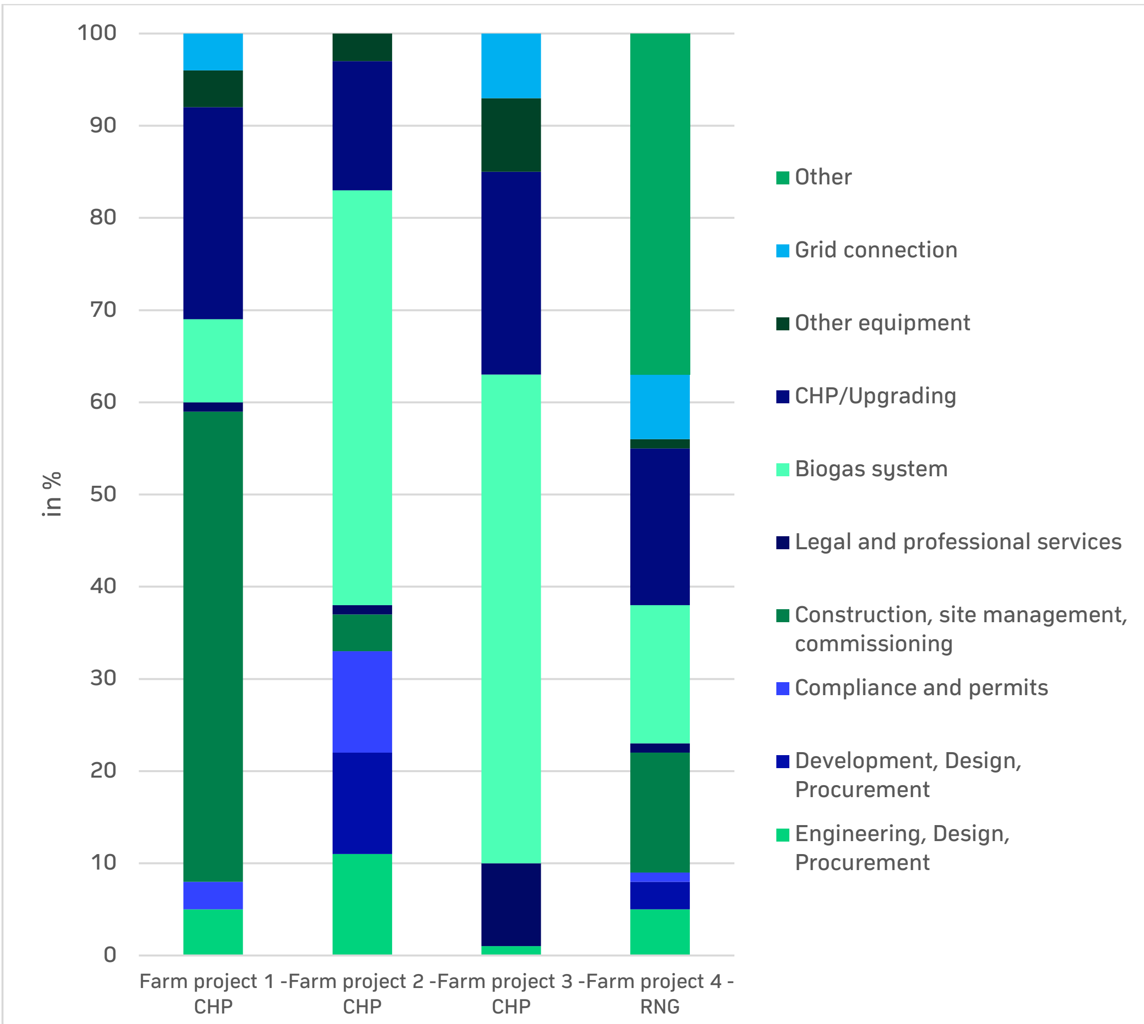


Figure 6. CAPEX Distribution for Several Agricultural and Agri-food Biogas Plants, %

The price ranges of major AD system equipment are presented in Appendix 2.

OPEX of On-farm Digesters and Food-processing AD Plants

As with capital expenses of the on-farm and agri-food biogas plants, the operational expenses show variability and may depend on several factors, including type of labour used at the plant, use of biogas, etc.

The rule of thumb will be to expect 5 to10% of CAPEX for operational expenses. The most important operating expenditures in a biogas plant are labour, maintenance, power and digestate transport. Although digestate transport could also be seen to offset manure transport.

Only four Canadian facilities shared the operational expenses for the study. The OPEX for these facilities represents from 4 to 8% of CAPEX as shown in Figure 7.

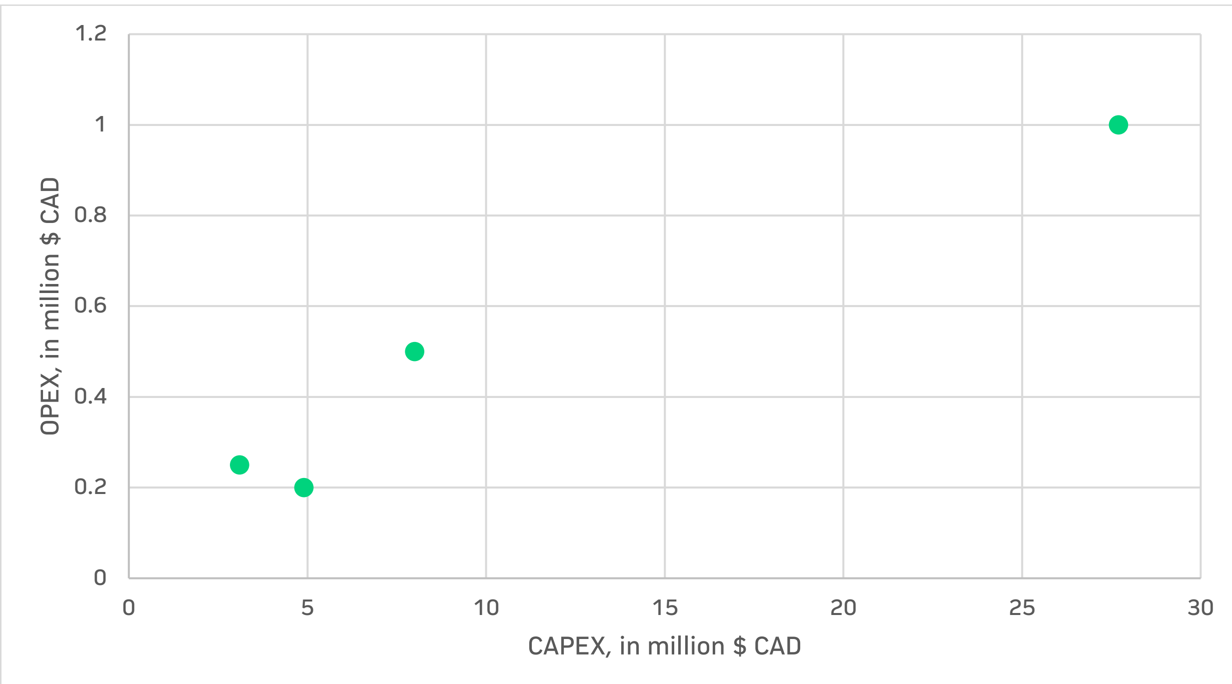


Figure 7. OPEX for Agricultural and Agri-food Biogas Plants, CHP, % of CAPEX, Adjusted to 2021 Dollar Value

The interviews with the project developers confirmed that the expected operational costs are expected to be 5 to 10 % of the CAPEX. This ratio is expected to stay the same even if we compare CHP and RNG projects, as both the CAPEX and OPEX of RNG projects are higher.

The OPEX for farm and agri-food AD systems that shared their information ranges between CAD$195,000 and CAD$500,000 per year.

The distribution of OPEX of three operational projects in Canada is presented in Figure 8.

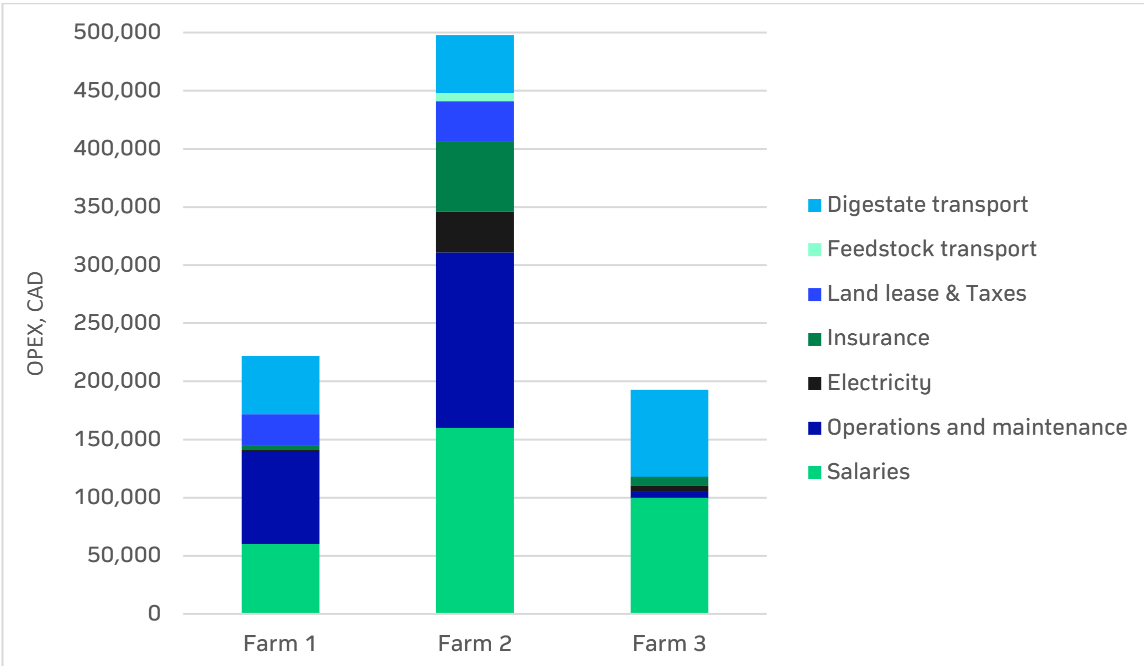


Figure 8. Farm OPEX Distribution, $ CAD per Year

The above graphs show that the most substantial operational expenditures at farms are salaries, operations and maintenance and power consumption.

Stand-alone Digesters that Process Municipal Organic Waste

Canadian Facilities

The majority of stand-alone digesters to treat municipal organic waste are currently under construction with only a handful of operational projects, including Surrey Biofuel Facility in British Columbia, Dufferin and Disco Road facilities in Ontario and Saint-Hyacinthe and Rivières-du-Loup plants in Quebec. These facilities are typically developed by municipalities or in close collaboration with them and aim to divert source-separated organic waste from landfills, thus providing the municipalities with a waste management solution.

There is at least one private project in Ontario, StormFisher Environmental, that treats a mix of municipal and ICI organic waste and one project in Alberta, Highwood Organics, currently under development that is planning to treat SSO.

CAPEX – Municipal Organic Waste Processing

Capital expenses of a municipal organic waste treatment plant that is using anaerobic digestion are very similar to the on-farm digesters and include the same types of expenses, namely equipment, services and permitting.

Major difference in expenses, as compared to agricultural digesters, will be the permitting and documentation, as this depends on the ownership of the plant. The CAPEX will include additional studies and permitting steps, thus increasing the investment costs of the project.

Analysis of the information for four facilities that are currently treating municipal organic waste shows that the estimated CAPEX for such projects range from CAD$369 up to CAD$1,230 per tonne of treated waste. The CAPEX of the facility has been adjusted to 2021 dollar value.

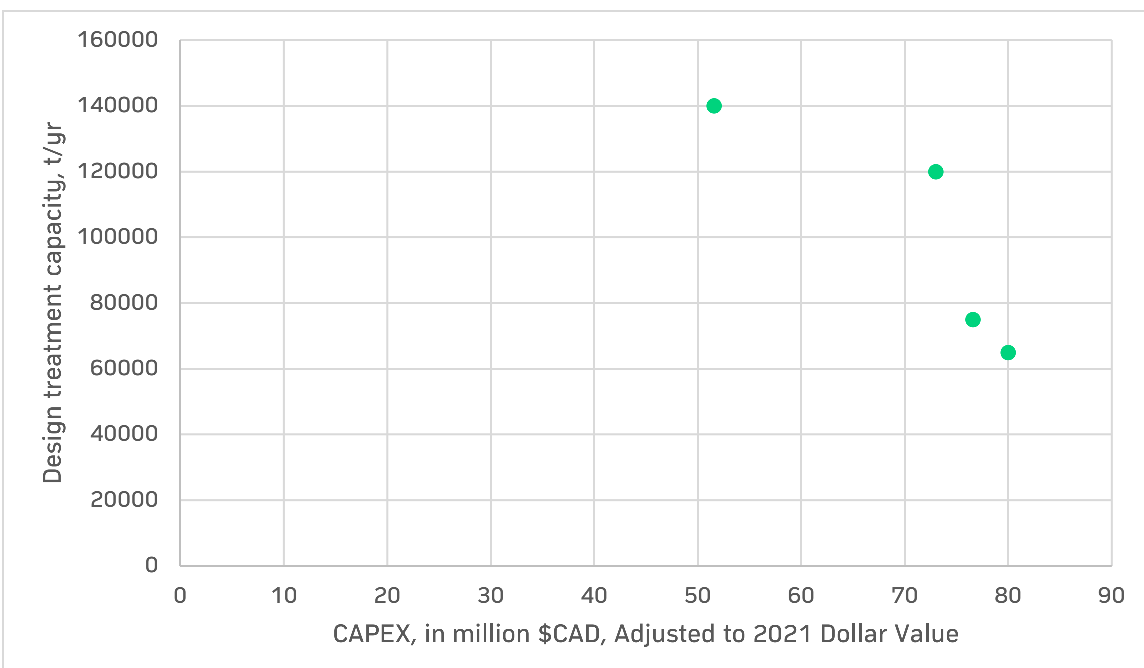


Figure 9. CAPEX of Facilities Treating SSO, $CAD/tonne, Adjusted to 2021 Dollar Value

The information on CAPEX for several projects in development in Quebec is available publicly and is presented in the following table.

Table 3. List of Municipal Organics Treatment Plants in Quebec

Facility	Feedstock details	Quantity (sludge at 25% TS), t/yr	Project CAPEX, $ CAD	RNG production, million m³/yr
SEMER, Cacouna	Municipal and ICI organics, wastewater	25,742	30,604,841	1.5
City of Quebec	Municipal and ICI organics, wastewater	182,600	217,559,190	10.2
SEMECS, Varennes	Municipal and ICI organics, wastewater	35,000	57,876,873	2.4
City of Montreal*	Municipal and ICI organics	99,000	349,742,467	3.5

* For information only, the total amount includes anaerobic and composting facilities

Distribution of CAPEX for two projects is available in the following Figure.

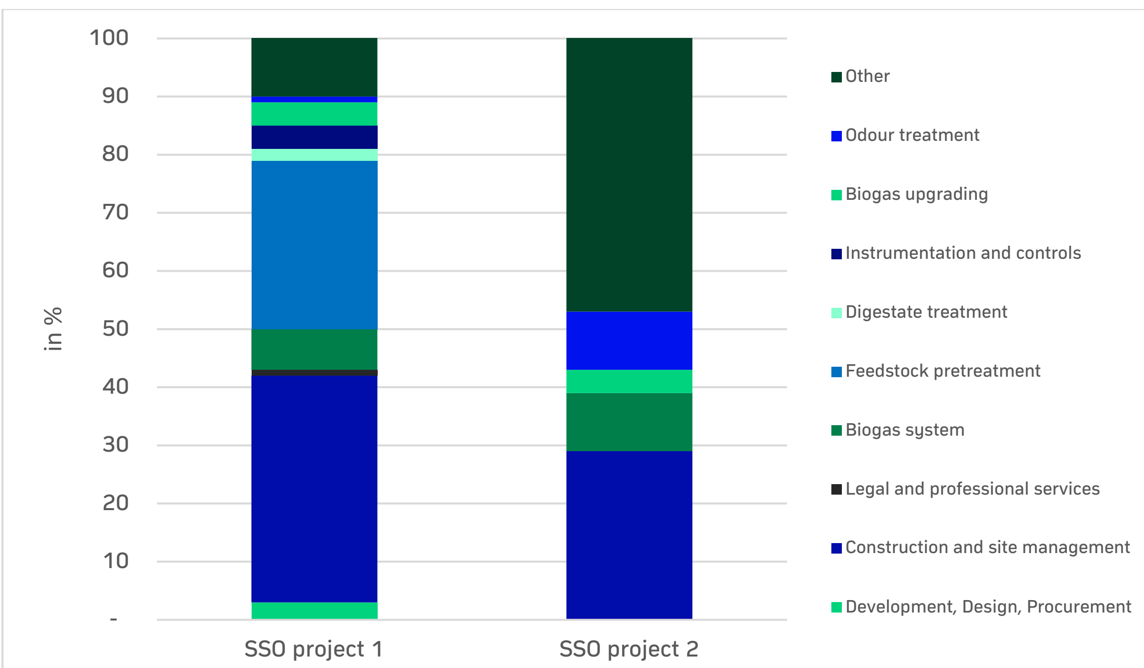


Figure 10. SSO Project Examples, CAPEX Distribution in %

OPEX – Municipal Organic Waste

Only partial information on OPEX is available for municipal organic waste facilities. In general, the operational costs will be similar in their structure to on-farm digesters costs. However, they will be higher due to salaries, maintenance costs, additional compliance, etc.

Overall, the number of employees in such plants is significantly higher as compared to farm biogas projects as such facilities are larger. The plants that participated in this study reported between 18 and 30 employees.

Another important expense for such projects is the digestate management and transport. Since the digestate of WWTPs originates from a mixture of sewage feedstock and food waste and ICI feedstocks (in the case of co-digestion), in most jurisdictions, this digestate will be subject to more strenuous sewage biosolids requirements. As for the transportation costs, as the plants treat larger amounts of organic waste as compared to farm plants, the digestate volumes are larger, thus driving these costs up.

Co-digestion at WWTP

System Particularities

Although the benefits of co-digestion (accepting food waste and ICI feedstock) at wastewater treatment plants (WWTPs) have been acknowledged by the industry, there are some particularities of WWTPs in Canada that influence the development of this option:

1. WWTPs are highly regulated facilities so the permitting process for a co-digestion facility is long and complex
2. Current ownership models do not allow for smooth project development and limits the options of raising the initial capital to start the project
3. Additional costs need to be approved as the wastewater rates are set
4. Low risk tolerance that accompanies such projects leads to longer approval periods as well as additional regulatory studies

CAPEX – Co-digestion of WWTP

In some cases, the capital expenses for WWTP AD projects appear to be lower than other facilities (e.g., AD projects that treat SSO) when they already have an anaerobic digestion system to stabilize the biosolids and there is excess capacity to receive additional feedstock. In this case, the digestion capacity is paid by the ratepayers, but it is not accounted in the CAPEX.

As with plants that treat municipal organic waste, the number of WWTPs with co-digestion in Canada is limited. These plants accept municipal and ICI organic material. Some of these projects and their CAPEX are presented in the table below.

Table 4. List of WWTP Using Co-digestion

Project	Feedstock details	Feedstock, t/yr	Capital cost, $CAD	RNG production, million m^3/yr
City of Saint-Hyacinthe (2017), Quebec	Wastewater, municipal and ICI organics	206,850	80,560,181	16.8
RAEVR, Mont Saint-Hilaire, Quebec	Wastewater	7,560	11,933,700	0.36 (biogas only)
Stratford, Ontario	Wastewater, municipal organics	N/A	22,500,000	2
Petawawa, Ontario	Wastewater, municipal organics	20,900 - organics, 5,000 - liquid waste 34,000 - WW sludge	7,000,000	N/A

OPEX – WWTP – Co-digestion

Due to a low number of operating plants in this category, the information on OPEX of plants that use co-digestion is not available. However, several WWTPs that produce biogas shared their OPEX that is presented below. As the processes of biogas generation in a WWTP that produces biogas with additional organic material (co-digestion) and without additional organics are similar, BiogasWorld believes it will be reasonable to assume that the co-digestion plants will have similar OPEX structure.

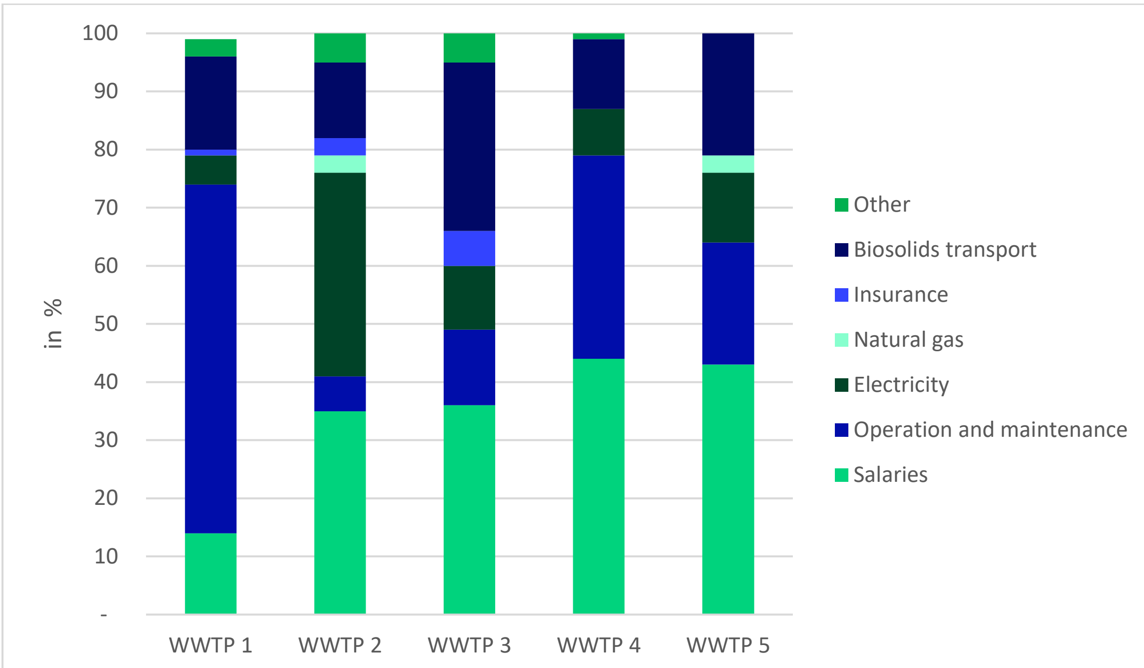


Figure 11. WWTP OPEX Distribution in %

As shown in the Figure above, the highest expenses of OPEX include salaries, operations and maintenance, electricity and transport of biosolids.

Higher salaries and operation and maintenance cost shares of OPEX are driven by regulated status of WWTPs. Additionally, the personnel of WWTPs should have the proper training and certification/licensing for wastewater treatment, increasing the salary expenses as compared to other types of biogas plants.

Project Expenditures of Biogas Plants in Other Countries

In order to compare the CAPEX of Canadian biogas plants with the typical expenses in other countries, BiogasWorld contacted several industry associations in other countries to collect the information. The information on CAPEX in three European countries is available in the Table below.

Table 5. Reference CAPEX in Selected European Countries

Country	CAPEX range, actual	CAPEX range, $ CAD per kW	Details
UK	£3,000 – £6,915 per kW	5,100 – 11,800	Small on-farm systems
Poland	15,000-16,000 Poland zloty per kW	4,700-5,000	1 MW biogas plant, 2012
Austria	2100 – 9500 Euro per kWel	3,100-13,600	N/A

The information obtained from different facilities in Canada shows that their CAPEX ranges from CAD $2,400 to CAD$30,000 per kW, with the average cost hovering around CAD$10,000 per kW. While the information is limited, these values fall into the high-cost range of European AD systems as shown in the references in the table above.

Interviews with several industry stakeholders that have the experience working in other countries confirmed the observation that the CAPEX in Canada is higher due to the reasons discussed in the next subsection.

As for the operating costs in Europe, they represent approximately the same percentage as in Canada, i.e., around 5 to 10% of CAPEX.

Operating costs distribution studied in France shows that the average operating costs of on-farm systems in France are equal to 460,000 Euro per year (CAD$662,000 per year). The cost breakdowns, not including feedstock purchase and labour, are presented in Figure 12.

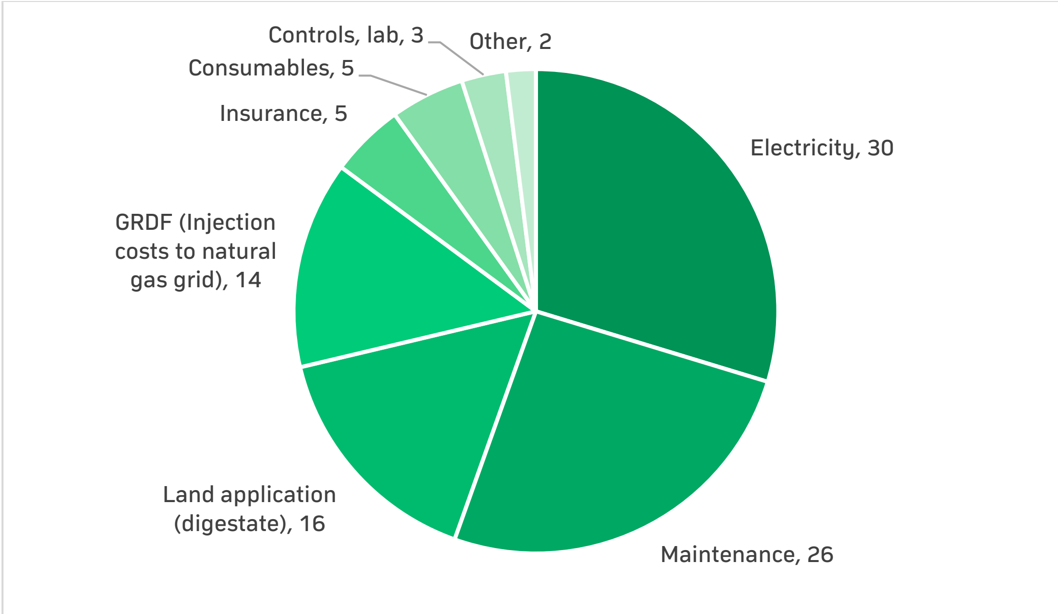


Figure 12. Operational Costs, France, On-farm Digesters

Another example of project economics from Europe (Gebrezgabher, 2010) is the Green Power Plant (operational since 2007) in Netherlands treating 70,000 tons of livestock manure (mainly pig slurry co-digested with poultry manure, energy maize, food waste and flower bulbs) and producing 2 MW of electricity. Its CAPEX of 6.75 million Euro translates into a cost of 96 Euro per tonne of feedstock or 3,375 Euro per 1 kW.

The operational expenses of this plant, without feedstock expenses and tipping fees, are presented below.

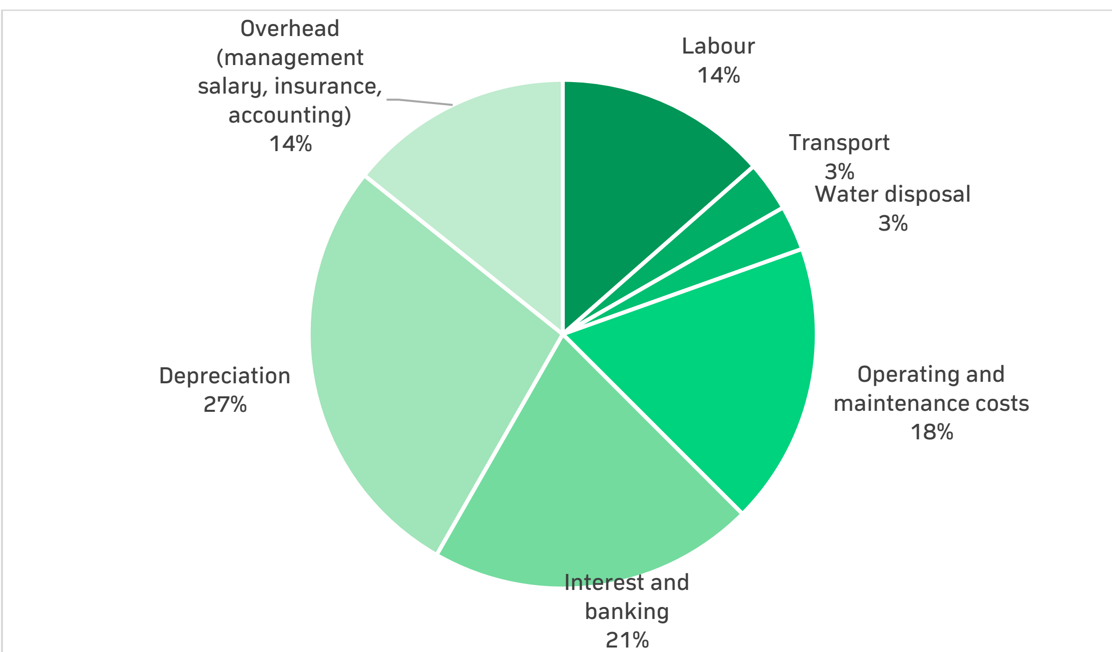


Figure 13. Operational Costs, Netherlands, On-farm Digester

Biogas Project Revenues

Revenues of biogas plants in Canada can be divided into four categories:

- Payment for the sale of energy (electricity or RNG)
- Tipping fees
- Sale of digestate or nutrients
- Environmental credits

Offtake Agreements

The premiums for the sale of energy are regulated by provincial utility commission and the payments for the sale of electricity and RNG are negotiated with the electric or natural gas utility. As the FiT program for electricity purchase is expiring in Ontario and Nova Scotia, there are several ways to sell the energy from a biogas plant. The most popular option is the sale of RNG through a contract with a utility to inject it into a pipeline. However, it is as well possible to have a contract with an industrial customer to sell biogas.

In Canada, Energir (Quebec), Gazifère (Quebec) and FortisBC (British Columbia) are the only active utilities that purchase RNG with dedicated programs. The prices and other types of support offered for projects are not made public. However, the current price caps are CAD$31/GJ for FortisBC in British Columbia and CAD$22/GJ for Energir in Quebec. Both price points are expected to go higher in the coming years in order to support the project's economics, as demand for RNG rises.

Additionally, in November 2021, Energir issued a competitive call for RNG projects that should be operational in 2023, aiming for the procurement of 50 million m^3 of RNG with this first request for proposals. This RFP allows the purchase of RNG from Quebec, other Canadian provinces and the USA. There is no set cap for the price to be paid.

Gas utility Enbridge in Ontario has just started its RNG pilot project in 2021, however, it does not offer long-term purchase contracts for RNG at this time.

The price paid by utilities to a project to offtake the biogas or RNG is not public and is not disclosed by the projects or utilities.

Presently, most of the RNG produced in Canada is sold in the USA under the Renewable Fuel Standard (RFS) and Low Carbon Fuel Standard (LCFS) programs. This RNG is produced at two landfill projects in Quebec. However, many projects are under development with RNG procurement contracts with FortisBC and Energir.

Tipping Fees

Typically, the tipping fee is paid by a municipality, an ICI facility or an agri-food facility to dispose of its organic waste. The tipping fees will depend on many factors, including location of the waste generator, availability of alternative waste management solutions in the area, local regulations for disposal of organic waste, etc.

Projects that participated in the present study reported tipping fees ranging from CAD$10 up to CAD$80 per tonne of organic waste.

Digestate and Nutrient Sales

Although presented as a resource for agricultural crop production, digestate is still a cost for most industrial and municipal projects, with only two projects interviewed for this study managing to sell a small portion of digestate as fertilizer. Out of all participating projects, the majority of facilities land spread their digestate for free, meaning that the farms that accept digestate do not pay for it. The use of digestate is not properly accounted for as it provides the savings connected to nutrient purchase and the use of digestate solids for bedding.

Environmental Credits

Only one facility in Canada reported the use of environmental credits (e.g., carbon credits) as a revenue source. The majority of facilities mentioned that the application of relevant regulations (state of carbon trading) is difficult to understand, but they plan to investigate this revenue opportunity in the near future.

It is important, however, to mention that in some provinces, the environmental credits are claimed by the utility as part of the off-take agreement. Therefore, projects do not benefit directly from credit trading, and there is no incentive to try to further reduce GHG emissions.

There is presently an emission offset system in place in Alberta. A carbon credit protocol is being developed in Quebec for cow manure digesters that should be public in 2022 and Ontario is developing Clean Energy Credit registry.

Marginal Abatement Cost of Anaerobic Digestion

The marginal abatement cost (MAC) allows to compare different abatement projects and is a simple way to identify which projects are the most cost effective per unit of CO_2eq. abated and which options offer the greatest abatement potential.

To calculate the MAC the following formula has been used

$$\text{Marginal Abatement Cost (\$/t CO}_2\text{e)} = \frac{(\text{Cost of AD scenario} - \text{Cost of base scenario})}{(\text{GHG of AD scenario} - \text{GHG of the base scenario})}$$

For the purposes of this study, two sets of scenarios were compared:

1. AD scenario producing RNG for natural gas pipeline injection compared to the production of natural gas
2. AD scenario producing RNG for injection compared to the landfilling of the same organic materials

The scenarios were chosen based on the available cost information for real biogas projects in Canada. As the most recent projects are upgrading the biogas into RNG, it was decided to analyze the production of RNG only.

The major challenge of calculating this metric for the present study is the lack of standardized data that will allow to assume several AD scenarios. All details and assumptions are presented in Appendix 3.

RNG Compared to Natural Gas

The first set of scenarios to calculate Marginal Abatement Cost compared the use of biogas to produce RNG for pipeline injection and the production and injection of natural gas. The baseline scenario used in the present estimation is the fossil CNG used as a vehicle fuel. The results are presented in the following Table.

Table 6. MAC – AD Scenario Compared to Natural Gas Scenario

AD scenario	RNG annual production, GJ	Annual GHG emissions, $tCO_2eq.$	MAC, CAD$/tCO2eq.
Municipal project: 60% sludge, 40% SSO	Confidential	(640)	575
Municipal project: 100% SSO	70,000 – 225,000	(520) – (1,850)	209-703
Farm project: 50% manure, 50% food waste	88,000	(16,280)	41
Farm project: 70% manure, 30% ICI organics	80,000	(20,490)	33

As shown in the previous table, when comparing between RNG and natural gas, the MAC for the municipal projects treating different types of waste ranges from CAD$209 to CAD$703 per tCO_2eq. Two farm projects show lower MAC due to higher GHG emission reductions offered by these projects. The estimated MAC for farm projects is CAD$33 and CAD$41 per tCO_2eq.

All calculation assumptions and details are presented in Appendix 3.

AD Scenario Compared to Organics Landfilling

The second set of scenarios analyze different organic waste management scenarios - AD scenario producing RNG for injection is compared to the landfilling of the same organic materials. Table 7 contains the estimated MACs for these scenarios.

Table 7. MAC – AD Scenario Compared to Organics Landfilling

AD scenario	RNG annual production, GJ	MAC, CAD$/$tCO_2eq.$
Municipal project: 60% sludge, 40% SSO	Confidential	11
Municipal project: 100% SSO	70,000 – 225,000	(89) - 55
Farm project: 50% manure, 50% food waste	88,000	(31)
Farm project: 70% manure, 30% ICI organics	80,000	16

The comparison of different ways to treat the organic waste (AD versus landfilling) allows to calculate MAC that ranges from CAD$ -89 to CAD$55 per tCO_2eq. Negative MAC means that the cost of using AD scenario is lower than the cost of the baseline scenario. All assumptions are available in Appendix 3.

Levelized Cost of Energy for Biogas Utilization

The levelized cost of energy (LCOE) is the net present cost of energy over the lifetime of the facility. Due to the limited amount of data collected for the present study, the following assumptions were made for LCOE calculations:

- Two types of biogas utilization are analyzed: electricity and RNG production. The results are reported in $ per kWh.
- LCOE is calculated for 2021 as no information on OPEX for previous years is available
- As the start date of many facilities differ, it was decided to adjust CAPEX to 2021 dollar value to match OPEX (provided by facilities for 2021).
- The information for 4 CHP facilities and 5 RNG facilities has been used to calculate LCOE

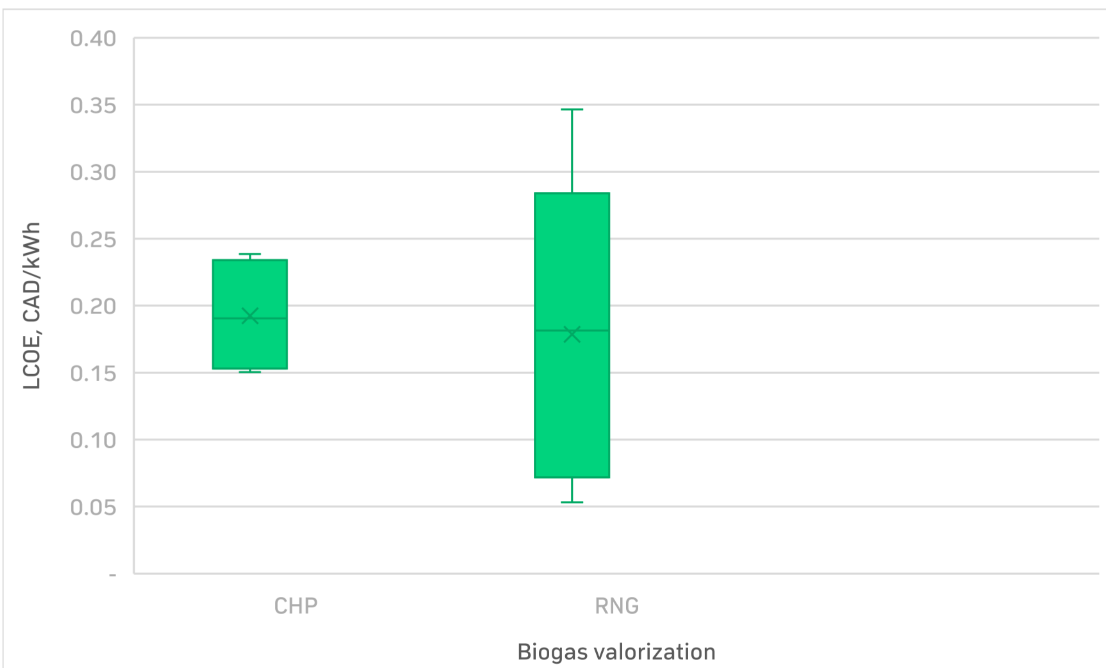


Figure 14. LCOE for CHP and RNG Biogas Valorization

As seen in the previous graph, the LCOE of CHP and RNG valorization of biogas are similar – an average of CAD$0.19 per kWh for CHP and CAD$0.18/kWh for RNG. However, the range is wider for RNG applications.

Details on LCOE calculations and assumptions are available in Appendix 3.

Economics of Biogas Projects – Canadian Particularities

Analysis of the responses received during the interviews and in questionnaires and the review of existing documents generated a list of the main factors that contribute to higher capital and operating costs in Canada.

Pan-Canadian particularities that influence project CAPEX and OPEX are presented in the Table 8.

Table 8. Canadian Particularities That Influence CAPEX and OPEX of Biogas Projects

Category	Particularity	Effect on	Parties involved	Details
Market	**Smaller projects in Canada**	CAPEX	Project developer	Majority of equipment is subject to economies of scale, thus the tendency of having smaller projects in Canada increases the CAPEX per tonne of treated waste.
Market	**Slower biogas and RNG development**	CAPEX, OPEX	Equipment suppliers and service providers	As compared to other countries, a slower pace of industry development makes this market less interesting for out-of-country suppliers. The lack of competition leads to fewer options a project developer has, thus less negotiating power to reduce the project expenses.
Market	**Equipment procured outside Canada**	CAPEX	Suppliers	All major equipment of biogas and RNG plants is procured outside Canada, adding additional costs of exchange rates, transport and margin (up to 20-25%).
Market	**Covid-19 related changes**	CAPEX OPEX	Project developer/owner	Covid-19 pandemic has increased the labour shortages affecting construction and project CAPEX and OPEX.
Regulations	**Complex and lengthy decision-making process for some projects**	CAPEX	Mainly WWTPs and municipal projects	This factor is especially impacting for projects involving municipalities (for example, WWTPs that are interested in co-digestion) where the decision process is longer and is characterized by a low risk tolerance. To reduce project risks, additional studies may be required to help the decision-making process and additional design and equipment requirements may be put forward (for example, more robust equipment, backup, etc.) to ensure efficient plant functioning.
Regulations	**Need to obtain Canadian certifications for equipment**	CAPEX	Equipment suppliers	As the majority of equipment comes from outside the country, the need to obtain Canadian certification impacts the equipment quotes and CAPEX. For example, Canada has different design standards than the USA for vessels and piping, and vessels must be certified for the individual province. This causes extra design, testing and manufacturing requirements, thus a higher price.

Category	Particularity	Effect on	Parties involved	Details
Regulations	**Specific project requirements**	CAPEX	Equipment supplier	It is common that as a part of the project proposal, a performance bond is required for larger projects (municipal or industrial). The suppliers have to purchase the bond and they pass this cost on to the project.
Regulations	**Strict compliance regulations for WWTPs**	OPEX	WWTPs	As WWTPs are regulated they have a set of compliance requirements that include, for example, lab analysis requirements (e.g., for co-digested feedstock), increasing the operational costs.
Regulations	**Low risk tolerance**	CAPEX	Municipal projects	Low or no risk tolerance approach in municipal sector leads to downloading all risks to suppliers and service providers. The use of Engineering, Procurement, Construction Companies (EPCs) is typically the solution for this issue, however, the services of EPCs are more expensive.
Economics	**Desire to save on CAPEX**	CAPEX	Project owners	The first plants in Canada were mainly built using the least expensive equipment to reduce the CAPEX of the projects. This approach negatively impacted the operator's experience and project economics as it often resulted in the need for equipment changes of slowing or stopping operation.
Economics	**RNG grid injection quotes**	CAPEX	Utilities	As RNG injection is still in development and only a small number of projects are operational, one of the new project concerns is the high capital cost that could be estimated by the utilities. It is reported that the utilities may provide a preliminary quote for connection that is too high. Additionally, the utilities may have requirements for injection station equipment that are suggested to be procured at specific suppliers without the possibility to bring in less expensive options.
Economics	**Cost of labour**	OPEX	Project operator	Some regulated facilities (for example, WWTPs) need to employ certified professionals for certain roles.
Economics	**Equipment price increase**	CAPEX	Suppliers	Increase in equipment price up to 10-25% due to raw material price increase (stainless steel), limited availability of parts and shipping costs.

Category	Particularity	Effect on	Parties involved	Details
Other	**Lack of industry specific training**	OPEX	Project operator	There are no available training programs in Canada for biogas plant operators. This frequently leads to the lower conversion efficiency and lower biogas yields, digester upsets, potentially unsafe operations and higher operating costs.

On a provincial level, the following factors influence the project costs:

British Columbia:

1. Current FortisBC offer generates interest from investment and equity firms not specialized in biogas or RNG but seeing the financial potential of such projects. Increased interest to the industry may potentially bring more competition.
2. Digestate management represents a major project obstacle due to limited land availability in some regions, thus increasing capital costs as the projects need to include more complex digestate treatment systems.
3. Local organics regulations, for example, Metro Vancouver's organics diversion policy, contribute to the development of the RNG sector in British Columbia.

Quebec:

1. Strict RNG standards by BNQ (Bureau de normalisation du Québec) require more performant biogas upgrading systems, increasing the total CAPEX of the project.
2. High labour costs are particular to Quebec due to unionization of the construction industry. Additionally, classification of the construction of biogas plants in the heavy industry category is being considered. If approved, this will lead to the high construction workers rates and safety measures in the province.
3. Current AD facilities design regulations for industrial and municipal systems require that all operations are done inside the buildings (for example, feedstock reception should be done indoors). These requirements increase the project CAPEX.

Alberta:

1. Energy market is deregulated, thus there is not fixed energy pricing making OPEX difficult to predict.

METHODS
AND BEST PRACTICES FOR REDUCING COSTS

Stakeholder feedback collected during this research indicates that there are multiple ways to improve biogas project economics by reducing the project capital and operational expenditures. While some methods and best practices can be followed by an individual project, others involve industry stakeholders or changes in the government approach including changes in regulations on provincial or federal levels. The information in this section is presented according to the main actor that should be involved in implementation of changes.

Methods and Best Practices at Project/Local Level

The methods and best practices to reduce expenses and increase revenue at the project level are presented in the following table.

Table 9. Best Practices to Reduce Expenses and Increase Revenue at Project Level

Method/Best practice	Impact on	Applicability in Canada
Economies of scale – plant sizing	CAPEX, OPEX	Difficult
Use of benchmarking as a tool to reduce costs	CAPEX, OPEX	Difficult
Use of efficient equipment (pumps, mixers, etc.)	OPEX, CAPEX	Possible
Feedstock review to boost biogas production	Revenue, OPEX	Possible
Increase of plant automation	OPEX, CAPEX	Possible
Optimization of manure handling practices – increase of biogas production and decrease in emissions with more frequent collection	Revenue	Possible
Use of preventative maintenance schedules or use of AI for maintenance planning	OPEX, CAPEX	Possible
Establishment of a spare parts stock with key components to avoid prolonged downtime	OPEX	Possible
Use of collective negotiating power (service providers and organics suppliers)	Revenue	Possible

Method/Best practice	Impact on	Applicability in Canada
Sharing professional resources between plants	OPEX	Possible
Use the best practices of electricity purchase (available in deregulated market)	OPEX	Not possible for this actor to initiate

The majority of best practices that could be implemented at the local/ plant level, listed in Table 9, can be used to improve the project financials in Canada.

The most frequently mentioned best practice to decrease the expenses of a biogas project is the economies of scale that can offer not only the reduction in CAPEX but also can improve the OPEX of the project. In Canada, this measure will not always be applicable for biogas projects due to smaller size farms and the distances between farms to ensure the waste collection.

To compare project performance, some countries use benchmarking. While it is an excellent and easy-to-use tool to reduce expenses, the main challenge is the lack of publicly available information on similar projects and the confidentiality of information, especially in private projects.

Best practices such as the reduction of the system downtime, increase of process efficiencies using better equipment and process automation may all lead to a higher CAPEX, however, will decrease the OPEX (reduction of labour costs, maintenance, power consumption) and improve the revenues.

ZooShare Biogas

By using self-cleaning digester, ZooShare Biogas in Ontario has been generating a full 500 kW while processing only 77% of their food waste capacity.

Another way to boost the biogas production is to optimize the feedstock mix within permitted levels (some regulations limit the off-site organics intake to a certain percentage of the total annual waste amount). Additionally, changes in manure management practices can be beneficial: more frequent collection of manure will, from one side, reduce the evaporation of the manure and its emissions and, from another side, will increase the biogas yield.

Preventative maintenance is often provided by the third party and involves expenditures that are rather high due to the lack of service providers, but the preventative measures help identify potential problems that can lead to plant downtime. The use of AI for maintenance is a new initiative currently in development and is mainly tested in Europe now.

European experience

European experience shows that available cost reduction strategies cannot always offset the new compliance requirements that tend to increase CAPEX and OPEX.

Another way to decrease downtime is to establish a spare parts stock with key components as the majority of equipment comes from abroad and due to recent supply chain problems. This best practice can reduce the plant downtime due to a broken part or need of part change.

To boost revenues, several farms in Ontario have been working together to negotiate tipping fees with waste haulers as a group to ensure more sustainable revenue. Additionally, as on-site professional services are not required full time, some farms that are located nearby share the services of agronomists, biologists, etc.

The management of electricity purchase agreements (via contract negotiations and other measures) has been identified as one of the best practices to reduce OPEX at AD plants in France as there are several options available for projects. However, as the power pricing is regulated in the majority of provinces in Canada, this method of reducing the OPEX will not be applicable.

Methods and Best Practices at Industry Level

At industry level, there are several best practices that have been identified as presented in the table below.

Table 10. Best Practices to Reduce Expenses and Increase Revenue at Industry Level

Method/Best practice	Impact on	Applicability in Canada
Equipment/project standardization	CAPEX	Difficult
Standardization of receiving stations, injection stations and other components	CAPEX	Possible
Local industrial fabrication capabilities	CAPEX	Possible
Involvement of industry associations (consulting services, training, guidelines)	OPEX	Possible
Long-term agreements with waste haulers or municipalities	Revenue	Possible

The first best practices involve the suppliers and service providers. Equipment and project standardization will reduce the price of equipment or services (CAPEX). This approach entails the use of standardized design for biogas projects to reduce design and engineering costs. Due to the limited number of projects and different legal requirements on provincial levels, this best practice will be difficult to implement across Canada. However, it can still be a viable option within a specific province if the demand for the AD facilities starts to grow. Standardization in RNG injection and interconnection will as well benefit the industry as it will lead to lower CAPEX for the project.

RNG Injection standardisation

Danish gas distribution company Evida has developed uniform practices and cost-optimization, by using framework agreements with suppliers and uniform connection principles.

As with the previous point, the use of local fabrication facilities by a supplier, can reduce the CAPEX. Right now, the majority of the biogas equipment is imported, which not only increases the CAPEX (transport costs, export levies, etc.) but makes the maintenance and parts purchase difficult.

Several European countries show a strong involvement in biogas facilities operations by providing consulting services connected to regulatory requirements or grant applications. As an example, German Biogas Association provides help in filling in the government documents to meet the new requirements. European Biogas Association together with the partners of the EVEMBI (Evaluation and Reduction of Methane Emissions from Different European Biogas Plant Concepts) project elaborated a report on minimum requirements and recommendations to facilitate the development and the implementation of national voluntary monitoring systems of possible methane emissions on biogas and biomethane plants in European countries.

The last method to provide more stability to the project is to allow for a long-term organics' procurement agreement as currently such agreements can be limited to 3-5 years thus increasing the project's financial risk.

Methods and Best Practices at Government Level

The recommended methods and best practices on a government level are presented in the following table. The term government is used broadly and includes various departments from different levels of government as well as utility commissions.

Table 11. Best Practices to Reduce Expenses and Increase Revenue at Government Level

Method/Best practice	Impact on	Applicability in Canada
Introduction of biogas/RNG off-take subsidy, instead of CAPEX subsidy	CAPEX, revenue	Possible
Use of CI score or GHG emissions reduction as basis for offtake revenue calculation, not production volumes	Revenue	Possible
Establishing a carbon credit market and offset protocols	Revenue	Possible
Recognition of US or European standards for equipment used in Canada	CAPEX	Possible
Training and education for operators	OPEX	Possible
Interconnection and injection done by the industry	CAPEX	Difficult

The majority of identified best practices are linked to subsidizing the industry.

According to the European and some Asian experience, the subsidies for offtake are more conductive for the industry development than CAPEX subsidies as they provide the necessary revenues to meet the minimum rate of return. The same suggestion has been made by industry stakeholders in Canada who are sure that long-term stable project revenue will improve the project economics better than CAPEX support. To date, all on-farm biogas projects have been constructed using a long term offtake agreement (10-20 years) either under a FIT program, bioenergy program or RNG contract necessary to obtain a bank loan.

Available government support and incentives should take into consideration available support in the U.S., if the import and export of RNG are allowed, to make sure there is no unfair competition.

Support of the industry based on carbon intensity (CI) scoring is used in carbon credit trading. The California LCFS and U.S. RIN designation for RNG are sending a strong message about the most attractive projects from the point of view of GHG emissions reduction. Currently, the support mechanisms in Canada are based on the biogas and RNG production without any premium for the specific GHG reductions associated with the use of agricultural feedstocks, for example. The credit trading system that is expected to emerge with the Federal Clean Fuel Regulation may offer opportunities to earn additional revenue based on a facility's GHG reductions.

European subsidy experience

There is an unfair competition between the RNG produced and imported from Denmark to Sweden and the RNG produced in Sweden, as Danish RNG can use production support available in Denmark and tax exemption for transportation use offered in Sweden.

Establishment of carbon credit market and approving offset protocols that recognize different Canadian biogas-energy pathways will be beneficial for the revenue generation of biogas and RNG projects.

Recognition of other approved equipment, connection and pipeline standards presents another way to reduce the CAPEX of projects in Canada. Countries in South America and Asia accept some U.S. design standards; thus, the project CAPEX does not increase due to compliance requirements.

Although not directly connected to costs, the lack of training in Canada represents an opportunity. Currently, Canada has only one biogas specific training program at a Quebec college and operators are sent to train in the USA or Europe.

Measures to Develop Biogas Industry in Canada

Following the best practices mentioned in the previous section, there are a number of other measures of more global level that will help the development of biogas and RNG industry in Canada. The main suggestions mentioned by the participants of this research are presented in the table below.

It is recognized that these many of these measures will be easier to implement as the number of facilities grows.

Table 12. Measures That Will Help Biogas and RNG Industry to Develop

Category	Details of measures
Resources and expertise	• Information on GHG emissions and CI score adopted for biogas and RNG industry. The GHG emissions calculator for waste sector projects currently being developed by the ECCC will be a helpful tool for the industry • Regional assessment and map of the feedstock available for biogas and clean energy RNG production (techno-commercial potential) • Regional assessment and map of energy demand by type of energy, seasonal demand, etc. • Project planning tools to assess when a biogas plant makes financial sense • Additional pilot project demonstrations and site tours (in person or virtual) of existing projects • Resources to promote biogas production and nutrient recovery as a GHG reduction, clean energy and circular economy solution targeting decision makers, financial institutions and the public • Tools for dissemination and knowledge sharing
Support programs	• Support based on GHG emission reductions (vs. produced RNG volumes) to account for the additional benefits of the use of certain feedstock, systems with higher biogas yields • Strong long-term power offtake support • Support for small-scale projects and demonstrations of new concepts • Support for local use of energy as electricity and heat and beneficial use of digestate (in the framework of circular economy) • Support for new products from digestate to enter markets • Revisit support programs as Canadian carbon markets mature
Resources efficiency, clean energy and circular economy solutions	• General reduction of natural gas consumption is necessary to compensate for higher costs of RNG • Promotion of local use of biogas energy in all forms (heat, electricity, vehicle fuel, substitution of propane or natural gas)

Category	Details of measures
	• Addressing infrastructure gaps related to collection, sorting and characterization of waste to develop markets for different waste materials • Integration of regional waste management and energy planning with agricultural resources • Scenario planning as part of the clean energy future of electrification and the hydrogen economy
Regulations, codes and standards	• Mandatory renewable blend for gaseous fuels and procurement targets to grow the market • Widespread regulations for limiting organics from landfilling (organics ban) and waste management strategies that include anaerobic digestion • Streamlined permitting processes to reduce time for project development • Standardization of equipment, connection and pipeline requirements for biogas and RNG industry

VALORIZATION OF END-PRODUCTS

Valorization of Biogas

Current Use of Biogas

Typically, biogas is used to produce electricity, heat, or is upgraded to RNG (biomethane). In recent years Canada saw a shift from electrical and heat valorization of the biogas to upgrading it to RNG following the support schemes and RNG purchase mandates of several Canadian utilities.

The majority of farm facilities that participated in the present study were built during the active Feed-in-Tariff in Ontario. These facilities use between 70 and 100% of produced biogas for electrical grid injection and 10-30% for their own electricity. Most capture heat from the CHP system to heat the digester and feedstock pre-treatment (pasteurization unit). Some facilities produce heat for on farm use. Many existing facilities are looking to expand and upgrade their biogas into RNG. Farms located in close proximity of natural gas pipelines are exploring opportunities to inject the RNG under an RNG purchase agreement, while others are examining other local energy uses. All recent plants and facilities in construction are upgrading or planning to upgrade, the biogas into RNG.

The use of biogas at WWTPs that participated in this study is quite different with 30-80% of biogas being flared. Many facilities use biogas to generate either electricity or heat for self-use (20-50% of produced biogas). This can be explained by the main purpose of the WWTP to treat wastewater, rather than generating power and revenue.

Innovations in Biogas Utilization

There are currently several new developments in biogas valorization that range from the direct use in solid oxide fuel cells to the production of syngas and renewable Dimethyl Ether (rDME). As the hydrogen economy develops, new technologies are expected to emerge.

According to the review by Zhao (Zhao, 2020) biogas reforming to syngas includes dry reforming, bi-reforming and tri-reforming to syngas (mainly consisting of H_2 and CO). The syngas can be utilized as raw material for the production of fuels (e.g., hydrogen, synthetic gasoline, dimethyl ether, ethanol, methanol) and other chemicals. Moreover, syngas can be applied in fuel cells and for direct production of energy and heat (use of boilers or turbines).

Biogas can be used to produce renewable Dimethyl Ether (rDME) fuel, the substitute of petroleum diesel that can as well serve as a carrier for hydrogen. There are currently two ongoing projects testing novel applications of DME as low-carbon alternative to fossil fuel funded by the US Department of Energy:

- University of Wisconsin, Madison for “Efficiency Mixing Controlled Compression Ignition Combustion of Propane DME Blends”

- WM International Engineering L.L.C. in Darrien, Illinois, for a project entitled "High Pressure Fast Response Direct Injection System for Liquified Gas Fuels Use in Light-Duty Engines"

Valorization of Digestate

Digestate contains the macro and micronutrients contained in the feedstock, some residual organic matter and water. In theory, all these components can provide a source of revenue for a biogas facility. The major challenges facing digestate valorization: its quality (i.e., contamination), costs associated with its treatment, storage and transportation and competition coming from compost industry.

The most common use of digestate that comes from on farm biogas systems is to apply it to agricultural land as it has value as soil fertilizer and reduce the use of synthetic fertilizers. On-farm digester systems will separate the solids from the digestate using a screw press and use these to replace animal bedding.

Digestate Quality

There is no federal standard that regulates digestate quality for all provinces. The Fertilizer Act is an overarching document. However, each province has its own regulations. For example, in Ontario the land application of digestate is regulated by Ontario regulation 267/03. In Quebec, the digestate is included in the group of fertilizing residuals and is subject to regulations of the MELCCC (Ministry of Environment and Fight against Climate Change). Additionally, BNQ (Quebec's standardization bureau) is currently developing a digestate standard in consultation with an industry committee where BiogasWorld is taking an active part.

Digestate quality depends on the feedstock inputs, the operations of the digester and the digestate treatment and storage. AD plants that use food waste and municipal organics or co-digest such organic waste with manure may have difficulties in managing the quality due to feedstock contamination. Partially treated manures and organic waste may as well result in the presence of pathogens and harmful bacteria, and therefore the digestate should be analyzed for pathogens. Biogas facilities may use a method to pre-treat feedstock such as hydrolysis or pasteurization before the feedstock is transferred to the digester to destroy pathogens.

At most facilities, the digestate quality will likely vary over the year. The research on quality and quantity variability by French Project DIVA (Dabert 2015) found that the variability is typically less than 10%.

One of the major emerging concerns with the development of the biogas industry in Canada is the presence of microplastics in digestate. This is especially true for plants that treat food waste and biosolids/sewage sludge. EPA factsheet (EPA, 2021) notes that food waste streams collected for composting had the plastic contamination of up to 2.8 % by weight. Additionally, food itself is also a source of microplastics. A study of organics fertilizers in Germany (Meixner, 2020) found that 35 billion to 2.2 trillion microplastic particles larger than 1 mm are released into the environment per year via compost and digestate, with the most microplastics present in the digestate generated at biogas plants that treat municipal organic waste.

The main areas of research on microplastics include:

- Environmental impact of microplastics
- Microplastics in AD plants and composting systems
- Methodology to detect, identify and quantify the microplastics in soil

As this area of research is emerging and the regulations to tackle microplastics pollution are not in place, the operating biogas facilities in Canada are not considering this issue a problem at the current time. However, as the research and regulations evolve, the industry's perception of this issue may change and new requirements could be introduced.

Digestate Treatment, Storage and Transportation

As digestate cannot be applied to agricultural land year round, a facility needs to have digestate storage. Typically, an on-farm system will have at least 6 months of storage. Uncovered digestate storage can be a significant source of ammonia and methane emissions that are considered air pollutants and result in a loss of potential revenue.

Another issue with digestate valorization is the high water content that requires the use of dewatering technologies that lead to a higher project CAPEX and higher energy consumption (OPEX). On-farm use of digestate solids as animal bedding can justify the cost of screw presses, however additional nutrient removal systems can be costly. Storage and transportation of digestate in liquid form limit its use to a very local market (for land-spreading). As the majority of biogas facilities that participated in the present study land spread their digestate, its transport represents an important operating cost of an AD facility. However, in the case of on-farm AD, the cost of digestate transport and application offsets the costs of manure application. For all biogas facilities, digestate transport is the third most important operating expenditure after salaries and operations & maintenance, ranging from 10 up to 30% of OPEX.

Competition

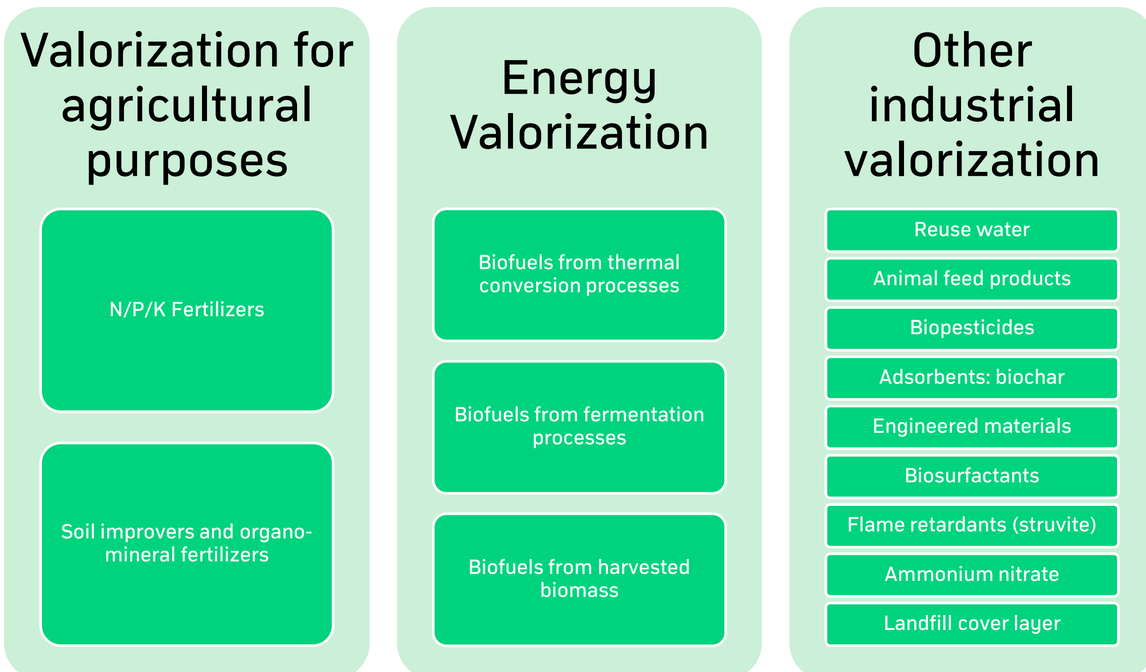
According to the feedback received from the industry, digestate in Canada is suffering from unfair competition coming from compost industry as the digestate is more regulated than compost. This is especially true for the use of digestate as fertilizer.

It is important to note that compost has an established market and is generally accepted by the general public as a soil amendment.

Although the digestate has comparable qualities nutrient wise, its acceptability is lower as compared to compost. The market for the digestate use as fertilizer should be developed, not assumed.

Digestate Valorization Options

In Canada, as well as in other countries, direct spreading of the digestate onto agricultural soils is the most common digestate management strategy. However, digestate can be used to produce value-added products that can be divided into three main groups presented below.



Source: Guilayn et al. (Guilayn 2020)

Agricultural valorization of digestates can be done using several techniques, including membrane filtration, evaporation, N-stripping, P-precipitation, composting and thermal drying. The main challenges of the agricultural valorization are as follows:

Phosphorus-removal at Goodrich Family Farm

To protect the Lake Champlain watershed (Vermont, USA), Goodrich Family Farm is using phosphorus-removing system that extracts the phosphorus from the digestate.

- Majority of technologies are new and still need to be optimized from technical and economic point of view
- Implementation of these processes will require additional capital investments
- The end-use market for these products and marketing of such products from digestate are in development

In North America, digestate treatment - beyond screw press solids removal - is not frequent. Only a handful of projects extract the nutrients in concentrated form. There is as well interest in digestate as input for fertilizing products already on the market, but these projects are at research stage.

Nutrient recovery at Seabreeze Farm

Seabreeze Dairy is operating a Trident nutrient recovery system that separated the digestate into coarse fibrous solids for cow bedding, nutrient-rich cake used as fertilizer and liquid portion used as flush-water in manure handling system.

Although investigated as an option, the valorization of digestate as an energy source seems unlikely if used in direct fermentative processes. However, the use of thermal conversion (combustion, pyrolysis and gasification) is interesting but controversial as they may require high capital expenditures and specific expertise (Guilayn, 2020).

As for the industrial valorization options, the majority is in development and will require optimization to be used as viable digestate treatment options. They are still very expensive and there is no established market for the end-products. Several research teams in Canada (e.g., University of Laval, AAFC Sherbrooke Research Station) have been working on new products from digestate.

Valorization of CO_2

CO_2 is produced when the biogas is upgraded to RNG. In Canada, the main challenges of CO_2 valorization are linked to the smaller size of biogas projects and the weather. So far, there is only one facility in Canada that is using CO_2 in its AD process.

CO_2 derived from biogas upgrading can be applied to three general areas: technological, biological (e.g., CO_2 as a feed stream for microalgae production) and chemical (production of chemical value-added products).

Use of CO_2 in Canada

Surrey Biofuel Facility is using CO_2 to reduce the oxygen content in its anaerobic digester by flushing the generated CO2 through the AD tunnels. This approach reduces the environmental impact of CO_2 and optimizes the AD process of the plant.

The use of CO_2 in greenhouses, called CO_2 fertilization, has potential as controlled environment agriculture is expanding in Canada. Use of CO_2 in macroalgae production or for temperature control, however, the market for this option is still rather limited in Europe. CO_2 utilization for the purpose of algae production creates the potential for supplying additional digester feedstock (2nd generation). This could provide another biomass feedstock with potentially high BMP that does not compete for agricultural land or food crops.

Additionally, CO_2 can be used to produce synthetic methane. As the hydrogen economy grows, synthetic methane production is expected to increase. At present, the cost of splitting water (to obtain green hydrogen) through electrolysis is still expensive.

Another option that is being explored is the CO_2 liquefaction that can be useful for fertilizer production.

OPPORTUNITIES FOR FURTHER RESEARCH

The present project allowed to highlight the major research themes as follows:

1. Detailed feedstock and local energy database and map that provide techno-economic potential of available organic wastes and local energy needs:
    a. Regional database and map, starting with the regions that have already been identified to have the highest biomass concentrations (e.g., Torchlight Bioresources, 2020, Aviseo Conseil, 2019, BC Bioenergy Network, 2022, AAFC VanderZaag and Wellisch, 2021)
    b. Map of local energy users (electricity, natural gas, heat, etc.)
    c. Map of emerging hydrogen hubs (where biogas can be used)
2. Development of life-cycle analysis specific for biogas and RNG industry that can be further used for biogas and other end-product commercialization
3. Measurement of fugitive emissions and leakages at biogas plants and developing best practices and technologies to reduce methane emissions.
4. Techno-economic and systems research into integrated small-scale biogas solutions with local use of produced energy (for projects that do not have connection to the natural gas grid or are too small)
5. Development and commercialization of marketable end-uses for digestate.
6. Development of the resources for industry interaction (network, contacts, lessons learnt, site and virtual tours, sharing of experience) and operator training.
7. Development of benchmarking tools to compare costs, best practices, etc.
8. Research into potential synergies by integrating different renewable methane production methods (e.g., anaerobic digestion, biomass gasification and power-to-methane) that may have the opportunity to drastically reduce the production costs and increase the process efficiency.
9. Research fate of plastics in digester systems and measures to avoid microplastics addition to soils
10. Explore the use of energy crops, crop residues and cover crops for biogas production

It is important to note that there are many more fields of AD research that can be beneficial for Canadian biogas and RNG sector. Some research should be done by the universities and some by stakeholders of the industry. Having research chairs in key areas, such as organic waste or digestate, can be good options to tackle part of the research. Specific mandates can be tackled by consulting firms.

Overall, investment-wise, depending on the priorities and the extend of the research, the funding requirements will vary, but it will be safe to assume that there is a need for funds injection of several million into research facilities and studies.

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APPENDIX 1.
CAPEX OF FARM BIOGAS PLANTS

CAPEX OF FARM BIOGAS PLANTS

City	Province	Project name	Status	Date - start of operation	Waste treated	Waste (t/year)	Biogas Usage	GJ	kW	Cost ($CAD) Actual	Cost ($CAD) Adjusted to 2021 dollar value
Coaldale	AB	GrowTEC/ McCain Foods	Online	2014	65% Manure, 35% Organic cull and waste	17,000	CHP	N/A	633	$ 7,200,000	$ 8,050,000
High River	AB	Cargill Meat Solutions	Online	2011	Beef processing facility (wastewater treatment)	N/A	Heat	N/A	1400	$ 36,000,000	$42,350,000
Lethbridge	AB	Lethbridge Biogas	Online	2013	Manure, ag proccessing waste, grocery organics	90,000	CHP	N/A	4200	$ 30,000,000	$33,960,000
Acme	AB	Korova Feeders Ltd.	Substantial Development	2022	Organic waste	N/A	RNG	N/A	N/A	$ 20,400,000	NA
Vegreville	AB	Highmark Renewables Biogas Project	Offline	2005	Organic waste (manure)	36,200	CHP	N/A	1000	$ 6,900,000	$ 9,067,300
St. Andre	NB	Laforge Bioenvironmental	Online	2011	Manure, potato skins	40,000	CHP	N/A	N/A	$ 7,000,000	$ 8,200,000
St. David's	NF	New World Dairy	NA	2010	Organic waste (cow manure)	N/A	CHP	N/A	N/A	$ 5,000,000	$ 5,900,000
Shubenacadie	NS	Windmill Holsteins Inc.	Online	2014	Organic waste (cow manure)	11,000	CHP	N/A	500	$ 3,000,000	$ 3,400,000
Weaver Settlement	NS	Southwest Ecoenergy	Offline	2015	Organic waste (mink manure)	N/A	CHP	N/A	N/A	$ 850,000	NA
Beachville	ON	Harcolm Farms	Online	2018	Manure	N/A	CHP	N/A	20	$ 395,000	$ 414,000
Cambridge	ON	Delft Blue Veal	Online	2010	Organic waste (veal manure and FOG)	N/A	CHP	N/A	N/A	$ 2,500,000	$ 3,000,000
Dundalk (Southgate)	ON	Mattawa Renewable Power Corp.	Substantial Development	TBD	Commercial & industrial food waste and agricultural waste (silage, tover, culled material from vegetable and tuber crops and animal manure)	73,000	RNG	N/A	400	$ 32,000,000	NA
Embro	ON	Greenholm Power 2	Online	2012	Organic waste (manure and off-farm organic)	30,000	CHP	N/A	250	$ 2,000,000	$ 2,300,000
Lemington	ON	Seacliff Energy	Online	2011	Organic waste (and SSO)	60,000	CHP	N/A	3200	$ 6,500,000	$ 7,600,000
Lindsay	ON	Maryland Farms	Online	2013	Organic waste (manure)	N/A	CHP	N/A	250	$ 2,000,000	$ 2,300,000
Millbrook	ON	CCS-agriKomp	Online	2011	Organic waste (manure, corn silage and waste fats, oils and grease from nearby restaurant)	N/A	CHP	N/A	100	$ 1,000,000	$ 1,200,000
Tecumseh	ON	O NEIL biogas	Online	2016	Organic waste (cow waste)	N/A	CHP	N/A	250	$ 3,000,000	$ 3,300,000
Toronto	ON	Zoo Share	Online	2021	Organic waste (2,000 tonnes zoo manure and 15,000 tonnes grocery store organic waste)	17,000	CHP	N/A	500	$ 5,400,000	$ 5,400,000
Summerside	PEI	Cavendish Farms	Online	2009	Organic waste (potato waste)	120,000	CHP	N/A	N/A	$ 25,000,000	$30,500,000
Baie-St- Paul	QC	Laiterie Charlevoix	Online	2011	Wastewater	25,000	Direct use	N/A	N/A	$ 2,700,000	$ 3,200,000
Bedford (Rivière-du-Loup)	QC	Bonduelle	Online	2015	Organic waste	30,000	Flare	N/A	N/A	$ 25,000,000	$27,700,000
Bromont	QC	Bromont	Substantial Development	2022	Organic waste	45,000	RNG	150,000	N/A	$ 28,000,000	NA
Farham	QC	Nature Energy	Concept	2023	Organic waste	750,000	RNG	N/A	N/A	$100,000,000	NA
Saguenay	QC	Agriméthane Saguenay	Substantial Development	2024	Organic waste	60,000	RNG	100,000	N/A	$ 25,000,000	NA
Ste-Sophie-de-Levrard	QC	Groupe Bioénertek inc.	Substantial Development	2023	Organic waste (from farms)	N/A	RNG	60,300	N/A	$ 16,300,000	NA

APPENDIX 2.
BIOGAS PLANT EQUIPMENT PRICE RANGE

Biogas Equipment Costs, Adjusted to 2021 Dollar Value

Equipment	CAD/tonne of organic waste	Farms, CAD	SSO/WWTP, CAD
Biogas system (tanks, mixing)	23 - 180	229,000 – 4,500,000	7,300,000 – 12,500,000
Feedstock pretreatment	0.6 – 460	Insufficient	Insufficient
Instrumentation and controls	8 - 63	Insufficient	Insufficient
Biogas upgrading	22-224	2,200,000 – 5,600,000	2,600,000 – 8,000,000
CHP unit	52-60	600,000 – 1,300,000	Insufficient
Flare	1 - 7	15,000 – 84,000	Insufficient
Injection station (RNG)	18-22	500,000 - 900,000	Insufficient
Odour treatment	22 - 61	Insufficient	2,600,000 – 7,300,000

Note 1: The data presented in this table has been collected as part of the study on the best practices for reducing costs of anaerobic digestion of organic waste and increasing the valorization of biogas and digestate

Note 2: Due to confidentiality requirements, some data on costs cannot be shared. It is marked as "insufficient" in the table.

Note 3: Cost adjustments to 2021 dollar value have been done using the Inflation Calculator of the Bank of Canada

APPENDIX 3.
DETAILS OF MAC CALCULATIONS

MARGINAL ABATEMENT COST OF ANAEROBIC DIGESTION – ASSUMPTIONS

The marginal abatement cost (MAC) calculated in the present study used the following formula:

$$\text{Marginal Abatement Cost (\$/t CO2e)} = \frac{(\text{Cost of AD scenario} - \text{Cost of base scenario})}{(\text{GHG of AD scenario} - \text{GHG of the base scenario})}$$

RNG compared to natural gas

The cost of AD scenario

- The cost of AD scenario was determined by using the following formula:

$$Cost\ of\ AD\ scenario = \frac{CAPEX}{Project\ lifetime} + Annual\ OPEX$$

- Project lifetime is assumed to be 20 years
- If the refence plant was built several years ago, available CAPEX was adjusted using the Inflation Calculator of the Bank of Canada.
- Where the OPEX of the plant was not available, 5% of CAPEX was assumed

The cost of base scenario

It was assumed that the base scenario cost will equal the cost of natural gas production (CAD 4 in 2021) per Economic Dashboard of Alberta.

GHG emissions of AD and baseline scenarios

- For projects that treat SSO, GHG emissions have been calculated using Organic GHG Calculator in development by Environment and Climate Change Canada
- GHG emissions for the scenario of natural gas production are based on the average CI of 79 g CO2 eq./MJ (EPA, 2021)
- GHG emissions of manure are based on technical document on potential project of regulation related to the projects using anaerobic digestion to treat manure (MELCCC, 2022)

AD scenario compared to organics landfilling

The cost of AD scenario

- The cost of AD scenario was determined by using the following formula:

$$Cost\ of\ AD\ scenario = \frac{CAPEX}{Project\ lifetime} + Annual\ OPEX$$

- Project lifetime is assumed to be 20 years
- If the refence plant was built several years ago, available CAPEX was adjusted using the Inflation Calculator of the Bank of Canada.
- Where the OPEX of the plant was not available, 5% of CAPEX was assumed

The cost of baseline scenario (landfilling)

Costs of landfilling the organic waste for projects that treat SSO were estimated using the tipping fee of CAD$100 per tonne for all provinces. No cost of transport was included in the landfilling cost assessment. The landfilling cost for agricultural projects assume the landfill cost only for off-farm waste.

For farm projects, it was assumed that the only the off-farm waste can be sent to the landfill (at the cost of CAD$100 per tonne for all provinces). The alternative to the manure disposal is the direct storage and use of manure as fertilizer, thus no costs were associated with this option.

GHG emissions of AD and baseline scenarios

- For projects that treat SSO, GHG emissions have been calculated using Organic GHG Calculator in development by Environment and Climate Change Canada
- GHG emissions of manure are based on technical document on potential project of regulation related to the projects using anaerobic digestion to treat manure (MELCCC, 2022)

APPENDIX 4.
DETAILS OF LCOE CALCULATIONS

Levelized cost of energy for biogas utilization

The levelized cost of energy (LCOE) calculated for the present report analyzed two types of biogas utilization: electricity and RNG production.

Due to the limits of data collected from actual biogas projects in Canada, it was decided to calculate annual LCOE (vs. modelling over the lifetime of the project). The following formula was used

$$Levelized\ cost\ of\ energy\ (\$/kWh)\ = \frac{Cost\ of\ AD\ project}{Electrical\ energy\ produced}$$

The cost of AD scenario

- The cost of AD scenario was determined by using the following formula:

$$Cost\ of\ AD\ project = \frac{CAPEX}{Project\ lifetime} + Annual\ OPEX$$

- Project lifetime is assumed to be 20 years
- If the project was built several years ago, available CAPEX was adjusted using the Inflation Calculator of the Bank of Canada.
- Where the OPEX of the plant was not available, 5% of CAPEX was assumed

Electrical energy produced

- For the calculation, the data for four CHP and five RNG projects was used

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