MASTER OF PUBLIC POLICY
CAPSTONE PROJECT

An Investigation into the Adoption Rate of Anaerobic Digestion and Biogas Systems in Alberta

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Executive Summary

Background

Waste is an innate by-product of human activity and waste management practices are integral to the sustainability of almost all industries. Such practices are increasingly important for Alberta given the large amount of waste produced and the growing environmental constraints. On a per capita basis, Alberta has the highest rate of waste generation in Canada. Agriculture and Municipal Solid Waste (MSW) are the top two sectors that produce the largest quantities of organic waste.

The production and management of waste entails a variety of costs that include substantial environmental costs, missed economic opportunity costs and landfill costs. These are primarily associated with the handling and processing of organic waste (i.e. manure and other substances). As well, the breakdown of organic waste streams generates Green House Gas (GHG) emissions, and, if left untreated or poorly managed, these organic waste streams can become a significant source of air and water pollution. Further, not employing more advanced methods of organic waste disposal that create valuable by products (such as renewable fuel) can be seen as a missed economic opportunity. Given these costs and the greater attention given to environmental constraints and quality, along with the expanding opportunity for livestock production and the growing municipal waste issues, there is a pressing need for solutions. In many jurisdictions at least a partial solution has been the implementation of Anaerobic Digestion (AD) and biogas systems.

Objective

Alberta has a seemingly considerable opportunity for the adoption of AD and biogas systems, yet adoption in the province has been very limited. The objective in this study is to investigate the potential barriers to the use of AD and biogas systems as part of both a waste management solution and energy production potential. Along with an evaluation of some key determinants to the viability of these systems, the study will focus on the types of policy changes required for a broader adoption within Alberta.

Methodology

The approach used in this study involves an assessment of the current livestock and municipal waste management industry in Alberta including a review of the AD and biogas systems in operation. This study then examines conditions and policies employed in other jurisdictions that have led to a more widespread adoption of AD and biogas systems. A review of key adoption determinants from other jurisdictions is used to evaluate and compare Alberta's approach to those key determinants identified. The following policy recommendations are developed based on this analysis.

Policy Recommendations

The major policy recommendations include a focus on securing certainty in policy programs to foster a higher level of confidence for producers and investors which, in turn, promotes increased investment by industry. The biogas and anaerobic digestion industry is still in infancy stages within Alberta and in order to support the growth of the industry an Alberta Biogas Association should be created. Anaerobic digestion technology comes with high capital costs. In order to overcome this cost, the beneficial attributes of the technology must be accurately priced. This applies to landfill tipping fees, pollution costs, and the values for renewable energy and digestate. Additionally, lengthy regulatory applications should be streamlined to reduce regulatory and policy barriers faced by potential adopters. In general, the biogas industry and the Alberta Government must work collaboratively to create an environment that fosters a supportive relationship and encourages producers to implement AD and biogas systems.

1. Dimensions of Livestock and Municipal Waste Management Issues in Alberta

1.1 Amount and Growth of Livestock and Municipal Waste

According to a report by the Conference Board of Canada, Alberta has the highest rate of waste generation per capita. Alberta produces 1,007 kg per capita compared to the Canadian average of 720 kg of waste per capita.[1] Alberta's annual per capita waste generation is also increasing, rising by 83kg from 2002-2012.[2] The report uses un-diverted waste levels as reported by StatsCan data. Un-diverted waste is that which is put into landfills, causing a host of environmental problems including air and water pollution from toxins, leachate and GHG emissions.[3] Alberta is also ranked among the lowest provinces in terms of waste diversion levels. The Prairie Provinces (including Alberta) have the lowest levels of waste diversion rates at around 15%.[4] In comparison, B.C and Nova Scotia divert 37% and 41% (respectively) of their waste to recycling, reuse or composting facilities. Considering the low level of waste diversion and the high level of waste generated in Alberta, it is important to look at methods for achieving a sustainable waste management strategy. Anaerobic Digestion (AD) and biogas systems can potentially be used part of a comprehensive waste management solution for Alberta.

1.2 Climate Change and Environmental Policy Imperatives

Closely related to waste creation, climate change is increasingly one of the most prevalent issues facing governments around the world. Regardless of the tangible outcomes of the Paris Agreement (COP 21), there has been a renewed international focus on combating climate change. The main human (anthropogenic) drivers of climate change are the Green House Gas (GHG) emissions from the use of fossil fuels and the effects of land-use changes globally.

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[1] "Waste Generation," The Conference Board of Canada, accessed July 29th 2016, http://www.conferenceboard.ca/hcp/provincial/environment/waste.aspx.
[2] "Waste Generation," The Conference Board of Canada.
[3] The Problem With Landfill, Environment Victoria, Accessed August 20th, 2016, http://environmentvictoria.org.au/content/problem-landfill.
[4] "Waste Generation," Conference Board of Canada.

The Alberta government has committed to address climate change with the implementation of the Climate Leadership Implementation Act that was passed on May 24th, 2016.[5] Part of this plan includes phasing out coal generation power by 2030 and the achievement of up to 30% renewable energy by 2030. The Alberta climate change strategy is based on four key elements:[6]

- Phasing out emissions from coal-generated electricity and developing more renewable energy
- Implementing a new carbon price on greenhouse gas emissions
- A legislated oil sands emission limit, and
- Employing a new methane emission reduction plan

In order to meet the 2030 targets, Alberta must focus and foster renewable industries that will provide increased opportunity for emission reductions and renewable energy production. Biogas systems with anaerobic digestion processes can contribute to the goals of the Alberta climate leadership plan. By 'closing the loop', biogas systems can take waste streams and turn the by-products into usable substances. Bioengineer researchers, Holm-Nielsen, Al Seadi and Oleskowicz-Popiel highlight the importance of having a closed system. They claim that in order to prevent "emissions of greenhouse gases (GHG) and leaching of nutrients and organic matter to the natural environment it is necessary to close the loops from production to utilization by optimal recycling measures". [7]

1.3 Study Objectives

The objective in this study is to investigate the potential barriers to the use of AD and biogas systems as part of both a waste management solution and an energy production potential. The study places a primary focus on the adoption of on-farm biogas systems with a subsidiary focus on co-digestion possibilities using Municipal Solid Waste (MSW). Along with an

[5] Alberta Recognized for For Commitment to Improving Air Quality, Government of Alberta, May 25, 2016, http://www.alberta.ca/release.cfm?xID=4181015ED8358-E29B-3068-71A61BB892E21369.
[6] Climate Leadership Plan, Government of Alberta, Accessed August 20th, 2016, http://www.alberta.ca/climate-leadership-plan.cfm.
[7] J.B. Holm-Nielsen, T. Al Seadi and P. Oleskowicz-Popiel, "The Future of Anaerobic Digestion and Biogas Utilization," *Bioresource Technology 100*, no. 22 (2009), pg 5478-5484, http://dx.doi.org/10.1016/j.biortech.2008.12.046.

evaluation of some key determinants to the viability of these systems, the study will focus on the types of policy changes required for a broader adoption within Alberta.

1.4 Study Outline

The study begins with an investigation into the state of the biogas system and AD technology in Alberta. Section 2 includes an outline of some of the AD technology that is (or has been) in operation in Alberta as well as the potential that biogas could have for energy creation and waste management solutions. Section 3 provides background on what AD is and the benefits that it can achieve. An economic model is presented in Section 4 which shows the elements necessary to achieve higher adoption rates of on-farm AD technologies. The elements of the model presented in Section 4 are then compared to the political and economic environment surrounding the AD industry in Alberta to provide reasoning for the low level of adoption. Section 5 investigates the policies used in other jurisdictions that have led to higher level of adoption and utilization of AD technology. The jurisdictions include Germany, Denmark, USA and Ontario. Policy recommendations are provided in Section 6, and the final section includes suggestions of areas requiring further research.

2. Adoption of AD and Biogas Systems in Alberta

Anaerobic digestion (AD) and biogas systems can benefit Alberta by providing a renewable energy resource as well as a contributing to a waste management solution. Biogas systems are suitable for Alberta if we consider the following observations: 1) the renewed focus on climate change and renewable energy production within Alberta; 2) Alberta is a major waste producer; and 3) Alberta has a large agricultural industry with potential for significant growth.

2.1 Biogas Systems in Alberta

Within Alberta there is currently only one biogas system that is located on-farm or that uses agricultural waste as part of the feedstock for biogas production. There are a handful of methane capture projects that produce biogas from a wastewater facilities and a few municipal waste treatment plants that use AD and biogas systems. These are noted below.

1) Lethbridge Biogas is a full-scale biogas co-generation plant that is able to process 150,000 tonnes per annum (t/a) of liquid and solid organic waste with the initial capacity to generate

2.8 MegaWatts (MW) with the potential to increase capacity to 4.2 MW. Agricultural and agro-industrial waste is used as feedstock for the anaerobic digestion. Lethbridge Biogas uses a "Zero Waste" or closed loop approach meaning that all by-products of the anaerobic digestion process are utilized. Waste heat produced by co-generation is utilized for heating the process and the digestive product is used as a nutrient dense fertilizer.[8]

2) Growing Power Hair Hill filed for bankruptcy and is no longer in operation. This plant was a bio-refinery that used an Alberta technology, IMUS, to convert agricultural organic waste into ethanol and bio-fertilizer.
3) Grow The Energy Circle LTD (GrowTEC) is currently at the application and approval stage with the Alberta Government. The technology is a bio-energy process that uses a farm scale 633kW (kilowatt) anaerobic digester to convert source separated organics and agricultural waste to renewable electricity and bio-fertilizer. GrowTEC anticipates the facility will decrease GHG emissions by over 10,000 tonnes of C02 equivalent per year.[9]
4) Cargill Meat Solutions operates a methane capture project at the wastewater treatment facility located in High River, Alberta. It captures 75% of the methane from the anaerobic wastewater lagoons.[10] The captured biogas is used on site to replace 25% of the natural gas requirements for the plant.[11]
5) Slave Lake Pulp Bio-Methanation Project is located at West Fraser's Pulp Mill. It involves completing the integration of an anaerobic digestion system into the mill's existing waste treatment facility. A closed looped system will then use the biogas for on-site electricity generation and heat generation.[12]
6) Enerkem is a waste-to-biofuels facility located near Edmonton. This facility uses a thermochemical technology that was developed to convert Municipal Solid Waste (MSW) and other organic waste streams into transportation fuels and advanced chemicals. Although

[8] "Lethbridge Biogas Lp Final Report," December 2013, accessed August 10th 2016, http://ccemc.ca/wp-content/uploads/2012/12/G101234-Lethbridge-Biogas-Final-Report.pdf.
[9] "CCEMC Project E120124 Final Report: GrowTEC "May 2016, accessed august 10th 2016, http://ccemc.ca/wp-content/uploads/2013/10/E120124-GrowTEC-Final-Report-Non-Confidential.pdf.
[10] "ECR Creation Report: Cargill High River Methane Capture Project," March 25 2009, accessed August 2nd 2016, http://www.csaregistries.ca/files/projects/prj_9123_849.pdf .
[11] Ibid, 1.
[12] "Slave Lake Pulp Bio-Methanation Project" CCEMC, accessed August 10th 2016, http://ccemc.ca/project/slave-lake-pulp-bio-methanation-project/

not technically an AD facility, Enerkem is a biogas system that uses thermochemical gasification instead of an anaerobic digestion.

2.2 Potential in Alberta

In a biogas market study, TEC Edmonton indicates that based on the amount of waste produced in Alberta (35 Mega Tonnes of waste/year), there could be 350 AD facilities in the province (assuming the typical 100,000 tonne size AD facility). These 350 facilities could produce 1400 MW of electricity or roughly 9% of the total amount of electricity on the Alberta grid. Yet it is unlikely that all waste can be used as feedstock in AD facilities, and, given this, TEC Edmonton highlights that even if just 10% of waste was used as feedstock, this would result in a reduction of at least 0.7 Mt of $C0_2$ equivalent per year and generate 140 MW of organic based electricity.[13]

3. Anaerobic Digestions and Biogas Systems

3.1 Basics of Anaerobic Digestion

Anaerobic digestion (AD) is a biological process that involves the breakdown of organic waste materials by bacteria in the absence of oxygen. There are four main stages in AD process; hydrolysis, acidogenesis, acetogenisis and methonogenesis.[14] Figure 1 shows the progression of the four stages of AD.[15] In the hydrolysis stage, longer chains of carbohydrates, fats and protein are broken down into shorter chains of sugar amino acids and fatty acids. During the acidegenesis phase, acid forming bacteria convert the simple compounds into volatile fatty acids, carbon dioxide and hydrogen sulfide. Volatile fatty acids are catabolism in the acetogenisis stage to produce acetic acid and CO2 and H2.[16] The final stage involves the use of a class of bacteria

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[13] TEC Edmonton, *Biogas Market Study: Understanding the Alberta Anaerobic Digestion Landscape*, last modified October 2015, http://ccemc.ca/wp-content/uploads/2015/11/Biogas-Market-Study-Oct-14-2015.pdf

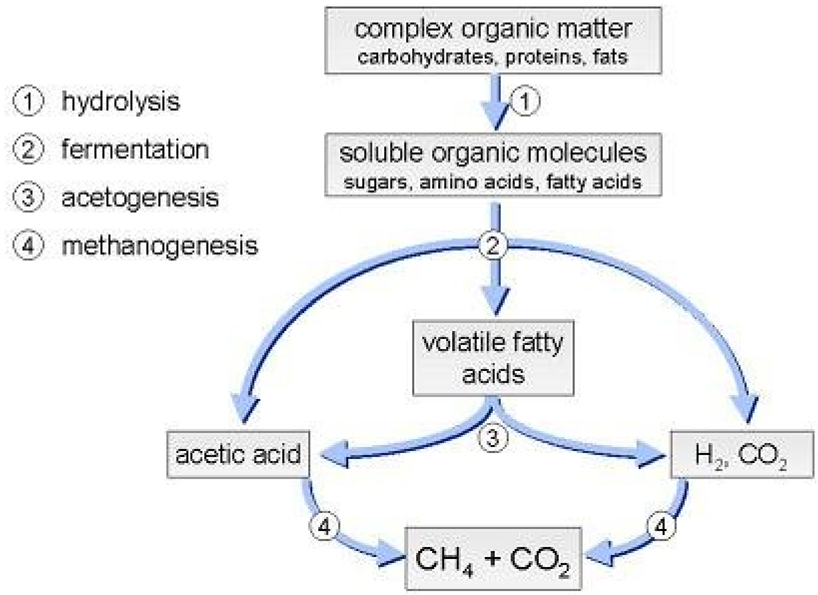
[14] Benefits of Anaerobic Digestion, Harvest Power, accessed August 19th, http://www.harvestpower.com/old/wpcontent/uploads/2012/01/Anaerobic_Digestion_2012.01.24_sm.pdf.

[15] "Anaerobic Digestion," Technologies for Economic Development, accessed August 19th, http://www.ted-biogas.org/index.php?id=3.

[16] Douglas W. Hamilton, "Anaerobic Digestion of Animal Manures: Understanding the Basic Processes," *Oklahoma Cooperative Extension Service*, (2009), 1–4.

called methogens that use the end products of fermentation (stages 1-3) and converts them into biogas.[17] Biogas is comprised of carbon dioxide, methane and trace amounts of other gases.

Figure 1: Schematic of the Stages of Anaerobic Digestion



Source: Technologies for Economic Development, "Anaerobic Digestion," accessed August 19th, http://www.ted-biogas.org/index.php?id=3.

3.2 Biogas Systems

Anaerobic digestion is one of stages of a larger process called a biogas system. A biogas system includes all the stages of converting organic waste streams like manure into usable energy. Figure 2 indicates the closed loop biogas system.[18] The biogas system begins with an input system, which is the organic feedstock for anaerobic digester. Biogas can be produced with nearly any kind of biological feedstock; this includes manure, food by-products and energy crops. A study done by the Canadian Biogas Association highlights the greatest potential for

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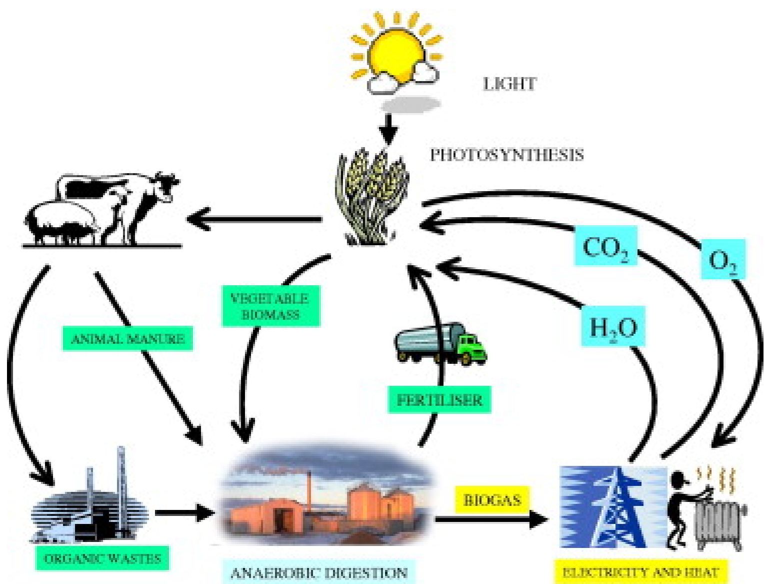
[17] Hamilton, "Anaerobic Digestion of Animal Manures: Understanding the Basic Processes," 2.
[18] Holm-Nielsen, Al Seadi, and Oleskowicz-Popiel, "The Future of Anaerobic Digestion and Biogas Utilization," 5479.

biogas production is feedstock from agriculture.[19] There are three conventional scales for biogas systems; a farm-based system, food-processing system or a centralized system.[20] On-farm and food processing systems are smaller in scale and are designed specifically to process the waste by-products of their operation. Centralized systems use co-generation to process multiple waste streams. Waste material from farm and food processing plants as well as source-separated organics are hauled to a centralized digester where heat and electricity created is used by neighboring residents.

Figure 2: Visual Representation of a Closed Loop Biogas System



Source: Holm-Nielsen, Al Seadi, and Oleskowicz-Popiel, "The Future of Anaerobic Digestion and Biogas Utilization," 5479.

The next stage of the bio gas system is the anaerobic digester, where the organic waste is broken down in a controlled facility. Anaerobic digestion can occur in three main types of digesters: hydraulic flow regimes include batch reactor (BR), sequencing batch reactor (SBR) or

[19] "Canadian Biogas Study," Biogas Association, 2013 , accessed August 19th 2016, http://www.biogasassociation.ca/bioExp/images/uploads/documents/2013/resources/Canadian_Biogas_Study_Summary.pdf, 9.
[20] "Anaerobic Digesters Basics," Government of Ontario, (Toronto: Minister of Agriculture, Food and Rural Affairs), accessed August 18th 2016, http://www.omafra.gov.on.ca/english/engineer/facts/07-057.htm#10.

continuous flow reactors (CFR).[21] Continuous flow reactors can be further broken down into completely mixed systems and plug flow reactors. Both types of CFR operate at a constant volume, meaning that the feedstock input is matched by equivalent volume of substrate being removed.[22] Anaerobic digestion can take place at different temperature ranges: psychrophilic (10–25°C), mesophilic (30–40°C) or thermophilic (50–60°C) temperatures. Depending on the feedstock used (i.e. liquid or dry) and the temperature, different AD systems are used. Annex 1 provides a detailed breakdown of comparable systems.[23]

The last step in the biogas system is using the by-products of anaerobic digestion for either on-farm purposes or for commercial purposes. The by-products of anaerobic digestion are a digestate and biogas. Digestate is concentrated "nutrient rich slurry"[24] that can be applied to crops as fertilizer. The biogas can be put through a generator to make electricity which can be used on farm to complete the closed loop system or sold back onto the grip. Biogas can also be used to fuel boilers and furnaces for heat. Additionally, biogas can be scrubbed to remove C02 content[25] and used as renewable natural gas (RNG) for vehicle fuel or for injections into natural gas pipelines.[26]

3.3 System Environmental Benefits

3.3.1 GHG Emission Reductions

Biogas systems have important GHG emissions reduction potential. There are many different types of AD facilities and different protocols for calculating GHG emissions reduction. Therefore, emissions reductions are calculated and presented in ranges. AD facility GHG emission reduction can occur through: 1) the diversion of waste from a landfill where uncultured waste from the decomposition process would enter the atmosphere; 2) creating renewable

[21] D.I. Massé, G. Talbot, and Y. Gilbert, "On Farm Biogas Production: A Method to Reduce GHG Emissions and Develop More Sustainable Livestock Operations." *Animal Feed Science and Technology* 166-167(2011), doi:10.1016/j.anifeedsci.2011.04.075, 437.
[22] Massé, Talbot, and Gilbert, "On Farm Biogas Production: A Method to Reduce GHG Emissions and Develop More Sustainable Livestock Operations," 438.
[23] Harvest Power, "Benefits of Anaerobic Digestion," 4.
[24] "Canadian Biogas Study," Biogas Association, 9.
[25] Anaerobic Digesters: Frequently Asked Questions, Government of Alberta, (Edmonton: Minister of Agriculture and Forestry, 2014), http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/%20all/agdex11290.
[26] "Canadian Biogas Study," Biogas Association, 17.

electricity from organic waste to substitute for fossil-fuel or other carbon intensive energy sources; and, 3) generating thermal heat to substitute for natural gas furnaces and boilers.[27] Researches at TEC Edmonton highlight some of the emissions reduction ranges for a typical 100,000 tonne waste processing AD facility: "240-480 kWh/t of waste can be generated, 14-28 kt C02 equivalent emission reduction from replacing fossil-fuel based electricity, and 40-50 kt Co2 equivalent emission reduction can be achieved if waste diversion form landfill is included."[28] A study conducted by the Canadian Biogas Association of Canada summarizes the potential emission reduction as follows: [by] "digesting half of animal manures and crop residues across Canada would reduce GHG emissions by an estimated 25.5 million tonnes of CO2e per year. This is the equivalent of taking 5,100,000 cars off the road."[29]

3.3.2 Reduced Water Contamination

Sound manure management practices are critical in order to avoid ground water contamination. The high concentration of organic pollutant livestock manure poses a threat to surface water quality. Livestock manure that enters into water sources (i.e. ponds, lakes, rivers) is of concern due to four principle factors: nutrients, oxygen depletion, suspended solids, and bacteriological quality.[30] If proper application and spreading of manure is not taken, nutrients such as nitrogen, phosphorus and potassium can find their way into water sources due to erosion, leakage or runoff. The chemical O2 demand contained in livestock manure will decompose and dissolve oxygen in the water, a process called water eutrophication that leads to fish kills. Sharply et al. show several cases of water eutrophication and fish kills, highlighting the need for proper manure management.[31] Nutrients such as phosphorus can cause increase growth in aquatic plants such as algal blooms, causing a disruption in ecosystems. Anaerobic digestion contributes to surface water protection by reducing the organics pollutants within livestock manure. AD reduces total oxygen demand levels and total volatile solids which lowers the

[27] TEC Edmonton, *Biogas Market Study*, 23.
[28] Ibid, 23.
[29] "Canadian Biogas Study," Biogas Association, 17.
[30] Ramasamy Rajesh Kumar, Park Bong Ju, and Jae Young Cho, "Application and Environmental Risks of Livestock Manure." *Journal of the Korean Society for Applied Biological Chemistry*, 56, no. 5 (2013): 497–503, doi:10.1007/s13765-013-3184-8.
[31] J.L. Hatfield, B.A Stewart (Eds.), *Animal Waste Utilization: Effective Use of Manure as a Soil Resource*, (New York: Lewis Publishers), 2002, 173, http://dlia.ir/Scientific/e_book/Agriculture/Fertilizers_Improvement_of_the_Soil/019596.pdf.

potential for depletion of dissolved oxygen in water sources and nonpoint source water pollution.[32] A study done by Natural Resource Canada showed that chemical oxygen demand can be reduced by 60-90% using biogas systems.[33]

Anaerobic digestion can reduce health risks associated with livestock manure by removing or reducing pathogens. Health risks caused by pathogens in livestock manure can arise if manure enters water sources. Pathogens in livestock manure can include, *Salmonella, Yersinia, Enterocolitica, Cryptosporidium, and Giardia.*[34] *A* study conducted by Dr. John Martin through the Eastern Research Group, Inc. found that Mesophilic anaerobic digestion (95–105 1F) reduced density of fecal coliform groups by 99.9%, and Mycobacterium avium paratuberculosis by more than 99%.[35] Additionally, Caroline Cote et. al, from the Research and Development Institute for the Agri-Environment found that psychrophilic anaerobic treatment (50–771F) significantly removed pathogens (e.g., Salmonella, Cryptosporidium, Giardia, E. coli and total coliform) by 97.94–100%.[36] Although there has been success with reducing pathogens through Anaerobic digestion, the effectiveness of removing pathogens depends on temperature levels and the type of digesters used; not every digester will destroy or greatly reduce all pathogens contained in livestock manure.[37]

3.3.3 Odour Reduction

Odour is one of the major issues for agricultural production, especially swine farms that are located near urban centers.[38] Anaerobic digestion helps break down the compounds with a foul odour (such as volatile organic acids, ammonia (NH_3), and hydrogen sulfide (H_2S)) into

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[32] Emmanuel K. Yiridoe, Robert Gordon, and Bettina B. Brown, "Nonmarket Cobenefits and Economic Feasibility of on-Farm Biogas Energy Production," *Energy Policy*, 37, (2009). (3): 1170–79, doi:10.1016/j.enpol.2008.11.018.
[33] Natural Resources Canada and Agriculture and Agri-Food Canada, "Discover the Production and Uses of Biogas," Bioenergy Series III, Catalogue No. M92- 253/2002E, 2002, Natural Resources Canada, Ottawa, Canada.
[34] Yiridoe, Gordon, and Brown, "Nonmarket Cobenefits and Economic Feasibility of on-Farm Biogas Energy Production," 75.
[35] John Martin, "An Evaluation of Mesophilic, Modified Pluc Flow Anaerobic Digesters of Dairy Cattle," *Eastern Research Group Inc*,(2002): 9, http://www.dvoinc.com/documents/gordondale_report_final.pdf.
[36] Caroline, Côté, Daniel I. Massé, and Sylvain Quessy. "Reduction of Indicator and Pathogenic Microorganisms by Psychrophilic Anaerobic Digestion in Swine Slurries," *Bioresource Technology* 97, 4, (2006.): 686–91. doi:10.1016/j.biortech.2005.03.024.
[37] Massé, Talbot, and Gilbert, "On Farm Biogas Production: A Method to Reduce GHG Emissions and Develop More Sustainable Livestock Operations," 39.
[38] Barth Correlating odor intensity index and odorous compounds in stored dairy manure

odourless compounds of biogas (i.e. methane and C02).[39] Using anaerobic digestion, Pain et al. claim that the odour can be decreased by 70-80%[40] with the potential of decreasing odor by 97% according to Lusk from the US Department of Energy.[41] Odour reduction benefits the community and the company as it leads to better community relations. According to the Annual Report published by Natural Resource Conservation Board, 16% of complaints filed are due to odour and 24% due to the concerns of surface water contamination.[42] The Canadian Agricultural Energy End Use Data and Analysis Centre (CAEDAC) claims that odour and water surface contamination are the two most heightened legal issues within agriculture in Canada.[43] CAEDAC highlight some of the major lawsuits that have been filed on the grounds of nuisance and negligence, sighting specifically *Rylands v. Fletcher i*n Saskatchewan.[44] On-farm use of Anaerobic Digesters can reduce odour nuisances and ground water contamination complaints and potentially avoid very costly lawsuits.

With the use of anaerobic digestion, the reduction in odour allows for better-timed land application of manure (or digestate). When applying untreated manure to the land, farmers would have to be cautious about timing due to odour and wind patterns. With the digestate produced through AD, land application of processed manure can be timed in accordance with the needs of the land thereby making the application more effective.

3.3.4 Reduced Use of Commercial Fertilizer

The digestate produced by an anaerobic digester can be used to replace commercial fertilizer. The Canadian Council of Ministers of the Environment (CCME) produced a set of guidelines, the *Guidance Document for the Beneficial Use of Municipal Biosolids, Municipal Sludge and Treated Septage* in 2009, recognizing the opportunity for bio solids. The CCME

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[39] Yiridoe, Emmanuel K., Robert Gordon, and Bettina B. Brown. 2009. "Nonmarket Cobenefits and Economic Feasibility of on-Farm Biogas Energy Production." Energy Policy 37 (3): 1170–79. doi:10.1016/j.enpol.2008.11.018.
[40] Ibid, 1171.
[41] P.D. Lusk, "Methane Recovery from Animal Manures: The Current Opportunities Casebook," National Renewable Energy Laboratory US Department of Energy,1998, Washington, DC, http://www.nrel.gov/docs/fy99osti/25145.pdf
[42] "Annual Report 2014-2015," Natural Resource Conservation Board, Accessed September 4th 2016, 10, https://www.nrcb.ca/Portals/0/Documents/Annual-Reports/Annual_Report_2014-15.pdf.
[43] Canadian Agriculture Energy End Use Data Analysis Center, "The Economics of Biogas in The Hog Industry," 1999, Accessed Sept 4th 2016, 14, http://www.usask.ca/agriculture/caedac/PDF/HOGS.pdf.
[44] CAEEDAC, "the Economics of Biogas in the Hog Industry," 18.

highlights that land application of bio solids is favored to enhance soil fertility, soil structure and plant growth.[45] Digestate produced in the anaerobic digestion process is more nutrient dense in minerals such as Nitrogen and Phosphorous as compared to original manure. The Biogas association of Canada claims that the land application of bio solids or digestive can “reduce the need for fertilizer, allows for storage of carbon in the soil, thereby minimizing GHG emissions, lower nitrous oxide emissions, provide porosity, bulk density and water holding capacity to the soil, and adds micronutrients as well as macronutrients.”[46]

3.4 Alternative Waste Management Solution

Anaerobic digestion can be used as part of a comprehensive waste management solution. An AD system has been commonly used in high-density regions, particularly in European countries. AD facilities can use a wide variety of feedstock including Municipal Solid Waste (MSW), agricultural waste, food scraps, yard waste and source separated organics. They can also provide an alternative method for disposing organic waste streams, diverting waste away from decomposition in landfills. As jurisdictions move towards “zero waste” initiatives, technologies such as anaerobic digestion will become increasingly required. In response to the Landfill Directive under the European Commission, the UK identified the importance of promoting an increase in energy creation from waste using anaerobic digestion.[47] Within Alberta there are divers that provide incentive to strive for a zero organic waste policy initiative. A report done by Alberta Innovates identifies these factors to include “limited landfill capacity, the cost of operating landfills and potential economic gains through recovering resources to their full

[45]Canadian Council of Ministers of the Environment, “Guidance Document for the Beneficial Use of Municipal Biosolids, Municipal Sludge and Treated Septage,” 2012, accessed September 4th 2016, 30, http://www.ccme.ca/files/Resources/waste/biosolids/pn_1473_biosolids_guidance_eng_1.0.pdf.

[46] Canadian Biogas Association, “Canadian Biogas Study: Benefits to the Economy, Environment and Energy Technical Document.” 2013, accessed Septemeber 4th 2016, 47, http://www.biogasassociation.ca/bioExp/images/uploads/documents/2014/biogas_study/Canadian_Biogas_Study_Technical_Document_Dec_2013.pdf.

[47] Sara Evangelisti, Paola Lettieri, Domenico Borello, Roland Clift, “Life Cycle Assessment of Energy from Waste Via Anaerobic Digestion: A UK case study,” *Waste Management* 34, no. 1 (2014): 257, http://dx.doi.org/10.1016/j.wasman.2013.09.013.

potential."[48] The report identifies anaerobic digestion as a solution which would divert organics away from landfills and have a positive environmental impact.[49]

4. Determinants of System Viability

4.1 Model of Technology Adoption

The adoption of AD systems has not been uniform across European countries or even across Canada. A strand of economic literature suggests that the adoption of a technology is based on the threshold principle. Researchers Zilberman, Zhao and Heiman suggest that new technologies are adopted by heterogeneous agents when the perceived benefits outweighs the perceived costs and that early adopters usually gain the most from adoption of the technology.[50] There is a gradual rate of adoption across heterogeneous socio-economic and biophysical geographical locations that is facilitated by learning by doing.[51]

Bangalore, Hochman and Zilberman developed a model to highlight the different factors that lead to an increased adoption of a technology in agriculture.

- Farmers produce output q at price p and waste z
- Farmers chose between two waste disposal technologies; traditional technology i=0 and new technology (AD system) i=1, where the new technology produces a new product (electricity)
- Where $\beta_0 = 0$ and $\beta_1 > 0$. The price paid for this co-product is w, but it requires extra investment k_1 (q) > 0. They assume that $k_0(q) = 0$ and that $k_1(q) > 0$ and is increasing with q.

[48] Annaliese Behrens and Arifa Sultana "Zero Organic Waste In Alberta: Policy Recommendations," *Alberta Innovates- Energy and Environment Solutions*, (2014): 2, http://www.ai-ees.ca/wp-content/uploads/2016/04/zero_organic_waste_alberta-_jan_2015.pdf.
[49] Behrens and Sultana "Zero Organic Waste In Alberta: Policy Recommendations," 14.
[50] David Zilberman, Jinhua Zhao and Amir Heiman, "Adoption Versus Adaption with Emphasis on Climate Change," *Resource Economics* 4, (2012):30, DOI: 10.1146/annurev-resource-083110-115954.
[51] Mook Bangalore, Gal Hochman and David Zilberman, "Policy Incentives and Adoption of Agricultural Anaerobic Digestion: A Survey of Europe and United States," *Renewable Energy* 97, (2016): 561, http://dx.doi.org.ezproxy.lib.ucalgary.ca/10.1016/j.renene.2016.05.062.

- The investment is subsidized by the government such that the farmer pays for technology *i* $s_i * k_i(q)$ where $s_0 = 1$ and $s_1 < 1$. The pollution z_i is equal to $\alpha_i * q$ where $\alpha_0 > 0$ and $\alpha_1 = 0$
- There is a penalty on pollution that is equal to ψ. Also, the cost of production is normalized to zero, and it is assumed that the farmer is a price taker, both in the input markets as well as at the output markets.
- The farmer produces given amount *q* and must pick between whether or not to adopt technology 0 or 1.

Figure 3. Adoption Levels Model

$$\mathbf{e}_i = \beta_i * \mathbf{q},$$

$$\max_i (\mathbf{p} - \psi * \alpha_i + w * \beta_i) * \mathbf{q} - \mathbf{s}_i * \mathbf{k}_i(\mathbf{q}).$$

$$(w * \beta_1 + \psi * \alpha_0) * \mathbf{q} > \mathbf{s}_1 * \mathbf{k}_1(\mathbf{q})$$

Source: Bangalore, Hochman and Zilberman, "Policy Incentives and Adoption of Agricultural Anaerobic Digestion: A Survey of Europe and United States,"561.

Figure 3 is a profit maximization formula where producers seek to maximize profits by producing an output where their marginal revenue equals their marginal cost. In this model farmers will choose to adopt a technology when the gains or benefits form adoption outweighs the costs. From the model, Bangalore et al. illustrate that "high electricity prices *w*, high penalties for pollution ψ, and subsidizing investments s_1, yields more adoption" of new waste disposal technology.[52] When assessing the biogas industry in Alberta, based on this model the low levels of adoption could be due to one or a combination of all three factors identified by Bangalore et al. Policy and regulations that are in place are the foundation in which the three factors identified above are based upon and therefore have a significant impact of the adoption rates of AD systems. Bangalore et al. show that adoption follows policy and that lucrative and

[52] Bangalore, Hochman and Zilberman, "Policy Incentives and Adoption of Agricultural Anaerobic Digestion: A Survey of Europe and United States,"561.

stable incentives for the adoption of AD policy lead to the adoption of the technology.[53] It follows that the fourth and most foundational factor that either inhibits or fosters the growth of AD technologies and biogas systems is the policies and regulations used.

4.2 Potential Causes of Limited Adoption in Alberta

4.2.1 Density of Feedstock

The first barrier for the creation of a biogas system is the feedstock. Does Alberta have enough quality of feedstock to support the biogas industry? As noted earlier, Alberta has the largest amount of waste per capita in Canada.[54] Alberta also has access to a substantial level of agricultural feedstock.[55] These two points suggest opportunities for the development and implementation of biogas systems within Alberta. However, it is also necessary to qualify this by looking at the amount that is technically and logistically feasible for anaerobic digestion. Table 1 highlights the livestock and municipal feedstock and the corresponding biogas energy potential within Alberta. [56] From Table 1 it is clear that livestock manure is the most available feedstock for biogas production. However not all livestock manure is recoverable. Manure produced from open range farming is not recoverable whereas manure produced by confined feeding operations is. The government of Alberta has indicated that the "estimated recoverable percentages of manure from the available statistical data for beef cattle, dairy cattle and swine are 46, 82 and 91 per cent, respectively."[57]

[53] Bangalore, Hochman and Zilberman, "Policy Incentives and Adoption of Agricultural Anaerobic Digestion: A Survey of Europe and United States," 561.
[54] TEC Edmonton, *Biogas Market Study*, 23.
[55] Biogas Energy Potential in Alberta, Government of Alberta, Department of Agriculture and Forestry, last modified May 30, 2011, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex11397
[56] Biogas Energy Potential in Alberta, Government of Alberta.
[57] Ibid.

Table 1. Inventory of livestock and municipal feedstock materials and biogas energy

Feed material	Total solids %	Volatile solids % of total solids	Biogas yield m^3/tonne	Annual biomass production in tonnes	Annual energy potential in PJ	Methane content %
Beef cattle manure	8-12	80 - 85	19 - 46	22,955,019	8.7 - 21.1	53
Hog manure: grower to finisher	9-11	80 - 85	28 - 46	1,848,415	1.0 - 1.7	58
Dairy manure	12	80 - 85	25 - 32	3,217,714	1.6 - 2.1	54
Poultry manure	25 - 27	70 - 80	69 - 96	284,342	0.4 - 0.5	60
Animal fat	89 - 90	90 - 93	801 - 837	87,000	1.4 - 1.5	N/A
Animal carcass (homogenized-bovine)	34 - 39	90 - 93	348 - 413	264,023	1.8 - 2.2	N/A
Municipal wastewater sludge	30 - 20	90	17 - 140	539,835	0.2 - 1.5	65
Household waste	N/A	N/A	143 - 214	N/A	N/A	N/A
Total straw and other roughages	70	90	105 - 158	2,654,585	5.6 - 8.4	60 - 70
Thin stillage (ethanol by-product)	7	–	58	105,000	–	50 - 60
Total manure (including municipal sludge) and straw and other roughages	–	–	–	31,850,933	21 - 39	50 - 70

Source: Biogas Energy Potential in Alberta, Government of Alberta, Department of Agriculture and Forestry, last modified May 30, 2011, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex11397

Within Alberta there is a relatively large amount of livestock manure production, yet there are technical challenges with specific types of manure. Solid manure such as that produced from beef cattle production contains sand and feed spills as well as inorganic waste which can cause operational problems in the anaerobic digestion process. Cattle manure requires additional processing steps before it can be used as feedstock, such as diluting, sorting and pumping or mixing. The additional processing steps add extra capital costs to the biogas project. Technologies have been developed to process manure produced from confined feedlots. For example High Mark biogas created a technology called IMUS which is a patented system that uses a certain type of microorganism to break down high-solid, high fiber feedstock such as that from a cattle feedlot.[58]

[58]IMUS- Integrated Biomass Utilization System, Environmental Expert, accessed September 2016, http://www.environmental-expert.com/products/imus-integrated-biomass-utilization-system-180059.

A co-digestion system uses multiple organic waste streams and may further reduce the amount of feedstock available due to logistical issues. Co-digestion systems have multiple benefits for biogas systems including a higher energy production yield and a greater opportunity for flexibility in crop rotations. However, when using multiple waste streams from different locations, the logistics of transportation of waste must be considered. Transportation of waste streams to co-digestion facility may present extra costs that must be internalized in the cost of production. A study done the Department of Agriculture and Forestry quantified the waste produced by livestock operations, food processors, grocery stores and yard waste. Figure 4 shows a geographical representation of the organic waste densities within Alberta. From that figure it is evident that the higher concentration of organic waste is in the southern part of Alberta because of the higher concentration of livestock operations.[59] To reduce logistical transportation issues, co-generation plants would likely be located in the higher organic waste producing regions of Alberta.

Despite the fact that there are logistical and technical factors that qualify absolute levels of waste, there remains a substantial amount of feedstock available in both Canada and Alberta to support a biogas industry. Jeff Bell from The Department of Agriculture and Forestry found that from the four sub-sectors of Alberta's Agrifood industry (livestock operations, food processors, grocery stores and yard waste), approximately 3.4 million tonnes of organic waste is produced with livestock producing 2.6 million tonnes/year, which is just under 80% of total organic waste. The most common methods of disposal are putting the waste in a landfill and applying waste directly onto land.[60] In his conclusions Bell states "Feedstock limitation is unlikely to be the limiting factor preventing Albertans from getting more value from their organic wastes."[61]

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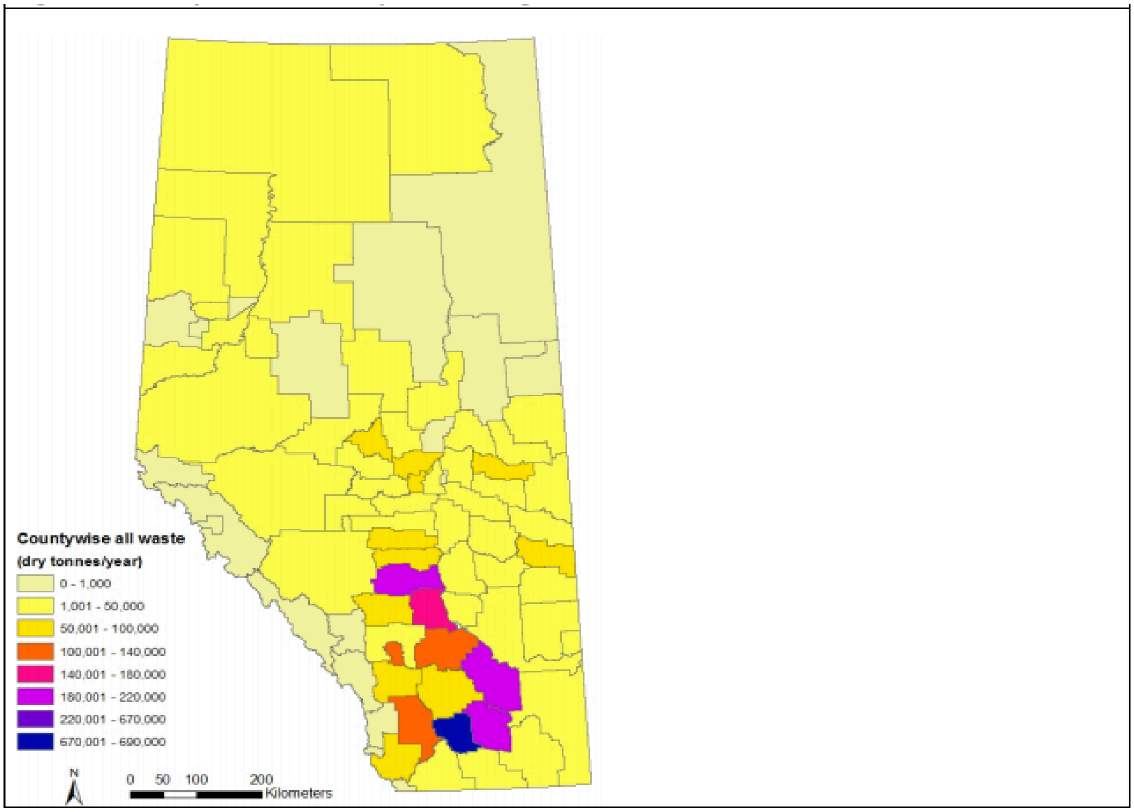
[59] Jeff Bell, "An Organic Waste Inventory for Alberta," Government of Alberta Agriculture and Forestry, (2015): 18, http://www.ai-ees.ca/wp-content/uploads/2016/04/an_organic_waste_inventory_for_alberta_oct7.pdf.
[60] Jeff Bell, "An Organic Waste Inventory for Alberta," 21.
[61] Ibid, 17.

Figure 4. County-level Availability of Agri-Food Waste in Alberta



Source: Jeff Bell, "An Organic Waste Inventory for Alberta," Government of Alberta Agriculture and Forestry, (2015): ii.

4.2.2 Economic Feasibility: Capital Costs and Commodity Prices

As modeled in Section 4.1, the level of adoption of new technologies is based on the principle of maximization of expected utility (or expected profit).[62] An individual company's decision to adopt a new waste management technology involves tradeoffs between the gains of adoption (i.e. input saving, increased revenue from electricity sales, carbon offsets, tipping fees) and the costs of adoption (i.e. higher fixed investment costs, more skill/time required, opportunity costs of investing elsewhere).[63]

[62] Gershon Feder, Richard E. Just and David Zilberman, "Adoption of Agricultural Innovations in Developing Countries: A Survey," *Economic Development and Cultural Change* 33, No. 2 (Jan., 1985): 255-298, http://ezproxy.lib.ucalgary.ca/login?url=http://search.proquest.com/docview/236515060?accountid=9838.

[63] Bangalore, Hochman and Zilberman, "Policy Incentives and Adoption of Agricultural Anaerobic Digestion: A Survey of Europe and United States," 561.

Capital Costs

AD systems are capital intensive and for that reason require financing. One of the key barriers to implementation of AD systems is the inability to attract financing.[64] Tim Shelford and Curt Gooch form Cornell University claim that the uncertainties about the rate of return and high capital costs are the main obstacles to securing financing and are the most difficult step of implementing an AD system.[65] This is supported by Bangalore et al. who indicate that capital investments are a barrier to adoption of AD technologies, especially among farmers. Additionally, Bangalore states that investment loans or grants are required initially to incentivize farmers to invest in AD facilities.[66]

The capital cost for an AD facility in Alberta can range from $26,750,000 to $34,000,000 based on a report done by the municipal Waste Integration Network and Recycling Council of Alberta.[67] Similarly, the Alberta Government reports that the typical capital cost for a biogas electricity generating plant is $3,700 to $7,000/kWh.[68] The capital costs for biogas systems range based on the technologies used, ranging from simple flaring of biogas to processing facilities for electricity generation.[69] A study done of the energy production costs from US livestock facilities claim that the electrical generation equipment accounts for 36% of total capital cost and is responsible for the majority of maintenance costs.[70] The electricity produced is also a source of revenue from selling power generated and from the possibility of carbon offsets.

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[64] Tim Shelford and Curt Gooch, "Small Farm Anaerobic Digestion Systems and Barriers to Increasing their Implementation In New York State," *University of Cornell: Biological and Environmental Engineering*, (Nov., 2012): 21.

[65] Shelford and Gooch, "Small Farm Anaerobic Digestion Systems and Barriers to Increasing their Implementation In New York State," 21.

[66] Bangalore, Hochman and Zilberman, "Policy Incentives and Adoption of Agricultural Anaerobic Digestion: A Survey of Europe and United States,"560.

[67] TEC Edmonton, *Biogas Market Study*, 34.

[68]Mahendran Navaratnasamy, Ike Edeogu and Lawrence Papworth "Economic Feasibility of Anaerobic Digesters," Government of Alberta Agriculture and Forestry, accessed Sept. 2016, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex12280.

[69] Holm-Nielsen, Al Seadi, and Oleskowicz-Popiel, "The Future of Anaerobic Digestion and Biogas Utilization," 5479.

[70] "An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities," United Sates Department of Agriculture, (October 2007): 21, http://www.agmrc.org/media/cms/manuredigesters_FC5C31F0F7B78.pdf.

If we compare capital costs of AD facilities with the costs of landfill it is evident that AD facilities are either on par with landfill capital costs or even less. The capital costs of a 366,666 tonnes landfill site is $22,750,020 and the cost of a 52,233 tonne facility is $3,250,003.[71] Current expenditures for local governments across Canada increased 12% from 2008 to 2010 and one of the largest contributions to this overall increase was the 60% increase in expenditures on landfill post closure and maintenance funds.[72] Alberta currently surpasses the national average for per capita operating expenditures and per capita capital expenditures on the waste management industry.[73]

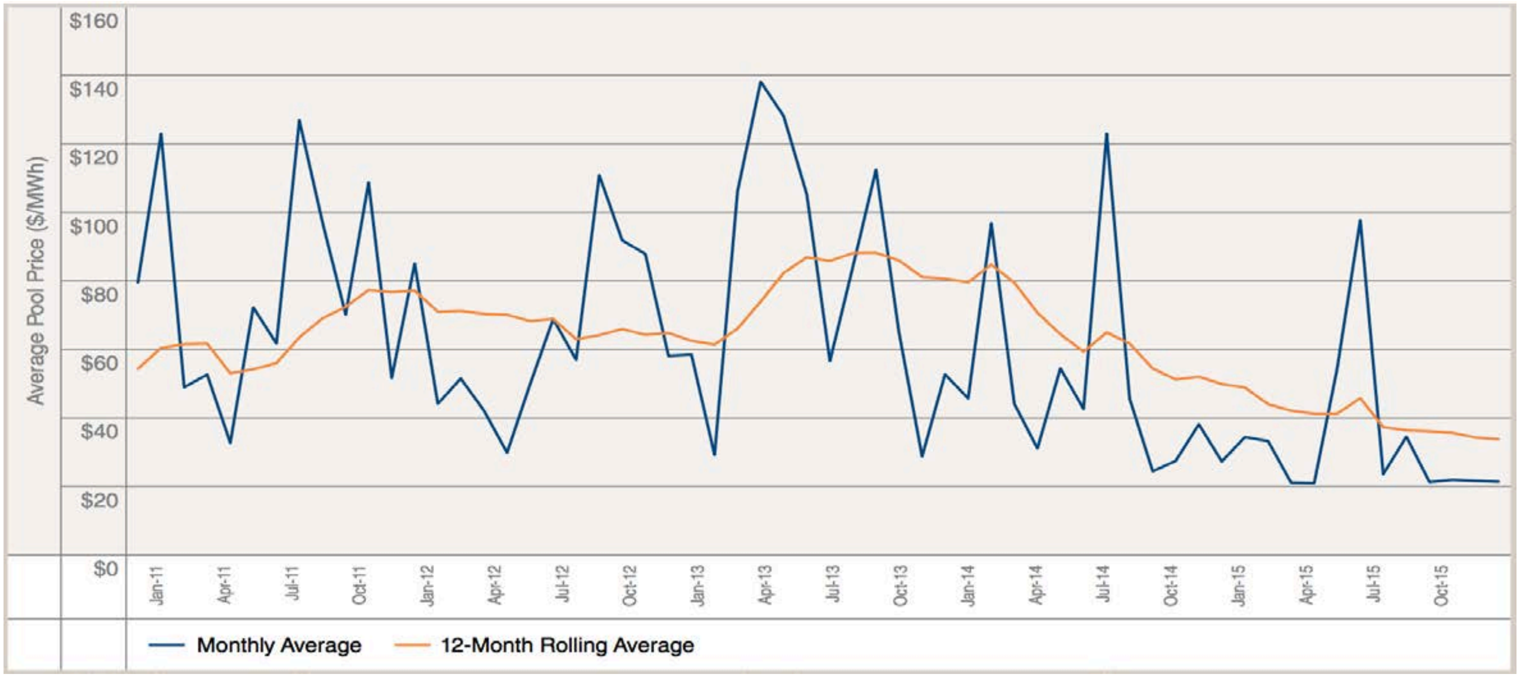
Capital costs of AD facilities are high, and in order to have a reasonable payback period, the commodity prices of the biogas systems by-products must be high enough to make it a sound investment. The other alternative is to subsidize the industry through grants/loans or performance-based financial incentives.

Commodity Prices

A revenue stream is created for biogas systems by selling renewable byproducts as energy sources, either as electricity, heat or converted to compressed natural gas. One of the barriers to implementing biogas systems is that revenue streams based commodities are susceptible to the ebb and flow of the energy market. Figure 5 highlights the average pool price of electricity over the past 2 years within Alberta. [74] Figure 6 shows the trends in Henry Hub Natural Gas prices. It is apparent that natural gas prices and electricity prices are both volatile as well as low in recent years. Recall rom the model produced by Bangalore et al, commodity prices (i.e. electricity) are important factors determining the rate of adoption of waste management technologies.[75] Higher prices lead to a greater increase in the adoption of AD technology.

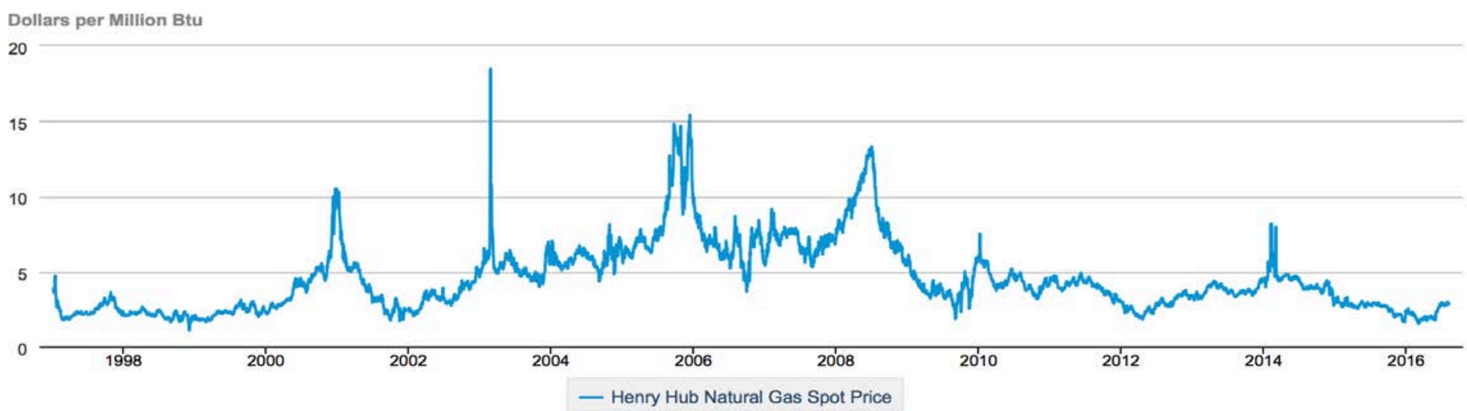
[71] TEC Edmonton, *Biogas Market Study*, 34.
[72] Statistics Canada, *Waste Management Industry Survey: Business and Government Sectors* (Ottawa: Minister of Industry, 2010), 6, http://www.statcan.gc.ca/pub/16f0023x/16f0023x2013001-eng.pdf.
[73] Statistics Canada, *Waste Management Industry Survey: Business and Government Sectors*, 6.
[74] Henry Hub Natural Gas Spot Prices, US Energy Information Administration, accessed August 15th 2016, https://www.eia.gov/dnav/ng/hist/rngwhhdd.htm.
[75] Bangalore, Hochman and Zilberman, "Policy Incentives and Adoption of Agricultural Anaerobic Digestion: A Survey of Europe and United States," 561.

Figure 5. Average Pool Price in Alberta



Source: Henry Hub Natural Gas Spot Prices, US Energy Information Administration, accessed August 15th, https://www.eia.gov/dnav/ng/hist/rngwhhdd.htm.

Figure 6. Henry Hub Gas Spot Price



Source: Annual Market Statistics 2015, Alberta Energy Systems Operator, accessed august 15th 2016, 3, http://www.aeso.ca/downloads/2015_Annual_Market_Stats_WEB.pdf.

4.2.3 Economic Feasibility Studies

In order to assess the feasibility of small scale AD projects based on returns from power prices, a study done by Tim Shelford and Curt Gooch from Cornell University is used. Shelford and Gooch's study focuses on small-scale farm anaerobic digesters in New York. In their study a cost benefit analysis of different benefit pricing, electricity sales methods and costs are used to assess the economic feasibility of small scale AD projects. The variables used for the cost-benefit modeling include: sale price of surplus generated electricity (prices used were $0.05, $0.16 and $0.31 per kWh), carbon credit pricing (10$ and 20$ per metric tonne), co-digestion ratio, tipping fee price, and project capital cost.[76] The detailed results of the study are summarized in Annex 2.

The cost/benefit economic analysis of the 5 scenarios suggests that co-digestion is the key to the viability of a small scale AD biogas system. Co-digestion adds a greater degree of feasibility to the plants based on the revenue generated by tipping fees and the increased biogas production leading to a higher revenue from electricity sales. The net metering laws in NY do not significantly help the economic feasibility of the projects. Shelford and Gooch also found that a feed-in tariff for electricity sales is beneficial but not as beneficial as tipping fees from co-digestion. [77]

The results produced in scenario 4 show the effects of electricity prices on the feasibility of AD systems. Shelford and Gooch show that with a herd size of 153 milking cows, capital costs of $2,700 per cow, no co-digestion and no carbon credits, the required premium for surplus power is extremely high at $4.66 per kWh. Shelford and Gooch state that co-digestion is a critical benefit to covering the capital expenses of AD system based on the increased electricity production and increased tipping fee. The study found that with net metering and co-digestion with maximum tipping fees that an electricity price $0.06-$0.08 USD is required to make the projects generate a neutral or positive benefit/cost ratio.

[76] Prices are recorded in US dollars

[77] Tim Shelford and Curt Gooch, "Small Farm Anaerobic Digestion Systems and Barriers to Increasing their Implementation In New York State," 55.

The academic research supports the conclusions drawn by Shelford and Gooch with regards to the relationship between the feasibility of AD systems and the electricity prices required. Table 2 summarizes a literary review done by Shawn Mallon and Alfons Weersink from the Department of Food, Agriculture and Resource Economics at the University of Guelph.[78] It shows the economic feasibility results of nine major studies.

Table 2. Literary Review of Feasibility Studies

Reference	Farm Type and Location	Methods	Capital Cost and Electricity Price	Results	Feasible or Not Feasible
1) Sullivan and Peters (1981)	-centralized and farm scale digester -Huron County, Ontario	-linear programming model -interest rate 10% over 25 years	- commercial price of methane production per cubic meter was $0.06	-predicted cost of methane of $0.18 per cubic meter	-Not feasible
2) Nelson and Lamb (2002)	-Haubenschild Farms a 750 cow dairy in Princeton, Minnesota	-payback period -operating cost per year is 3% of total cost	-$372,750 CDN -price $0.076/kWh CDN	-5 year payback period	-Feasible
3) Martin (2004)	-AA Dairy a 550 cow dairy in Candor, New York	-payback period -operating cost per year is 5% of total cost	-$257,460 CDN -price $0.11/kWh CDN	-7.5 year payback period -11 years payback period if a 7% interest rate is included	-Feasible
4) Martin (2005)	-Gordondale Farms a 860 cow dairy in Nelsonville, Wisconsin	-payback period	-$575,500 CDN -price $0.16/kWh CDN	->25 year payback period	-Not feasible
5) Higham (1998)	-option 1- farm scale 25kW AD plant -option 2- centralized 1MW AD plant -Europe	-payback period and IRR	-option 1- 750,000 CDN -option 2- 13,669,000CDN -price 0.09/kWh CDN	-option 1- 20 year payback, IRR 0.2% -option 2- 15 year payback, IRR 3.1%	-Not Feasible

[78] Shawn Mallon and Alfons Weersink, "The Financial Feasibility of Anaerobic Digestion for Ontario's Livestock Industries," Department of Food, Agriculture and Resource Economics, University of Guelph, (2007): 18, http://ageconsearch.umn.edu/bitstream/7295/2/wp070001.pdf.

6) Ernst et al (1999)	-option 1- 18,000 hogs swine farm -option 2- >18,000 hogs swine farm -Iowa State	-payback period and NPV	-option 1- $1,573,568 CDN -option 2- $4,274,599 CDN -price $0.32/kWh CDN	-option 1- 9 year payback period, NPV $1,974,016 CDN -option 2- 9 year payback period, NPV $9,087,354 CDN	-Both options feasible
7) Davis (2006)	-Mills Dairy, in Scott County, Mississippi	-NPV and IRR -loan rate of 8%, discount rate of 4.5%, tax rate of 35% -FarmWare simulation software	-Capital cost not available -price $0.042/kWh CDN	-10 year payback period -NPV and IRR not reported	-Feasibility increases with government incentive programs
8) Mckevitt et al (2005)	-business plan for BioGreen Inc investing in a beef feedlot in Rosetown, Saskatchewan	-payback period, NPV, IRR and financial analysis - interest rate of 7%, income tax rate of 14% and inflation rate of 2%	-$1,785,567 CDN -$0.11/kWh CDN	-10 year payback period, NPV $89,005 CDN, IRR 22.9%	-Not feasible
9) Lensink (2007)	-option 1- 110kW plant option 2- 250kW plant -swine manure and other biomass wastes -Huron County, Ontario	-payback period, NPV, IRR and financial analysis -discount rate of 10%	-option 1- $733,000 CDN -option 2- $912,000 CDN -price $0.11/kWh CDN	-option 1- 10 year payback, NPV $-244,000, IRR -1% -option 2- 10 year payback, NPV $229,000, IRR 16%	-option 1- not feasible -option 2- feasible

Source: Shawn Mallon and Alfons Weersink, "The Financial Feasibility of Anaerobic Digestion for Ontario's Livestock Industries," Department of Food, Agriculture and Resource Economics, University of Guelph, (2007): 18, http://ageconsearch.umn.edu/bitstream/7295/2/wp070001.pdf.

4.3 Policy Barriers

The model in section 4.1 indicates that investment incentives are a critical factor to the adoption of AD and biogas systems. Currently in Alberta there is a lack of investment incentives for AD facilities. Programs that were previously put in place such as the Nine Point Plan are now expired and no new programs have been implemented. The investment incentive policies that are available to farmers and other producers is funding from CCEMC (Climate Change and Emissions Management Corporation) and utilization of the Micro-Generation policy. Yet, there are aspects of both the funding from CCEMC and the Micro-Generation policy that act as barriers to adequately provide investment incentives.

The Nine Point Plan was developed in 2006 with the intent to expand and strengthen the bioenergy production capacity within Alberta. Under the Nine Point Plan, companies in the bioenergy industry could gain access to support feasibility, capital costs and obtain producer credit. The plan included three approved program initiatives: Commercialization/market Development Program (24$ million through 2008-09); Bioenergy Infrastructure Development Grant Program ($6 million through 2008-09); Renewable Energy Producer Credit Program; or Bioenergy Producer Credit program ($209 million from 2007-2011).[79] In April 2011 the Bioenergy Producer Credit program (BPCP) was expanded and extended to a five-year program that ended March 31 2016.[80] BCPC allowed biofuels producers a credit that at minimum equaled the Alberta Fuel Tax ($0.09 cents per litre). There are currently no similar grant programs available for biogas systems in Alberta. The Government of Alberta claims that through the Climate Leadership Plan they are committed to growing the renewable energy sector and exploring options to secure a viable bioenergy industry.[81] A workshop with the major biogas industry players revealed that the industry would like to see a reinstatement of the credit program and similar programs as those contained in the Nine Point Plan.[82] This would allow greater certainty for the economic feasibility of biogas systems in Alberta.

The Micro-Generation Regulation under the Electric Utilities Act came into force in February 2009 and will expire December 2016.[83] The intent of the micro generation policy is to encourage Albertans to create their own renewable energy sources and receive credit for the power they send to the grid. The regulation allows for net-billing up to for biogas systems whose nominal capacity does not exceed 1 MW.[84] Net billing is defined as subtracting power supplied out of micro-generator's site from the power supplied into the micro generator's site during the

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[79] Alberta's Nine-Point Bioenergy Plan, Alberta Energy, accessed Sept. 6 2016, http://www.energy.alberta.ca/Org/pdfs/BioE9pointPlan.pdf.
[80] Closed Bioenergy Programs, Alberta Energy, accessed Sept. 6 2016, http://www.energy.alberta.ca/About_Us/3428.asp.
[81] Ibid.
[82] TEC Edmonton, *Biogas Market Study*, 41.
[83] *Micro-Generation Regulation*, Alta Reg 27/2008, s. 10, http://www.qp.alberta.ca/documents/Regs/2008_027.pdf.
[84] *Micro-Generation Regulation*, Alta Reg 27/2008, s. 1 (h)iv

billing period; a net charge or credit is given based on the difference between power produced and power consumed on site.[85]

The main issue with the micro generation policy is that the 1 MW limit excludes many of the larger scale biogas plants. Economies of scale for biogas systems using AD favor larger operations that produce more feedstock (i.e. manure or other organics): the larger the farm or operation the more economically feasible the AD system becomes.[86] In order to achieve economies of scale with biogas systems a higher energy yield is required. Therefore, the current micro-generation policy does not adequately support the biogas systems within Alberta. Biogas systems that are larger than 1MW would be better able to compete with large power producers such as ATCO Power, TransAlta or Capital Power. In order to allow biogas systems to benefit from net-metering policy, the limit should be increased to encompass more plants and encourage economies of scale.

The Climate Change and Emissions Management (CCEMC) is a not-for profit organization created in 2009 to support Alberta's Climate Change Strategy. The CCEMC gives financial support to projects and initiatives that reduce GHG emissions or improve Alberta's ability to adjust to climate change.[87] One of the challenges with CCEMC funding is that it does not support new technologies beyond the end of implementation and many projects would require support during at least part of the early operations phase.

4.4 Regulatory Barriers

Despite popular views to the contrary, the energy industry in Alberta is highly regulated. Protocols and regulations are set in place to balance environmental concerns with economic viability of the energy industry. Increased regulations bring additional costs as companies must spend limited resources assuring compliance to regulations that are in place. The cost of compliance is higher in relative terms for smaller companies and for less established energy production technologies such as AD systems. The regulatory process for the implementation of

[85] *Micro-Generation Regulation*, Alta Reg 27/2008, s. 1 (j)
[86] Shelford and Gooch, “Small Farm Anaerobic Digestion Systems and Barriers to Increasing their Implementation In New York State,” 13.
[87] About, Climate Change and Emissions Management (CCEMC) Corporation, accessed Sept. 2016, http://ccemc.ca/about/.

biogas facility involves four different government departments: Municipal/County; Alberta Agriculture and Forestry; Alberta Environment and Parks ; and, Alberta Energy. Coordination among and compliance with the various departments is a significant hurdle for the implementation biogas systems as each department has a different set of requirements and guidelines for approvals. According to an industry survey done by TEC Edmonton, the regulatory process takes a minimum of three years, with most taking up to eight years.[88] The reasons for the lengthy approval process are based on a number of factors that include the following[89]

- small size and relative new biogas industry in Alberta
- delays in getting access to electrical transmission systems due to procedural requirements set by transmission agencies
- requirement of noise assessment
- need for coordination among at least three government departments
- redundancies in application process with multiple departments requiring similar procedures
- lengthy process for negotiating terms set out in Interconnection Proposals
- time consuming process to identify, secure and provide financial security in the event of bankruptcy and meet other requirements for financing
- differences in rules/regulations from Alberta Agriculture and Forestry and Alberta Environment and Parks adds time and expense to meet application and approval requirements

The regulatory process varies depending on the type of feedstock used, the end use for digestate and on whether it includes an application for carbon offsets. Table 3 outlines the regulatory process for an on-farm (i.e. manure only) facility, which involves 3 out of the 4 departments mentioned above (Municipal/County, Alberta Agriculture and Forestry, Alberta Energy). Table 4 outlines the regulatory process for a facility using co-digestion of both manure

[88] TEC Edmonton, *Biogas Market Study*, 27.
[89] Ibid, 27.

plus additional organic waste as feedstock; co-digestion facilities require the approval of all four departments.[90]

Table 3. Regulatory Process for On-Farm Facility

Municipal	**Alberta Agriculture and Forestry**	**Alberta Energy**
Developing permits for zoning and construction	Governing act: Agricultural Operation Practices Act (AOPA)	Governing Act: Electric Utilities Act Governing Regulation: Rule 007 Governing board: Alberta Utilities Commission
Construction permits	Governing board under the AOPA: Natural Resources Conservation Board	three eligible policies available: 1)micro-generation 2)small power plant regulation 3)full power plant regulation
	regulations for land application of digestate fall fall under Alberta Agriculture and governed by NRCB	AUC performs upstream assessment of biogas
		producers need to provide: a) municipal development permits b) access to the grid approval form a distributer c) noise assessment
		Interconnection proposal gives 60 days to provide full upfront costs of connecting to the grid
		AUC gives permit and producer can then start construction

Source: Based on Author and TEC Edmonton.

[90] Anaerobic Digestion: Frequently Asked Questions, Government of Alberta Agriculture and Forestry, accessed Sept. 2016, http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex11290.

Table 4. Regulatory for On-Farm Facility Using Co-Digestion

Municipal	**Alberta Agriculture and Forestry**	**Alberta Environment and Parks**	**Alberta Energy**
Developing permits for zoning and construction	Feedstock goes beyond just agricultural feedstock and therefore governing act and enforcement move to Alberta Environment	Governing acts: Environmental Protection Enhancement Act, contained in Schedule 2 is the Activities Designation Regulation	Governing Act: Electric Utilities Act Governing Regulation: Rule 007 Governing board: Alberta Utilities Commission
Construction permits		considered a waste management facility and must apply for both AUC power generation permits and show financial security to Alberta Environment in the even of bankruptcy	Three eligible policies available: 1)micro-generation 2)small power plant regulation 3)full power plant regulation
		Alberta Environment performs upstream biogas process review	producers need to provide: a) municipal development permits b) access to the grid approval form a distributer c) noise assessment
		must adhere to petroleum standards for storage guidelines and biogas due to the lack of specific biogas facility regulations	Interconnection proposal gives 60 days to provide full upfront costs of connecting to the grid

Municipal	Alberta Agriculture and Forestry	Alberta Environment and Parks	Alberta Energy
		Alberta Environment requires additional odour control system and building filtration systems	AUC gives permit and producer can then start construction
		Additional land application regulations	

Source: Author and information fromTEC Edmonton.

In addition to the regulatory process of government departments that a producer must comply with, to connect to the grid a producer must adhere to an application process under the Alberta Electric System Operator (AESO). The AESO is responsible for operating the Alberta Interconnected Electric System, which is Alberta's transmission system (the 'grid') consisting of nine main companies that distribute electricity to the grid.[91] In order to connect to the Alberta Integrated Electrical System? (AIES), there is a seven stage process that takes approximately 96 weeks. The application process is summarized in Table 5.

Table 5. AESO Application Process

Stage	Description	Time
Stage 0	Identification of project through a System Access Service Request	2 weeks
Stage 1	Connection Study Scope and determination of responsibilities	8 weeks
Stage 2	Connection proposal including a consideration of connection alternatives	14 weeks

[91] Including ENMAX Power Corp, Fortis Alberta Inc, ATCO Electric, City of Lethbridge, City of Medicine Hat Electric, City of Medicine Hat Natural Gas, EPCOR Distribution Inc, and the City of Red Deer Electric Light and Power

Stage 3	NID and Facility application made by TFO	32 weeks
Stage 4	Application made to AUC and issued a Permit and License is approved	24 weeks
Stage 5	Construction of of transmission facilities and signing of SAS agreement	16 weeks
Stage 6	Energize , commission and close out occurs	N/A

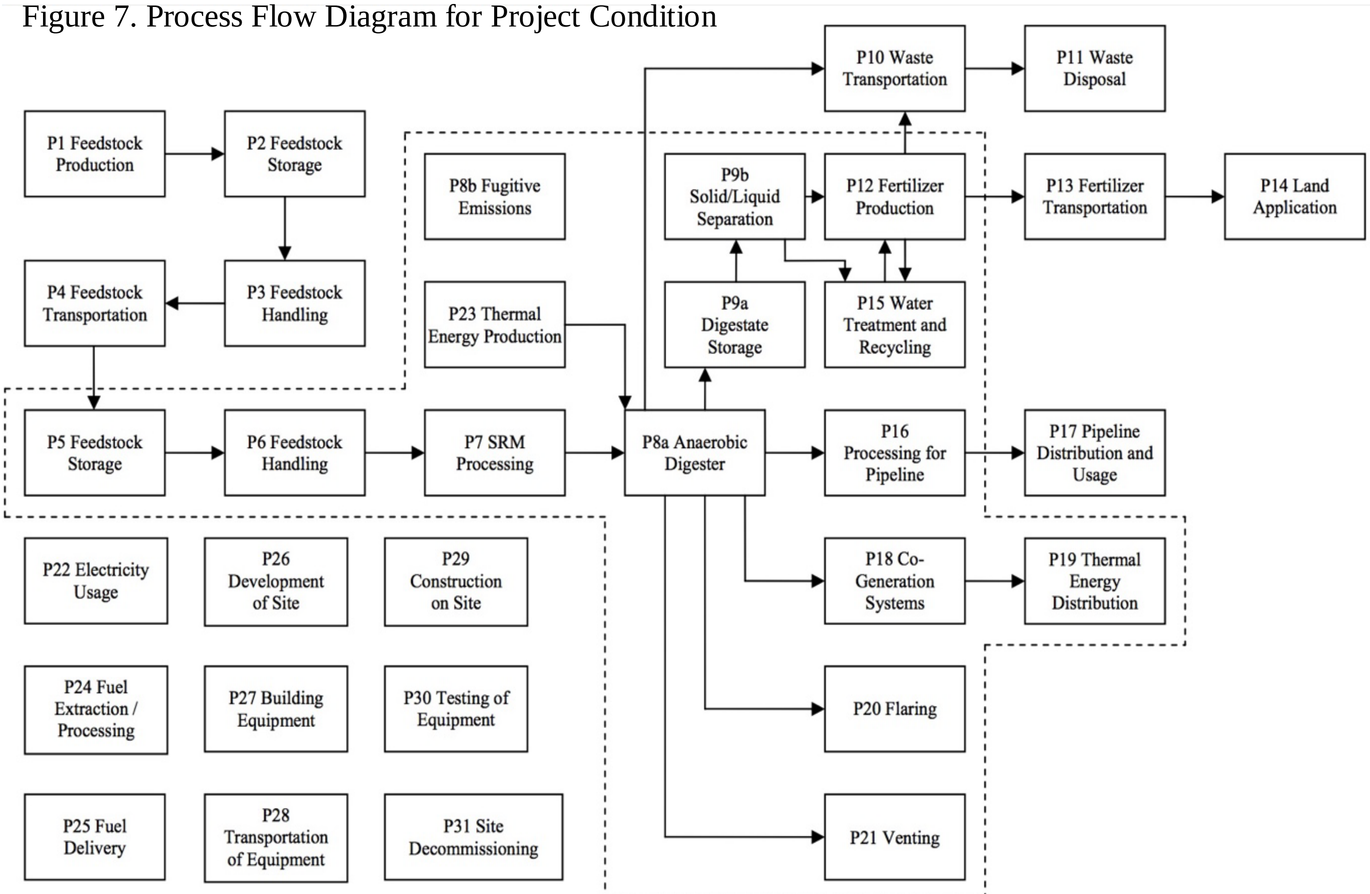
Source: Connection Process, AESO, accessed August 2016, http://www.aeso.ca/connect/#stage0.

Producers are able to apply for Carbon Offset Credits to create a revenue stream from selling offset credits to buyers seeking to adhere to emission regulations. In order to apply for Carbon Offset Credits producers must follow a protocol under the Specific Gas Emitters Regulation. Alberta Environment and Parks developed a protocol for the adoption of on farm AD systems in 2007, referred to as the *Quantification Protocol for the Anaerobic Decomposition of Agricultural Materials*. Under this protocol producers must provide evidence that: the material diverted to AD facility would have been managed differently; where methane products are enhanced, producer must show that the facility has managed risk of fugitive emissions; digestate cannot go through active windrow composting; quantification of reductions of emissions are based on actual measurements according to the specifications in the protocol; and, the project must meet project eligibility criteria as stipulated in the guideline document for the Alberta Offset System.[92] Being able to measure and quantify the avoided C02 emissions adds another layer of compliance costs. Project developers must adhere to the protocol and section 7 of the *Specified Gas Emitters Regulation*; this includes a third party verified project plan and project report, a verification report, and a greenhouse gas assertion.

[92] Specified Gas Emitters Regulation: Quantification Protocol For the Anaerobic Digestion of Agricultural Material, Alberta Environment, (2007):4, http://open.alberta.ca/dataset/7432a4c8-b36f-49a7-a546-e5b7096691ba/resource/105e51c8-cf11-4e7a-86a9-9de425afdfae/download/4073653-2007-09-Quantification-Protocol-Anaerobic-Decomposition-Agricultural-Materials-Version-1.pdf.

The protocol is a result of negotiations between key industry players and the provincial government. As with most negotiations, an end result is achieved through compromise. Figure 7 shows the project process flow diagram for a typical project.[93] As shown there the protocol does not include avoided methane emissions from open liquid manure lagoons. An industry survey done by TEC Edmonton indicates that industry participants see this as a missed opportunity for an increased capacity to sell offset credits. The protocol was established in 2007 and was intended to be revisited, but no review of the protocol has taken place to date.

Figure 7. Process Flow Diagram for Project Condition



Source: Specified Gas Emitters Regulation: Quantification Protocol for the Anaerobic Digestion of Agricultural Material, Alberta Environment, 4.

[93] Specified Gas Emitters Regulation: Quantification Protocol for the Anaerobic Digestion of Agricultural Material, Alberta Environment, 4.

5. Experience and Evidence from Other Jurisdictions

5.1 Germany

Germany has become a world leader in biogas systems and has implemented policies to support the growth of the industry. In 2014 there was 7,944 biogas plants in Germany that generated 27.6 billion kWh, providing 4% of total electricity consumption.[94] The biogas produced is predominantly used for electricity generation, heat or as transportation biofuel.[95] Biogas producers in Germany are able to sell electricity generated at a guaranteed price based on a fixed feed-in tariff. The Feed in tariff was established in 2000 with the adoption of the Renewable Energy Sources Act (EEG).[96] Depending on the size of the plant, the feedstock used and the year the plant was completed, the operator's share can range between 12-25 cents per kWh. [97] In 2014, the biogas industry within Germany was responsible for saving 17.6 million tonnes of $C0_2$ from being released into the atmosphere.[98]

Energy and climate change policies play an important role in the development of biogas industry. Australian researcher Joel Edwards, Maazuza Othman and Steward Burn state that energy security is a key policy driver for fostering renewable energy and AD, especially in net-energy importing countries such as Germany, UK and USA.[99] Germany's energy policy include a target to provide 12.5% of electricity from renewable energy by 2010 and 20% by 2020.

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[94] German Biogas Industry, "Biogas: The Energy Revolution's All Rounder," *Renewable Insight- Energy Industry Guides,* (2015): 12, http://www.german-biogas-industry.com/fileadmin/pdf/download/IBBG_E_14-GW-Screen.pdf.
[95] Joel Edwards, Maazuza Othman and Stewart Burn, "A Review of Policy Drivers and Barriers for the Use of Anaerobic Digestion in Europe, the United States and Australia," *Renewable and Sustainable Energy Reviews* 52, no. 1 (2015): 817, http://dx.doi.org.ezproxy.lib.ucalgary.ca/10.1016/j.rser.2015.07.112
[96] German Biogas Industry, "Biogas: The Energy Revolution's All Rounder," 21.
[97] Ibid, 21.
[98] Ibid, 22.
[99] Edwards, Othman and Burn, "A Review of Policy Drivers and Barriers for the Use of Anaerobic Digestion in Europe, the United States and Australia," 821.

Financial incentives have been identified in the model of section 4 as one of the key aspects leading to higher adoption rate of AD and biogas systems. Policies such as performance based financial incentives and renewable energy certificates provide financial support to foster the development in an industry and to allow the AD systems to compete against established energy generation technologies. Germany has performance based incentives in the form of a Feed-In Tariff which was established through the Renewable Energy Act (EEG). The EEG guaranteed priority access for renewable energy to the grid and a set rate for the period of 20 years. Feed-in tariffs are designed to decrease gradually to foster an economically competitive industry. Additionally, the biogas systems were aided with substantial grant and loan programs. The Federal Government created many grant and loan opportunities for biogas facilities, including a €5.1M program from 1996-1998 to provide a direct investment grant to aid in the development of AD systems.[100] Additionally, investors receive a 4% unit reduction on interest rates when investing in biogas technology.[101] Along with financial incentives, Germany has also made an integrated application process for biogas facilities which has decreased the compliance cost for project developers.

5.2 Denmark

Denmark is generally identified as one of the pioneers of AD technology. Through the 1990s the Danish government heavily subsidized AD industry with research grants, investment funds and tax breaks.[102] There was an increased demand for AD systems as district heating systems were generally built alongside.[103] This resulted in a substantial increase in biogas systems throughout the late 90s and early 2000s; in 1990 there was 12 AD plants and by 2002 that number had increased to 57.[104] Denmark currently has 174 AD facilities for bioenergy generation purposes including 22 centralized plants.[105]

[100] Åke Nordberg , “Legislation in Different European Countries Regarding Implementation of Anaerobic Digestion,” Swedish Institute of Agricultural Engineering, accessed Sept, 4 2016, 6, http://agrienvarchive.ca/bioenergy/download/europe_ad_legislation.pdf.
[101] Ibid,6.
[102] Edwards, Othman and Burn, “A Review of Policy Drivers and Barriers for the Use of Anaerobic Digestion in Europe, the United States and Australia,” 817.
[103] Ibid, 817.
[104] Edwards, Othman and Burn, “A Review of Policy Drivers and Barriers for the Use of Anaerobic Digestion in Europe, the United States and Australia,” 817.
[105] Ibid, 818.

For net importing countries such as Australia and Denmark, renewable energy targets contained within climate change polices are the main driver for biogas systems. Denmark's long-term renewable energy policy has helped ensure the success of AD, resulting in 16.2% of their primary net-exported energy coming from biomass and waste through AD technologies.[106] Denmark's renewable energy targets are the following: 30% primary energy from renewable energy by 2020; fossil free by 2050; and 52% of electricity from renewable energy by 2020.

Financial incentives provided in Denmark for biogas facilities included a policy of enhanced buy back rates for renewable energy projects. The electricity companies set a fixed price with tariffs divided into three time zones (peak, high and low), the average price being €0.07/kWh.[107] Additionally, there is a subsidy of €0.036 /kWh given to all renewable energy projects..

5.3 US

The USA biogas industry is also growing significantly. The American biogas Association states that "…there is currently over 2,100 plants producing biogas: 242 anaerobic digesters on farms, 1,241 wastewater treatment plants using an anaerobic digester (~860 currently use the biogas they produce), 38 standalone (non-agriculture and non-wastewater) anaerobic digesters, and 645 landfill gas projects."[108] The 242 on-farm livestock AD projects generated 981 million kWh of renewable energy and resulted in 3.0 MMT C02e of avoided emission. Statewide policies that have encouraged the creation of biogas plants include state renewable portfolio standards, organic waste bans, net metering policies and tax incentives.[109]

At the federal level The Renewable Portfolio Standard (RPS) administers the selling of renewable energy credits and establishing renewable energy electricity quotas.[110] This legislation

[106] Edwards, Othman and Burn, "A Review of Policy Drivers and Barriers for the Use of Anaerobic Digestion in Europe, the United States and Australia," 817.
[107] Nordberg, "Legislation in Different European Countries Regarding Implementation of Anaerobic Digestion," 6.
[108] American Biogas Council, "Frequent Questions," accessed Sept 2016, https://www.americanbiogascouncil.org/biogas_questions.asp.
[109] U.S. Energy Infroamtion Administration, "Feed-in tarrif: A policy tool encouraging deplyment of renewable electricity technologies," (May 2013), http://www.eia.gov/todayinenergy/detail.cfm?id=1147.
[110] Edwards, Othman and Burn, "A Review of Policy Drivers and Barriers for the Use of Anaerobic Digestion in Europe, the United States and Australia," 821.

is voluntary and has not been ratified by all states. Financial incentives are mostly provided at the state level. There are 21 states with electricity feed-in tariff (FIT) policies, with California having the highest tariff.[111] The number of AD facilities has increased substantially since the implementation of the RPS and there has been an even greater increase in states with financial incentives such as FIT's.[112]

In addition to energy policies and financial incentives, the AD industry is further supported by waste diversion policies. Several states have enacted organic waste in landfill bans including: Massachusetts, Vermont, Rhode Island, Connecticut and California.[113] Massachusetts legislation requires that if an organization produced more than one tonne of organic waste a week, the food must be donated and the remainder must be transported to an AD facility or to composting.[114] In Vermont the Universal Recycling Law will require that all food scraps and yard waste be directed to solid waste management facilities by 2020. Through policy and legislation, states are able to divert waste away from landfills, thus increasing the demand for composting and anaerobic digestion facilities.

5.4 Other Canadian Jurisdictions

Ontario's biogas industry has been growing substantially over the past 2 decades, as Ontario strives to be a forerunner in green energy development. Within Ontario there are over 50 biogas plants that use agricultural and municipal waste as substrate.[115] The government of Ontario has taken a similar policy approach as Germany with the implementation of a feed-in tariff (FIT) that is regulated by the Electricity System Operator (IESO). The FIT provides a standard price for different renewable energy technologies, with prices depending on the cost of developing and delivering the project.

[111] Edwards, Othman and Burn, "A Review of Policy Drivers and Barriers for the Use of Anaerobic Digestion in Europe, the United States and Australia," 818.
[112] Ibid, 818.
[113] Global Methane Initiative, "A Global Perspective of An Anaerobic Digestion Policies and Incentives," (November 2014): 30, https://www.globalmethane.org/documents/tools/a-global-perspective-of-ad-policies-incentives.pdf.
[114] Global Methane Initiative, "A Global Perspective of An Anaerobic Digestion Policies and Incentives," 31.
[115] Canadian Biogas Assiociation, "Projects," accessed sept 4 2016, http://www.biogasassociation.ca/bioExp/index.php/projects/projects_ontario.

5.5 Summary Main Policy Tools

The jurisdictions discussed above highlight the main policy tools that are available to support the development of a biogas industry. One of the most important policy tools used in all jurisdictions is a performance based financial incentive structure such as feed-in tariffs. Another important aspect that is present in all of the above jurisdiction is an apparent drive by policy makers to pursue AD technology as a partial solution to either a renewable energy development or a waste management solution. A long term policy initiative as used in jurisdictions such as Germany and Denmark decreased the amount of uncertainty faced by producers and investors and thus led to a greater development of AD and biogas facilities. As noted in the above section the main elements that have led to successful use of AD and biogas technology include: a performance based financial incentive structure; an initiative taken by policy makers to address renewable energy demand or waste management issues; and, a long term policy plan that works to reduce the level of uncertainty in regards to the return on investments.

6. Policy Recommendations

The biogas and anaerobic digestion industry is still in infancy stages within Alberta as compared to the jurisdictions discussed in section 5. AD and biogas systems are a relatively new technology to Alberta and carry high capital costs. Therefore, the following policy recommendations include a focus on policies and programs that foster a higher level of certainty which in turn gives producers and investors increased confidence in the economic feasibility of AD and biogas projects.

There are many barriers that are faced by producers and farmers upon implementation and creation of a biogas system. As mentioned in section 4, barriers include: regulatory and policy barriers; economic feasibility barriers; and, concerns with feedstock supply. In order to overcome these barriers, changes to current polices are required. In general, the biogas industry and the Alberta Government must work collaboratively to create an environment that fosters a supportive relationship and encourages producers and others to invest in AD and biogas systems.

6.1 Provide Greater Financial Incentive

a) Reinstate Grant Programs

In order to provide a financial incentive for investors, grants and loans should be clear and dependable. In order to reassure investors and AD operators that the Internal Rate of Return can be realized, there must be a level of certainty in amount of funding and loans available. Based on the infancy of the AD industry within Alberta, substantial grants and funding are required to overcome the high initial capital costs. Similar to the Nine Point Plan implemented in 2007, the current government should create a similar long term plan to recommit funding in an explicit manner.

b) Develop a Performance Based Financial Policy Tool

As indicated by the analysis in section 4, financial incentives are a key determinant of AD and biogas system adoption. This is further supported in the review of several jurisdictions provided in section 5. As seen there, the most commonly used performance based financial incentive policy used is the feed-in-tariff (FIT). A study done by the Global Methane Initiative found that 86% countries that provide incentives for anaerobic digestion in an agricultural setting use a FIT policy.[116] Other popular policy tools included Carbon Credit, Tax Exemptions, Renewable Energy Credits and Renewable Fuel Credits.[117] Using the jurisdictions discussed in section 5 as an example, Alberta should seek to develop a performance based financial policy that will support the initial growth of the AD industry through its primary stages.

6.2 Reduce Regulatory and Policy Barriers

a) Expand the Micro Generation Policy to support AD industry

The current Micro Generation Policy has a net-metering opportunity up to 1MW of electricity. This policy is important for promoting and fostering renewable energy at a local level. However, the policy does not adequately support the AD industry because it only applies to a small scale of electricity generation. As indicated in the feasibility studies of section 4.2.3, economies of scale are achieved through larger facilities with higher levels of electrical

[116] Global Methane Initiative, "A Global Perspective of An Anaerobic Digestion Policies and Incentives," (November 2014): 18, https://www.globalmethane.org/documents/tools/a-global-perspective-of-ad-policies-incentives.pdf.
[117] Global Methane Initiative, "A Global Perspective of An Anaerobic Digestion Policies and Incentives," 18.

generation. Further research is required to determine the exact level of net-metering required to fully support the AD industry within Alberta. There have been suggestions by industry that this number should be around 3- 5MW.[118]

b) Streamline Application Process

As indicated in the analysis of section 4.2 the regulatory barriers in regards to the application process are extensive, with a project approval process taking up to 7-8 years. By consolidating the application process to single government department, the permit issuance process would be significantly reduced in time and complication. As indicated in tables 3 and 4, much of the upstream review process is redundant and lacks a level of coordination among departments. By simplifying and consolidating the application or permit process involved with AD facilities, compliance costs will be greatly reduced resulting in an increased adoption of AD technology across Alberta.

6.3 Make the Cost of Pollution Higher

a) More Stringent Landfill Policies

In order to divert waste away from landfills, tipping fees must be high enough as to correctly reflect the environmental costs of pollution, the opportunity cost of landfilling biowaste and a consideration of the finite resources used. According to Edwards, experts claim that levies are set too small to have any short-medium term effects on diversion in that "they do not sufficiently meet the externality costs associated with landfills."[119] Currently in Alberta the average landfill tipping fee is $71.30 per tonne with costs ranging from $30 to $65 depending on the municipality. Tipping fees are set according to operating costs of landfill and do not reflect the environmental externality costs.[120] TEC Edmonton suggests that one way in which tipping fees could be increased to reflect environmental costs is to add on a carbon levy as an additional fee.[121] An alternate policy option is to move towards a zero organic waste initiative, similar to that of US jurisdictions of Massachusetts or Vermont.

[118] TEC Edmonton, *Biogas Market Study*, 42.
[119] Edwards, Othman and Burn, "A Review of Policy Drivers and Barriers for the Use of Anaerobic Digestion in Europe, the United States and Australia," 826.
[120] TEC Edmonton, *Biogas Market Study*, 42.
[121] TEC Edmonton, *Biogas Market Study*, 41.

6.4 Support the Growth of the Industry

a) The creation of a Biogas Association

Creating a Biogas Association would foster a grassroots support and provide for better dissemination of information through the industry. The association would focus on engagement and collaboration to remove barriers that industry players face upon adoption. The Biogas Association can develop a clear and single voice to engage more effectively with policy makers. Similar associations have been developed in other jurisdictions. Examples include the European Biogas Association, the American Biogas Association, and the Anaerobic Digestions and Biosources Association (UK). As the biogas industry is relatively new industry in Alberta, a biogas association will aid with the challenges faced by early adopters.

Summary and Directions for Further Research

The AD industry within Alberta is still in its infancy. With only one on-farm AD facility in operation within Alberta, the renewable energy production and emission reduction possibilities are not being realized. AD and biogas technology has many benefits including $C0_2$ emissions reductions, water contamination reductions, elimination of odor, and the creation of a renewable energy source. Yet these benefits come at a significant cost. AD and biogas systems have a high initial capital cost which requires substantial financial support, especially because it is a new industry. The rate of adoption of AD and biogas facilities within Alberta has been very low. The principal reasons for the lack of adoption in Alberta include a lack of financial incentives, large regulatory and policy barriers and low prices for commodities (i.e. electricity and natural gas). When compared to jurisdictions with large numbers of AD facilities it is evident that performance based financial incentives are a key policy initiative that leads to a higher level of adoption. Additionally, long term energy policies and organic waste management policies can contribute to encouraging industry to develop innovative energy and waste solutions such as AD technologies. If Alberta wants to continue to be the energy hub of Canada, we must acknowledge the demand for innovative renewable energy and invest accordingly. AD and biogas facilities can be an important part of both a waste management solution and a renewable energy based future within Alberta.

This analysis is a general overview of the on-farm AD and biogas industry within Alberta. There is a plethora of topics that need to be researched further in order to develop and implement comprehensive policies that will help the development of the industry. In order to establish the level of financial support needed for a facility within Alberta, a detailed economic feasibility study should be conducted. From this study, research can then be expanded to investigate supportive policies such as the micro generation policy and the levels of grants and funding required to allow for higher adoption of AD facilities. Further research into the correct performance based financial policy tool is required, including a cost benefits analysis of a FIT policy within Alberta. Additionally, an investigation in conjunction with Biogas Association consultations should be initiated in order to stream line the regulatory process.

Annex 1 Anaerobic Digester Technologies

	BATCH HIGH SOLIDS ANAEROBIC DIGESTION	CONTINUOUS HIGH SOLIDS ANAEROBIC DIGESTION	LOW SOLIDS ANAEROBIC DIGESTION
Solids Content	>20%	18-40%	5-15% (any greater requires dilution)
Ideal Waste Stream Types	Solid food waste (including source separated organics, commercial, industrial, and some fats, oil grease) and green waste	Solid food waste, green waste, biosolids, fats, oils, grease, liquid organic wastes	Dewatered residuals, food waste, manure, fats, oil, grease, liquid organic wastes
Contamination Tolerance	HIGH due to fewer moving parts; contaminants removed post-anaerobic digestion	LOW; pretreatment options are available	LOW due to pumping of material
Temperature	Mesophilic or Thermophilic	Mesophilic or Thermophilic	Mesophilic or Thermophilic
Process	Batch	Continuous	Continuous
End Product	Compost	Liquid and granular fertilizer	Liquid and granular fertilizer

Source: Harvest Power, "Benefits of Anaerobic Digestion," accessed August 19th, http://www.harvestpower.com/old/wpcontent/uploads/2012/01/Anaerobic_Digestion_2012.01.24_sm.pdf.

Annex 2: The Results of the Small Scale on Farm Study in New York State

Scenario 1: Net metering approach to electricity sales (based on the current NY policies)

- With capital costs of $3,000 - 10/63 combinations resulted in neutral or positive annual cost/benefit. Successful combinations had max co-digestion ratio and max tipping fee charges ($0.10 per gallon).

- With capital cost of $1,500 per cow -34/63 combinations resulted in positive or neutral cost/benefit outcome. All positive or neutral outcomes has a level of co-digestion (90:10 or 75:25).

Scenario 2: Feed-in tariff approach to electricity sales

- With capital costs of $3,000 per cow- 13/42 combinations were viable. All positive or neutral combinations required co-digestion with a tipping fee included.

- With capital costs of $1,500 per cow with highest value for feed-in tariff ($0.31 per kWh) - 31/42 combinations were viable. Shelford and Gooch state that it is unlikely to have a capital costs of $1,500, making these outcomes highly unlikely.

Scenario 3: Annualized capital costs of long term storage as an additional cost with net metering

- With capital costs of $3,000- 2/21 combinations were potentially viable. Viable combinations included a maximum co-digestion with tipping fee and surplus power of either $0.16 or $0.31 per kWh.

- With capital costs of $1,500 - 8/21 combinations were viable. All positive or neutral combinations included co-digestion with tipping fees and surplus power price negligible because power produced did not exceed on farm demand.

Scenario 4: Farm size fixed at U.S national average of 153 milking cows and fixed capital costs at national average of $2,700 per cow

- Price of $4.66 per kWh necessary when no co-digestion or carbon credits.

- No surplus power sales necessary when max co-digestion (75:25) and highest tipping fee (0.10 per gallon).

- $0.08 -$0.06 necessary with max co-digestion and net metering at avoided cost rate of $0.05 per kWh.

- If no co-digestion or carbon credits and net metering at $0.05 per kWh systems capital costs would need to be less than $561.28.

- Capital costs $3,722 or less required if max co-digestion with max tipping fee and surplus power sold for $0.31 kWh. Capital costs of $3,122 if surplus power is sold for $0.05 per kWh.

- Intermediate co-digestion level (90:10), net tipping fee of $0.05, and a capital cost of $2,700 and a grant covering 50% of capital costs would result in a neural cost/benefit.

Scenario 5: Amount of Manure Required for a Small Farm AD

- 118 milking cows required to create enough biogas to power for 20-kW engine generator at full capacity.

- 95 milking cows required with co-digestion of 75:25 to created biogas for 20kW engine generator with co-digestion at 90:10 VS basis, 108 milking cows are required.[122]

[122] Tim Shelford, and Curt Gooch, "Small Farm Anaerobic Digestion Systems and Barriers to Increasing their Implementation In New York State," *University of Cornell: Biological and Environmental Engineering,* (Nov., 2012): 1-74.

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