
# ANAEROBIC DIGESTION

## Pathways for using waste as energy in urban settings

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# 1. Executive Summary

The City of Vancouver established the *2020 Greenest City Action Plan* as a roadmap for addressing priority actions. This report focuses on two of these goals; zero waste and community GHG emissions. A potential means in meeting these goals is the use of anaerobic digestion within the City boundary. This process would utilize organics that would otherwise be sent to the landfill to produce biogas, a low carbon energy source which could then be used in place of natural gas for hot water and heating.

There were approximately 108,000 tonnes of food waste sent to the Vancouver landfill in 2013, a slight decrease from 2012 when 110,000 tonnes of food waste were disposed of at the landfill. Additionally, nearly 50% of all community GHG emissions are due to natural gas use for heating and hot water. The purpose of this study was to investigate the feasibility of an anaerobic digestion system in the City of Vancouver.

The findings indicate that anaerobic digestion of organics from solid waste for energy is not only practiced in many parts of the world, but can be found in major cities, such as Toronto and Chicago. Additionally, anaerobic digestion could help the City of Vancouver achieve the Greenest City targets of zero waste by diverting the estimated 108,600 tonnes of food waste still sent to the Vancouver landfill, more than half of the remaining 184,000 tonnes to be diverted in order to reach the 2020 target. This is further aided by regional policies such as the organics ban, and the use of biogas as a substitute fuel for natural gas offers additional incentives by creating a sustainable drop-in fuel that also helps the City achieve GHG reduction targets. However, the analysis also indicates that a reduction in GHG emissions can only be achieved if the digestate is used as a substitute for artificial fertilizers. Lastly, the economic analysis indicates that a single facility utilizing 108,600 tonnes of food waste per year would have a capital cost of approximately $34 million and an annual operations cost of $23/tonne. If these digesters were established to function as neighborhood energy systems with an annual capacity of 40,000 tonnes, the capital cost would be approximately $20 million with an annual operations cost of $44 per tonne. Additionally, neighborhood energy system size like this avoid additional costs of upgrading the biomethane for injection into the natural gas infrastructure which can cost $6.21/GJ or higher.

Anaerobic digestion of food waste is a sensible option considering the organics ban going into effect. However, in order for anaerobic digestion to be a viable option as a neighborhood energy system there are some roadblocks that need to be in addressed. The most important roadblock is the current low price of natural gas which in turn creates uncertainty around the price of biogas in the region through the biomethane program offered by FortisBC. It is important to note that with any nascent program there is a learning curve and time is required for this program to gain momentum. The city could also take a proactive stance in formulating policy by establishing guidelines for development of anaerobic digestion that address issues such as air emissions and transportation routing through neighborhoods. Additionally, utilizing the mobile anaerobic digester currently located at Harvest Power at public events could familiarize the public with the technology. Lastly, the co-mingling of food waste with yard waste and wood waste detracts from optimum anaerobic digestion system parameters.

Anaerobic digestion is a promising technology and it is the recommendation of this report that the City of Vancouver address roadblocks to adoption, and also further investigate the biogas potential from City of Vancouver waste sources. Additionally, investigating the use of alternative technologies such as pyrolysis and gasification could show where a synergistic relationship might exist. An integrated system that produces large volumes of biogas and more efficiently decreases the volume of organic material at the end of the process while being able to handle food waste, yard waste, and wood waste might be worth pursuing.

In conclusion, there are several pathways that the City of Vancouver could take to put itself in a better position to explore the use of anaerobic digestion:

**Short-term:**

- Conduct a thorough waste characterization study that is restricted to the CoV
- Identify the waste materials which are most amenable to anaerobic digestion
- Conduct an in-depth economic analysis assessing the role of biogas price, carbon credits, and tipping fees that could demonstrate additional economic benefits
- Investigate the challenges of other renewable systems such as gasification as a primary source of waste processing in tandem with anaerobic digestion
- Identify green leaders in the community that can encourage adoption and build political support
- Develop education programs and organize seminars targeting pre-sorting, recycling, and reuse behavior

**Medium-term:**

- Work with Metro Vancouver and the provincial government to develop codes and regulations that would serve as a guide for development of anaerobic digestion in urban areas
- Investigate the use of property tax, by-laws, increased tipping fees, and connection policies that encourage diversion of organics for waste-to-energy purposes

**Long-term:**

- Encourage national policy that creates secure cost competitive measures similar to those in Europe
- Develop a green certification system that encourages the use of renewable energy by ensuring waste is diverted in the best appropriate manner and by adopting an eco-logo that symbolizes the efforts of residents and businesses

## 2. Acknowledgements

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# 4. Glossary and Acronyms

| | |
|---|---|
| AD | Anaerobic Digestion |
| BC | British Columbia |
| BCUC | British Columbia Utilities Commission |
| Biomethane | Biogas that has been upgraded to natural gas quality |
| CHP | Combined Heat and Power |
| CoV | City of Vancouver |
| CSTR | Continuously stirred tank reactor |
| DE | District Energy |
| Digestate | Material produced from the anaerobic digestion process |
| FEI | Fortis Energy Incorporated |
| FIT | Feed-in tariff, a government policy that encourages renewable energy development through long-term agreements and guaranteed pricing |
| GCAP | Greenest City Action Plan |
| GHG | Greenhouse Gas |
| GJ | Gigajoule |
| ICI | Institutional, Commercial, and Industrial |
| IPCC | Intergovernmental Panel on Climate Change |
| ISWRMP | Integrated Solid Waste and Resource Management Plan (Metro Vancouver) |
| kW | Kilowatt |
| kWh | Kilowatt hour |
| kWhe | Kilowatt hour electrical |
| kWht | Kilowatt hour thermal |
| LCA | Life-cycle Assessment |
| LCOE | Levelized Cost of Energy |
| MF | Multi-Family |
| MJ | Mega joule |
| MSW | Municipal Solid Waste |
| MWh | Megawatt hour |
| MWhe | Megawatt hour electric |
| MWht | Megawatt hour thermal |
| NES | Neighborhood Energy Systems |
| NPV | Net Present Value |
| OFMSW | Organic Fraction of Municipal Solid Waste |
| PJ | Petajoule |
| RNG | Renewable Natural Gas |
| RPS | Renewable portfolio standards, a government policy that encourages renewable energy development typically through requiring a percentage of electricity generated to come from renewable sources |
| SF | Single Family |

| | |
|---|---|
| TS | Total solids, also known as dry matter (DM), is the percentage of all dry material |
| VLF | Vancouver Landfill in Delta, BC |
| VS | Volatile solids, also known as organic dry matter (ODM), is the % (VS) or g/l (ODM) of material that is organic |
| WTE | Waste-to-Energy |
| WWTP | Wastewater Treatment Plants |

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# 7. Introduction

Anaerobic digestion (AD) is a technology used commonly in both agricultural and wastewater treatment settings to process the sectors concentrated organic waste streams. The first known AD plant was built in France in 1891 known as the Mouras Automatic Scavenger [1]. Within four years' time, the concept of anaerobic digestion would be utilized within a WWTP to produce heat and light from the biogas. Since the 1970's, MSW has been used as a feedstock, typically mixed with sludge from a WWTP to produce biogas [2].

Historically, due to waste collection practices, urban environments have commonly lacked the concentrated supply of organic material required for AD, however; in Vancouver this is changing. Approximately 40% of Vancouver's solid waste stream is currently made up of compostables [3], the collection of which has been identified as the greatest near-term opportunity for meeting the City's Greenest City 2020 Action Plan (GCAP) zero waste goal [4]. In response, the City has already successfully rolled out a food scrap and garden waste collection program for single family residents. Building off the success of this program, and the upcoming Metro Vancouver landfill organics ban [5], the collection and diversion of organics from landfill is expected to ramp up in the coming years.

With the CoV's GCAP outlining targets specific to both solid waste and GHG emission reductions (Table 1), AD offers a potential synergistic solution to achieving these goals. Organic waste would be diverted from the VLF and the local utilization of biomethane could generate thermal energy for a Neighbourhood energy system, clean electricity put into the grid, or be incorporated directly into the gas pipeline.

| POLICY | TARGET |
|---|---|
| GCAP Solid Waste | Reduce solid waste sent to the VLF by 50% from 2008 levels by 2020 (baseline 480,000 tonnes) |
| GCAP GHG | Reduce community-based GHG emissions by 33% from 2007 levels by 2020 (baseline 2,750,000 $tCO_2e$) |
| Metro Vancouver organics | Beginning in 2015, all organics banned from the VLF |

*Table 1: Identified Policy Drivers Supporting Anaerobic Digestion*

In response to an emerging urban organic waste feedstock and ambitions for reduced GHG emissions, the purpose of this study was to examine the challenges and assess the economic and technical feasibility of an urban AD system in Vancouver.

## 7.1. Research Objectives

The overarching question of this project is: **What is the current state of anaerobic digestion around the world, and what factors influence the development of these system in urban settings?**

To answer this question several objectives were investigated. These are:

1. Conduct a resource assessment to characterize the organic fraction of MSW
2. Conduct a needs assessment to identify what services anaerobic digestion could meet
3. Conduct a screening study of anaerobic digestion facilities around the world
4. Identify risks and benefits associated with the development of an anaerobic digestion

This report will provide an overview of the feasibility of locating, building, and operating an AD facility within the CoV, and under what conditions would a system prove most successful. A description of the methodology used in this analysis can be found in Appendix A: Methods and Data.

## 7.2. Anaerobic Digestion

During decomposition, microbes break down organic material and this process produces methane [6]. This occurs anaerobically, without the presence of oxygen. Different from an aerobic process, similar to a backyard compost pile, anaerobic decomposition frequently occurs in burial sites or at the bottom of lakes. Both of these processes release nutrients and gases back to the environment, however, the AD process can be conducted in a closed vessel. This allows for easier collection of outputs such as gases like methane, and digested material like compost and liquid fertilizer. Additionally, the anaerobic process produces less biosolids. The organic material for this process can be manure from animals, plant material, or food waste [7]. For the purposes of this report, specific attention will be paid to food waste. Food waste is an ideal material for anaerobic digestion because of the high degradability.

The process of converting food waste into methane and digestate typically begins with shredding of the food waste to ensure similarity in size. Following this, the food waste is added to the digester where the material undergoes the four phases of digestion as shown below [8].

- **Hydrolysis** – In this stage carbohydrates, proteins, and fats are broken down into simple sugars, amino acids, and fatty acids.

- **Acidogenesis** – The simple sugars, amino acids, and fatty acids from the first phase are converted into alcohols, organic acids, and hydrogen and carbon dioxide by acidogenic bacteria.

- **Acetogensis** – The products of the previous phase are used as a food source for acetogenic bacteria, and are converted into acetic acid, hydrogen, and carbon dioxide.

- **Methanogenesis** – Methanogen bacteria use acetic acid from the previous phase, and convert this into methane, carbon dioxide, and water. Methane is a valuable compound which can be used to generate power. Additionally, the digestate from the process can be utilized as a soil amendment, or further refined for beneficial purposes.

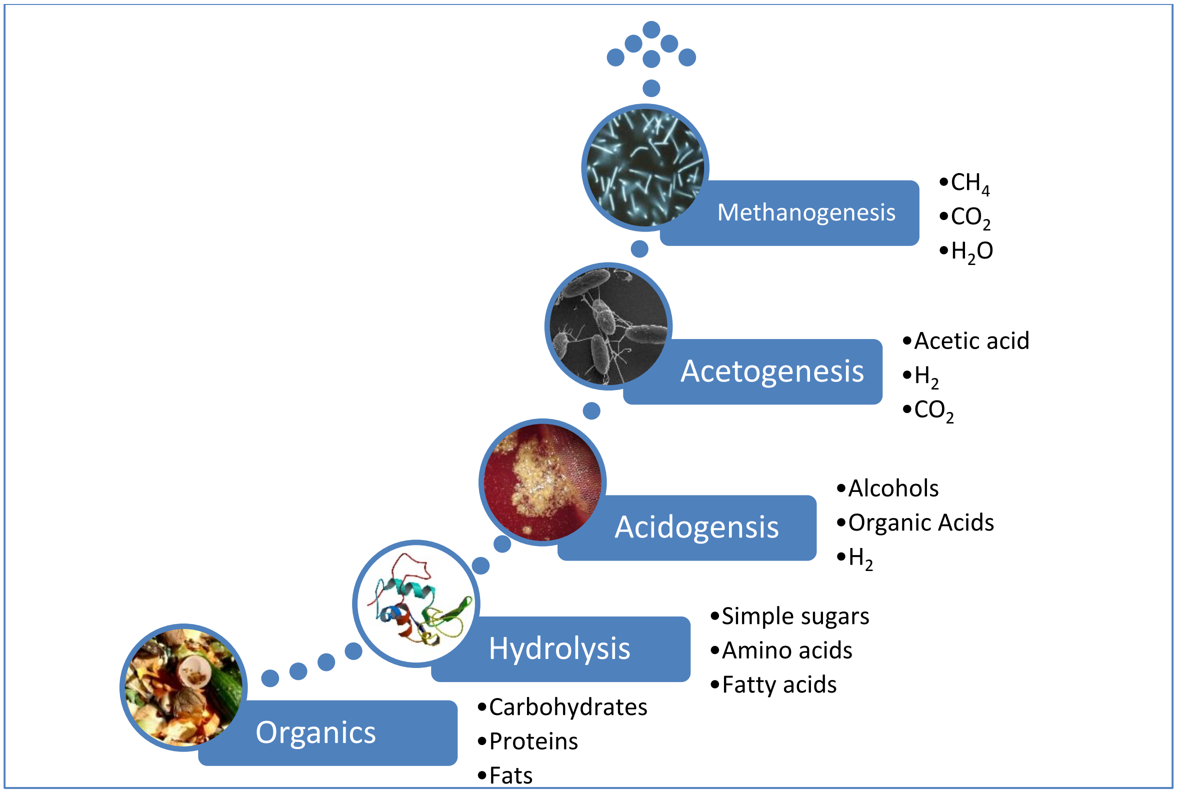


*Figure 1: Anaerobic digestion process*

## 7.3. Benefits and Tradeoffs

The benefits and tradeoffs associated with AD are summarized below [6] [9] [10] [11]:

| **BENEFITS** | | **TRADEOFFS** | |
|---|---|---|---|
| Useful byproducts | Biogas<br>Solid and liquid digestate | Susceptible to: | Changes in feedstock characteristics |
| GHG Minimization | | | Contamination of feedstock with non-organic material |
| Less expensive then incineration | | More expensive than landfilling | |
| AD process is capable of destroying pathogens | | Biogas requires upgrading if it is to be injected into natural gas pipeline | |
| Reduces initial volume of MSW | | Large volume of digestate to handle and dispose of | |
| Controls odours | | Digestion takes place over several weeks | |
| Space requirement of AD facility is low | | Feedstock & digestate may require storage | |

*Table 2: Pros and Cons of anaerobic digestion*

## 7.4. Types of Anaerobic Digestion around the World

There are many types of anaerobic digesters on the market for use with food waste. These include: one-stage continuous, two-stage continuous, and batch systems [12]. The continuous processes are the most widely used and require feedstock, such as food waste, to be added to the digester frequently. Some AD systems only use one digester whereas others use several to ensure each phase of the AD process is optimized. Batch systems are utilized to even out the production of biogas by staggering different AD process phases.

In addition to the layout of the AD system, the process can be further distinguished by the temperature of the operation, and the solids content of the feedstock [7]. At temperatures between 30-40°C the process is called mesophilic and at temperatures between 53-58°C the process is called thermophilic. Thermophilic systems produce biogas earlier and at a higher rate compared to mesophilic systems, but they also require higher capital costs. Wet AD systems are typically those with solids of 15% of less, and dry AD systems have solids content ranging from 20-45% [11]. Overall, there are more dry systems then wet, and more single stage then multi-stage and batch systems [13].

An accurate number of AD systems in the world is difficult to measure. Many sources cite Europe as having the majority, however, international development programs have built over 579,000 AD systems of various size and complexity in 18 developing countries [14]. While this far exceeds the number in Europe, the region does have a strong history of AD use. Many of the AD facilities in Europe today can be found in Germany, which has approximately 7,000 facilities, most of which are located on farms [15].

While most AD facilities in Europe use wastewater or manure as feedstock, there are an estimated 244 systems that use MSW as a feedstock [16]. This is a large increase from the estimated 74 AD systems in Europe, as shown in Figure 2, using MSW in 2005 [17], and the nearly doubling of this to 127 facilities a year later [18]. Figure 3 shows the total installed capacity, and average installed capacity of these 244 AD systems [16]. Germany, which has a total annual capacity of 2 million tons (1.8 million tonnes), and an average annual capacity per plant of 23,000 tons (20,800 tonnes).

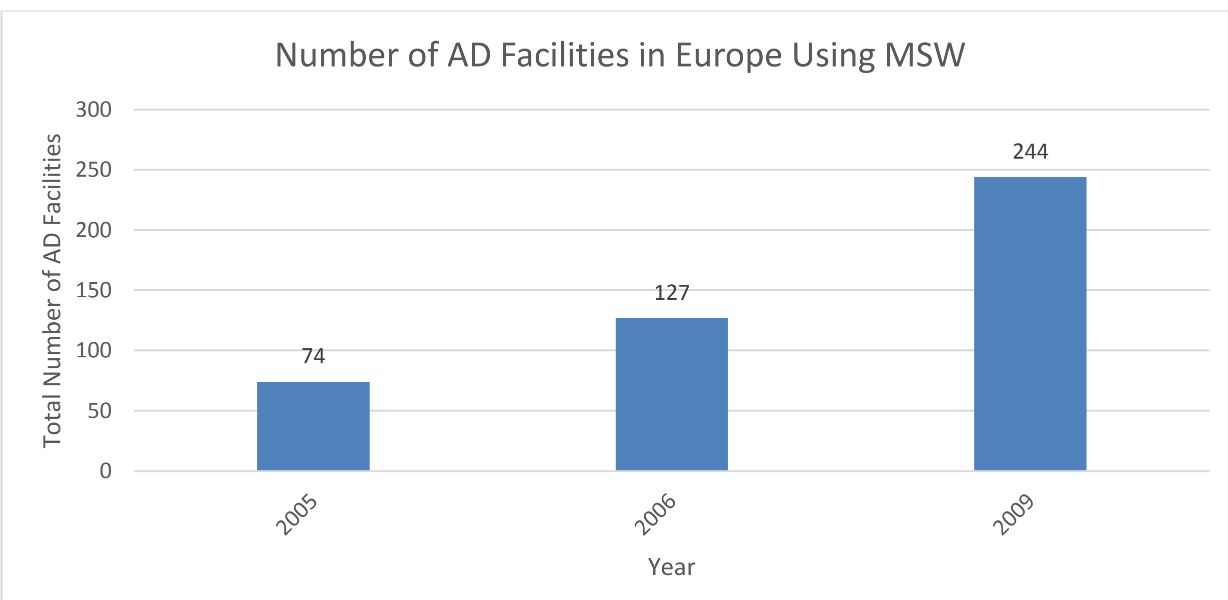


*Figure 2: Growth of AD facilities in Europe utilizing MSW from 2005 to 2009*

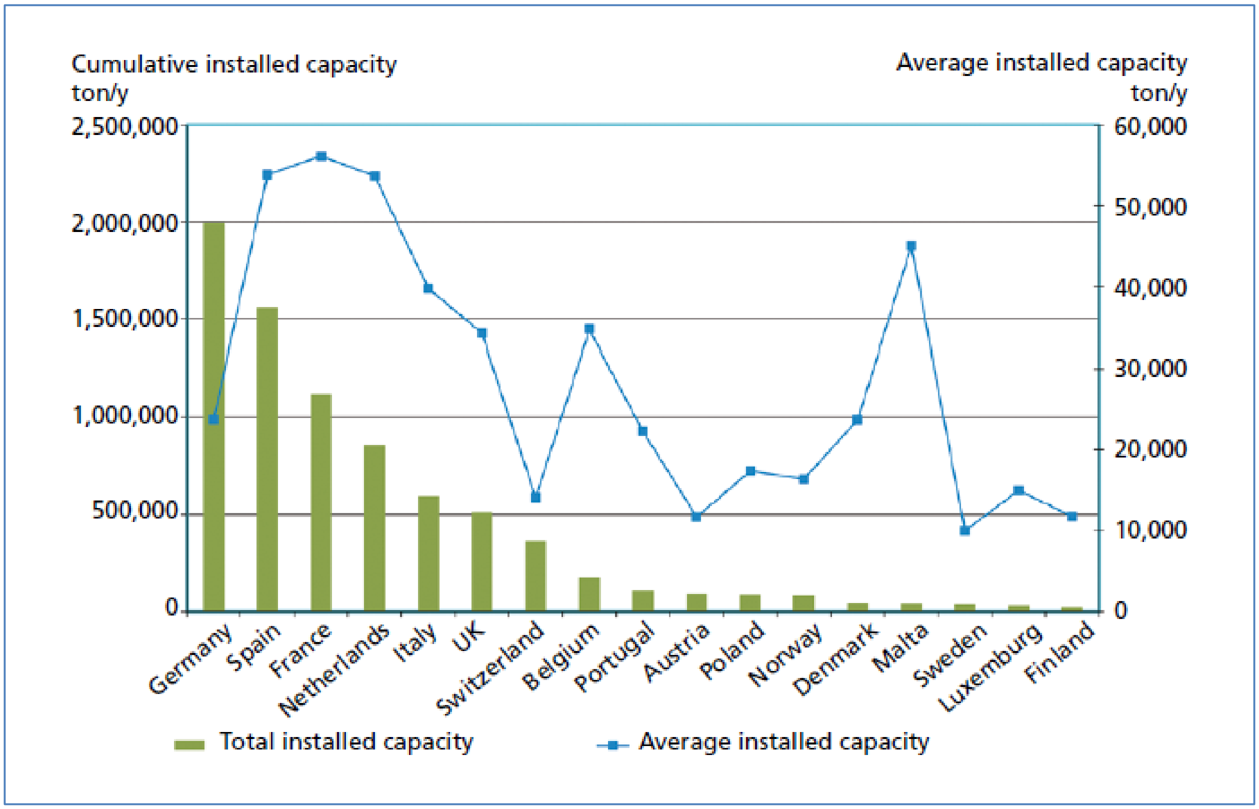


*Figure 3: Total installed capacity as of 2009. Source 1:* [16]

The large increase of AD installations and capacity is largely driven by regulatory and policy incentives. As Table 3 shows, there are a variety of drivers including FITs and RPS, and such drivers can be found around the world. All of these policies listed focus specifically on the development of AD systems, and the absence of Canada and the US are noticeable. However, several US States and Canadian Provinces have now adopted similar policies. One of the earliest pioneers in implementing landfill bans of organic waste is the State of Massachusetts[1]. The ban goes into effect on October 1, 2014, and to encourage development of AD systems the State is also offering $1 million in grants, and $3 million in low interest loans. The State of Vermont[2] and the State of Connecticut[3] have replicated the Massachusetts legislation. The Vermont legislation was passed in 2012 with the 2014 as the year the law went into effect. Unlike the Massachusetts legislation, the Vermont bill implemented a stepwise approach affecting only facilities that produce >104 tons/year and eventually including all commercial and residential users by 2020. Additionally, the law increased the pay-as-you-throw fee from $3 to $6 per 32 gallon bag. It should also be noted, that just recently, the US EPA announced that RNG form AD of MSW can now be considered as part of the renewable fuel standard. This change is a step in promoting the use of biogas from AD of MSW since the biogas produced from this process can now enter new markets that were previously constrained to ethanol based fuels.

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[1] http://www.mass.gov/eea/agencies/massdep/recycle/solid/massachusetts-waste-disposal-bans.html
[2] http://www.rutlandcountyswac.org/Assets/pdfs/Spencer%20Act%20148%20Article%202014.pdf
[3] http://www.ct.gov/deep/cwp/view.asp?a=2718&q=325464&deepNav_GID=1646%20

| Country | Target |
|---|---|
| Austria [19] | No national renewables target<br>200,000 cars will be using natural gas, with 20% RNG by 2020 |
| Bangladesh | 4 MW of biogas by 2014<br>150,000 AD plants by 2016 |
| France [19] | 2% of total gas consumption will come from RNG by 2020 |
| Germany [19] | 6% of total gas consumption will come from RNG by 2020<br>10% of total gas consumption will come from RNG by 2030 |
| Lebanon [14] | 15-25 MW of biogas by 2015 |
| Mozambique [14] | 1,000 AD plants (no installation date) |
| Portugal [14] | 59 MW of biogas by 2020 |
| Rwanda [14] | 300 MW of biogas by 2017 |
| South Korea [14] | 161 GWh of biogas (non-landfill gas) by 2030<br>1,340 GWh of biogas from landfill by 2030 |
| Spain [14] | 400 MW of biogas by 2020 |
| Sudan [14] | 150 MW of biogas by 2031 |
| Thailand [14] | 600 MW of biogas by 2021 |
| The Netherlands [19] | Biomethane FIT of 202 ktoe (2.3 TWh/y) by 2015<br>Biomethane FIT of 582 ktoe (6.8 TWh/y) by 2020 |
| United Kingdom [19] | Injection of 7 TWh/y of RNG by 2015 (1.5% of total gas consumption) |

*Table 3: Regulatory and Policy drivers of AD in several countries*

# 8. Results

The results were collected in an iterative manner, with information from one objective informing the scope and direction of analysis in another. For example, investigating the risks and benefits, in particular costs, also aided the investigation of needs in selecting what services AD could best support.

## 8.1. Local Resource Assessment

In the 2013, the VLF handled 416,947 tonnes of MSW, a decrease from 468,975 tonnes of MSW in 2012 [20]. Approximately 40% of MSW consists of food scraps and food soiled paper [3]. The CoV instituted the food scraps recycling program in 2010, with a pilot program beginning in 2011. In September of 2012, the food scraps recycling program was increased to include all single family and duplex residents. In 2013, an estimated 39,000 tonnes of yard and food waste was diverted from the VLF [21]. These diverted organics from SF homes are predominantly yard waste (95%) with relatively little food scraps (5%) [3]. However, in 2015, Metro Vancouver's regional ban on all organics from the VLF will be implemented. It is expected that the organics collected from multi-family and commercial operations will be predominantly food waste since these establishments rarely have yards to maintain.

Based on information provided by Patrick Chou of the CoV, there is an estimated 108,600 tonnes of food waste sent to the VLF that could be captured. A breakdown of the sources of this waste are presented in Figure 4. Of particular note is the quantity of food waste generated by

MF units. There are approximately 5,000 MF buildings housing 160,000 suites [21]. Currently, the CoV is developing plans for the 1,300 buildings serviced by CoV waste collection, and working with the private haulers who service the remaining 3,800 buildings.

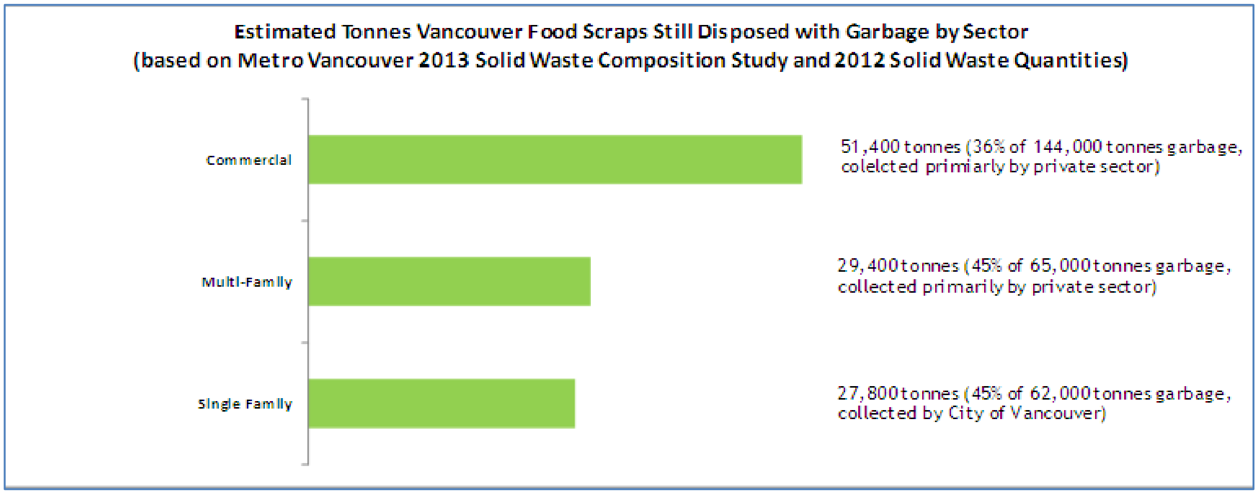


*Figure 4: Tonnes of food scraps from three sectors still sent to the Vancouver landfill Source 2: Patrick Chuo City of Vancouver*

Based on this, the biogas yield potential of these uncaptured organics was calculated using the equation provided by UC Davis[4] and assumptions listed in Table 4: Assumptions for biogas yield calculation below:

$$Biogas\ Yield = TS * \ MP * \ MC * ME$$

Where:
$TS = Total\ solids\ wet\ (kg)$
$MP = Methane\ production\ (m^3/kg)$
$MC = Methane\ content\ (\%)$
$ME = Methane\ \ calorific\ value\ (MJ/m^3)$

| Assumptions based on peer-reviewed journals on food waste characteristics [22] | |
|---|---|
| Total solids wet | On average is 30.9% |
| Methane production | Varies, but a conservative figure is 0.31 $m^3$/kg |
| Methane content | Varies, but a conservative figure is 55% |
| Methane calorific value | 35.7 MJ/$m^3$ |
| Conversion efficiency to electricity | 32% |
| Heat recovery efficiency using engine jacket | 35% |
| Heat recovery efficiency using engine exhaust | 18% |
| Conversion efficiency to heat | 85% |

*Table 4: Assumptions for biogas yield calculation*

The potential annual biogas yield is 204,258,860 MJ/year, which equates to 155,448 kWh. Using the biogas in a CHP system; 2,072 kW of electricity, and a combined 3,432 kW of

4 http://biomass.ucdavis.edu/tools/energy-cost-calculator/

hot water could be produced. If the biogas were to be used for hot water purposes only 5,505 kW of thermal energy could be produced.

It should be noted that there are varying reported values on the total solids wet, methane production, and methane potential of various biomass types. This includes different values reported for food waste. The reason for this is due to the large variation in waste characteristics. For example, fats and grease have a higher energy density than green leafy vegetables. A digester that has greater amounts of fats will tend to outperform a digester with greater amounts of leafy vegetables. Furthermore, information on characteristics of waste in the CoV was not available. However, a waste characterization study for the Metro Vancouver area was conducted in 2013 [23]. The study sampled four facilities including; the Surry Transfer Station, the Metro Vancouver WtE facility, the Vancouver South Transfer Station, and the North Shore Transfer Station. Samples were taken at the Vancouver South Transfer Station between August 19-24, 2013 and November 25-29, 2013. Appendix B: Waste Characterization for the City of Vancouver gives an overview of the findings for the sampling conducted pertaining to the CoV. Of particular note is that there were no multi-family residences in the CoV included in the study. Of the 29 samples representing the CoV; 10 are from drop-off, 11 are from ICI, and eight are from SF residences. All these samples combined resulted in a total mass of 2763 tonnes of which food waste represented 22.4% of the total (619.5 tonnes), yard waste represented 1% of the total (29.85 tonnes), and clean wood represented 2.8% of the total tonnes (78.9 tonnes).

In addition to the volume of food waste available, there is also a mobile anaerobic digestion unit available that is currently in the care of Harvest Power [24]. The mobile unit, as shown in Figure 5, was built with partial funding from the BC Bioenergy network with the intent to demonstrate the feasibility of anaerobic digestion, and then to be toured around North America. The size of the unit is small enough to fit inside a standard shipping container for easy transport.

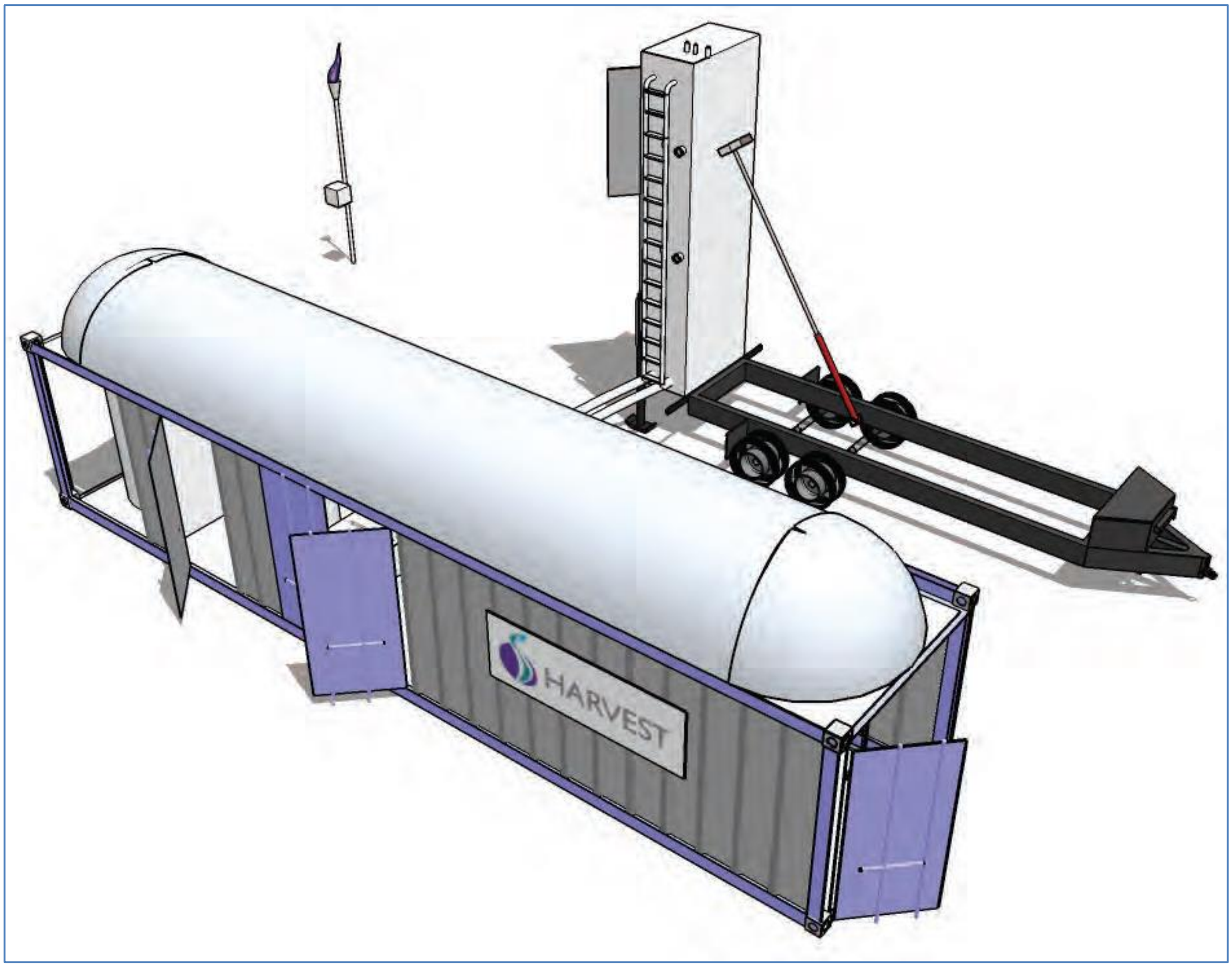


*Figure 5: Graphic of the mobile anaerobic digestion unit*

## 8.2. Local Needs Assessment

Currently, the CoV has outlined a reduction of community GHGs by 33% from 2007 levels by 2020 [4]. The most recent estimate shows a decrease from 2007 levels of 2,750,000 $tCO_2e$ (tonnes of $CO_2$ equivalent) to 2,585,000 $tCO_2e$ in 2013, a 6% decrease [21]. In addition to a reduction of community GHGs, the CoV has also indicated a goal of reducing MSW sent to the VLF or incinerator by 50% from a 2008 total of 480,000 tonnes by 2020 [4]. The most recent data, indicated there has been a 12% reduction (56,000 tonnes) to 424,000 tonnes in 2013 [21]. The vast majority of this reduction, 39,000 tonnes, was due to the implementation of the green bin program in SF homes. While there has been progress made, the CoV still needs to work on meeting these two goals.

Of the community GHGs emitted in Vancouver for 2010, 6% came from solid waste, 46% came from on-road transportation, and 48% came from buildings as shown in Figure 6 [25]. Of the GHGs emitted by buildings, residential and commercial/industrial natural gas use accounts for nearly 90%. Natural gas use in buildings consumed 19,767,143 GJ to provide heat and hot water, and this consumption resulted in the emission of 991,521 $tCO_2e$. Capturing the food waste still sent to the VLF, converting it into biogas, and substituting the natural gas used in buildings with biogas would aid in reducing these GHG emissions.

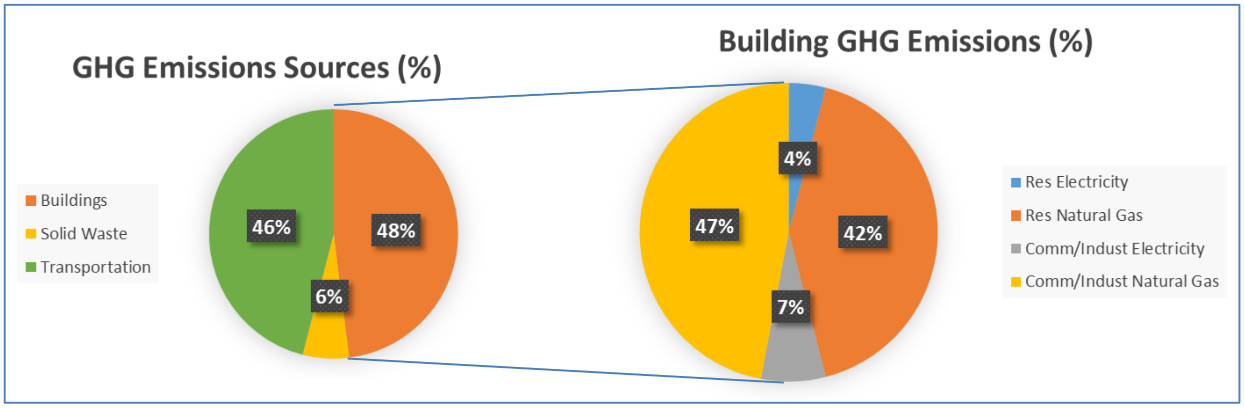


*Figure 6: Community GHG emissions*

## 8.3. Urban Anaerobic Digestion Screening Study

The screening of AD systems around the world that utilized MSW and were located within 500m of residential areas provided only a handful of results. Of several identified, this section focuses on three systems. A majority of the AD system found during the screening used MSW along with wastewater, and were not selected because of this co-digestion. Additional information on these case studies is provided in Appendix B: Waste Characterization for the City of Vancouver

| Date | Type | Sample Size | Food Waste | Yard Waste | Clean Wood |
|---|---|---|---|---|---|
| August 19, 2013 | ICI | 95.3 | 24.75 | 2.4 | 0 |
| August 19, 2013 | ICI | 88.75 | 7.5 | 0 | 25.25 |
| August 19, 2013 | DO | 94.2 | 0 | 0 | 2.65 |
| August 19, 2013 | SF | 93.15 | 17.1 | 0.95 | .3 |
| August 20, 2013 | DO | 105.1 | 0 | 0 | 0 |
| August 20, 2013 | DO | 100 | 0 | 0 | 0 |
| August 20, 2013 | ICI | 97.55 | 61.05 | 1.05 | 0.25 |
| August 21, 2013 | DO | 122.1 | 0 | 0 | 34.6 |
| August 21, 2013 | ICI | 92.3 | 7.75 | 0 | 0.5 |
| August 21, 2013 | ICI | 91.7 | 38.8 | 0.6 | 0 |
| August 21, 2013 | SF | 90.1 | 17.7 | 0 | 0.4 |
| August 21, 2013 | SF | 82.65 | 33.4 | 0 | 0.35 |
| August 22, 2013 | ICI | 88.8 | 24.45 | 8.85 | 0.05 |
| August 22, 2013 | ICI | 79.6 | 7.6 | 0.6 | 0.3 |
| August 22, 2013 | SF | 89.1 | 31.45 | 1.5 | .1 |
| August 23, 2013 | SF | 92.05 | 29.9 | 0.55 | 0.05 |
| August 23, 2013 | ICI | 148.4 | 30.25 | 4 | 11.85 |
| November 25, 2013 | ICI | 95.7 | 45.4 | 1.5 | 0.15 |

| | | | | | |
|---|---|---|---|---|---|
| November 25, 2013 | ICI | 102.15 | 27.25 | 0.3 | 0.05 |
| November 25, 2013 | DO | 150 | 0 | 0 | 0 |
| November 26, 2013 | DO | 100 | 0 | 0 | 0 |
| November 26, 2013 | SF | 103.4 | 40.2 | 1.05 | 1.8 |
| November 27, 2013 | DO | 75 | 55.2 | 0.05 | 0 |
| November 27, 2013 | DO | 60.75 | 6.2 | 0.05 | 0.05 |
| November 27, 2013 | SF | 101.9 | 25.65 | 0 | 0.1 |
| November 28, 2013 | DO | 60.75 | 0 | 0 | 0 |
| November 28, 2013 | SF | 101.95 | 36.2 | 3.7 | 0.05 |
| November 28, 2013 | DO | 59.16 | 6.3 | 1.4 | 0 |
| November 28, 2013 | ICI | 101.9 | 45.4 | 1.3 | 0.05 |
| **All values are reported as tonnes** | | | | | |
| SF | Single Family residential | | | | |
| ICI | Industrial, Commercial, and Institutional | | | | |
| DO | Drop-off or self-hauling | | | | |

Appendix C: Case Studies.

**Dufferin Plant – Toronto, Ontario**

| | |
|---|---|
| Name | Dufferin Plant[26] |
| Location | Toronto, Ontario |
| Area | Building is <2,200 $m^2$ on 1 acre of land |
| Governance | City owned with private operator |
| Digester Characteristics | BTA process (CCI BioEnergy is the licensee)<br>Wet – single stage mesophilic |
| Capacity | 60,000 tonnes/year, increased capacity from 40,000 to 60,000 in 2012 |
| Output | 15,450 tonnes/year of digestate – used for composting/fertilizer<br>110-125 $m^3$ of biogas/tonne SSO (used locally) |
| Capital Expense | $15 million – used existing building<br>$11 million upgrading cost (2012) |
| Additional Comments | Average of 2 odour complaints per year<br>Plant located near dense urban neighborhood, <100 m |

**The Plant – Chicago, Illinois**

| | |
|---|---|
| Name | The Plant |
| Location | Chicago, Illinois |
| Area | Building is 8686 $m^2$ |
| Governance | Owned and operated by building owner |
| Digester Characteristics | Eisenmann BIOGAS-GW system<br>Dry – continuously mixed, horizontal, high solids |
| Capacity | 4,500 tonnes/year sourced from building organic refuse |
| Output | 2,650 tonnes/year of digestate – used for composting/fertilizer<br>CHP unit generates 650 kW of heat and 200 kW of electricity per hour |
| Capital Expense | $3 million USD with the option of doubling capacity for $1 million |
| Additional Comments | Located on building premises<br>Received $700,000 USD in tax credits and $1.5 million in government grants |

**Dagenham Plant, United Kingdom – London Sustainable Industries Park**

| | |
|---|---|
| Name | Dagenham Plant |
| Location | London Sustainable Industries Park, United Kingdom |
| Area | Facility sits on a 4 acre land parcel |
| Governance | Privately owned and operated |

| | |
|---|---|
| Digester Characteristics | Anaergia's AD technology<br>Dry – continuously mixed, thermophilic |
| Capacity | 50,000 tonnes/year sourced from City of London |
| Output | 14,000 tonnes/year of digestate – used for composting/fertilizer<br>CHP unit generates 1.15 MW of heat and 1.4 MW of electricity annually |
| Capital Expense | £21 million with the option of doubling capacity for $1 million |
| Additional Comments | Electricity is sold on the national grid, partially supported by a FIT<br>Heat is used by other Eco-Park businesses<br>An additional facility is being built in the north of London<br>Has a 20 year contract with the City of London<br>Composting also occurs at this facility |

## 8.4. Identify Risks & Benefits

AD is used around the world, but not in as great a capacity as it is in Europe. Estimates from 2012, indicate that in Europe by 2014 there will be 244 urban AD systems that operate using MSW [16]. This amounts to a total capacity of approximately 7 million tonnes. Germany has the highest urban AD capacity with 1.8 million tonnes of MSW per year, but countries like The Netherlands and Switzerland have the highest capacity per capita. The sizes of these facilities vary with a European average capacity of 28,800 tonnes per year. These systems have been in operation throughout Europe for several decades, as such there are lessons that can be learned.

### 8.4.1. Technical

The benefits of AD systems with energy recovery are most pronounced when compared to alternative MSW disposal options, namely landfilling. Compared to landfilling, AD of MSW reduces harmful environmental effects through pathogen destruction and climate change mitigation [27]. Additionally, AD allows for the recovery of nutrients from organic waste in the form of digestate, and greater efficiency in biogas collection for renewable energy purposes. The AD facilities also require less land area then landfills, while also reducing the overall volume of the digestate. The AD system is similar to landfills, in that waste is placed in an oxygen-free environment, however, unlike landfills, the decomposition of the waste is conducted in a matter of days instead of years. Additionally, there are a variety of AD system types which allow for the development of a system best suited to the waste characteristics and the end goal of the operator.

Biogas is a remarkable gas in that it is the only renewable gas that has similar enough properties to be used in place of natural gas without drastic altering of infrastructure. However, there are risks associated with AD systems and the byproducts. As with any facility that utilizes heavy machinery, worker safety is a concern. Proper ventilation is necessary to prevent the buildup of noxious gases, and methane monitors are required to inform plant operators of a potential explosive hazard [28]. These concerns require additional capitally intensive monitoring and evaluative controls [29]. Additionally, AD systems require low contamination rates with some systems requiring less than 0.1% in order to operate [30]. These systems also require feedstock with a neutral pH, and a carbon-nitrogen ratio from 20:1 to 30:1, which may require the addition of dry matter or liquid in order to achieve the desired ratios. Lastly, the feedstock should be clear of organic pollutants, pesticides, antibiotics, and detergents as these can be harmful to the microbes in the digestion unit.

### 8.4.2. Social

Energy recovery from AD using MSW has several benefits compared to landfilling, but as Rolfe Philips from Yield Energy stated in a personal communication; "you never get a second chance with a community". The emphasis here was on the public's acceptance of AD as a technique for production of an energy source, but also as a replacement for the existing MSW disposal method. While the AD process might be simple for some, for others the introduction of a new technology, especially one that would supplant two existing regimes could be worrisome [31]. This point is further emphasized when the use of flaring is considered. An AD system would require the use of a flaring station which can be minimized if an upgrading plant is used, but the visual of a flaring station within the CoV could create concern in the community. As part of Metro Vancouver's Solid Waste Plan, social sustainability is a key parameter for developing a sustainable region [5].

The introduction of AD systems within the boundaries of the CoV could be problematic if truck traffic or air pollution from truck traffic is seen as increasing [32]. Additionally, for the CoV, moving from a landfill disposal system operated by the CoV, to an AD system operated by private firms could cause controversy. Concerns over corporate social responsibility, and whether the public's best interests would be put first, are common in many renewable technology projects [33]. Whether the implementation of an AD system is a voluntary or involuntary arrangement, the ownership type, and the process of implementation should all be considered before moving forward. When communities show concern over a project, in this case the development of AD systems within the CoV, concerns expressed by the community may not be so much about the hazard (air pollution, truck traffic, and odour) as it is about the procedure, transparency, and level of involvement [34]. A lack of input on decision making, and a perception of less equitable power relationships between the CoV, developers, and citizens results in a greater perception of risk [35].

### 8.4.3. Environmental

Several studies have been conducted on the environmental benefits of AD systems, in particular the GHG mitigation capacity especially as it compares to landfill practices with and without gas capture systems [36]–[38]. The findings tend to indicate the reduced GHG impact of AD systems compared to landfilling, however, the use of biogas as a substitute for natural gas is only seen to reduce GHG impact if the digestate is used to displace the use of artificial fertilizers [39]. In addition to these studies, a GHG emissions analysis of the VLF was conducted in 2009 [40]. The findings in this study indicated that GHG emissions from the VLF were 382 $kgCO_2e$ per tonne of MSW in 2009, and this would decrease to 243 $kgCO_2e$ per tonne of MSW post-2015 due to the organics ban.

A recent study conducted for the CoV compared the GHG impacts of using collected food waste for composting or anaerobic digestion using life-cycle assessment [41]. In this analysis, several scenarios were investigated and the results indicated that AD has beneficial and negative GHG impacts. The AD process has a higher global warming impact as well as a higher respiratory effect. The upgrading process consumes electricity, and the quality of the digestate isn't as high as compost and so there is less displacement of artificial fertilizers. However, AD captures biogas and if this is used for heating it offsets natural gas consumption.

Additional studies have provided more generalizable results. For example, a nation-wide EIO-LCA[5] of AD using MSW showed that AD have an emissions intensity between 212 and 228 $gCO_2e/MJ$ – depending on whether offsets would be from coal or natural gas – while landfilling had an intensity of 324 $gCO_2e/MJ$ each over a 25 year lifespan [42]. These intensity factors indicate that per-MJ used, AD emits less GHGs than landfilling. Other studies have reported varying figures. It is important to note that each study is unique and have different scopes and boundaries. For example, the study cited above did not include landfill gas capture systems which could have reduced the emissions intensity. It also did not include using the digestate from AD as fertilizer, and it assumed that all MSW would be sent to the AD facility where it would be sorted instead of pre-sorting being done to remove this extra transportation step. If pre-sorting was carried out, the emissions intensity would decrease to between 41 and 58 $gCO_2e/MJ$.

#### 8.4.4. Economic

There are a range of economic benefits and risks associated with AD. According to the Biogas Association [43], the recommended minimum capacity for an AD system is 15,000 tonnes per year for plants to operate economically. Figure 7 and Figure 8 are proposed costs of an AD facility in Canada. These figures are based on a cost function developed using information on AD facilities in Europe [44]. It is important to note that these costs are sourced from European facilities, however they are the best available indicator as there is a lack of such off-farm systems in North America.

[5] EIO-LCA or economic input-output life-cycle analysis is a particular type of LCA that accounts for environmental impacts, but also economic transactions between sectors.

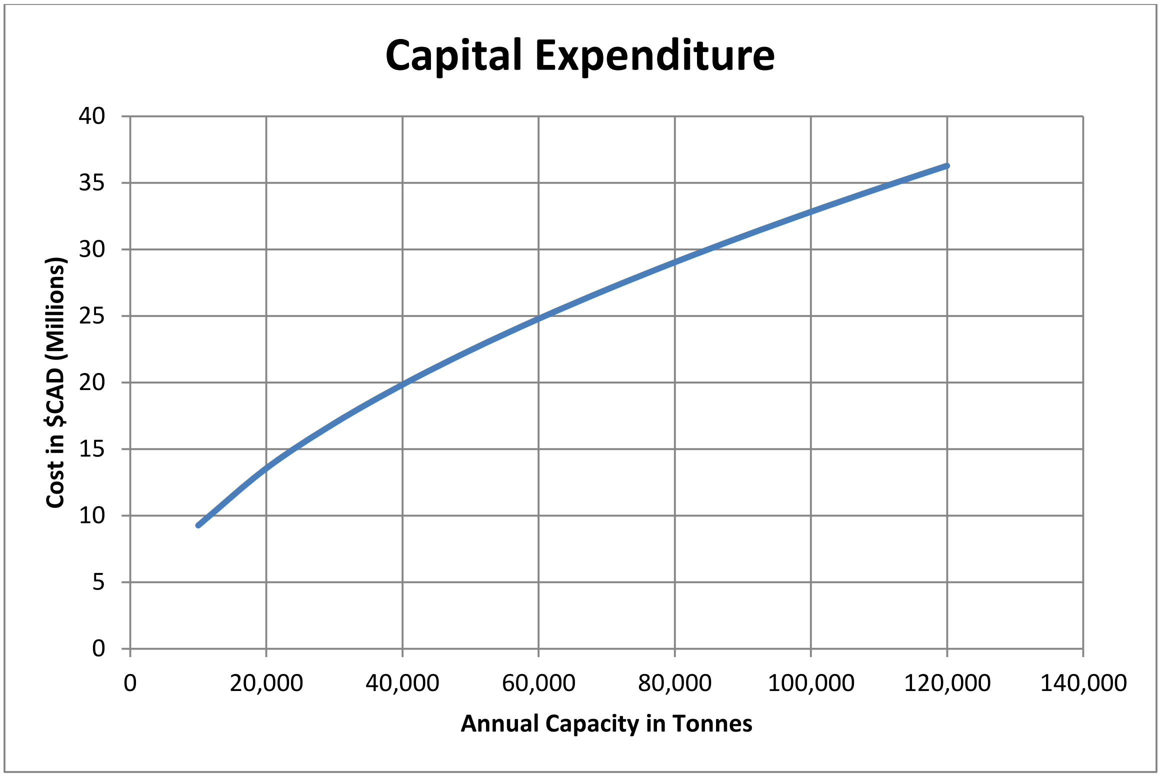


*Figure 7: Capital expenditure of AD facility based on capacity*

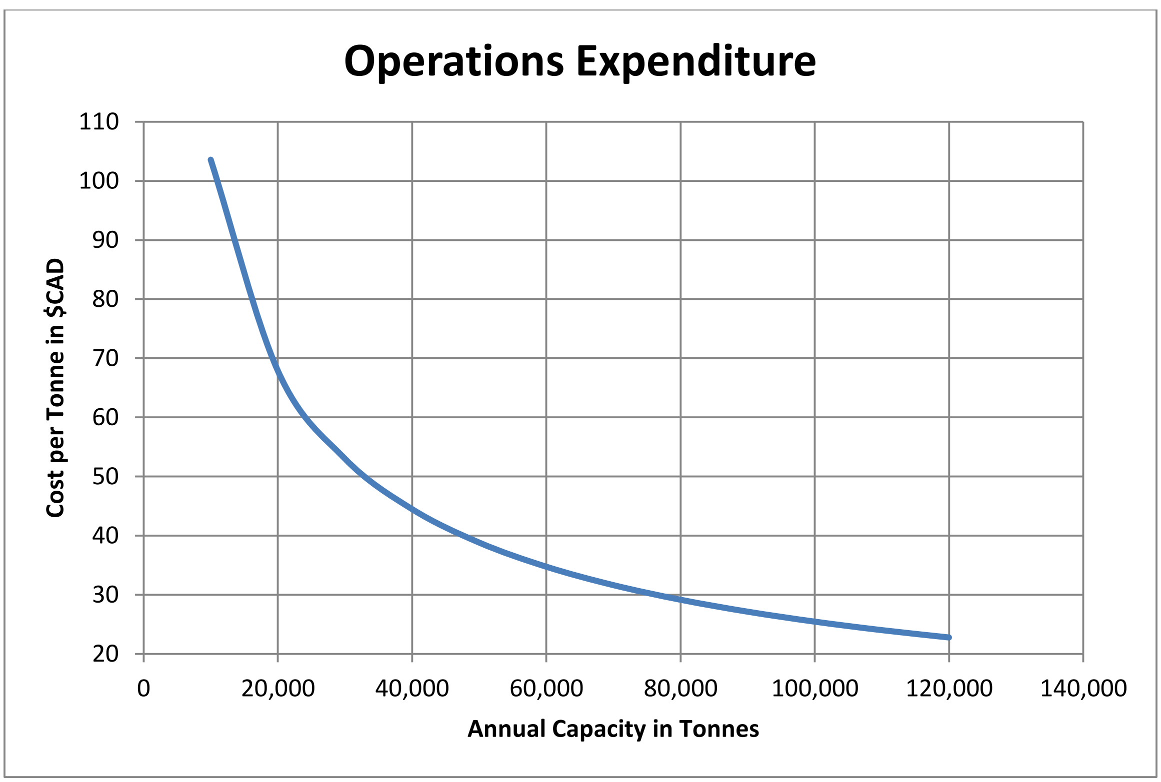


*Figure 8: Operations expenditure of AD facility based on capacity*

The data for these cost functions was normalized and included costs of project development (site selection, permitting, and engineering), construction (site preparation, service roads, processing equipment), and operation (labour, insurance, maintenance, training, and overhead). The figures above have been adjusted for currency exchange (Euro to CAD), inflation, and purchasing power parity similar to Guilford [45].

These figures are important indicators of benefits in economies of scale. These are not linear relationships because there are gains with increases in size. This is partly due to the relatively small increase in project development and construction that would be required to increase the capacity since the plant is already being built. This same concept holds for Figure 8 as well which is where the majority of the benefits of economics of scale are seen.

However, as seen in Figure 8 there are also diminishing returns, in that the gains for each additional increase in capacity is lower than the previous increase. For example, increasing the capacity of the facility from 10,000 tonnes to 40,000 tonnes has a cost savings of nearly $60,000 per year, but an increase of the same size from 40,000 tonnes to 70,000 tonnes only produces a cost savings of $12,000 per year. From these two figures, a facility that has an annual capacity of 40,000 tonnes per year appears to be an optimal size economically. The facility would cost approximately $20 million and have an annual operations cost of $44 per tonne.

### 8.4.5. Local Conditions

While there is a lack of AD manufacturing in Canada, there is potential employment in the operations of the facility. The Dufferin facility in Toronto processes 25,000 – 40,000 tonnes per year and has a staff of 13, running three shifts per day. Other important economic considerations are the avoidance of a landfill capacity replacement cost that could then be used to offset the capital and operations costs of an AD facility, and from the cost of a city-wide green bin program. Additional revenue could come from tipping fees and energy sales. However, the sale of energy as biogas through FortisBC or as electricity through BC Hydro should not be considered as a guarantee.

As Figure 9 indicates, the price of natural gas in North America is relatively low, especially when compared to prices overseas. Furthermore, the price has been low consistently since 2009. North America has an abundant supply of natural gas which has resulted in the fall in price. Unlike, Europe and Japan, where gas has to be imported through costly liquefaction and transport resulting in a higher price, natural gas is a relatively abundant resource. In a phone conversation with Scott Gramm, an engineer in the FortisBC biomethane supply group, the introduction of renewable natural gas has been slow to develop because of the price of natural gas. Currently, FortisBC runs a voluntary RNG program where customers can sign up and pay for 10% of their gas consumption to come from RNG. The current price for RNG is $14.065/GJ whereas natural gas is priced at $4.64/GJ. Mr. Gramm recognized that there is a challenge in making the price more palatable to consumers. Additionally, as an entity regulated by the BCUC, FortisBC has a mandate of ensuring utility rates are fair. This creates issues for the RNG program since BCUC has capped annual capacity at 1.5 PJ.

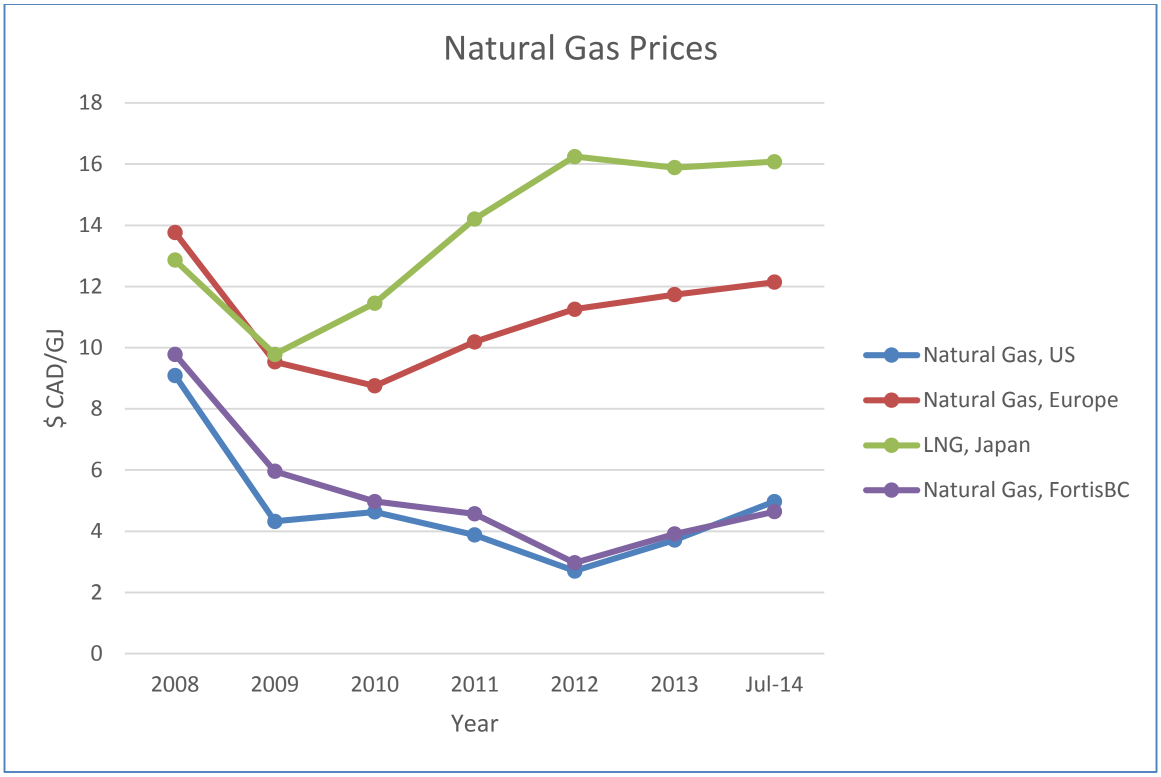


*Figure 9: Natural gas price. Source 3: Data compiled from the World Bank*

The RNG program through FortisBC has experienced underperformance in the number of customers originally thought would sign up for the program. In a letter dated December 19, 2012 to BCUC, Fortis Energy Inc. submitted a post-implementation report on the biomethane program [46]. In this letter, FEI reported on a survey conducted amongst existing customers, and identified that "doing the right thing" and "status in your peer group" were the strongest motivating factors commercial and residential customers respectively. This may not be too surprising, especially when considering that 34% and 33% of commercial customers were from the service and food/hospitality sectors indicating the importance of public image. In fact, FEI is looking into eco-labeling to publically recognize biomethane program participants.

However, the overall impact is lessened because only 72 businesses had signed up for the program. Additionally, FEI had anticipated that there would be 3,085 residential customers by December 2011, and 6,170 by December 2012. Only 1,089 costumers had signed up by December 2011, and only 4,693 had signed up by December 2012, with a total number of 4,769[6] costumers instead of the expected 6,170. While the overall annual consumption in 2012 did exceed their target of 58,613 GJ with the actual demand being 59,964 GJ, the BCUC decided against the expansion of the biomethane program to 3 PJ annually that FEI had requested. Instead they approved a limit of 1.5 PJ citing the lower than expected participation rates [47]. Additionally, BCUC felt that greater success could be had with a stronger focus on commercial

[6] In addition to the residential and commercial customers, FEI also counts 3 on system sales to their total costumer number.

customers rather than residential, especially if "green leaders" are identified and encouraged to promote the biomethane program.

The lack of certainty around the biomethane program not only tests the viability of the biomethane program, but it also serves as a deterrent to potential suppliers and customers alike. Harvest Power decided against partnering with FortisBC and partnered with BC Hydro instead, partly because of the certainty BC Hydro offered in their energy purchase program. Furthermore, the lack of security of the biomethane program factors into decisions large institutions such as UBC, who are interested in a supply of 100% biomethane to meet renewable energy targets. One potential solution to this issue that FEI promoted as a measure to increase capacity was the use of biomethane to meet renewable portfolio standards [46]. However, BCUC decided against this logic because they felt there was no guarantee that RPS would consume the increase in supply, with the fear that this would then translate into lost revenues [47]. Steve Harpur of Earth Renu indicated in a communication that without such command and control measures an increase in adoption of biomethane for substitution of natural gas would not occur. This is partly the reason why companies like Harvest Power have decided to convert biogas from their AD system into electricity. The State of California has also experienced similar issues, and in a phone conversation with Jason Gray, who works for California in the offsets program, one measure taken there to encourage the use of biomethane as a transportation fuel was the rescinding of offsets for projects that converted biogas or biomethane into electricity.

Additionally, the appeal of converting biogas into electricity rather than for use either as a substitute for transportation or heating fuel is the cost of upgrading. In a report on the feasibility of biogas upgrading in BC, the average cost of upgrading over 16 projects in BC was \$6.21/GJ with larger plants having lower upgrading costs [32]. For example, Carbotech, a small scale biogas supplier with a flow of 250 $m^3$ per hour had an upgrade cost of \$10.18/GJ compared to the King County WWTP with a flow of 1429 $m^3$ per hour at an upgrade cost of \$5.04/GJ. Part of this economy of scale has to do with geographic location of the plant. Depending on the location, the pressure at which biomethane would need to be injected varies. There are three injection pressures for biomethane; high pressure at 750 PSI, intermediate pressure at 120 PSI, and distribution pressure at 60 PSI. High pressure systems, don't require as stringent quality control as other injection points because the biomethane will be diluted by natural gas, but the cost of compression is uneconomically high. Intermediate pressure systems, requires less compression than the high pressure system, but the biomethane quality control standards are more stringent. Lastly, distribution pressure systems, may be the most practical because many of pressure is lower, but this system requires the most stringent quality control measures.

The economic potential extends beyond the sale of biogas. Companies like Harvest Power also market the digestate as compost and liquid fertilizer. The compost market volume, as noted by Joe Canning at Harvest Power, is not large enough and there is some saturation. In response to the market trend towards saturation, Harvest Power has focused on the quality of the digestate. Harvest Power is placing efforts in the sale of organic compost, increasing production of this to approximately 70% of their digestate stream. The quality of the compost is essential, and Harvest Power is working with researchers at UBC to test the NPK (nitrogen, phosphorus, potassium) values which are indicators of the fertilizer quality. The demand for organic compost is potentially not being met by current supply. Veronik Campbell at UBC Farm, indicated in a phone conversation that finding suppliers of organic compost can be difficult, and that prices are very high for the product. An AD facility located within the CoV could potentially look at the market volume for compost (organic and non-organic), but the handling, transportation of, and the odours associated with the product could increase costs as well as result in community concerns. For example, in Europe, a ban on application of fertilizers during the winter months, means that digestate needs to be stored from 4-9 months depending on the local climate [48].

There are additional uses of digestate that have been investigated. Due to increases in the price of wood pellets, sawdust and wood shavings are increasingly expensive. Farmers have begun to incorporate digestate as animal bedding in order to offset the costs of traditional bedding material [49]. Digestate has also be investigated as a growing media for mushrooms, for uses in forestry, for use in municipal flower beds, for additional nutrient extraction, for use in vermiculture, as a media for bio-pesticides, and in construction materials (wood plastic composites) and medium density fiberboards [50].

# 9. Discussion

Much is known about AD technology and lessons can be learned from the several decades worth of experience, however the technical and economic efficiency of small plants (<100 kW) is unknown [29]. The potential 204,258,860 MJ/year of biogas, roughly the same energy scale of the Southeast False Creek heat recovery facility, if utilized for heating would offset 173,620 GJ/year of natural gas consumption. This would offset less than 1% of current natural gas consumption from buildings is 19,767,143 GJ/year. The 173,620 GJ noted above is an estimate of the potential volume of biogas that could be produced, and it should be noted that the figures used for biogas yield (0.31 $m^3$/kg) and methane content (55%) are conservative, and much higher figures have been reported in the literature. A detailed seasonal waste characterization of the MSW in Vancouver could give a more accurate figure.

The issue the CoV is presented with is, what the available options for managing organics are once the landfill ban goes into effect? Considering *i.* Availability of local resources, *ii.* Needs of city residents and the goals the CoV has established, *iii.* Operation of AD facilities with varying capacities of food waste, and ***iv.*** Risks and benefits of AD, a facility in the CoV would be difficult to develop without the implementation of policy, regulatory, and economic aids.

The appeal of biogas is due to the low-carbon nature of the resource. However, biogas must still be able to compete with existing technologies and processes. As it currently exists, there is an abundance of natural gas, FEI has not achieved the demand goals originally predicted for the biomethane program, and the cost of natural gas is much cheaper than biomethane. As an institution, the BCUC has a mandate to provide natural gas at a reasonable price. The reluctance and uncertainty of the biomethane program, influenced Harvest Power's decision to sign a contract with BC Hydro to provide electricity. Utilizing biogas to provide electricity may have potential in some regions, but for BC, more than 90% of electricity is derived from hydro sources, thus creating little incentive for biogas to compete with other forms of renewables that already have a dominate position. Additionally, there remains questions as to whether the digestate could be utilized as fertilizer or whether it would require disposal. However, additional economic analysis that accounts for tipping fees, carbon offsets, and savings from shortened transport distances could have positive economic effects.

These constraints translate into potential barriers from the regulatory and permitting processes that could prove burdensome. Flaring of gas, air quality issues, and social acceptance may lead to a lengthy and costly process, and even if approved interconnection requirements may prevent access to the pipeline network. Furthermore, the consortium of private haulers along with the CoV create an environment of competing entities which may preclude the ability of an AD operator to sign a franchise agreement that covers the CoV. Furthermore, the development of neighborhood scale anaerobic digesters may create issues for waste haulers that are optimized for city-wide collection schemes.

However, there are instances of community based waste haulers such as the operation in place within the Strathcona Business Improvement Association. Meg O'Shea, the sustainability coordinator for The Strathcona BIA reported that they work with Mission Possible[7] to collect organics and recyclables which are then transported to the resource park. Any unused organics are sent to Enviro-Smart[8] and the recyclables are sent to Recycling Alternatives[9] and West Coast Plastic Recycling[10]. The organics are treated on site, Figure 10: Photo of Strathcona BIA Resource Park and composting unit, through a series of aerobic composting units. Since beginning operation in 2012, the BIA has collected 48 tonnes of organics, processed two tonnes as compost, and collected three tonnes of mixed containers and four tonnes of soft plastic for recycling.


*Figure 10: Photo of Strathcona BIA Resource Park and composting unit*

[7] http://mission-possible.ca/
[8] http://westcoastlawn.com/enviro-smart-organics/
[9] http://www.recyclingalternative.com/
[10] http://www.westcoastplasticrecycling.com/#/Plastic-Recycling/

In summary, while MSW can be used to provide biogas, thus reducing the volume of waste sent to the VLF and offsetting the use of natural gas, the low price of natural gas will continue to place downward pressure on the demand for biogas. However, neighborhood energy systems are a promising option and the Strathcona BIA offers a template for local collection of organics.

# 10. Recommendations

While the development of an AD facility may not be currently feasible for the CoV, there are measures that can be taken to aid the adoption of AD. The principle steps that can be taken include reducing uncertainty created by the BCUC in regards to the biomethane program, working with other governmental agencies on the implementation of policies supporting biogas, and networking to share information and develop standards of practice that can help overcome permitting and regulatory barriers.

With regard to the biomethane program, exploring the use of RNG as a transportation fuel may yield greater benefits then substituting natural gas with RNG. Policy and regulations need to be made clear, and energy policies that encourage the adoption of AD systems can provide developers not only with incentives, but clarity as well. Additionally, policies regarding the financing of these projects can overcome one of the largest barriers, capital cost. Lastly, networking can help develop the current lack of skilled labour, manufacturers of AD technology, and entrepreneurs. Restrictions on the technologies available lead to additional transaction costs by requiring interested parties to work with licensees of AD systems from Europe. By developing the manufacturing and labour in the renewable energy sector locally, capital and operational expenses can be reduced.

Anaerobic digestion is a promising technology, but there are barriers that would make the development difficult. The CoV should considering identifying and comparing alternative biomass treatment techniques. It might be that an integration of different technologies such as gasification and anaerobic digestion could lead to synergistic results. Currently, food waste is co-mingled with yard waste and this presents problems for the achieving the greatest benefit of AD. AD systems are not robust enough to handle the higher lignin content of yard waste, and gasification is not the best technique for handling material with higher cellulose content. Moving forward these are the short, medium, and long-term pathways the CoV can take. Implementing anaerobic digestion alongside a technology capable of handling yard waste efficiently could prove successful.

**Short-term:**

- Conduct a thorough waste characterization for the CoV
- Identify the waste materials which are most amenable to AD
- Investigate the challenges of other renewable systems such as gasification as a primary source of waste processing in tandem with anaerobic digestion
- Identify green leaders in the community that can encourage adoption and build political support

- Develop education programs and organize seminars targeting pre-sorting, recycling, and reuse behavior

**Medium-term:**

- Work with Metro Vancouver and the provincial government to develop codes and regulations
- Investigate the use of property tax, by-laws, increased tipping fees, and connection policies that encourage diversion of organics for waste-to-energy purposes

**Long-term:**

- Encourage national policy that creates secure cost competitive measures similar to those in Europe
- Develop a green certification system that encourages the use of renewable energy by ensuring waste is diverted in the best appropriate manner and by adopting an eco-logo that symbolizes the efforts of residents and businesses

# 11. Appendix A: Methods and Data

A combination of methods were utilized for this report. A literature review of academic and grey literature on anaerobic digestion was conducted. For academic literature Science Direct, Web of Science, EconLit, Global Reference on the Environment, Energy, and Natural Resources (GREENR) and Google Scholar databases were searched. For grey literature BioCycle, the International Solid Waste Association (ISWA), and the International Energy Agency document libraries were search along with searches on Google. A broad sweep of the literature was conducted at first and then more specific search terms were used. These particular criteria included; urban environments, organics diversion, siting of facilities, aids and barriers to development, cost, and biogas production. Concomitantly, CoV and Metro Vancouver documents on MSW characteristics, management plans, and report were analyzed. This literature review assisted in answering all four of the research objectives, and most prominently, resulted in the formation of case studies.

In addition to the literature review, conversations with experts and stakeholders were conducted. This included individuals from industry, government, and regulatory agencies. Semi-structured interviews with each individual were conducted. This method of interview is useful since it allows for greater flexibility in inquiring on important issues brought up during the conversation. Elements from the interviews focused on identifying individuals attitudes on what factors influence anaerobic digestion development. These elements were used to summarize key points from the case studies.

Analysis of quantitative data was undertaken. Data was compiled from a variety of sources, and when possible was from peer-reviewed academic work, or governmental sources. The techno-economic analysis was conducted using the Energy Cost Calculator: Biogas Model[11] provided by the UC Davis Biomass Collaborative. This excel based calculator includes net present value, internal rate of return, and payback period functions. The inputs for this first analysis were taken from government reports, current market prices, and academic literature.

In summary, below is a listing of the objectives of this report along with data sources and methods of analysis.

- **Resource assessment**
  - Data
    - Primary sources – CoV & Metro Vancouver
    - Secondary sources – academic journals
  - Energy density of food waste

- **Needs assessment**
  - Data
    - Primary sources – CoV & Metro Vancouver
    - Secondary sources – academic journals

[11] http://biomass.ucdavis.edu/tools/energy-cost-calculator/

- **Screening study**
  - AD systems around the world in urban settings
    - Approximately 500 m from residences
  - Data
    - Primary sources – government documents/web info
    - Secondary sources – vendor websites with listing of AD locations & web search
  - Case studies – Appendix C

- **Identify risks/benefits**
  - Data
    - Primary sources – EPA, IEA, Eurostat, CoV, stakeholders, IPCC
    - Secondary sources – academic journals, CoV Landfill GHG Study, AD vendors and operators, Compost facility operators
  - Technical
    - Plant size and adaptability
    - Compared to landfills
  - Social
    - Public acceptance
  - Economic
    - Capital and Operations Expenditures of AD systems
    - Biogas cost compared to current natural gas prices
    - Policy tools to support fuel switching
    - Compost market
  - Environmental
    - GHG balance

# 12. Appendix B: Waste Characterization for the City of Vancouver

| Date | Type | Sample Size | Food Waste | Yard Waste | Clean Wood |
|---|---|---|---|---|---|
| August 19, 2013 | ICI | 95.3 | 24.75 | 2.4 | 0 |
| August 19, 2013 | ICI | 88.75 | 7.5 | 0 | 25.25 |
| August 19, 2013 | DO | 94.2 | 0 | 0 | 2.65 |
| August 19, 2013 | SF | 93.15 | 17.1 | 0.95 | .3 |
| August 20, 2013 | DO | 105.1 | 0 | 0 | 0 |
| August 20, 2013 | DO | 100 | 0 | 0 | 0 |
| August 20, 2013 | ICI | 97.55 | 61.05 | 1.05 | 0.25 |
| August 21, 2013 | DO | 122.1 | 0 | 0 | 34.6 |
| August 21, 2013 | ICI | 92.3 | 7.75 | 0 | 0.5 |
| August 21, 2013 | ICI | 91.7 | 38.8 | 0.6 | 0 |
| August 21, 2013 | SF | 90.1 | 17.7 | 0 | 0.4 |
| August 21, 2013 | SF | 82.65 | 33.4 | 0 | 0.35 |
| August 22, 2013 | ICI | 88.8 | 24.45 | 8.85 | 0.05 |
| August 22, 2013 | ICI | 79.6 | 7.6 | 0.6 | 0.3 |
| August 22, 2013 | SF | 89.1 | 31.45 | 1.5 | .1 |
| August 23, 2013 | SF | 92.05 | 29.9 | 0.55 | 0.05 |
| August 23, 2013 | ICI | 148.4 | 30.25 | 4 | 11.85 |
| November 25, 2013 | ICI | 95.7 | 45.4 | 1.5 | 0.15 |
| November 25, 2013 | ICI | 102.15 | 27.25 | 0.3 | 0.05 |
| November 25, 2013 | DO | 150 | 0 | 0 | 0 |
| November 26, 2013 | DO | 100 | 0 | 0 | 0 |
| November 26, 2013 | SF | 103.4 | 40.2 | 1.05 | 1.8 |
| November 27, 2013 | DO | 75 | 55.2 | 0.05 | 0 |
| November 27, 2013 | DO | 60.75 | 6.2 | 0.05 | 0.05 |
| November 27, 2013 | SF | 101.9 | 25.65 | 0 | 0.1 |
| November 28, 2013 | DO | 60.75 | 0 | 0 | 0 |
| November 28, 2013 | SF | 101.95 | 36.2 | 3.7 | 0.05 |
| November 28, 2013 | DO | 59.16 | 6.3 | 1.4 | 0 |
| November 28, 2013 | ICI | 101.9 | 45.4 | 1.3 | 0.05 |
| **All values are reported as tonnes** | | | | | |
| SF | Single Family residential | | | | |
| ICI | Industrial, Commercial, and Institutional | | | | |
| DO | Drop-off or self-hauling | | | | |

# 13. Appendix C: Case Studies

**Dufferin Organics Processing Facility – Toronto, Ontario**

The Dufferin facility was first constructed in 2002 as a demonstration unit as part of the City of Toronto's Target 70 goal of diverting 70% of waste from the landfill. The original AD had a design capacity of 25,000 tonnes per year which was upgraded to 40,000 tonnes per year, and then upgraded again to 60,000 tonnes per year in 2012. As Figure 11 shows, the facility located within the City of Toronto and is within close proximity to residential areas.

*Figure 11: Google map view of the Dufferin Organics Processing Facility*

The location of the facility allowed for decreased transportation of waste to the landfill, but a smaller AD size was constructed because it was located within the city. Additionally, cost savings was achieved by using an existing building as a tip floor and storage, thus decreasing the capital expense to $15 million and offering a greater control over odour. In 2012, the capacity upgrade to the plant was completed costing $11 million effectively doubling the capacity. Currently, 110-125 $m^3$ of biogas is produced per tonne of organics which is used locally.

The decision process was a lengthy one, especially since this was the first such facility in Toronto. However, the city was able to move forward and with enough success that in 2007, an additional AD facility was approved. The Disco Road facility also had a lengthy decision process, and the report of the evaluation can be found online[12]. In the end the most important aspects for AD in Toronto were ranked in this order; social (potential for land use conflicts),

[12] http://www.toronto.ca/legdocs/mmis/2007/pw/bgrd/backgroundfile-3867.pdf

environmental (emissions), financial (annual cost), technical (system redundancy), technical (development time), technical (potential to increase capacity), and environmental (land required).

**The Plant – Chicago, Illinois**

The Plant is framed as an ecological, social, and economic sustainability projected in a renovated meat packing plant located in a former economically distressed area of Chicago (Figure 12)[13]. The facility houses a vertical farm, an aquaponics system, a brewery, and a commercial kitchen (Figure 13). The food waste from each of these processes is fed into an AD, with a capacity of 4,500 tonnes per year [51]. The biogas from the AD process is used in a CHP system to produce 650 kWh of heat and 200 kWh of electricity.


*Figure 12: Google map view of The Plant*

The Plant's AD, completed in 2012, was a novel system for the City of Chicago. As a result, The Plant was the first case for the permit and regulatory environment of Chicago. In email exchanges with Jennifer Hesse, a lawyer in the City of Chicago's Permitting and Enforcement Office, the novelty of the AD and the challenges this presented to the City were described. Since installation of the AD system, The City has received no complaints from nearby residents, however, air and recycling permits were necessary in order for The Plant to operate the system. Handling and operation of the system also required regulators to become better informed of the AD process. This was point was also reiterated by John McDowell, an engineer with Eisenmann, an international technologies company specializing in environmental technology among other products.

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[13] http://www.plantchicago.com/

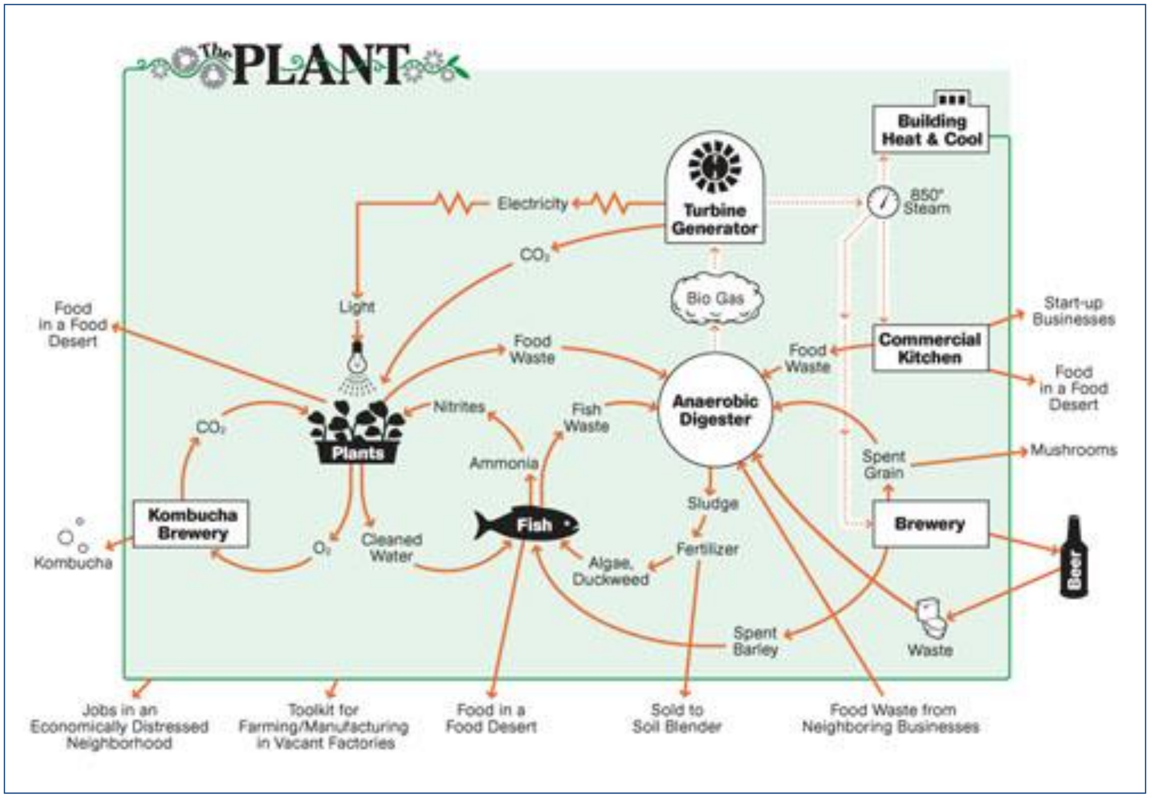


*Figure 13: The Plant sustainability concept*

Mr. McDowell was involved in the installation of the AD system at The Plant. In a conversation over the phone, Mr. McDowell, indicated that regulation and permitting was a large barrier during the installation process. Siting of the system was less burdensome because the land the system would sit on was owned by The Plant. However, the remediation plan, a required 20 year proposal on how the site would be cleaned after the system was shut down, was offered as one example of just one barrier that was encountered. While the regulation was well intended, there was difficulty in explaining that once the system is shut down all that is left is the steel infrastructure which wouldn't require any clean up.

In addition to the difficulty experienced in Chicago, Mr. McDowell, also described the development of a new AD system in California. This system would be located in a remote area of Perris, CA and utilize 72,500 tonnes of MSW a year to produce biogas. The challenge that presented itself to Eisenmann, was the strict emissions limits set for $NO_x$, a by-product of CHP systems. So, instead of installing a CHP system like the system in Chicago, Eisenmann had to instead divert all the biogas for use as transportation fuel.

Mr. McDowell, cites many difficulties in the development of AD in North America. Chief among these is the lack of precedence and familiarity with this technology for regulators. Additionally, the large capital necessary for installation, and the longer pay-back period means many developers are less interested in this technology. For example, the 72,500 tonne facility in California is estimated to have cost $20-30 million USD, compared to the 4,500 tonne system in Chicago which is estimated to have cost $3 million USD. These high capital costs can be offset in many cases. For The Plant, $700,000 in tax credits, along with a $1.5 million grant from the State of Illinois helped to offset the initial cost.

**Dagenham Plant, United Kingdom – London Sustainable Industries Park**

Promoting the cluster economy concept, the Mayor of London's office established the London Sustainable Industries Park[14]. Part of the 60 acres set aside with a £30 million investment by the Mayor of London, houses a £21 million AD system (Figure 14) [52]. The AD system has a capacity of 50,000 tonnes of organics per year with a majority of this being food and green waste from the City of London and nearby boroughs. The biogas is sent to a CHP system where 1.4 MW of electricity is sold on the national grid, and 1.15 MW of thermal energy is utilized by nearby facilities. Income for the facility is expected to come largely from feed-in tariffs and tipping fees, however, the plant is expected to produce 14,000 tonnes of compost which is then to be sold for agricultural purposes [53].

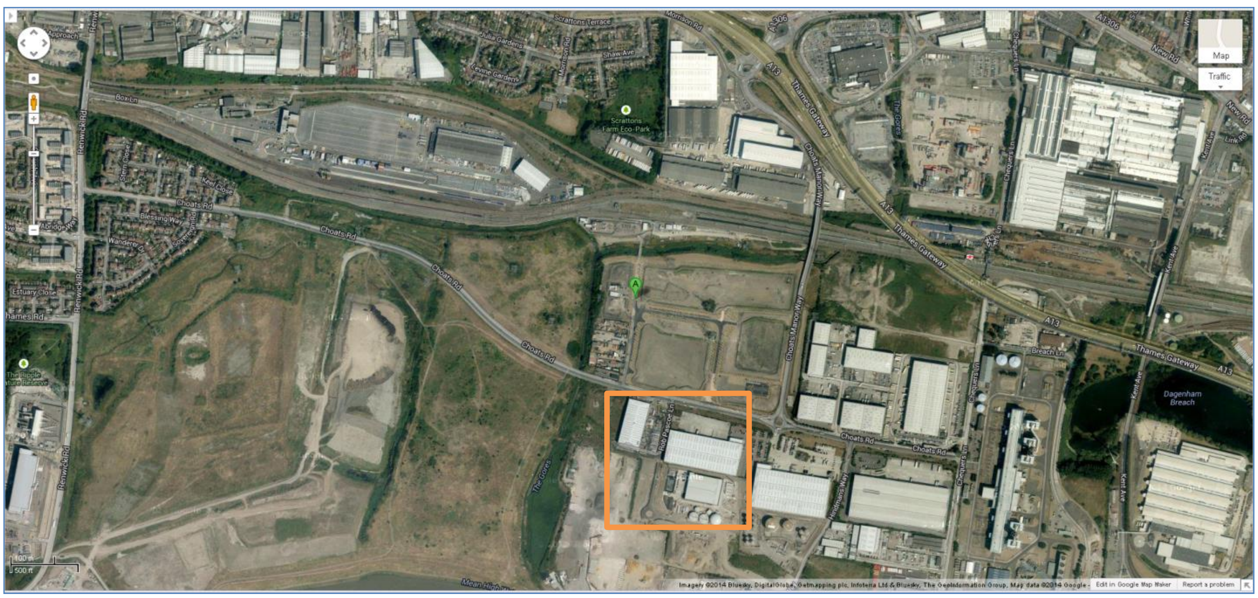


*Figure 14: Google map view of Dagenham Plant*

TEG Group was the technology provider as well as operator of the AD system with a 15 year contract [53]. The system began operation in April 2014, and was financed through several entities. The Green Investment Bank and the UK Waste Resources & Energy Investment Fund made a £2 million equity investment, the Foresight Environmental Fund (a subsidiary of the European Investment Bank) and the London Waste & Recycling Board made a £9 million equity investment, private investors contributed £2 million, and TEG Biogas assumed a debt of £7.9 million to finance the project.

[14] http://www.londonsip.com/

**Flitenbreite Ecological Housing Estate – Lübeck, Germany**

One of many AD systems in Germany, this neighborhood utilizes a local digester to offset heat and electricity from fossil fuel sources. Located in Flitenbreite, a town near Lübeck, Germany, this neighborhood (Figure 15)Figure 15: Google map view of Flitenbreite Ecological Housing Estate is a demonstration project for the German Federal Ministry of the Environment [54]. The project, which hasn't reach full build out yet, has a capacity of 117 units or approximately 380 inhabitants.


*Figure 15: Google map view of Flitenbreite Ecological Housing Estate*

The system began operation in 2002 with an estimated cost of €600,000 and a total of €20 million for the entire estate including the AD system [54]. The AD system uses organic material from residential units to supply the units with heat and electricity. The AD system is also equipped to handle black water (feces and urine) from residential units, but as of 2009 this co-digestion of black water and food waste had not been started. The cost for the project was partially supported by government funding, but also through banks, private companies, and home owners [55]. During the first year of operation, the operation costs of the system were 20% lower than conventional systems. Overall, the system has been successful technically and socially.

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