Biogas Association

Canadian Biogas Study

Benefits to the Economy, Environment and Energy

Technical Document

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Executive Summary

In May, 2013, the Biogas Association contracted with Kelleher Environmental (in association with Robins Environmental) to carry out a Canadian Biogas Study to identify existing, available metrics which support the benefits of biogas energy. The potential for biogas production from agricultural digesters, landfill gas, digestion of source separated organics from residential and commercial sources and from wastewater treatment plants across Canada was estimated, as well as the energy, environmental and economic and social/community benefits of increasing the production of biogas energy in Canada.

This Technical Document identifies the metrics found through the research, and also identifies areas where data gaps were identified and where new research is required.

Biogas is a flexible, dispatchable, renewable energy source that can interface uniquely with the growing diversity of Canada's energy mix. The reliability, flexibility, economic and environmental attributes of biogas should be recognized and should be supported through a suite of strong policies in all Canadian provinces. Biogas creates reliable energy regardless of the weather - in the form of heat, power, and pipeline quality gas that can be used for transportation (i.e. natural gas fueled vehicles), household heating or industrial, commercial and institutional processes.

Biogas is distinct from other non-hydro based renewables because it can reliably produce power during times of system peak demand, can be dispatched, and configured to store its fuel during periods of excess power or surplus baseload generation by electricity systems. In addition, biogas systems located on rural electricity distribution systems utilizing synchronous generators have demonstrated positive impacts on distribution system operations by providing stable voltage support in areas of voltage lag and improving power quality. Other benefits of biogas generated electricity include controlled power factor, reduced line losses, improved voltage control on rural feeders, and increasing service stability of electrical supply to local homes and businesses

Biogas projects are also unique in how they create solutions to managing waste streams and recycling nutrients and carbon back to the soil, and in doing so, protect the local environment, and provide rural economic development. Biogas projects also convert methane (a powerful GHG) to CO_2, creating significantly higher GHG emission reduction value than conventional renewable energy sources.

Biogas can be converted to biomethane (also called renewable natural gas - RNG), a growing commodity in Europe, the US and Canada. It has the potential to reduce greenhouse gas (GHG) emissions from transportation, and provides a range of additional benefits.

Biogas is a 'good news' sustainability story for all: for farmers, for municipalities, for food processors and for the sustainability of the quality of life and environment Biogas is a renewable energy technology that is on the verge of major growth in North America. Biogas technology development can be a source of technology transfer, job creation and rural economic development.

The destruction of harmful pathogens and methane, the reduction of odours, rural grid support through voltage regulation and the provision of reactive power are examples of biogas benefits. In addition, biogas can be used in a combined heat and power (CHP) configuration as well as injected into the natural gas distribution network to offset the use of fossil fuels. All of these value streams need to be fully supported through strongly supportive procurement and renewable energy policies across Canada.

Replacing fossil with renewable fuels, including biogas, means the reduction of fossil fuel use in the energy and transportation sectors and increased local sustainability of the national energy supply. Biogas can significantly contribute to the protection and improvement of local natural resources and the environment. As biogas is produced locally and within local boundaries, the use of biogas reduces the dependence of local communities on fuels imported from elsewhere and increases the local energy supply.

Five key potential sources of biogas production in Canada were addressed in the Biogas Metrics Study:

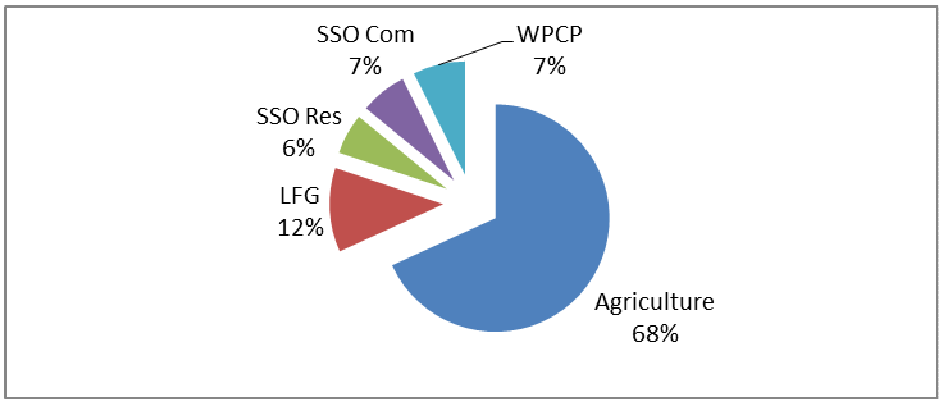
- Agricultural;
- Landfill gas (LFG).
- Source separate organics (municipal/residential)
- Source separated organics from commercial sources (such as hotels, restaurants, etc. but not including industrial organics which are generally managed on-site and not included in Statistics Canada research used for the study) and
- Wastewater treatment plant residuals.

The energy potential of the five sources of biogas energy is estimated at 810MW or 2,420 Mm^3/year of RNG. The relative contribution of biogas from the five major sources addressed in the study are presented in Table 1 and Figure 1.

Table 1: Energy Potential From Biogas Sources in Canada

	Agriculture	Landfill gas (LFG)	SSO Residential	SSO Commercial	Wastewater	Total
Electricity Production (MW)	550	95	48	54	60	810
Renewable Natural Gas (RNG) Production (million m^3/year)	1,650	290	140	160	180	2,420
Contribution to Canada's Electricity Demand	0.9%	0.2%	0.1%	0.1%	0.1%	1.3%
Contribution to Canada's Natural Gas Demand	2.1%	0.4%	0.2%	0.2%	0.2%	3.0%

Figure 1: Contribution of Biogas Sources to Energy Production (Mm^3/year of RNG and MW)

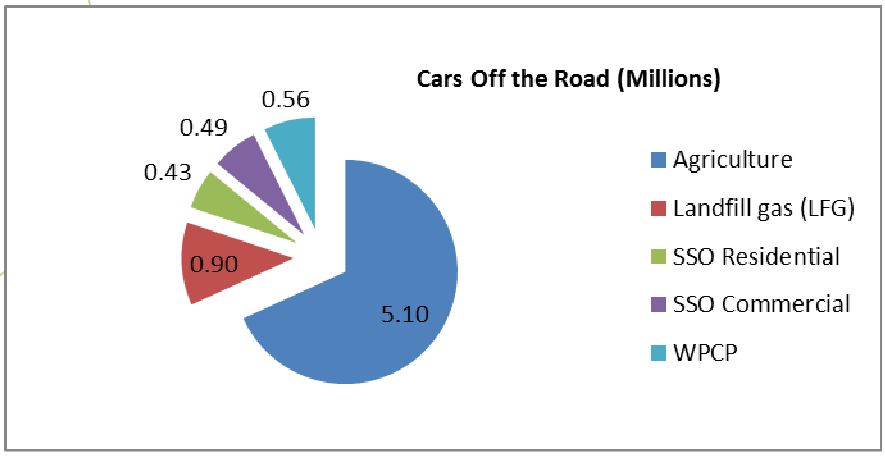


All biogas sources together have the potential to reduce Canada's GHG emissions by 36.5 million tonnes eCO_2 per year, which is the equivalent of taking 7.3 million cars off the road. The potential contribution of each biogas source to GHG reduction shows that agricultural digesters have significant potential to reduce GHG (68% of the biogas opportunity), followed by LFG projects (12% of the biogas opportunity). Digesters for commercial and residential SSO and also for wastewater treatment residuals present opportunities of approximately equal size, at 6% to 7% each of the total opportunity.

Table 2: Environmental Benefit Potential From Biogas Sources

	Agriculture	Landfill gas (LFG)	SSO Residential	SSO Commercial	Wastewater	Total
GHG Reduction (million tonnes eCO_2/year)	25.5	4.5	2.2	2.5	2.8	37.5

Figure 2: Environmental Benefits of Biogas - GHG Reduction Equivalent to Cars Off The Road



Realizing the full potential of biogas development would lead to up to 1,800 separate construction projects with a capital investment of $7 billion and economic spin-off of $21 billion to the Canadian economy. These construction projects would create 16,800 construction jobs for a period of one year and 2,700 on-going long term operational jobs. In addition, over 100 new and expanded companies, including biogas system designers and developers, equipment suppliers, laboratories, etc can be supported through this expanded sector. This figure does not include the many construction companies, building supply companies, mechanical and electrical contractors and suppliers who would benefit from biogas development across Canada.

Table 3: Economic Benefit Potential From Development of Biogas Projects

	Agriculture	Landfill gas (LFG)	SSO Residential	SSO Commercial	Wastewater	Total
Construction jobs (for one year)	10,200	2,000	1,800	1,800	1,000	16,800
On-going operating jobs	1,320	120	500	500	250	2,700
Direct capital investment ($billion Can)	$3	$0.3	$1.7	$1.3	$0.6	$7.0
Indirect economic spinoff ($billion Can)	$9.3	$1.0	$5.1	$4.0	$1.7	$21.0

Figure 3: Direct Capital Investment For Biogas Projects ($ billion)

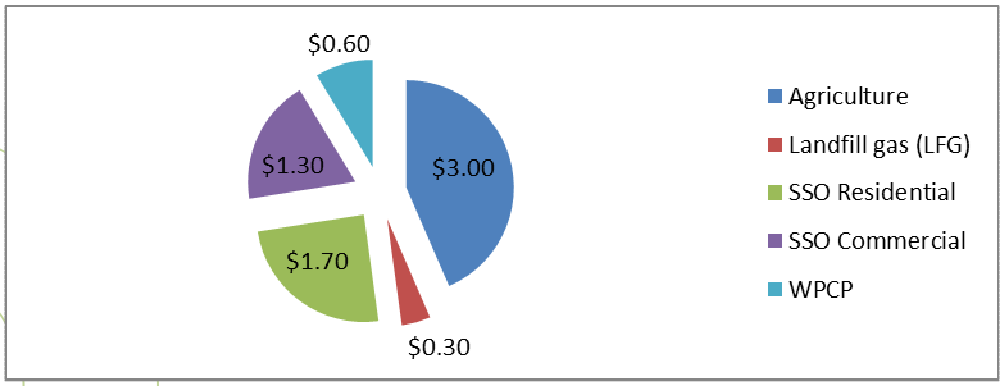
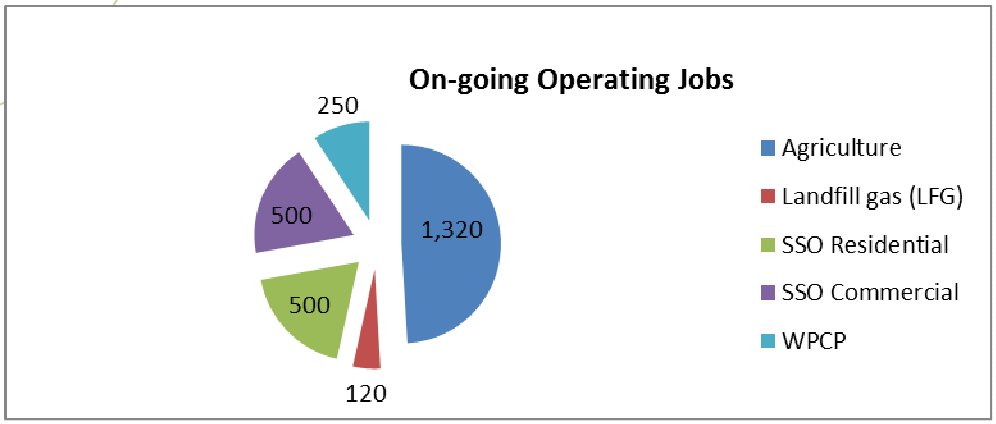


Figure 4: Long-Term Operating Jobs From Biogas Project Development



The study concluded that development of biogas projects in Canada has potential to create significant benefits, particularly GHG reduction benefits, as well as creating a stable, reliable, dispatchable energy source which can be used locally. Key conclusions regarding the investment required and the energy potential of biogas projects across Canada, as well as the employment and economic benefits are summarized in the table below.

Table 4: Economic Benefits of Developing Biogas Energy

	Agriculture	Landfill Gas	SSO Residential	SSO Commercial	WPCP	Total
Construction jobs	10,211	2,000	1,800	1,700	1,000	16,700
On-going operating jobs	1,320	120	500	460	250	2,650
Direct capital investment ($billion Can)	$3.0	$0.3	$1.7	$1.3	$0.6	$7.0
Indirect economic spinoff ($billion Can)	$9.3	$1.0	$5.1	$4.0	$1.7	$21.0

Barriers to Biogas Project Development in Canada

There are a number of barriers to realizing the full potential of biogas energy identified in this document. Some are common to all biogas projects and some are unique to specific waste streams:

1. Financing of AD projects is challenging due to a reported lack of familiarity with the technology by financial institutions. Many more full scale facilities need to be constructed in Canada to address this barrier; financing institutions need to be able to "kick the tires" of existing facilities to have a comfort level that their investment is secure;
2. Wastewater treatment plant biogas projects generally are not developed as energy generation is not the "core business" of wastewater treatment plant operating staff. When capital budgets are set, other capital projects generally receive more attention than biogas recovery projects;
3. Receiving approvals for interconnections with the electricity system are slow and expensive. Some plants simply waste energy rather than trying to sell it into the electricity grid;
4. Except for Ontario, feed in tariffs or revenues available for electricity from biogas facilities are not at a level which makes most biogas projects related to electricity generation economically viable;
5. Biogas projects related to processing of SSO need to compete with composting which is generally less expensive, although the price gap between the two technologies narrows at capacities of above 60,000 tonnes/year (the amount typically produced by a Green Bin program in a city of 300,000 households, or a population of 1 million);
6. Policies in provinces and municipalities across Canada are not sufficiently supportive of biogas projects. This could be changed through procurement specifications which require e.g. RNG fuelled trucks or other requirements to support production of more RNG.
7. Low prices of natural gas present challenges for the RNG industry

Gaps and Research Needs

A number of information gaps and research needs were identified during the research:

- Partnerships should be explored with associations which represent wastewater treatment facility research and support to complete two areas of research related to biogas energy generation at wastewater treatment plants:
    - A study of the 50 largest WWTPs in Canada was carried out by Environment Canada in 2000. This assessment needs to be updated. A current inventory of all biogas projects at wastewater treatment plants across Canada should be developed; the potential for development of biogas energy projects at wastewater treatment plants across Canada should be explored and the most promising opportunities should be identified;
    - In the US, a total of 2.3 million metric tons of carbon dioxide emission reductions can be achieved annually through increased use of CHP at WWTPs. These reductions are equivalent to planting approximately 640,000 acres of forest, or the emissions of approximately 430,000 cars[1]. A similar assessment should be carried out for Canada, updated to 2014.
- The most recent detailed publication of LFG data by province in Canada is based on 2005 data. A recent Environment Canada study is not yet public. A current listing of all landfill gas projects in Canada should be developed.
- A research study should be considered to quantify the existing situation with respect to management of high strength food waste in the industry sector across Canada, including existing on-site energy recovery through AD and the potential for additional on-site energy recovery through AD.
- A methodology should be developed to accurately estimate the net GHG emission impacts of biogas energy use from different sources (agriculture vs LFG, etc) and in different applications (e.g. electricity vs transportation, etc)

[1] Case Study Primer for Participant Discussion: Biodigesters and Biogas, May 14, 2012. USEPA

- Emission factors for different energy sources including biomass and natural gas (but not biogas specifically) were found in various studies. Biogas specific emission factors need to be developed.

Table of Contents

1. Introduction 1
2 Approach and General Assumptions 2
2.1 Literature Search 2
2.3 Interviews 3
2.4 General Assumptions Used For Metrics Development 3
2.4.1 Canada's National Electricity and Natural Gas Demand 3
2.4.2 Household Energy Demand 4
2.4.3 Converting Energy Metrics to Natural Gas and Electricity 5
2.4.4 Converting Methane To Cars Off the Road 6
2.5 Structure of Report 7
3 Potential Biogas Opportunity From Agricultural Sources in Canada 8
3.1 Existing and Potential Biogas From Agricultural Sources in Canada 8
3.2 Biogas Production From Energy Crops 9
3.3 Current Status of Agricultural Digesters Across Canada 10
3.4 Environmental Benefits of Farm Digesters 12
3.5 Economic Benefits Of Farm Digesters 14
3.6 Social and Community Benefits of Farm Digesters 18
3.7 Energy Benefits of Biogas From Farm Digesters 19
3.8 Summary Of Benefits of Agricultural Digesters 20
3.9 Case Study of a Farm Digester 21
4 Landfill Gas (LFG) Biogas Opportunity in Canada 22
4.1 Existing and Potential Biogas From Landfill Gas (LFG) in Canada 22
4.2 Environmental Impacts of Landfill Gas Projects 24
4.2.1 GHG Impacts of Landfill Gas Projects 24
4.3 Economic Benefits From Landfill Gas Projects 26
4.4 Social and Community Benefits of LFG Projects 28
4.5 Energy Production Potential of LFG Projects 28
4.6 Summary of Energy, Environmental and Economic Benefits of Landfill Gas (LFG) Biogas Projects 29
4.7 Case Study of A Landfill Gas Project 30
5. Source Separated Organics From Residential Sources 31
5.1 Biogas Potential From Residential SSO in Canada 31
5.1.1 Existing AD Facilities To Process Residential SSO in Canada the US and Europe 31
5.1.2 Potential Biogas Production From Residential SSO in Canada 33
5.2 Environmental Benefits of AD of Residential SSO 34
5.2.1 GHG And Other Air Emissions Benefits of Residential SSO Digestion 34
5.2.2 Air Quality Impacts of AD of Residential SSO 35
5.2.3 Nutrient Management Impacts of AD of Residential SSO 35

5.2.4 Biogas Utilization Options Compared to Landfilling of Organics 35
5.3 Economic Impacts of AD of Residential SSO 37
5.4 Social and Community Benefits of AD of Residential Waste 38
5.5 Energy Impacts of AD of Residential SSO 39
5.6 Summary of Benefits of Digesters for Residential Source Separated Organics 39
6 Source Separated Organics (SSO) From Industrial, Commercial and Institutional Sources in Canada 41
6.1 Opportunity for Biogas Production from Commercial Sector SSO in Canada 41
6.1.2 Potential Biogas Opportunity for Commercial Organics 42
6.2 Environmental Benefits of Commercial SSO Digestion 43
6.3 Economic Impacts of Commercial SSO Digestion 43
6.4 Social and Environmental Benefits of Commercial Digesters 44
6.5 Energy Impacts of Commercial Digesters 44
6.6 Summary of Benefits of Digestion Of Commercial Source Separated Organics 45
6.7 Case Study: Harvest Power Fraser Richmond BC 45
7 Biogas From Wastewater Treatment Plants 47
7.1 Existing Inventory of Municipal Wastewater Treatment Residuals in Canada 47
7.2 Environmental Impacts of Biogas From WWTP Biosolids 50
7.3 Economic Impacts of Biogas From WWTP Biosolids 50
7.4 Social and Community Benefits of AD at WPCPs 51
7.5 Energy Impacts of Biosolids Digesters 51
7.6 Barriers to WWTP Biogas Project Development 51
7.8 Summary of Benefits of Digesting Wastewater Treatment Plant Residuals 53
7.9 Case Study: Renewable Natural Gas Production at a Wastewater Treatment Plant Hamilton, Ontario 53
8 A Comparison Of Biogas With Other Energy Sources 55
8.1 Carbon Intensity of Electricity By Province 55
8.2 Air Emissions and GHG Compared To Other Energy Sources 56
8.3 Comparison of RNG From Biogas As A Vehicle Fuel 58
8.4 Comparison of Biogas With Other Energy Sources – Miscellaneous Metrics 60
9 Policies Which Support Biogas Projects 62
9.1 Existing Supportive Policies In Canada 62
9.1.1 Federal Policies Supporting Biogas Projects 62
9.1.2 Provincial Policies Supporting Development of Biogas Facilities 62
9.2 Policies in The United States 64
9.3 Biogas Policies in the EU and Selected European Countries 66
9.4 Barriers to Biogas Project Development 69
10 Summary 71
10.1 Potential Biogas Opportunity in Canada 71
10.2 General Benefits of Biogas 73

10.3 Environmental, Economic, Social and Community Benefits of Biogas Energy 73
10.4 Barriers To Developing Full Biogas Energy Potential 73
10.5 Policies Which Support Biogas Project Development 74
10.6 Conclusions 74
10.7 Next Steps and Research Needs 75
Appendix A – List Of Reports and Literature Sources Reviewed 76

List of Tables

Table 1: Energy Potential From Biogas Sources in Canada ii
Table 2: Environmental Benefit Potential From Biogas Sources iii
Table 3: Economic Benefit Potential From Development of Biogas Projects iii
Table 4: Economic Benefits of Developing Biogas Energy iv
Table 5: Canada's Electricity Demand 2010 and 2020 3
Table 6: Installed Capacity (MW) in Ontario 4
Table 7: CEA Member Performance At A Glance (Sustainability Report, 2012) 4
Table 8: Average Household Energy Use in Canada By Fuel Type 5
Table 9: Factors Used to Convert Metrics To Natural Gas Equivalents 6
Table 10: Conversions from Watts, kW and larger units 6
Table 11: Potential RNG, Biogas and Electricity Production by Provincial Agricultural Feedstock in Canada (based on 2007 data) 9
Table 12: Estimated Employment Created By Farm Digester Development in Canada 16
Table 13: Capital Costs For Farm Digesters of Different Sizes (Electrigaz, 2011) 16
Table 14: Estimated Potential Capital Costs and Economic Impacts of Farm Digester Construction Across Canada 17
Table 15: Potential Revenues And Cost Savings From Farm Digesters 18
Table 16: Energy, Environmental and Economic Benefits of Agricultural Biogas Projects in Canada 20
Table 17: Number of LFG Projects By Canadian Province and Annual Methane Gas Generation and Capture From Canadian Landfills (2005) 23
Table 18: Potential Power Generation From LFG Biogas Projects In Canada 24
Table 19: Potential Annual GHG Reduction At Canadian Landfills (78 Landfill Sites) 25
Table 20: Air Quality Effects Of LFG Combustion 25
Table 21: Costs of GHG Reduction At Canadian LFG Projects (63 Landfill Sites) 26
Table 22: Summary of Landfill Site Ranking by Annual Revenue from Additional LFG Utilization (41 Landfill Sites) 27
Table 23: Energy, Environmental and Economic Benefits of Landfill Gas Projects in Canada 29
Table 24; Available Information on Planned AD Facilities in Quebec 32
Table 25: Installed Capacity Of AD Facilities Processing SSO And Municipal Solid Waste in Europe in 2010 32
Table 26: Estimated Potential for Biogas From Residential Waste in Canada 34
Table 27: Comparison of Energy Use and Emissions from AD, Landfilling and Composting 35
Table 28: Potential Environmental Impact/ Benefits of Landfill, Digestion, and the Difference of the Two Options (Net Benefit = Digestion - Landfill) 36
Table 29: Estimated Potential Capital Investment in Residential SSO AD Facilities in Canada 37
Table 30: Energy, Environmental and Economic Benefits of Residential SSO Biogas Projects in Canada 39
Table 31: Estimated Potential RNG and Electricity Produced from IC&I Food Waste in Canada 42
Table 32: Estimated Potential Capital Investment and Economic Indirect/Spin-off Effect of Commercial AD Facilities in Canada 44
Table 33: Energy, Environmental and Economic Benefits of Commercial SSO Projects in Canada 45
Table 34: Annual Methane Production From Canadian Wastewaters (2006) 48
Table 35: Current Biogas Usage by WWTPs in Ontario 49

Table 36: Energy, Environmental and Economic Benefits of Wastewater Treatment Biogas Projects in Canada 53
Table 37: Carbon Intensity of Electricity Across Canada (tonnes/MWhr) 55
Table 38: Carbon Intensity of Ontario's Electricity 56
Table 39: Emission Factors For Different Energy Sources (ICF, 2005) 57
Table 40: Emission Factors For End Use Electricity (2005) 57
Table 41: Comparative Energy Values for Biogas and RNG Compared to Other Energy Sources 58
Table 42: Relative Employment From Biogas Systems Compared To Other Energy Sources 61
Table 43: Bioenergy Policies and Incentives in Canada 63
Table 44: Estimates of RNG Available By Source in Canada (Mm^3/year) 71

List of Figures

Figure 1: Contribution of Biogas Sources to Energy Production (Mm^3/year of RNG and MW) ii
Figure 2: Environmental Benefits of Biogas - GHG Reduction Equivalent to Cars Off The Road iii
Figure 3: Direct Capital Investment For Biogas Projects ($ billion) iii
Figure 4: Long-Term Operating Jobs From Biogas Project Development iv
Figure 5: Logic Flow Chart for Canadian Biogas Study Research 2
Figure 6: Corn Silage Biogas Yield Per Hectare 10
Figure 7: Carbon Intensity of Electricity Across Canada (tonnes carbon per MWhr) 56
Figure 8: Greenhouse Gas Savings From The Use Of Alternative Fuels 60
Figure 9: Price of Natural Gas in Canada, 2001 to 2013($/MMBTU) 70
Figure 10: Future Biogas Potential in Canada Compared To Existing Biogas Energy By Source 72
Figure 11: Potential Biogas Energy By Source and Region in Canada 73

1. Introduction

Kelleher Environmental, in association with Robins Environmental, was contracted to carry out a *Canadian Biogas Study* for the Biogas Association of Canada. The project workplan involved the following elements:

- An extensive literature search to identify published literature sources on metrics quantifying the benefits of biogas;
- A review of the identified literature to summarize and document known benefits of biogas projects;
- Interviews with key informants to supplement the data identified through the literature review;
- Peer review of the study findings by industry experts;
- Identification of information gaps and areas which require additional research;
- Documentation of study findings in a Technical Report;
- Summary of key information points to be used in communicating the benefits of biogas projects to different audiences in a Summary Document.

The information from this study will be used to communicate the benefits of biogas projects to different audiences including government officials and local communities.

2 Approach and General Assumptions

The approach to the study is outlined in this section. It was based on the logic flow chart shown in Figure 5.

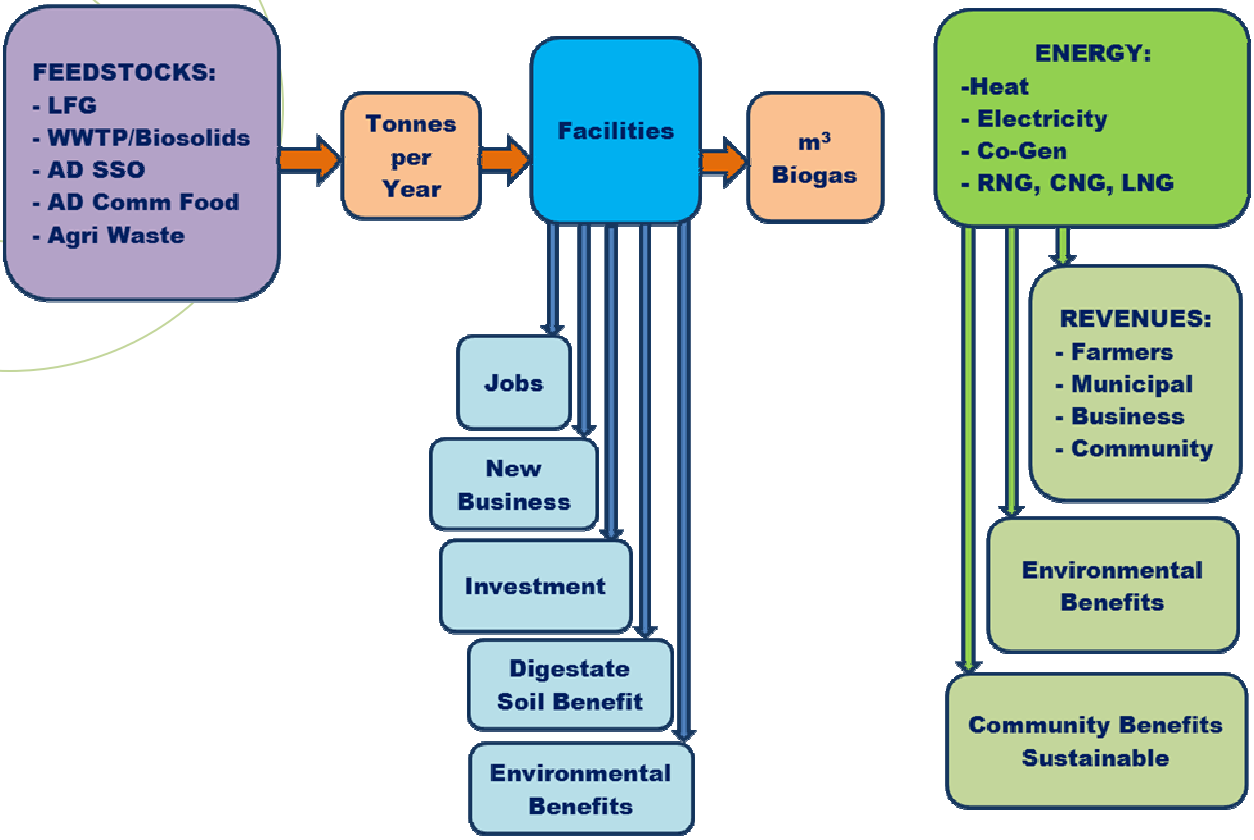


Figure 5: Logic Flow Chart for Canadian Biogas Study Research

2.1 Literature Search

Information on biogas metrics is contained in a number of literature sources including:

- Published reports;
- Published scientific articles;
- Articles in technical/trade/professional magazines and journals;
- Newspaper/magazine articles ;
- Conference presentations and proceedings and
- Articles on websites.

Each of these sources was reviewed to identify reports which would contain information potentially relevant to the *Canadian Biogas Study*. Research efforts focused on recent publications (2008 or more recent) where possible.

Rotman Information Solutions (a division of the Rotman School of Management at University of Toronto) was hired to carry out a literature search, procure literature sources and search the academic literature on topics of interest to the study.

The reports reviewed focused on key potential sources of biogas production in Canada in five categories:

- Agricultural;
- Landfill gas (LFG).
- Source separate organics (municipal/residential)
- Source separated organics from commercial sources (such as hotels, restaurants, etc. but not including industrial organics which are generally managed on-site and not included in Statistics Canada research used for the study) and
- Wastewater treatment plant residuals.

For each of these waste types, documents were reviewed to collect available data on the following topics:

- Jobs and economic development;
- Greenhouse gas (GHG) and climate change impacts;
- Water quality and air quality impacts;
- Nutrient management and residue management;
- Contribution to social resilience and sustainability;
- Supportive policies and incentives for biogas project development;
- Barriers to biogas project development and
- Miscellaneous information on the benefits of biogas.

2.3 Interviews

A number of contacts in biogas related businesses were interviewed to fill various information gaps remaining following completion of the literature review.

2.4 General Assumptions Used For Metrics Development

The following assumptions were used for metrics development.

2.4.1 Canada's National Electricity and Natural Gas Demand

Canada's national electricity demand was found in *Canada's Energy Outlook: The Reference Case 2006 Analysis and Modelling Division of Natural Resources Canada*[2]. The total demand in 2010 and 2020 are presented in Table 5.

Table 5: Canada's Electricity Demand 2010 and 2020

[2] Table EL1 – Electricity Demand (TWh)

	2010	2020
Electricity Demand (TWh)	523	593
MW[3]	59,703	67,694

A value of 37,000 MW was used for Ontario's electricity demand, based on the values in Table 6.

Table 6: Installed Capacity (MW) in Ontario[4]

Ontario Installed Capacity	2003	2010 Projection	2030 Projection
Nuclear	10,061	11,446	12,000
Renewables- Hydro-Electric	7,880	8,`127	9,000
Renewables - Wind, Solar, Bioenergy	155	1,657	10,700
Gas	4,364	9,423	9,200
Coal	7,546	4,484	0
Conservation	0	1,837	7,100
Total	30,006	36,975	48,000

National electricity statistics for Canada are summarized by source in Table 7.

Table 7: CEA Member Performance At A Glance (Sustainability Report, 2012)[5]

Net Generation By Fuel Type	2012 (GWhrs)
Coal	42,957
Oil	1,408
Diesel	273
Natural Gas	16,769
Hydroelectric	170,765
Nuclear	49,457
Other Renewables	3,496
Total Net Generation	285,126
Renewables Purchased From Non-CEA Member Companies	6,552

Canada's annual natural gas demand is about 80,000Mm^3/year[6]. An estimated 6.3 million locations use natural gas. About 91% of natural gas sales are to the residential sector; an estimated 9% are to the commercial sector and a small amount is to the industrial sector.

Ontario's natural gas demand was estimated at 28,310 Mm^3/year of natural gas[7].

2.4.2 Household Energy Demand

Where a metric was used involving annual household energy demand, the values in Table 8 (taken from a Statistics Canada report) were used. GJ of energy were converted to cubic metres of natural gas using various conversion factors in Table 9.

[3] TWh = 106 MWhs; divided by 8,760 hrs/year to calculate MW
[4] Ontario Long-Term Energy Plan, *Achieving Balance*, Released 2nd December, 2013
[5] www.powerforthefuture.ca
[6] www.cga.ca/resources/gas-stats/ - 80,000,000 thousand cubic metres of natural gas sales in Canada
[7] The Future of Ontario's Natural Gas Infrastructure, Mark Isherwood, Union Gas, May 30th, 2012 presentation to Ontario Energy Board (www.unongas.com/media/storage-transportation/communications/pdf/presentations/2012/OEB Presentation May 30th, 2012

Table 8: Average Household Energy Use in Canada By Fuel Type[8]

	Electricity	Natural gas	Oil	Wood and wood pellets	Propane	All fuel types
	gigajoules per household					
Canada	**40**	**92**	**62**	**88**	**20**	**105**
Newfoundland and Labrador	58	F	64	110	10	111
Prince Edward Island	29	F	71	135	9 E	142
Nova Scotia	35	F	62	75	11 E	101
New Brunswick	53	F	59	96	7 E	92
Quebec	60	72	57	117	13	95
Ontario	**30**	**93**	**70**	**77**	**26**	**107**
Manitoba	48	78	F	57 E	F	98
Saskatchewan	32	88	F	31 E	F	110
Alberta	31	105	F	36 E	F	130
British Columbia	37	84	50	58	22 E	99

All conversions to household usage used in the document are based on average household values of 2,400 m^3/year of NG and 0.952kW (952 watts) per household per year of electricity. Conversions from various units to m^3 of natural gas are summarized in Table 9.

2.4.3 Converting Energy Metrics to Natural Gas and Electricity

Metrics were found in the literature often used different units of measure (GJ, Mm^3/year of natural gas; kW or MW; kWhrs or MWhrs, etc. The values in Table 9 were used to convert all metrics to Mm^3/year of natural gas.

Where values found in the literature expressed biogas production as Mm^3/year (million cubic metres per year), these values were converted to Mm^3/year of renewable natural gas (RNG) assuming that 1 cubic metre of biogas would produce 0.5 cubic metres of RNG.

Electricity production from biogas was calculated assuming that 3Mm^3/year (3 million cubic metres per year) of RNG (or 6Mm^3/year of biogas) would produce 1MW of electricity.

[8] Statistics Canada Households and the Environment: Energy Use, 2011 Table 3-2: Household energy use, by fuel type and by province, 2011 – Average energy use

Table 9: Factors Used to Convert Metrics To Natural Gas Equivalents

Unit	Conversion to Heat and Electricity	Conversion to m^3 natural gas
1 gigajoule (GJ) of 1.0 gigajoule (GJ) = 10^9 joules energy	0.948 MMBtu 278 kWh.	26.137 cubic meters (m^3) 26,137 litres
1 kilogram (kg) natural gas		1.406 cubic meters (m^3)
1 tonne natural gas		1,406 m^3 NG or RNG
1 MM BTU (I million BTU's (British Thermal Units of heat		28.3168 m^3 of natural gas
93 GJ is average annual household demand for energy		25,854 kWh 2,430 m^3 natural gas 1,728 kg natural gas
Household per year energy use in Ontario 2011 is 30 GJ (electricity)	8,340 kWh 0.952 kW year.	

Many of the metrics in the literature were quoted in terms such as GJ, TJ or PJ. Table 10 summarizes the order of magnitude involved.

Table 10: Conversions from Watts, kW and larger units

Value	Term	Term
10^3	Kilo	kWh
10^6	Mega	MWh
10^9	Giga	GWh
10^{12}	Tera	TWh
10^{15}	Peta	PWh

2.4.4 Converting Methane To Cars Off the Road

Where impacts of projects were expressed as tonnes of methane (CH_4), these were converted to tonnes of eCO_2 by multiplying tonnes of methane by a GWP (global warming potential) factor of 21.

One tonne of methane is equivalent to 1394.7 m^3 of methane, therefore values expressed as volume of methane were converted first to tonnes of methane and then to tonnes of CO_2.

It was assumed that each car would travel 20,000 km/year, consume 8 litres per 100km, therefore 1,600 litres of diesel per year, and 1 m^3 of RNG is equivalent to about 1 litre of diesel. Cars were estimated to emit 5 tonnes of CO_2 per year.

2.5 Structure of Report

The report addresses specific issues in the following sections:

- Section 3 addresses biogas from agricultural sources;
- Section 4 addresses biogas produced as landfill gas (LFG) at landfills across Canada;
- Section 5 addressed biogas produced by AD (anaerobic digestion) of SSO (source separated organics) from residential sources;
- Section 6 addresses biogas produced by AD of SSO from commercial sources;
- Section 7 addresses biogas produced at WPCP (water pollution control plants);
- Section 8 presents the benefits of biogas compared to other energy sources;
- Section 9 presents a policy overview and
- Section 10 presents a summary of study findings, identifies information gaps and suggests areas of additional research required.

3 Potential Biogas Opportunity From Agricultural Sources in Canada

The agricultural sector in Canada can produce biogas from animal manures, crop residues and custom grown energy crops. For this study, all biogas estimates are converted to methane values (50% to 60% of biogas) and are expressed and presented as renewable natural gas (RNG).

Farm digesters result in improved manure management. The digestate from farm digesters is easier to spread on land; digesters result in a substantial reduction in pathogenic bacteria from animal manures; and nutrients from digested manure are more readily absorbed by crops. Farm digesters provide a source of on-farm energy for heat and electrical power. They can provide an additional source of revenue from energy sales as well as tipping fees from off-farm materials, and farm digesters provide sufficient activity to create employment for a member of the farm family, thereby reducing the need for off-farm employment. This allows the farm to remain sustainable and resilient in the longer term.

3.1 Existing and Potential Biogas From Agricultural Sources in Canada

Estimates contained in a report by the Canadian Gas Association - "*Potential Production of Methane from Canadian Wastes, Canadian Gas Association and Alberta Research Council, Sept. 2010*" were used for the *Canadian Biogas Study* as they were the most recently available figures which estimated the potential of biogas production from both animal manures as well as crop residues by Province across Canada. The CGA study estimated the Canadian potential of methane production from digestion of all agricultural sources (crop residue and manure) to be 3,294,000 Mm^3 CH_4/year. Values of potential biogas and RNG production by province are presented in Table 11. The table shows the potential biogas production if 100% of all manures and crops were digested and if 50% of the available supply were digested. The 50% scenario is considered more realistic for short to medium term planning, but the 100% scenario is shown for information.

Other sources were also reviewed for the analysis. The *Potential Production of Renewable Natural Gas from Ontario Wastes, Alberta Innovates Technology Futures, May 2011* estimated the Ontario agricultureal RNG potential to be 575 Mm^3/year in the near term from digestion of crop residues and animal manures (dry tonnes) based on 2007 Statistics Canada data. The research study *Market Assessment of Agricultural and Industrial Anaerobic Digestion Potential in Canada. BBI Biofuels, NRCan 2008* estimated the potential biogas and RNG production potential for animal manure digestion at 1,627,000 Mm^3/year and 976,000 Mm^3/year respectively for Canada. CANMET is updating these estimates with results expected at the end of 2013.

Table 11: Potential RNG, Biogas and Electricity Production by Provincial Agricultural Feedstock in Canada (based on 2007 data) [9]

	Animal Manure RNG Production Potential (Methane CH_4)	Removable Crop Residues RNG Production Potential (Methane CH_4)	RNG Production Potential (Methane) 100% Utilization	RNG Production Potential (Methane) 50% Utilization	Electricity Production Potential[10] MW	Electricity Production Potential (Rounded) MW
	Mm^3/yr	Mm^3/yr	Mm^3/yr	Mm^3/yr		
Canada	1,747	1,547	3,294	1,647	549.0	549
BC	140	7	147	73	24.3	24
AB	431	386	817	409	136.3	136
SK	229	509	739	369	123.0	123
MB	172	211	383	191	63.7	64
ON	382	283	666	333	111.0	111
QC	322	142	464	232	77.3	77
NB	24	3	26	13	4.3	4
NS	28	2	29	15	5.0	5
PEI	7	4	12	6	2.0	2
NL	1	0	1	0	0.2	0

3.2 Biogas Production From Energy Crops

The Ontario Federation of Agriculture (OFA) evaluated the use of surplus farmland in Ontario (as a result of a contraction of the beef industry) to grow energy crops for biomass and bio-products markets[11]. The OFA research estimated that there are over 850,000 acres or surplus pasture land currently available in Ontario which could be used to grow energy crops. Assuming 0.5kW per acre (compared to 1kW per acre for corn), it was estimated that the surplus Ontario agricultural land could produce up to 400 MW of energy. Equivalent estimates could not be found for other provinces, therefore it was assumed that the Canadian potential might be 800MW. This total would need to be confirmed through additional studies covering other provinces.

In Germany, digestion of purpose grown crops for energy production exceeds the amount of manure digested. Also, in Northern Ireland, considerable amounts of grass silage are digested to produce renewable energy from farm digesters.

The relative energy production from corn silage based biogas is shown in Figure 6.

[9] Potential Production of Methane from Canadian Wastes, Canadian Gas Association and Alberta Research Council, Sept. 2010
[10] Based on 1MW from $3Mm^3$/year RNG
[11] Assessment of Hay Crop Acreage and Pasture Land for Biomass Production in Ontario, Prepared for Ontario Federation of Agriculture by Western Sarnia-Lambton Research Park, June, 2013

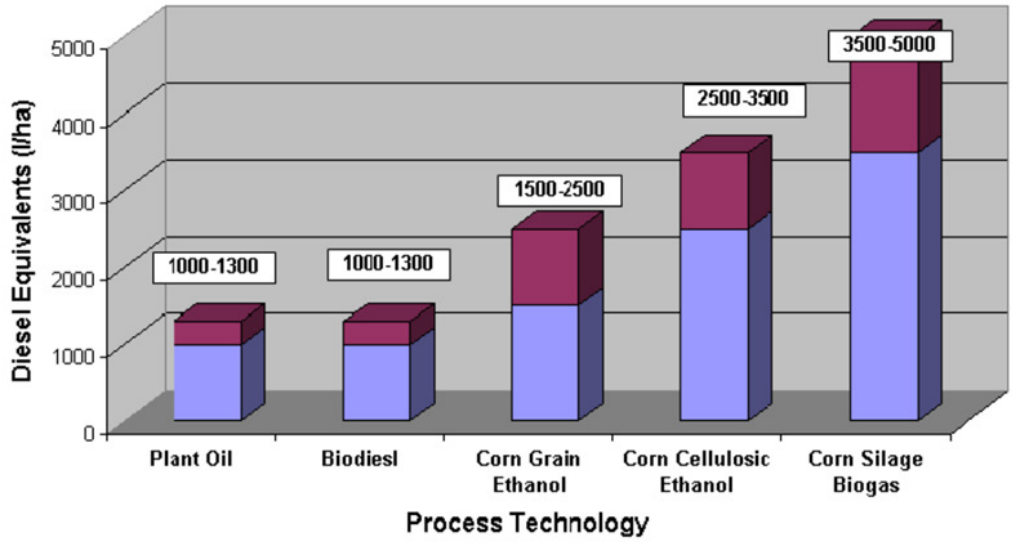


Figure 6: Corn Silage Biogas Yield Per Hectare

3.3 Current Status of Agricultural Digesters Across Canada

Information on the number of agricultural digesters already in place or planned across Canada was collected through a combination of website review, followed by interviews with selected agricultural sector and business representatives.

Quebec and the Maritime Provinces: There is minimal agricultural digester activity in Quebec and the Maritimes, and there is no program such as the Ontario FIT to support the sale of electricity from farm digesters. Most of the farms in Quebec do not have sufficient manure to support an economically viable digester at the available electricity purchase rate of 10 cents/kWhr. There is only one farm with more than 1,000 cows in the Province. There is one 600kW digester located at a dairy farm in New Brunswick which digests food waste from a McCain food processing operation. There are some plans to expand the capacity to 1.6MW. There is also some AD project development activity underway in the Halifax, Nova Scotia area as a result of a recent 17 cent/kWhr incentive announced in that province.

Ontario: In Ontario there are currently 30 agricultural digesters in operation[12]. The supportive policies in Ontario have encouraged the construction of these facilities through the Feed In Tariff (FIT) program which pays high prices for electricity from biogas facilities. In the past, agricultural digesters were permitted to accept 25% off-farm waste (excluding residential Green Bin material) as a source of additional revenue. The allowable off-farm amount was increased to 50% under the Nutrient Management Act in October, 2013. In addition to providing tipping fee revenues to agricultural digester operators, off-farm waste is a good source of additional biogas, particularly for high-biogas generating materials such as FOG (fats, oils and greases) produced from restaurants, animal processing by-products, waste feed materials, etc.

Manitoba: Biogas production in farm digesters has two challenges in Manitoba – cold winters and a low price paid for energy. One large dairy farm, Sweet Ridge Dairy Farm (in Winkler, Manitoba) is participating in a digestion demonstration/pilot using an in-floor heating system to prevent tank contents from freezing, with Manitoba Hydro using the biogas as fuel to displace electricity currently purchased by the farming operation . A private potato processor (Simplod) has processed wastewater using AD project

[12] Biogas Association

for about 8-10 years. The company uses the biogas for their gas boilers (a small portion of the total heat demand is provided by the biogas) as a supplement to the natural gas used for plant needs. Two other farm digester projects (dairy farms digesting manure) are reportedly stalled.

Saskatchewan: There are reportedly no agricultural digestion plants in Saskatchewan at this time, however there is one in the planning stages[13]. The Prairie Agricultural Machinery Institute (PAMI.ca) in Humbolt, Saskatchewan has an AD research demonstration facility - a liquid state AD facility (not operating) and a solid state AD facility targeting agricultural residues (straw, food waste, solid manure). This group is actively trying to promote farm digesters. The existing pilot scale batch system has a capacity of 20 tonnes per batch with flaring of the methane. The group is working on quantifying the environmental benefits of AD. The work started in summer, 2013 with a report expected end of December, 2013. One operating AD farm facility shut down due to lack of feedstock and no economic incentives. There is reportedly "nothing in the works" at the provincial level to provide incentives for farm digesters. In spite of this, interviewees felt that there are some farms that will be pursuing AD in the future.

Alberta: A 2007 report stated that Alberta had 5 AD facilities running on feedlots (2), hog farms (2), and potato processing plant (1) for heat and electricity production. Highmark Renewables in Two Hills, Alberta operates a 1MW digester to process manure and waste. Lethbridge Biogas is a stand-alone, private AD facility that can produce up to 2.8MW of electricity. It is designed to process manure and farm waste from other farms, as well as animal by-products and Specified Risk Material (SRM)[14]. Both AD operations convert biogas to electricity. There is reportedly "lots of interest" in agricultural AD in Alberta. Five farms are pursuing AD and an additional 15-20 farms are investigating AD facilities.

British Columbia: There is a standing offer program in BC for electricity from biogas projects but the rates are not high enough to stimulate spending on biogas projects. Interviews with BC government representatives identified 2 farm AD facilities in operation in BC: Bakerview EcoDairy (Abbotsford, BC) – a small pilot project – 50 cows and Fraser Valley Biogas in Abbotsford, BC (was Catalyst Power) which processes manure from 5-7 area farms as well as food and agricultural wastes. The facility produces biogas which is upgraded to produce renewable natural gas. Two other farm AD facilities are expected to be under construction in 2014. The RNG route precludes many farms in BC pursuing AD facilities because they cannot produce enough biogas and are not near the NG grid therefore the projects are not economically viable. Fortis BC currently offers customers a "green" natural gas option for a higher rate per month. Residential customers have the option to pay an additional $5 per month for an average home, and designate 10% of the natural gas they use as renewable natural gas. Fortis BC then injects the equivalent amount of renewable natural gas into their distribution system. The BC government may require 2-3% of RNG in natural gas at some point in the future.

[13] J. Robins correspondence with Joy – PAMI (Prairie Agricultural Machinery Institute) – Project Manager July, 2013
[14] Matt Lemsink comments Sept 2013

3.4 Environmental Benefits of Farm Digesters

3.4.1 GHG Emission Reduction Impact of Farm Digesters in Canada

Biogas projects reduce GHG in two ways:

- They convert methane, which might be released to the atmosphere if manure was not digested, into CO_2 (a less damaging GHG) when used to produce energy and
- They displace other fossil based energy sources.

CO_2 emissions reductions from biogas will vary depending on whether the biogas is used for heat, electricity, co-generation, RNG or fuel. CO_2 emissions reductions are based on current energy sources used for energy generation. Jurisdictions that generate electricity from coal have greater GHG emission reductions, while jurisdictions (such as Quebec) which use hydroelectricity have lower GHG emissions reductions from the production of electricity.

Various metrics were found in the literature to calculate the GHG reduction benefit of farm digesters. The most relevant was considered to be an 80% reduction in methane emissions in a dairy farm with AD compared with no AD, measured by research based out of University of Guelph, Ontario[15];

In one report, Natural Resources Canada calculated a potential GHG emission reduction value of 2.7 million tonnes of CO_2 emissions per year for Canada, should all of the potential from agricultural AD be realized.

Specific emissions from biogas compared to other fuels are presented in Section 8 of this document.

3.4.2 Water Quality Benefits of Farm Digesters

On-farm anaerobic digestion can help reduce water contamination, improve manure management and use, and reduce eutrophication (Nelson and Lamb, 2002). Anaerobic digestion of manure reduces total oxygen demand (TOD) levels, thereby decreasing the environmental effects of such water contamination. Similarly, chemical oxygen demand (COD) can be reduced by 60-90% and biochemical oxygen demand (BOD) by up to 80%. These environmental quality improvements, along with reduced total volatile solids (TVS) can lower the potential for depletion of dissolved oxygen in natural waters and nonpoint source water pollution[16]

Well operated digesters reportedly achieve reduction of pathogens of more than 99%[17]

In an EPA evaluation of a plug flow digester in Wisconsin, a reduction in fecal coliform concentration of more than 99 % was determined. The same report claims a 90 % reduction in fecal streptococci concentration. Both types of bacteria were analyzed as colony-forming units (CFU) per 100 ml of manure[18].

[15] The Addition of Biomethane to GHGenius. 2009. Natural Resources Canada
[16] ibid
[17] Anna Crolla research on Fepro Farms
[18] Feasibility Study – Anaerobic Digester and Gas Processing Facility in the Fraser Valley, British Columbia, November, 2007. Prepared by Electrigaz for the BC BioProducts Association

3.4.3 Air Quality Benefits of Farm Digesters

Farm digesters reduce volatile fatty acids which cause odours by 95% to 98%[19];

These benefits are discussed in more detail in this section. The use of biogas can reduce emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from storage of manures, thereby reducing contributions to climate change.

AD results in production of virtually odourless high grade organic liquid or marketable solid soil amendment (depending on digester configuration). Application of digestate wadds nitrogen, phosphorous and carbon to the soil, and in some cases digestate can be applied to growing crops without damage. This results in significant reductions in odours associated with the land application of manure and is a significant social benefit to local communities.

3.4.4 Nutrient Management and Soil Benefits of Farm Digesters

Where farms digest manure and crop residues and apply the digestate back onto the land, the natural nutrient cycle can be maintained through recycling nutrients from manure. The nutrients in the manure remain at the same level but are converted into a more bio-available form through the digestion process. The nitrogen tends to concentrate in the liquid digestate (80%) and the phosphorous concentrates in the solid digestate (80% of P from manure)[20]. Solids content of manures in digesters is typically 5% to 11%.

Digestion stabilizes manures and creates digestate which has good soil enhancement qualities[21]. The metabolized substrate (which is converted to digestate) is an excellent soil amendment rich in phosphorus, potassium, trace elements, more readily available nitrogen and no nitrates. It can be land spread with conventional equipment for manure and slurry. Compared with fresh cattle manure, the metabolized substrate is more effective - it is homogeneous, has a higher nutrient content, a better C / N ratio, it is almost odorless (which attracts less insects) and does not contain pathogenic biological organisms.

The mineralization of nitrogen in the biogas plant increases the crop nutrient value of the manure, thereby reducing the need for synthetic fertilizers.

The solid fiber in the digestate may be extracted using a liquid/solid separator to make bedding for use on the farm. This is applicable primarily to the cattle and dairy industries.

Dairy cows excrete approximately 114kg (250 lbs) N, (25kg (55 lbs) P_2O5 and 55kg (120 lbs) K_2O per year in manure. These nutrients can be re-applied to the land in a controlled way after digestion.

Anaerobic digestion of manures reduces land base requirements for manure applications, and allows for better control of manure application because of the somewhat smaller volumes to be managed.

[19] Anna Crolla Fepro Farm Research
[20] Personal communication Chris Duke, OMAFRA, October, 2013
[21] Highlights of socio-economic impacts from biogas in 28 target regions
http://www.biogasin.org/files/pdf/WP2/D.2.4_SINERGIJA_EN.pdf

3.5 Economic Benefits Of Farm Digesters

The economic (and community) benefits of farm digesters include:

- Local employment;
- They provide an additional income stream for farmers, who want to diversify their income sources to be sustainable long term;
- They provide an opportunity, and sufficient income, to keep one additional family member on the farm, rather than having to find a job off-farm.

This last point is particularly important for family farms where several generations are involved and three families or more need to be supported by one farm. The digester operation provides a separate business line to provide the equivalent of a part time job for one family member, thus avoiding the need for them to move off the farm for employment. It also provides local employment for hauling where off-farm material is digested. This contributes to community stability and sustainability, as well as to the long term sustainability of family farms across Canada.

3.5.1 Employment Impacts Of Agricultural Digesters

The following types of employment are generated when each farm digester is developed, constructed and operated:

- Permits and design by AD consultants;
- Construction of new AD facility;
- Commissioning of new AD facility;
- Daily operation of the farm digester;
- On-going maintenance (engine, mechanical and electrical, tanks, etc.)
- Laboratory analysis for monitoring
- Haulers of feedstock and
- Professional servicing.

Considerable research was carried out as part of the *Canadian Biogas Study* to identify the number of jobs linked to design and construction as well as on-going operations and maintenance of agricultural digesters producing biogas. The economic and community/society benefits of agricultural digesters are broad ranging, but generally do not translate into large numbers of direct and indirect jobs after the design and construction phase is complete. Agricultural digesters provide a farm family with an additional source of income, which can keep one additional family member on the farm. Literature sources cited support for rural livelihoods as an important societal value of farm digesters, and some producers suggested that without the steady income from the biogas facility, small dairy farms in many locations might not exist today[22]

A number of literature sources were reviewed to compile data published on job impacts of farm digesters. The literature review determined that there was a wide range of estimates – generally expressed per 1,000 m^3 of biogas produced, or per digester location. A number of industry contacts were then interviewed to firm up the estimates to be used for the study. The industry contacts also had wide ranging opinions on the employment potential of digesters.

[22] Got gas? An analysis of Wisconsin's Biogas Opportunity. March 2011. University of Wisconsin-Madison. And Got Gas? An Evaluation of the German Biogas Experience and Lessons for Wisconsin. September 2010. Great Plains Institute

Based on interviews with a number of Canadian designers, developers and field operators, the following estimates were developed:

- **Design and development of 500kW digester:** 5.3 FTE for one year based on 3.3 person-years for design and development per 500kw project and 2 person years for sub-contractors during construction (concrete, electrical, plumbing)):
- **Construction of 500kW digester**: An assumption of 4 FTE for one year was used for construction jobs. Estimates varied widely but the number is loosely based on the BC estimate of 3.71 construction jobs per MW, and on the fact that construction of farm digesters is more straightforward than construction of other digesters addressed in this study;
- **Operation of 500KW digester:** 1.2 FTE on an on-going basis, based on the assumption that two professional people (one technical, one biological) can operate 10-15 digesters per year on an on-going basis through periodic site visits etc. Therefore each digester requires 0.2FTE per digester of professional support. Digester operation generally requires an operator for 4 hours/day and staff hauling material from other locations. An assumption of 0.5 FTE for operation, 0.5 FTE for hauling and 0.2FTE for professional/technical support totals 1.2 FTE for operations on an on-going basis.

Three types of AD facilities are generally used for farm manures:

- On-farm with no off-farm supplements (manure only);
- On-farm with off-farm supplements (manure supplemented with industrial organics), or
- Centralized anaerobic digesters which digest manure from a number of farms and also feedstocks from local industries (off-farm materials).

An estimate of the potential number of anaerobic digesters which could be established to manage agricultural wastes in Canada was developed in order to estimate the number of jobs which could be generated by agricultural biogas opportunities.

Discussions with industry experts identified a 500 kw farm digester as being a practical size (or smaller) to assume for the estimates. The estimates recognize that many smaller units of 100kW will also be constructed, as well as larger 2-3MW units which will take off-farm material and possibly manures from a number of local farms (like an existing 2.8MW facility in Southern Ontario). Very few farm digesters of 1MW or larger exist therefore estimates for this study have been carried out assuming practical size limits. The estimated number of digesters is presented in Table 12 along with employment estimates by digester assuming and average rates developed from the literature review and interviews.

Table 12: Estimated Employment Created By Farm Digester Development in Canada

Region	Methane (CH_4) Production from AD (Mm^3/yr) (million m^3/year) From manure and crop residues combined		No of AD Plants at 500kW per plant 1.5Mm^3/y RNG per 500kW unit	Jobs (Development) Assumes 5.3/digester	Jobs (Construction) 4 FTE for one year	Jobs (Development & Construction) One Year	Jobs (Operation) Permanent Assumes 1.2FTE per digester
	100% capture	50% capture					
Canada	3,294	1,647	1,098	5,819	4,392	10,211	1,318
BC	147	73	49	258	195	453	58
AB	817	409	273	1,445	1,091	2,536	327
SK	739	369	246	1,304	984	2,288	295
MB	383	191	127	675	509	1,184	153
ON	666	333	222	1,177	888	2,065	266
QC	464	232	155	820	619	1,438	186
NB	26	13	9	46	35	81	10
NS	29	15	10	53	40	93	12
PE	12	6	4	21	16	37	5
NL	1	0.5	0.3	1.8	1	3	0.4
NT, YK, NU	0	0	0	0	0	0	0

The table shows that construction of almost 1,100 farm digesters to process 50% of available manures and crop residues would create 10,211 construction related jobs for one year and about 1,320 permanent operational jobs across Canada. Estimates by province and territory are included in the table.

3.5.2 Capital Investment in Farm Digesters in Canada

Table 13 summarizes AD facility costs developed in a 2011 study[23].

Table 13: Capital Costs For Farm Digesters of Different Sizes (Electrigaz, 2011)

Scenario name	Baseline Farm (450kW) 130 m^3/hr biogas 77 m^3/hr RNG 674,520 m^3/yr RNG	Large Farm (920kW) 300 m^3/hr biogas 158 m^3/hr RNG 1.38 Mm^3/yr RNG	Co-op Farm (1.4MW) 239 m^3/hr biogas 239 m^3/hr RNG 2.1Mm^3/yr RNG
AD process	**$ 2,252,000**	**$ 3 ,055,000**	**$ 4,579,000**
Upgrading process	$ 1,561,000	$ 2 ,030,000	$ 2,896,000
Injection, pipe, compression	$ 529,930	$ 529,930	$ 529,930
IDC	$ 105,989	$ 1 37,032	$ 195,359
Total capital costs	$ 4,448,919	$ 5 ,751,962	$ 8,200,289

Table 14 shows the total capital investment and indirect economic impact assuming construction of over 1,000 digesters across Canada to process 50% of available manures and crop residues. The estimates are based on an average capital cost of $3 million per digester (to construct a project of about 500kW or 1.5 Mm^3/year of methane), and a multiplier of 3.1 for indirect economic effects based on limited research out of the US that identified an average job multiplier of 3.1 for direct, indirect, and induced jobs, including

[23] Economic Study on Renewable Natural Gas Production and Injection Costs in the Natural Gas Distribution Grid in Ontario-Biogas plant costing report. Enbridge Gas Distribution Inc. Union Gas Limited Prepared by: Electrigaz Technologies Inc. September 2011

total jobs associated with AD generated from landfill gas, livestock manure and wastewater treatment plants.[24]

Table 14 shows that the total investment is estimated at $ 3 billion across Canada with an economic spin-off of $9.3 billion for a total economic impact of $12.3 billion. Estimates by Province are presented in the table.

Table 14: Estimated Potential Capital Costs and Economic Impacts of Farm Digester Construction Across Canada

Province or Territory	No of AD Plants at 500 kW (Assumes 50% of Methane is Captured)	Construction Cost @$5 Mil/Digester ($Millions)	Indirect Economic Benefit (@3.1 Multiplier) ($Millions)	Total Economic Benefit ($Millions)
Canada	1,098	$3,294	$10,211	$13,505
BC	49	$147	$456	$603
AB	273	$819	$2,539	$3,358
SK	246	$738	$2,288	$3,026
MB	127	$381	$1,181	$1,562
ON	222	$666	$2,065	$2,731
QC	155	$465	$1,442	$1,907
NB	9	$27	$84	$111
NS	10	$30	$93	$123
PE	4	$12	$37	$49
NL	0.3	$1	$3	$4

3.5.3 Revenues from Farm Digesters

The primary motivator for farm digester owners is the diversification of revenue beyond conventional agricultural sources. Farm digesters create a number of tangible revenue streams for their owners, with the primary stream being renewable energy. Other potential revenue streams include tipping fees, thermal usage, bedding savings, nutrient recovery and carbon offsets[25].

The mineralization of nitrogen in the digester increases the crop nutrient value of the manure, thereby reducing the need for synthetic fertilizers. A generally accepted rule of thumb used in the European biogas industry calculates an avoided fertilizer cost of $15 Can (10€) per animal unit per year[26].

The solid fiber in the digestate may be extracted using a liquid/solid separator to make bedding for use on the farm. This is applicable primarily to the cattle and dairy industries. A 200-head dairy may have annual bedding costs of $30,000 of more that could be completely offset with the use of separated digestate organic material[27].

In Ontario, for example, 13 farms have separators (screw presses and screen augers) which can de-water solid digestate to a moisture content of 70% (solids content of 30%). The material can then be used as animal bedding, offsetting the costs to use straw and buy sand for that purpose. An additional benefit is

[24] The Potential for Renewable Gas: Biogas Derived from Biomass Feedstocks and Upgraded to Pipeline Quality. September 2011. American Gas Foundation
[25] British Columbia on-farm anaerobic digestion benchmark study. No date. B.C. Agricultural Research and Development Corporation.
[26] Feasibility Study – Anaerobic Digester and Gas Processing Facility in the Fraser Valley, British Columbia. November 2007. Prepared by Electrigaz for the BC BioProducts Association
[27] ibid

that digestate apparently may protect cows against mastitis. Recent research has shown that the somatic cell count (bacteria found in milk related to mastitis) did not increase in cows where digestate was used as bedding[28]. In Wisconsin, of the farms that have anaerobic digesters, 20 farms report using the digested material for bedding, representing a savings of $7.25 per cow per month. Of these farms, 12 produce enough bedding to sell to other farmers, creating an additional income stream[29]. On farms that do not wish to use the solid portion for bedding, the digested manure solids bedding can be sold as a soil additive for an estimated value of $20 per tonne.

The trading price for a tonne of CO_2eq reduction in the European Union Emissions Trading Scheme (EU ETS) –the world's largest carbon market–was 5.60 Euros, or about $7.85 Can in late, 2013, and 0.6 Euros (less than $1Can) in the US. The potential revenues and cost savings from farm digesters are summarized in Table 15.

Table 15: Potential Revenues And Cost Savings From Farm Digesters

Potential Revenue or Cost Saving	Metric
Energy savings and revenues	Electricity cost is 10c/kwhr but varies across Cnaada Energy revenues are 16.4 to 26.5 cents/kWhr in Ontario FIT program RNG revenue similar to NG In BC, RNG revenue $13/GJ (much higher than NG)
Tipping fees and revenues	Similar to local landfill tipping fees which vary from $25 to $115/tonne across Canada. Only viable where local tipping fees are high
Fertilizer savings	$10-$15/animal NPK 3:2:2 stays the same – added value is organic matter in digestate, not nutrients
Animal bedding saving and revenues	Savings of $86/cow/year Potential to sell surplus digestate as animal bedding for $20/tonne
Carbon credits revenues	Varies depending on market. Could be up to $15/tonne eCO_2 in Alberta Sale of carbon credits may increase in value as carbon market stabilizes and establishes in the future

3.6 Social and Community Benefits of Farm Digesters

There is considerable overlap between the environmental, community and social benefits of agricultural digesters, therefore they are all included in this section together. Economic impacts are discussed in Section 3.5. These benefits include:

- Production of energy from renewable (and therefore sustainable) sources;
- Better management of manures, thus protecting waterways and the environment;
- Capture of nutrients in digestate which can be applied to land in a controlled fashion;
- Conversion of nitrogen to more available forms for crop fertilizer

Reasons[30] given by farmers for using on-farm anaerobic digesters included:

- Decrease in import of electrical and heat energy
- Increase in value of livestock wastes as fertilizers
- Decrease in import of mineral fertilizers
- Soil improvement from use of digested slurry
- Decrease of offensive odour around the farm

[28] Personal discussion Chris Duke, OMAFRA October, 2013
[29] Got gas? An analysis of Wisconsin's Biogas Opportunity. March 2011. University of Wisconsin-Madison... And … Got Gas? An Evaluation of the German Biogas Experience and Lessons for Wisconsin. September 2010. Great Plains Institute
[30] Scotland Anaerobic digestion, storage, oligolysis, lime, heat and aerobic treatment of livestock manures

- Less weeds on the fields and
- Ecologic aspects like recovery of renewable energy, decrease of methane emissions etc.
- Production of homegrown clean energy;
- Production of energy from waste materials;
- Reduced emissions of methane, a potent greenhouse gas;
- New income streams for farmers;
- Save local governments money and create rural regional wealth[31].

3.7 Energy Benefits of Biogas From Farm Digesters

The broad benefits of biogas as an energy source are discussed in Section 8. Biogas from farm digesters is a flexible energy source, suitable for different purposes:

- for heating / cooling of water or for direct combustion in boilers;
- for co-generation of heat and power;
- for tri-generation of heat, power and cooling;
- if the farm digester is at a suitable location, the biogas can be upgraded to biomethane and it can be injected either into the natural gas network, or into public district heating systems;
- depending on location, it can supply large heat consumers (crop drying, greenhouses, swimming pools etc.), and
- it can be used as a fuel for vehicles after upgrading to biomethane.

As biogas is produced locally and within local boundaries, the use of biogas reduces the dependence of local communities on fuels imported from elsewhere and increases the local energy supply. Also, biogas provides a stable source of baseload power for rural communities.

[31] The Biogas Opportunity In Wisconsin 2011 Strategic Plan. 2011. Wisconsin Agricultural Secretariat

3.8 Summary Of Benefits of Agricultural Digesters

The energy, environmental and economic benefits of agricultural digesters are summarized in Table 16.

Table 16: Energy, Environmental and Economic Benefits of Agricultural Biogas Projects in Canada

Energy	• Agricultural digesters in Canada using 50% of available manure and crop residues have the potential to produce 1,650 Mm^3/year of methane, which can be converted to 550 MW of renewable electricity. • Together, agricultural digesters could supply 2.1% of Canada's natural gas demand. • If energy crops were added, agricultural digesters could produce an additional 800MW of electricity, contributing up to 2% of Canada's electricity demand. • Biogas systems provide unique benefits to the electricity system as they are distributed throughout the grid and can provide electricity supply, reliably, regardless of the weather, 24/7. • Biogas can be stored when the electricity is not required, a significant benefit in some systems. • Electricity generated by biogas systems is synchronous and can provide voltage and power quality support to local, rural feeders which may be challenged by poor power quality.
Environment	• Anaerobic digestion of animal manures reduces pathogenic bacteria by up to 99%. • The addition of a biogas system at a dairy farm can reduce methane emissions by 75% • 6.4 Mt eCO2 equivalent were emitted from manure management in 2011 • Digesting half of animal manures and crop residues across Canada would reduce GHG emissions by an estimated 25.5 million tonnes of eCO_2 per year. This is the equivalent of taking 5,100,000 cars off the road. • Biogas systems typically achieve odour reduction in the order of 80% • 90% of the phosphorus and 43% of the total nitrogen can be concentrated in the waste solids, enabling better control and efficiency in nutrient management. • Digestion reduces weed seeds by up to 99%. This can reduce farm costs for herbicides while reducing the requirement for the broad-spectrum application of synthetic pesticides.
Economy	• On-farm biogas systems create a number of revenue streams that support income diversification and long-term sustainability for farm families. They provide an opportunity, and sufficient income, for an additional full-time job. • Renewable energy is the primary income source for biogas systems; other potential revenue streams include tipping fees (from off-farm materials), sale of thermal energy, bedding savings, nutrient recovery and carbon offsets where available. • Agricultural digesters provide local employment, consisting of 1.2 FTE at the digester and additional haulage jobs if off-farm waste is accepted. • Avoided cost of fertilizer is estimated to equal $15 per animal unit per year. • Solid fiber in digestate may be extracted using a liquid/solid separator to make bedding for use on the farm. This can save as much as $84 per cow per year. • Surplus digested manure solids bedding can be sold as a soil additive for up to $20 per tonne. • It is estimated that the construction of more than 1,100 digesters to process 50% of available manures and crop residues would create 28,900 construction-related jobs for one year. • Establishing 1,100 farm digesters across Canada will create about 1,320 permanent operational jobs across Canada. • Construction of 1,100 farm digesters would require a total investment of $3.5 billion with an economic spin-off of $10.5 billion for a total economic impact of $14 billion across Canada.

3.9 Case Study of a Farm Digester

Case Study:
Farm-Based Biogas Production with a Feed-in Tariff (FIT) Contract for Renewable Energy Generation
Cobden, Ontario

Overview

Fepro Farms is a dairy farm with 300 head of cattle, including 142 milking cows, as well as 350 acres of corn, 70 acres of small grain and 210 acres of alfalfa. It is owned and operated by brothers Paul and Fritz Klaesi and located in Cobden, Ontario, near Ottawa.

Biogas-powered generators on the farm supply electricity for all farm operations and residential uses. Heat captured from the generators is used to supply hot water and the heating requirements of the biogas system. Surplus electricity is fed into the electricity distribution grid and sold under a Feed-In Tariff (FIT) contract. The FIT Program was developed by The Ontario Power Authority (OPA) to encourage the development of renewable energy generation projects. Qualified renewable energy producers have an opportunity to enter into a 20-year contract with the Province of Ontario, through which the Province agrees to purchase all electricity that is delivered into the distribution grid, at a price sufficient to cover the costs of the project with a reasonable return on investment.

Fepro Farms uses biogas production to meet on-farm energy needs and create a substantial new revenue source. The system also provides an efficient and environmentally sound method for converting animal manure into a high-quality, nutrient-rich digestate for land application.

Features

- A 500 cubic metre (m^3) anaerobic digester generating 50kW of electricity was installed at Fepro Farms in 2003. This system was expanded to its current capacity of 2,500 m^3 and a 500 kW in 2007.
- The primary feedstock for anaerobic digestion is manure from the farm. In addition, off-farm organic residuals collected from restaurants, grocery stores and commercial SSO, are heat treated prior to digestion and used to increase biogas production.
- Heat is used seasonally for grain drying and heating of buildings on site.
- The digestate, a nutrient enriched soil amendment, is land applied to enhance crop production.
- Since signing the FIT contract, Fepro Farms has been able to eliminate electricity costs that were over $30,000 per month, while generating an additional revenue source.
- The biogas system also has a number of environmental benefits: The capture of methane from manure helps to reduce greenhouse gas emissions. Pathogens are reduced in the high-temperature anaerobic digestion process, thereby reducing the risk of ground or surface water pollution. The odours associated with conventional manure spreading are removed. The off-farm materials used in the process are diverted from local landfills.

Creating Opportunities

The biogas project at Fepro Farms represents an innovative form of local economic development. The project has supported renewable technology providers who are developing expertise and capacity in an emerging market. It has created opportunities for on-farm revenue diversification and employment for family members, at a time of limited growth in the dairy industry. By delivering reliable, dispatchable electricity into the distribution grid, the project is also helping Ontario move toward a cleaner, more sustainable energy system.

4 Landfill Gas (LFG) Biogas Opportunity in Canada

Landfill gas (LFG) is a by-product from the decomposition of organic waste in landfills. LFG biogas contains about 50% to 55% methane. It can be flared or captured and used as an energy source to create heat; heat and electricity (co-generation) and more recently, landfill operators are converting LFG into fuel for vehicles. This is particularly of interest to municipalities or waste management companies with large fleets of garbage collection trucks currently running on diesel.

LFG is already generated at the landfills, and the infrastructure is already in place at the landfill sites for many of the services needed to utilize biogas as an energy source, Capturing landfill gas can improve local air quality, reduce health and safety concerns and minimize odours from landfills. If left un-captured, non-methane organic compounds can contribute to smog and released sulphur can contribute to acid rain. Other pollutants in landfill gas can lead to respiratory health problems and methane gas from landfills can become an explosion hazard if the LFG comes in contact with oxygen.

4.1 Existing and Potential Biogas From Landfill Gas (LFG) in Canada

There are over 10,000 landfills in Canada including dumps (non-engineered landfills)[32], and about 800 active landfills in 2001 (Environment Canada). These landfills together are the third largest source of anthropogenic methane emissions in Canada. LFG contribute 3% of Canada's GHG emissions through the escape of methane which is a powerful GHG (21 times more powerful than CO_2). Approximately 7 Mt eCO_2 are captured and combusted at Canadian landfills, representing the equivalent of removing about 5.5 million cars from the road.

An inventory of LFG projects prepared by the Greenhouse Gas Division of Environment Canada in January, 2011[33] report that:

- There were 66 active landfills in Canada involved in capturing landfill gas in 2008 (68 in and 2009). About 53% of the captured landfill gas was utilized for heat and electricity, and the remaining 47% was flared with no energy recovery:
- Together, these projects capture about 30% of Canada's LFG (therefore 70% is not yet captured);
- 68MW of electricity and 2 million BTUs of heat[34] were produced through existing LFG projects across Canada[35].

A Canadian Gas Association study estimated that Canadian landfills emit 1,447,350 tonnes per year of methane (2,034 Mm^3/y of methane[36]) with only 21% captured[37]. Table 17 presents LFG recovery projects by Province and Territory across Canada in 2005. This information provides a sense of the distribution of LFG project activity prior to new initiatives such as Ontario's and BC's requirement for LFG recovery in landfills over a certain size, as well as the Ontario FIT program. The table shows GHG capture and GHG emissions (not captured) across Canada. In 2005, about 23 million tonnes of eCO_2 were emitted from

[32] Sustainable Best Practices and Greenhouse Gas Emissions at Canada's Landfills: Results From National Survey, Presented at SWANA 2008 in Edmonton by Rathan Bonam and Dr Shirley Thompson, University of Manitoba
[33] An Inventory of Landfill Gas Recovery and Utilization in Canada 2008 and 2009. Prepared by: The Greenhouse Gas Division of Environment Canada, January, 2011
[34] 2 million BTU is 0.6MW
[35] These estimates do not include recent Ontario projects resulting from FIT contracts.

[36] 1 tonne methane = 1,406 m^3 methane
[37] Potential Production of Methane from Canadian Wastes. September 2010. Canadian Gas Association

landfills across Canada. This is a significant contributor to Canada's GHG emissions and could readily be converted to energy utilization projects in many cases.

Table 17: Number of LFG Projects By Canadian Province and Annual Methane Gas Generation and Capture From Canadian Landfills (2005)

	Methane Generation 2005[38]	GHG Generation 2005[39]	Methane Captured 2005	Methane Emitted 2005[40]	GHG Emitted 2005	LFG projects 2012
	(kt CH_4/yr)	(kt CO_2 eq/yr)	(kt CH_4/yr)	(kt CH_4/yr)	(kt CO_2 eq/yr)	Number
NL	38.57	810	0.00	38.57	810	0
PE	6.69	141	0.00	6.69	141	0
NS	39.66	833	5.39	34.28	720	2
NB	43.34	910	0.00	43.34	910	3
QC	469.46	9,859	143.97	325.50	6,835	8
ON	465.17	9,769	126.09	339.08	7,121	29
MB	44.10	926	0.00	44.10	926	0
SK	43.71	918	0.00	43.71	918	1
AB	103.55	2,175	5.39	98.16	2,061	5
BC	189.60	3,982	27.89	161.71	3,396	16
NT	2.34	49	0.00	2.34	49	0
NU			0.00			0
YK	1.15	24	0.00	1.15	24	0
Canada	**1,447.35**	**30,394**	**308.74**	**1,138.62**	**23,911**	**64**

A recent study prepared for Environment Canada By Conestoga-Rovers and Associates in August, 2012[41] ranked Canadian landfills for potential LFG recovery projects. Because one of the objectives of the assessment was to reduce GHG, flaring of methane (CH_4) was considered a viable LFG management option in the study. Environment Canada shared the executive summary of the report (which is not public) with the study team for preparation of this report. Key conclusions from the study were:

- Not all LFG generated at landfills in Canada is available for recovery for a number of reasons including the size of the landfills (small landfills do not generate a sufficient amount of LFG to make recovery economically viable), remote locations, geology, etc.
- It was assumed that for sites with potential, 75% of the LFG would be recovered (collected);
- 88 sites were studied. Of the 88 sites, 10 were considered to have no potential for additional LFG recovery;
- An additional 15 landfill sites did not meet the study cost and recovery criteria for flaring (to reduce GHG);
- Flaring was the only cost effective CH_4 reduction measure at some sites, because the economics of LFG utilization did not make sense;

[38] Sustainable Best Practices and Greenhouse Gas Emissions at Canada's Landfills: Results From National Survey, Presented at SWANA 2008 in Edmonton by Rathan Bonam and Dr Shirley Thompson, University of Manitoba
[39] Calculated as methane generation x 21
[40] Calculated as the difference between the methane generated and captured
[41] Identification of Potential Additional Greenhouse Gas Emissions Reductions From Canadian Municipal Solid Waste Landfills. Contract Number K2A82-11-0009.

- LFG utilization was considered feasible at 41 of the sites studied. Approximate estimates of the potential energy generation from these sites is presented in Table 18.

Existing and future potential LFG generation values are summarized in Table 18, along with an estimate in MW of the power generation potential if all of the future LFG projects generated electrical power.

Table 18: Potential Power Generation From LFG Biogas Projects In Canada

Existing Landfill Gas Capture: 2009 Environment Canada GHG Inventory of Existing Landfill Gas Projects	• 349,000 tonnes of landfill methane (CH_4) captured
	  ○ 51% is used for energy production
	  ○ 49% flared
	• Of the landfill methane which produced energy:
	  ○ 127,000 tonnes of captured CH_4 produced 594,412MWhrs of energy (67.9MW)
	  ○ 10,000t of captured CH_4 generated 1 million million BTU of heat
	  ○ 32,000 t CH_4 generated 7.8MW of power and 824.7 million BTU of heat

Future Potential Landfill Gas Capture: 2012 Environment Canada Study of LFG Potential Projects in Canada	• Total Canadian potential 1.45 million tonnes methane (Canadian Gas Association)
	• Environment Canada 2012 analysis(unpublished as of late 2013):
	  ○ 261,900 t/y CH_4 potential LFG projects
	  ▪ 140MW could be produced if all captured LFG is used for electricity generation.
	  ○ Economically practical LFG potential projects at 41 landfills
	  ▪ 4.4[42] m tonnes eCO_2 = 209,429 t/y CH_4. (284Mm^3/y of RNG)
	  ▪ Potential 95MW for Canada if all electricity (assuming that 3 Mm^3/y of RNG can generate 1MW)
	• Environment Canada 2012 analysis is not public therefore identification of which landfills are close to the natural gas pipeline, or the locations of the most promising LFG projects is not public

4.2 Environmental Impacts of Landfill Gas Projects

Landfill gas projects have significant environmental benefits including GHG reduction, odour reduction and improved air quality. Each of these is discussed separately below.

4.2.1 GHG Impacts of Landfill Gas Projects

Landfill gas projects have significant GHG reduction potential, as they take landfill emissions (mostly methane, 21 times more potent as a GHG than CO_2) and convert it to CO_2. Where the LFG projects displace other fossil based energy sources, they contribute additional GHG benefits.

Landfills in Canada are the third largest sources of anthropogenic methane emissions in Canada and contribute 3% of national GHG emissions[43]. Aside from the fact that LFG projects produce energy at

[42] Using a GWP (global warming potential) of 21 for methane
[43] Municipal solid waste (MSW) landfills are the third-largest source of human-related methane emissions in the United States, accounting for approximately 17 percent of these emissions in 2009.

economically viable costs, they are a significant source of carbon emission reduction credits when the carbon credit market increases in value[44].

Approximately 27 Megatonnes (Mt) of carbon dioxide equivalent (eCO_2) are generated annually from Canadian landfills, of which 20 Mt eCO2 are being emitted to the atmosphere annually[45]. Unfortunately, the most recent detailed publication of LFG data by province is from 2005. A recent Environment Canada study is not yet public. Therefore, a current listing of all landfill gas projects in Canada, current to end of 2013 would be a useful document and is listed as a data gap

Table 17 presents data for the estimated methane generation from Canadian landfills, as well as the amounts captured and the amounts which are not captured, (as CO_2 eq.) due to the release of methane from landfill, and therefore emitted to the atmosphere. Most of the generated methane is in Ontario and Quebec; smaller amounts are found in BC and Alberta. Most of the captured landfill methane is in Ontario (27% of the emitted), Quebec (31%), Nova Scotia (14%), BC (15%) and Alberta (5%) with much lesser quantities (< 1%) in the other provinces[46].

The 2012 CRA study completed for Environment Canada focused on LFG projects as a method of GHG reduction. The study identified the relative costs of reducing GHG through various LFG projects across Canada. Table 19 shows that landfill sites in Canada (locations not identified) have significant potential for additional LFG (biogas) recovery and the added benefit of GHG reductions. There are 62 sites that have less than 100,000 tonnes of eCO_2 LFG individually, but have a cumulative total of 2.5 million tonnes of CO_2 of LFG that could be collected and utilized for energy production.

Table 19: Potential Annual GHG Reduction At Canadian Landfills (78 Landfill Sites)[47]

Range of GHG Reduction	Number of Landfill Sites	Cumulative Number of Sites	Potential Additional GHG Reductions	Cumulative GHG Reductions
Tonnes eCO2			Tonnes eCO_2	Tonnes eCO_2
300,000 to 400,000	3	3	1,049,000	1,049,000
200,000 to 300,000	3	6	759,000	1,808,000
100,000 to 200,000	10	16	1,400,000	3,208,000
1 to 100,000	62	78	2,547,000	5,755,000

4.2.2 Air Quality Benefits of Landfill Gas Projects

Test data shows that landfill gas combustion is a highly effective means of reducing greenhouse gases and VOCs (which cause odours and also smog). Table 20 presents available data on the net environmental benefit of landfill gas combustion on air quality and emissions from the landfill site, and the significant reductions achieved

Table 20: Air Quality Effects Of LFG Combustion

	Landfill Gas IN	Stack Gas OUT	Change
Greenhouse Gases (GHGs)	**(g/m^3 CH_4)**	**(g/m^3 CH_4)**	**(%)**
Methane	654	0	-100%
Common Air Contaminants (CACs)			
Total Volatile Organic Compounds	0.92	0.018	-98%
Selected Hazardous VOCs			

[44] As of June 2012, there are 594 operational LFG energy projects in the United States and approximately 540 landfills that are good candidates for projects. Of the 2,400 or so currently operating or recently closed MSW landfills in the United States, more than 550 have LFG utilization projects. EPA estimates that approximately 540 additional MSW landfills could turn their gas into energy, producing enough electricity to power nearly 716,000 homes[44].

[45] Environment Canada website viewed 7th Sept 2013

[46] Potential Production of Methane from Canadian Wastes. Alberta Research Council & Canadian Gas Association,September 2010

[47] Identification of Potential Additional Greenhouse Gas Emissions Reductions From Canadian Municipal Solid Waste Landfills. Contract Number K2A82-11-0009. Prepared for Environment Canada By Conestoga-Rovers and Associates, August, 2012

Polycyclic Aromatic Hydrocarbons	0.052	0.00001	-100%
Benzene	0.0044	0.0013	-71%

4.3 Economic Benefits From Landfill Gas Projects

LFG projects are significant energy and revenue generators for local communities. These benefits are summarized below.

4.3.1 Costs and Revenues From LFG Projects

The best source of economic data on LFG projects is the recent CRA study completed by Environment Canada in 2012. The study has not been released publicly therefore only summary data are available. The focus of the study was on GHG reduction rather than on biogas generation for energy projection, however the study provides very valuable "high order" estimates:

- The capital costs of the potential LFG projects at the 41 identified sites are estimated at $322 million, with annual costs of $61 million.
- Total annual revenues are estimated at $119 million for a net annual revenue of $57 million for the 41 landfill sites[48].

4.3.2 Carbon Credit Revenues

Table 21 presents an analysis of the costs of reducing GHG from Canadian landfills converted to a $/tonne of eCO_2. Should carbon trading develop a more robust market in Canada, these GHG credits could have a value significantly higher than the cost to generate them. There has been significant uncertainty in the value of carbon credits across Canada over the last few years. In Alberta, under the Specified Gas Emitters Regulation (SGER), large (mostly industrial and power plant) emitters are charged a penalty of $15/tonne if they do not meet GHG reduction targets. This obligation can be met by purchasing GHG credits from LFG projects with registered credits (normally at a cost of less than $15/tonne) thereby giving LFG GHG reductions a market value in Alberta. Current values of carbon credits are low, but this may change when active trading starts as a result of Quebec's cap and trade system.

Table 21 shows that GHG credits of 3.7 million tonnes eCO_2/year can be created by landfills across Canada at a very attractive rate of under $4/tonne. This provides significant opportunities for landfills to capture and reduce GHG and sell credits at a profit should the market value increase.

Table 21: Costs of GHG Reduction At Canadian LFG Projects (63 Landfill Sites)[49]

Total Annual Cost per GHG Reduction	Number of Landfill Sites	Cumulative Number of Sites	Potential Additional GHG Reductions	Cumulative GHG Reductions	Total Annual Cost	Cumulative Total Annual Cost
Tonnes eCO2			Tonnes eCO_2	Tonnes eCO_2	1000's of 2012 $	1000's of 2012 $
$0.00 to $2.00	6	6	1,386,000	1,386,000	2,105	2,105
$2.00 to $4.00	20	26	2,344,000	3,730,000	6,532	8,637
$4.00 to $6.00	16	42	864,000	4,594,000	3,933	12,570

[48] Identification of Potential Additional Greenhouse Gas Emissions Reductions From Canadian Municipal Solid Waste Landfills. Contract Number K2A82-11-0009. Prepared for Environment Canada By Conestoga-Rovers and Associates, August, 2012

[49] ibid

$6.00 to $8.00	15	57	670,000	5,264,000	4,654	17,224
$8.00 to $10.00	4	61	167,000	5,431,000	1,470	18,694
$10.00 to $12.00	2	63	78,000	5,509,000	852	19,546

4.3.3 Revenues from the Sale of Electricity

Table 22 presents potential revenues from 41 landfills in the 2012 CRA study if LFG projects used reciprocating engines to produce electricity for sale. The revenue potential from sale of electricity generated from LFG is dependent on each province's purchase policy or program. The locations of the potential LFG projects are not known. The table shows that 4 of the landfills could generate annual electricity revenues of $3 million or more. Assumptions used to develop the estimates are not known.

Table 22: Summary of Landfill Site Ranking by Annual Revenue from Additional LFG Utilization (41 Landfill Sites) [50]

Net Annual Revenue (1000's of 2012 $)	Number of Landfill Sites	Cumulative Number of Sites
➢ $3,000	4	4
$2,000 to $3,000	6	10
$1,500 to $2,000	6	16
$1,000 to $1,500	8	24
$0 to $1,000	17	41

4.3.4 Employment From LFG Projects

Construction of landfill gas projects can require anywhere from 10-100 jobs depending on the size and complexity of the project. Using an average of 50 jobs for one year, and 41 landfill gas projects, development of all of the LFG projects could result in about 2,000 construction jobs for one year.

Incremental jobs related to LFG projects were studied in detail by the USEPA (United States Environmental Protection Agency) LMOP (Landfill Methane Outreach Program) division and were initially presented at a conference in Baltimore, MD in 2005. A multiplier of about 3.1 was identified for LFG projects by the USEPA research[51] [52] which states that a typical 3 MW LFG electricity project is estimated to have the following economic and job creation benefits during the construction year:

- Add more than $1.5 million US in new project expenditures for the purchase of equipment during the construction year;
- Directly create at least 5 jobs for the construction and installation of the equipment during the construction year
- Considering a multiplier effect, increase economic output by $4.3 million US and employ 20-26 people during the construction year.

LFG projects are located at landfills where most of the infrastructure required for the recovery of LFG is already in place. Based on discussions with Canadian experts as part of this project, the actual long term job impacts (after the construction period) of LFG projects are typically 2-3 jobs per year.

[50] Identification of Potential Additional Greenhouse Gas Emissions Reductions From Canadian Municipal Solid Waste Landfills. Contract Number K2A82-11-0009. Prepared for Environment Canada By Conestoga-Rovers and Associates, August, 2012

[51] Landfill gas energy: fueling the economy and a sustainable energy future while improving the environment. December 2010

[52] http://www.epa.gov/lmop/documents/pdfs/LMOPGeneral.pdf

Should all 41 new LFG projects with potential identified across Canada by the 2012 Environment Canada report be implemented, they would generate about 80-120 long-term operational jobs, and contribute a larger amount to the Canadian economy.

4.4 Social and Community Benefits of LFG Projects

Today, regulations require proper management of LFG either for safety, odour or emission reduction.

LFG recovery projects reduce or eliminate odours from LFG, which contains trace amounts of sulphur. The destruction of VOCs and other smog pre-cursors through the LFG capture and flaring/utilization process contributes to improved air quality by reducing the potential for smog creation.

Landfills are usually the largest source of community GHG emissions over which the community has control, therefore LFG biogas projects significantly contribute to community GHG reduction goals and targets, and help communities meet renewable energy targets set in community energy plans or vision statements in a cost effective way (compared to other renewable energy approaches). As an example, the Salmon Arm BC LFG project creates 1,250 tonnes of CO_2 reduction per year, the equivalent of taking 250 cars off the road. The project provides heating needs of 300 homes.

Each new LFG project creates 2-3 full time local operating jobs long term, 10 to 100 construction jobs during the construction phase and creates $3.10 for each $1 spent on construction.

Where implemented, LFG biogas projects contribute significant revenues to the local economy for purchase of process equipment, operation and maintenance contracts, supplies, royalty payments to landfill owners, etc. If the landfill is owned by the municipality, then the revenues help to offset other municipal expenditures.

4.5 Energy Production Potential of LFG Projects

An estimate of the energy which could be produced from LFG projects across Canada was presented earlier in this section. The CRA Environment Canada 2012 project estimated a potential conversion of 262,000 t/y of methane (CH_4) to electricity, producing 95MW of electricity. The recovered LFG could also be converted to RNG. This approach is gaining in popularity, with examples such as the recently launched LFG to RNG project at the Lacheanie landfill near Montreal.

4.6 Summary of Energy, Environmental and Economic Benefits of Landfill Gas (LFG) Biogas Projects

The energy, environmental and economic benefits of landfill gas projects are summarized in Table 23.

Table 23: Energy, Environmental and Economic Benefits of Landfill Gas Projects in Canada

Energy	• An estimated 68MW of electricity and large amounts of heat are produced through existing LFG projects across Canada. • The opportunity exists to almost double existing energy capture at landfills across Canada economically, resulting in significant GHG reductions. • About half of the methane captured at landfills across Canada is used for energy production while the other half is currently flared with no energy recovery. • There is significant potential to utilize LFG at existing sites to produce 95 MW of electricity economically. Alternatively, the recovered LFG could be upgraded to RNG and injected into the natural gas grid, or be used to fuel trucks and replace diesel which is a higher GHG emitting fuel.
Environment	• There are more than 10,000 landfills of which 800 are active landfills in Canada. • LFG is the third largest source of anthropogenic methane emissions in Canada. • LFG represents 3% of Canada's national GHG emissions. • LFG is generally the largest source of GHG over which a local community has direct control. • Approximately 27 megatonnes (Mt) of eCO_2 are generated annually from Canadian landfills, of which 20 Mt eCO_2 are being emitted annually. Approximately 7 Mt eCO_2 are captured and combusted at Canadian landfills today, representing the equivalent of removing about 1.5 million cars from the road. • LFG biogas projects significantly reduce community GHG emissions and help communities to meet GHG reduction targets. For example, the LFG project in Salmon Arm BC reduces eCO_2 emissions by 1,250 tonnes, the equivalent of taking 250 cars off the road, while supplying heating energy for 300 homes. • Each diesel truck replaced with a gas fueled truck is equivalent to taking 475 cars off the road from a GHG perspective.
Economy	• There are at least 41 economically viable LFG projects which are currently undeveloped across Canada • The estimated capital cost of these 41 projects is $322 million with net annual revenues of $57 million. • Each new LFG project creates 2-3 full time local operating jobs long term and creates $3 in economic output for each $1 spent on construction. • The 41 LFG projects would create about 80-120 long-term operational jobs. • A typical 3 MW LFG electricity project adds more than $1.5 million in new project expenditures for the purchase of equipment during the construction year • A typical 3MW LFG project increases economic output by $4.3 million and employment by 20-26 people during the construction year. • LFG projects will be a significant source of carbon emission reduction credits as the carbon credit market increases in value. • GHG credits of 3.7 million tonnes CO_2 per year can be created by landfills across Canada at a very attractive rate of under $4/tonne. This provides significant opportunities for landfills to capture and reduce GHGs and sell credits at a profit. • Where LFG is used to fuel truck fleets, CNG-powered trucks are significantly cheaper to operate than conventional diesel-powered alternatives. Large LFG projects provide the opportunity to produce RNG for truck fleets.

4.7 Case Study of A Landfill Gas Project

Case Study:
Converting landfill waste into green energy – BFI Canada launches largest transformation project of biogas into biomethane (green gas) in Quebec

About one third of the waste from Greater Montreal is landfilled at the **Lachenaie** landfill in Terrebonne, Quebec. In September, 2013, BFI Canada, a subsidiary of the Canadian company Progressive Waste Solutions, announced that it is investing $ 40 million to convert the biogas produced by the waste from Greater Montreal into RNG.

Approximately 17,000 m^3 / hour will be used to power the equivalent of 1,500 heavy trucks for a period of twenty years, avoiding the consumption of 350,000 barrels of fuel oil per year.

The new plant is expected to reduce GHG emissions by about 1.2 million tonnes of carbon dioxide ($CO_{2)}$ over a period of ten years.

The new biogas processing facility should be in operation from the mid-year 2014. The RNG produced will be injected into the TransQuébec & Maritimes Pipeline adjacent to the landfill in Terrebonne,

BFI Canada opened the first power plant fueled by biogas in Quebec in 1996, which generates electricity for the equivalent of 2,500 homes each year.

BFI Canada operates the largest fleet of trucks running on compressed natural gas (CNG) in the waste collection and recyclable materials industry. By the end of 2013, the company plans to have about 150 trucks powered by CNG in Canada. In 2014, it is expected that 50 to 55% of the total number of new trucks, acquired through the normal fleet replacement, will run on CNG.

5. Source Separated Organics From Residential Sources

Source separated organics (SSO) refers to mostly food waste which is separated from the residential garbage stream for separate collection and processing. A number of municipalities across Canada (Halifax, Ottawa, Toronto, etc.) have implemented Green Bin programs where residents source separate organics which are then collected separately by the municipality for separate processing. Leaf and yard waste is also separated in many communities for separate collection or drop off. Leaf and yard waste is generally processed at open windrow composting sites whereas SSO is generally composted in enclosed composting facilities.

In the industrial, commercial and Institutional (IC&I) sector, source separation of food waste is less developed, except for food processing facilities which produce large amounts of food residuals. These facilities often have arrangements for the separate management of food waste through their hauling companies. Section 6 contains a separate discussion on organic waste from IC&I sources.

Separating food waste from other garbage has considerable benefits at the landfill or disposal site, as organics break down in landfills and generate potent greenhouse gases and leachate which is acidic and precipitates metals from the landfilled material.

5.1 Biogas Potential From Residential SSO in Canada

5.1.1 Existing AD Facilities To Process Residential SSO in Canada the US and Europe

The use of AD technology to treat municipal SSO has been slow to penetrate the North American market, mostly because of high costs compared to aerobic composting which has been used by most Canadian cities with SSO programs (Halifax, Guelph, Ottawa, Kingston, etc.). The North American market currently has only one operating municipal AD facility that processes municipal SSO, located at the City of Toronto Dufferin Transfer Station (the Dufferin Digester with a rated capacity of 25,000 tonnes/year but it has operated at capacities of up to 40,000 tonnes/year). A second City of Toronto AD facility is being commissioned at the Disco Transfer Station (75,000 tonnes/year capacity) and will be in full operation in 2013. The Dufferin Digester facility will be expanded to a capacity of 55,000 tonnes per year in 2016 (two years after the Disco AD facility has been operational). The City of Surrey, British Columbia has initiated a procurement process for a clean energy demonstration project featuring an AD facility to be operational by 2015.

The Province of Quebec announced a landfill ban on organics by 2020 with support for a “bio-methanization” (or AD) program to convert SSO to vehicle fuel and “de-carbonize” (lower the carbon footprint) of municipal fleets. Support for AD in Quebec has been part of the Climate Change Action Plan. Initially, in 2009, $650 million was committed to the construction of AD facilities in the Province ($170 million from the federal government; $187 million from the Province and the remainder from municipal governments). To be eligible for funding the biogas must replace fossil fuels, the digestate must be recycled, and the feedstock can contain no more than 10% manure.

Progress between 2009 and 2012 was relatively slow, therefore a review in 2012 extended the funding to 2017. Planning level studies are in progress to issue RFPs for AD facilities in the following Quebec municipalities: Montreal (2), Quebec City, Rivieres du Loup, Ste-Hyacinthe, Varennes, Beauharnois,

Laprairie, Brome-Missisquoi, Magog, Sherbrooke, Haute-Yamaska. Funding support is 66.6% for municipal AD facilities and 25% for private AD facilities. Available details on planned facilities in Quebec are summarized in Table 24. Some of the AD facilities co-digest SSO with wastewater treatment plant biosolids (discussed in Section 7)

Table 24; Available Information on Planned AD Facilities in Quebec

Location	Capital Cost ($ million)	Capacity (tonnes/year)	Notes
Semer (Riviere Du Loup)	$27	26,000	Announced 2009; planned but construction not started
St. Hyachinthe	$47.2	215,000	Biosolids Phase 1 SSO Phase 2 Started before funding program announced
RAEVR	$11.9	26,000	Planning
Quebec City		85,000	Being discussed
Montreal (South and East)		2 @ 60,000 t/y each	Being discussed
Laval		92,000	Being discussed

Development of AD projects for residential SSO has been very challenging as AD competes with composting. Many larger cities have already chosen composting technology, however, projects are moving forward

In the last 10 years, a number of large communities in the United States pursued AD. These communities entered into agreements to process SSO using AD, or entered into negotiations with AD suppliers or had undertaken feasibility studies examining AD among a range of other "Conversion" technologies. Communities which include the Los Angeles, Lancaster, San Diego, San Jose, Santa Barbara and others in California, as well as Seattle, Washington, Portland, Oregon and Columbia, South Carolina, have all pursued AD. Projects are in different stages of development across the US at this time. A few communities co-digest SSO with wastewater treatment residuals (e.g. East Bay MUD and others in California and recent projects in Florida). Various renewable energy incentives and a desire to meet green energy targets have been some of the drivers for AD projects for municipal waste.

Table 25: Installed Capacity Of AD Facilities Processing SSO And Municipal Solid Waste in Europe in 2010[53]

Country	Total AD capacity (tonnes/year)	Average AD Facility Capacity (tonnes/year)	Number of AD Facilities By Country
AT (Austria)	84,500	12,071	7
BE (Belgium)	173,700	34,740	5
DE (Germany)	1,732,805	23,104	75
DK (Denmark)	31,000	40,500	1
ES (Spain)	1,495,000	59,563	25
FI (Finland)	15,000	15,000	1
FR (France)	862,000	66,308	13
IT (Italy)	397,500	36,136	11
LU (Luxemburg)	23,000	11,500	2
MT (Malta)	45,000	45,000	1
NL (Netherlands)	476,500	59,563	8
PL (Poland)	52,000	13,000	4
PT (Portugal)	85,000	21,250	4
SE (Sweden)	40,000	10,000	4
UK (United Kingdom)	202,500	40,500	5

[53] Source: Joint Research Centre, European Commission. October 11, 2011. Technical Report for End of Waste Criteria on biodegradable waste subject to biological treatment.

Total	5,715,505		166

Virtually all examples of AD facilities treating residential SSO are located in Europe, primarily in northern European countries such as Denmark, Belgium, France, Germany and Switzerland. Table 19 presents a partial list of AD facilities operating in European countries in 2010[54], and shows that there were at least 166 AD facilities processing over 5.7 million tonnes/year of SSO at that time.

Various policies in the EU have encouraged the development of AD at a faster rate than in Canada and the US, including feed in tariffs, landfill taxes/surcharges and regulations prohibiting unprocessed organic waste to be disposed in landfills. Germany is considered the leader in promoting and adopting AD technology as a renewable energy source. AD is also being driven by landfill taxes and other policies in the United Kingdom but at a slower rate. Currently, there are 44 commercial scale AD facilities in the UK that process food waste from commercial/industrial and municipal sources with a processing capacity of around 3.7 million tonnes per year[55].

5.1.2 Potential Biogas Production From Residential SSO in Canada

Table 26 presents estimates of the total amount of residential waste disposed in Canada in 2010 (the most recent data available from Environment Canada); the estimated organic fraction in the disposed waste; the number of AD facilities this organic waste could support (assuming each AD facility was 60,000 tonnes/year capacity, and that 100% of the SSO was captured); the amount of RNG that could be produced by each digester and the amount of electricity which could be produced, if the digesters were used for electricity generation. Opinions on the potential for RNG and electricity from the digesters varied between different sources. The estimates were developed assuming 38 digesters, each 60,000 tonnes/year capacity would be constructed. Conservative and high value energy estimates were developed using the following assumptions:

- 3 Mm^3/year of RNG can produce 1MW of electricity;
- Conservative Energy Production Estimate: On average, 38 digesters, each with a capacity of 60,000t/yr @ 60m^3CH_4 per tonne of SSO[56] would conservatively produce 137 $Mm^3$of CH_4 per year and generate 55MW or 1.44 MW per digestion facility;
- High Energy Production Estimate : A high estimate would assume production of 180 Mm^3/yr of methane with an energy density of 10 kWh(th)/$m^{3.,}$ generator electrical efficiency of 38% and generator availability of 92%. This would yield electricity generation of 629 M kWh (71.8 MW(e)).

The more conservative value was chosen for this assessment, and was rounded up to 48MW and 140Mm^3/year of methane production.

[54] Luc De Baere & Bruno Mattheeuws. February 2010. Anaerobic Digestion of MSW in Europe. Biocycle, Vol. 51 p.24
[55] AD infrastructure in the UK: September 2011 WRAP
[56] 110m^3 biogas per tonne of SSO @ 55% CH_4 content is 60m^3CH_4 (methane) per tonne of SSO.

Table 26: Estimated Potential for Biogas From Residential Waste in Canada

2010	Residential tonnes disposed	Residential Organics 2010 tonnes Captured[57] (100%)	Residential Organics Captured 2010 kilotonnes	AD Units at 60kt per unit	RNG Mm^3/year	MW
Canada	**9,256,540**	2,314,135	2,314	37.6	**139**	**46**
NL	x		-		14	5
PEI	x		-		15	5
Nova Scotia	145,589	36,397	36	0.6	4	1
New Brunswick	219,486	54,872	55	0.9	6	2
Quebec	2,853,189	713,297	713	11.9	48	16
Ontario	3,204,264	801,066	801	13.4	43	14
Manitoba	388,683	97,171	97	1.6	3	1
Saskatchewan	283,726	70,932	71	1.2	2	1
Alberta	970,422	242,606	243	4.0	0	0
British Columbia	953,761	238,440	238	4.0	0	0
Yukon, NWT, Nunavut	x		-			

5.2 Environmental Benefits of AD of Residential SSO

5.2.1 GHG And Other Air Emissions Benefits of Residential SSO Digestion

Several authors have investigated the overall environmental and economic impacts of AD of residential SSO using the LCA (life cycle analysis) methodology. All of the studies found that AD produced less air and water pollution than aerobic composting or landfilling of SSO.

A Canadian LCA compared AD, open windrow composting, and landfilling of MSW (municipal solid waste) where landfills with and without energy production were included[58]. The report used an average value for landfills across Canada including the average capture rate for landfill gas in the comparative assessment. The report found that AD produced less air and water pollution than any of the other technologies. The study also found that over the life of the project, AD had a positive net energy balance, while the other technologies–including landfilling with gas collection–consumed energy over their lifetime.

Table 27 shows a comparison of the energy use and emissions from anaerobic digestion (AD), open windrow composting (WC), and landfilling without energy recovery (LF). All emissions are air emissions with the exception of lead, which is a water pollutant. The data were adapted from Haight[59]. It should be

[57] Assuming 25% of disposed residential waste is organic and suitable for digestion
[58] Haight, M., Assessing the environmental burdens of anaerobic digestion in comparison to alternative options for managing the biodegradable fraction of municipal solid wastes. Water Science and Technology, 2005. 52(1-2): p. 553-559.
[59] Haight, M., Assessing the environmental burdens of anaerobic digestion in comparison to alternative options for managing the biodegradable fraction of municipal solid wastes. Water Science and Technology, 2005. 52(1-2): p. 553-559.

noted that a negative value in the table (which is the LCA convention) indicates a lower emission for AD compared to landfilling or composting.

Table 27: Comparison of Energy Use and Emissions from AD, Landfilling and Composting.

	Units	AD vs. LF (average LFG capture assumition)	AD vs. Open Windrow Composting
Energy Consumption	GJ/y	-400,000	-420,370
GHG Emissions	MT/y	-121,908	-84,795
NOx	MT/y	-48.8	-50.3
SOx	MT/y	-68.4	-74.6
PM-10	MT/y	-58.4	-50.8
VOC	MT/y	-8.6	-3.8
Lead	kg/y	-88.3	-93

5.2.2 Air Quality Impacts of AD of Residential SSO

AD facilities produce lower emissions than residential composting facilities which produce larger amounts of VOC's. (see table above). In communities where smog is an issue, (e.g Lower Fraser Valley BC), AD has a significant air quality benefit compared to composting.

When compared to composting (the other technology used to process residential SSO), AD of Green Bin material occurs in a tightly controlled environment where all air is cleaned in a biofilter so that odours do not occur. The Toronto Dufferin Digester has had no odour complaints in 8 years of operation.

5.2.3 Nutrient Management Impacts of AD of Residential SSO

In contrast to digestate produced by agricultural digesters, solid digestate produced by residential AD facilities requires further processing to convert it into a finished compost which can be used or sold. The process is generally referred to as curing, finishing or stabilization, and involves aerobic composting either in enclosed facilities or open windrow composting sites. It is more common practice to send digestate off-site for curing because of the space required for an on-site curing facility. As an example, the digestate from the City of Toronto Dufferin AD facility is sent for curing to a number of composting operations including Al Treat Farms (in Arthur, Ontario), Miller Waste (in Markham, Ontario) and Gro Bark (in Georgetown, Ontario).

The amount of solid digestate produced by an AD facility is typically about 30% to 40% of the incoming tonnage – the remainder of the incoming material (after a 10% mass conversion to biogas) is contained in wastewaters from the AD facility which are reused, with some being treated and discharged. When this digestate is sent for compostng there is a further reduction in mass. The final finished compost is sold to soil blenders by the compost facility operator. The soil blenders use the compost as a soil amendment, adding carbon structure to soil through blending into triple mix and other products sold in garden centres and to landscape contractors.

5.2.4 Biogas Utilization Options Compared to Landfilling of Organics

The American Dairy Council supported an LCA[60] study to compare various approaches to managing food waste, and end markets for the biogas produced from an LCA point of view. Three end market options were considered for the biogas produced: pipeline quality biomethane; compressed natural gas (CNG); or electricity generation. The results of the analysis are presented in Table 28.

Table 28: Potential Environmental Impact/ Benefits of Landfill, Digestion, and the Difference of the Two Options (Net Benefit = Digestion - Landfill)[61]

Impact category	Unit	Baseline: Landfill	Digestion: Biomethane	Digestion: CNG	Digestion: Electricity	Net Benefit: Biomethane	Net Benefit: CNG	Net Benefit: Electricity
Human Health								
Carcinogenic effects	CTUh	-12.2	4.2	-1.2	254.8	16.4	11.0	267.0
Non-carcinogenic effects	CTUh	-1049.1	152.9	-20.0	612.6	1,202.0	1,029.1	1,661.7
Respiratory effects	TMT PM 2.5 eq	-0.1	2.0	0.5	2.1	2.1	0.6	2.2
Ozone layer depletion	kg CFC-11 eq	45.7	91.9	876.1	306.1	137.6	921.8	351.8
Photochemical oxidation	TMT O_3 eq	-26.2	25.4	83.5	245.8	51.6	109.7	272.0
Ecosystem Quality								
Ecotoxicity	Billion CTUe	-2.0	2.6	0.2	4.6	4.6	2.2	6.6
Acidification	TMT SO_2 eq	-0.7	22.6	-3.7	22.2	23.3	-3.0	22.9
Eutrophication	TMT N eq	-73.9	4.9	6.5	23.0	78.8	80.4	96.9
Climate Change								
Global Warming	MMT CO_2 eq	-11.2	4.0	4.8	4.9	15.2	16.0	16.1
Resources & Water Use								
Fossil fuel depletion	Million MJ surplus	9.6	0.6	-1.9	65.7	-9.0	-11.5	56.1

* Abbreviations: CTUh = comparative toxic units human; PM= Particulate matter; CFC-11 eq = TriChloroFluoroMethane equivalent; CTUe = comparative toxic units Ecotoxicity; SO_2 eq = Sulfur Dioxide equivalent; N eq= Nitrogen equivalent; CO_2 eq = Carbon Dioxide equivalent; TMT= thousand metric tons; MMT: million metric tons; MJ = mega Joules or 1000 Joules. Impact assessment methods: TRACI v2.1 Life Cycle Impact Assessment (Bare, 2011)

The LCA study results indicated that digestion is preferable to landfill for all environmental impact categories when biogas is used for electricity generation. However, despite the advantage in other environmental impact categories, the use of biogas for biomethane or compressed natural gas generates trade-offs for the environmental indicator of fossil fuel depletion. The reason for these tradeoffs is that some landfill gas is used to offset electricity production. As average U.S. electricity production uses large amounts of fossil fuels, offsetting electricity production provides a significant benefit for the landfill option. And, when digester gas is not used for electricity production, it does not reduce the use of fossil fuels to

[60] LCA is a tool implemented to assess the environmental benefits or drawbacks of decisions and actions across a wide range of industries. It provides a unique ability to quantitatively measure and manage environmental impacts across the full life cycle of products and production systems, beginning with material extraction and including all aspects of transportation, production, use, and end-of-life treatment as shown below. It can be integrated with existing corporate programs around product design, procurement, and beyond to provide a lens for assessing and acting in the area of environmental sustainabilityraw

[61] National Market Value of Anaerobic Digester Products by Informa Economics for Innovation Center for US Dairy, Feb 2013.

the same extent. It should be emphasized that the assessment is a preliminary examination intended to provide a rough sizing of the potential environmental benefit of co-fermentation of food waste. There is clearly a need for a more detailed quantification of the benefits of such systems under different conditions of implementation and to address various sources of uncertainty in the current results.

5.3 Economic Impacts of AD of Residential SSO

The economic impacts of AD of residential SSO are generally compared to in-vessel composting of residential SSO. To date, most municipalities have chosen in-vessel composting because it is cheaper. However, odour issues at a number of centralized composting facilities in Ontario in summer, 2010 lead to increased requirements for odour control at centralized composting facilities processing SSO, thereby increasing the cost of composting compared to digestion. With the high FIT rates paid for all sized projects in Ontario for biogas generated electricity until mid-2013, AD facilities which received FIT contracts became cost competitive with composting facilities.

Toronto is the only municipality to date to treat residential SSO in a digester. The decision was made partly on cost, but also on a policy objective to locate the processing facility within city boundaries. AD has a much smaller footprint than composting for the same annual processing capacity.

5.3.1 Capital Investment and Operating Costs for Residential SSO Digesters

Currently, AD vendors recommend AD systems above 15,000 tonnes per year as the point at which they can be constructed and operated economically. Many of the earlier European AD facilities were in the 10,000 tonne/year range, but the size of facilities constructed has increased over time to reach better economies of scale. Recent studies show better economies of scale at 60,000t/y annual capacity[62].

Capital costs and amortized capital costs for the two AD facility sizes recently developed for a feasibility study for Region of Durham by Kelleher Environmental concluded that the capital cost of a 60,000 t/y AD facility was $45 million, with an additional $15 million if curing were to occur on-site. The potential costs of AD facilities to process residential SSO in Canada are presented in Table 29. These costs have been developed based on a cost of $45 million for an AD facility with a capacity of 60,000 tonnes/year. The capital investment required to construct 38 digesters would be about $1.7 billion, with an economic spin-off of an additional $5 billion (based on the USEPA multiplier of 3:1).

Table 29: Estimated Potential Capital Investment in Residential SSO AD Facilities in Canada

	Number of Digesters at 60,000t/y	MW	RNG Mm^3/year	Direct Investment at $45 million per digester	Economic Indirect Effect at 3:1 multiplier
Canada	38	**46.8**	**139**	$1,691	$5,073
NL		0.0	14	$0	$0
PEI		0.0	15	$0	$0
Nova Scotia	0[63]	0.8	4	$27	$82
New Brunswick	1	1.1	6	$41	$123
Quebec	12	14.8	48	$535	$1,605

[62] Kelleher/Robins Region of Durham Feasibility Study
[63] Due to Nova Scotia's organics landfill ban in 1998, most residential organics have been separately collected and composted for many years.

Ontario	13	16.6	43	$601	$1,802
Manitoba	2	2.0	3	$73	$219
Saskatchewan	1	1.5	2	$53	$160
Alberta	4	5.0	0	$182	$546
British Columbia	4	5.0	0	$179	$536

Operating costs for residential SSO digesters include labor, maintenance, materials, testing, insurance, overheads, and training costs. In some cases disposal of residue is included or identified; in other cases digestate curing is included or excluded as shown in the table.

5.2.3 Employment Impacts of AD of Residential SSO

AD of residential waste is different to the other sources of biogas discussed to date, in that the AD facility is generally a stand-alone facility, although it can be co-located at another municipal facility such as a transfer station, EFW facility or landfill.

The Toronto Dufferin Digester (a municipal AD facility handling a mixture of residential and commercial SSO) processes anywhere from 25,000 to 40,000 tonnes/year and has a staff of 13 to run three shifts per day (2 admin; 2 maintenance and 8 operators plus 1 plant manager).

Based on an average of 13 employees per facility, and potential for 38 facilities across Canada, up to 494 long term operations jobs could be created across Canada.

5.2.4 Revenues and Cost Savings From AD of SSO

Revenues from AD of residential SSO include:

- Tipping fees at the AD facilities for commercial loads (will vary from $25 to $100/tonne across Canada) and
- Energy revenues.

Cost savings result from preservation of landfill capacity and not paying tipping fees in cases where the municipality does not own its own landfill.

Green Bin programs can divert 200kg/household/year from disposal and into productive uses. A city of 300,000 households could divert 60,000 tonnes/year of Green Bin material, saving 60,000 cu metres of landfill capacity. At a landfill capacity replacement cost of $100/tonne, this would save $6 million per year, but will be offset by tipping fees or costs of AD, as well as the incremental costs of collecting SSO, therefore there is unlikely to be a net cost savings to the community.

5.4 Social and Community Benefits of AD of Residential Waste

The social and community benefits of AD (rather than composting) of residential waste collected in Green Bin programs across Canada are listed below. Most of these benefits also apply to AD of commercial organics which is discussed in Section 6. The benefits include:

- Preservation of landfill capacity which would have been consumed for some organic wastes;

- Reduced landfill impacts from organics degradation in landfill (leachate generation; lower methane production from landfills; lower escape of methane from landfills);
- Production and use of biogas from AD of residential SSO can contribute to the achievement of community related sustainability targets in 3 areas: energy production from renewable sources (contribution to local green energy and renewable energy targets);reduction of GHG emissions and sustainable waste management.
- AD of SSO facilitates the conversion of municipal fleets from diesel to RNG, which can be produced by the digester in a closed loop system, as the municipality typically has some control over fleet purchasing decisions and
- AD has a small footprint (compared to composting) which makes it feasible to locate the AD facility within or close to urban environments.

5.5 Energy Impacts of AD of Residential SSO

AD (rather than composting) of residential SSO produces green energy which can be used to meet renewable energy goals. AD of residential SSO remaining in the currently disposed waste stream could produce an estimated 140 Mm^3/year of RNG. If all of the biogas is used for electricity generation, an estimated 48MW could be generated across Canada.

The Green Bin waste from 300,000 households is sufficient to produce 1.4MW of electricity.

5.6 Summary of Benefits of Digesters for Residential Source Separated Organics

The energy, environmental and economic benefits of landfill gas projects are summarized in Table 30.

Table 30: Energy, Environmental and Economic Benefits of Residential SSO Biogas Projects in Canada

Energy	• About 40% of the residential waste discarded in Canada each year consists of biodegradable material (food, etc.) that could be used to generate green energy. • The Green Bin waste from 300,000 households is sufficient to produce 1.4MW of electricity, which is sufficient to meet the electricity needs of 800 homes. • Capturing half of the discarded organics in Canada could produce 48MW of power, or 140Mm3/year of RNG. • Municipalities involved in SSO digestion can integrate SSO biogas utilization with other potential biogas sources such as wastewater treatment plants and LFG facilities,
Environment	• Anaerobic digesters have a very small footprint compared to other organics processing technologies, and can therefore be located at existing waste management sites or in urban areas. • Capturing half of the discarded residential organics in Canada would result in reduction of 2.2 million tonnes eCO2/year, the equivalent of taking 430,000 cars off the road. • Anaerobic digestion, over the life of a project, has a positive net energy balance, while other technologies consume net energy. • AD of SSO facilitates the conversion of municipal fleets from diesel to RNG which can be produced by the digester in a closed loop system. Replacing a diesel truck with a CNG truck is equivalent to taking 474 cars off the road from a GHG point of view.
Economy	• The capital investment required for digesters across Canada is about $1.7 billion, with an economic spin-off of an additional $5 billion. • The Dufferin Digester in Toronto (which is the only municipal AD facility currently operating in Canada handling a mixture of residential and commercial SSO) processes 25,000 to 40,000 tonnes/year with a staff of 13 running three shifts per day. • Up to 494 long term operations jobs could be created across Canada should the biogas

	potential of residential SSO be developed. • Green Bin programs can divert 200kg/household/year from disposal and into productive uses. A city of 300,000 households could divert 60,000 tonnes/year of Green Bin material, saving 60,000 cu metres of landfill capacity annually, thereby delaying the need to establish a new landfill facility, which is becoming increasingly challenging across Canada.

6 Source Separated Organics (SSO) From Industrial, Commercial and Institutional Sources in Canada

Waste composition studies carried out for a number of communities by Kelleher Environmental have indicated that about 23% of waste generated by the non-residential industrial, commercial and institutional sector (IC&I) is food waste generated by businesses and institutions in all communities across Canada. Most of this food waste comes from dispersed sources like restaurants, hotels, hospitals and food processing facilities. Many of these facilities manage their waste through waste management hauling companies. Some companies offer a separate collection for source separated food waste, but most of the time the food waste ends up in the garbage. This is a lost resource as the food waste could generate considerable biogas if source separated, separately collected and digested.

6.1 Opportunity for Biogas Production from Commercial Sector SSO in Canada

6.1.1 Current Status of ICI AD Facilities in Canada

Many industries with high strength wastes (e.g. food waste processors, breweries, dairy operations, cheese factories) already have AD facilities on-site to manage their high strength waste prior to discharge to local sewers or disposal off site. These facilities produce heat and power which is generally used on site, or occasionally sold into the grid. The waste from these industries has traditionally not been counted by Statistics Canada (as the WMIS survey only tracks waste which is managed off site, and does not include direct business to business movements of materials). Various efforts have been made to quantify the amount of waste managed in this way and the energy produced, but all studies so far have run into difficulties collecting a full data set. A research study should be considered to quantify the existing situation with respect to management of high strength food waste in the industry sector across Canada, existing on-site energy recovery through AD and the potential for additional on-site energy recovery through AD.

Until recently, there were no “merchant” AD facilities operating in Canada designed to accept SSO for a tipping fee from a number of different haulers. However, this has recently changed. Harvest Power opened a 40,000 t/year AD facility at Fraser Richmond Soil and Fibre, their 200,000 tonne/year composting operation in Richmond, BC in September, 2013. A similar facility opened in London, Ontario in October, 2013, and Bio-En power is opening a 2.8MW facility in Elmira, Ontario in early 2014.. Zooshare recently secured a FIT contract for a 500kW facility in Toronto, Ontario.

Some IC&I materials are already source separated and processed through existing networks; slaughter house waste is rendered; bakery waste is used by the animal feed industry, etc. Millions of cubic metres per year of high strength liquid waste (from cheese factories, food processors, etc.) are already treated in on-site AD facilities. As an example, a Cavendish Farms potato plant in PEI runs a 12MW facility using the waste from a single facility.

6.1.2 Potential Biogas Opportunity for Commercial Organics

Statistics Canada (2010) WMIS (Waste Management Information System) survey data were used to estimate the biogas potential of the IC&I sector. Table 31 presents estimates of the amount of organic materials contained in non-residential wastes which are currently disposed. Organics currently diverted have already been subtracted from the totals. The number of digesters which would be constructed to process 50% of the currently disposed IC&I waste stream (if source separated) is presented in Table 24, assuming that each digester would be in the 45,000 to 50,000 tonne/year range. Depending on the feedstock, at least 160 Mm^3/year of RNG could be generated, although the actual production of RNG could be much higher. This conservative assumption is sufficient to produce 54MW of electrical energy.Some businesses produce materials which are an advantage to the AD process (FOG – fats, oils and greases and food or beverage processing in particular), as they produce high amounts of biogas.

It should be noted that data for some provinces is not included in the Statistics Canada WMIS survey report for confidentiality reasons. In other cases, some provinces or territories do not generate sufficient food waste to justify the cost of constructing one central digester with a capacity of 45,000 to 50,000 tonnes/year, based on available data.

SSO from the IC&I waste stream is amenable to processing in an AD facility, however, the challenges include:

- getting the generators to separate the food waste from the garbage or discarded waste;
- collecting the separated food waste in a cost effective way;
- securing IC&I food waste as a feedstock and
- providing a cost advantage over disposal for IC&I generators, otherwise the SSO will continue to be collected with garbage and disposed.

Table 31: Estimated Potential RNG and Electricity Produced from IC&I Food Waste in Canada

	Non-Residential Municipal Solid Waste (MSW) Disposal (tonnes)	Organics IC&I Disposed (tonnes) (23% of total MSW currently disposed)	Organics IC&I Captured (at 50%) (tonnes)	No of Digesters at 45,000 to 50,000 t/y per digester	MW	RNG Potential (Mm^3/y)
Canada	**15,627,006**	**3,594,211**	**1,797,106**	**38-40**	**54**	**160**
NL and PEI	n/a	n/a	n/a	n/a	n/a	n/a
Nova Scotia	221,657	50,981	25,491	<1	0.8	2.3
New Brunswick	255779	58,829	29,415	<1	0.9	2.6
Quebec	2,942,518	676,779	338,390	7	10.2	30.1
Ontario	6,043,151	1,389,925	694,962	15	20.8	61.8
Manitoba	562,929	129,474	64,737	1-2	1.0	5.8
Saskatchewan	653,541	150,314	75,157	1-2	2.3	6.7
Alberta	2,947,070	677,826	338,913	7	10.2	30.1
British Columbia	1,704,510	392,037	196,019	4	5.9	17.4
Yukon, NWT, Nunavut	n/a	n/a	n/a	n/a	n/a	n/a

An Ontario study estimated that between 1.2 and 9.8 million wet tonnes of food processing residues and plate food waste are produced annually in Ontario. These residues were estimated to have potential to produce between 106 and 1,393 GW-hr/yr of electrical energy (1.2 to 16.7 million GJ/yr of natural gas equivalent), assuming a biogas to electricity conversion efficiency of 30%.[64] The results of this study were not used for the current assessment because of the wide range of values derived through four different methodologies, and the fact that residential food wastes were included in the study and would be double counted. The study commented on the difficulty of collecting reliable data from existing industries because of the reluctance of most industries contacted to share statistics on the waste they produced. Canada is estimated by another study to discard 6 millon tonnes food waste which could generate 660 Mm^3 /year of biogas[65].

SSO from non-residential sources could be a potential feedstock to either agricultural digesters or to residential AD facilities, or in many cases, IC&I generators or waste management companies can establish a digester to manage source separated organics (SSO) from the non-residential sector. In all cases, a larger AD facility would reach better economies of scale and result in lower costs.

Provincial governments across Canada have recognized the benefits to farmers and the economics of farm digesters if off-farm waste can be accepted. Digesters located on farms offer the added advantage of having land on which digestate can be spread, in contrast to commercial digesters which generally need to compost digestate at an additional cost.

6.2 Environmental Benefits of Commercial SSO Digestion

Environmental benefits of commercial digesters are similar to those discussed in Section 5 for residential SSO facilities. Industry sources estimate that approximately 0.8 tonnes of CO_2e is saved per tonne of co-mingled organic waste digested. On this basis, each 50,000 tonne per year AD facility will capture and destroy approximately 38,000 tonnes of carbon each year[66]. The recently announced Zooshare project in Toronto will produce 500kW of electricity, which it states will lead to 12,000 tonnes of GHG reduction per year, the equivalent of taking 2,100 cars off the road. Also, the Georgian/Bay/Chatsworth 100kW digester in Ontario processing rural septage and food processing wastes and provides the added environmental benefits of managing septage in an environmentally sound manner which recovers green energy.

6.3 Economic Impacts of Commercial SSO Digestion

The estimated potential economic impacts of developing SSO digesters for IC&I waste across Canada are presented in Table 32 which shows that construction of commercial digesters in Canada to digest 50% of potentially available commercial SSO could require up to $1.5 billion in capital expenditures with a spin-off of $4.5 billion, assuming a capital cost of about $37 to $40 million per facility.

AD facilities typically require a plant manager, plant operators, labourers and an administrative person. A value of 11 employees per digester was used to estimate employment impacts, based on information provided by Harvest Power for their facility in London, Ontario.

[64] Final Report for the Study of Food Based Inputs for Biogas Systems in Ontario, May 9th, 2009, Ontario Ministry of Agriculture, Food and Rural Affairs
[65] Biogas prediction and design of a food waste to energy system for the urban environment, October 2011…
[66] Yield Energy

Table 32: Estimated Potential Capital Investment and Economic Indirect/Spin-off Effect of Commercial AD Facilities in Canada

	Organics ICI Captured (at 50%) (tonnes)	No of Digesters	MW	Direct investment ($ millions)	Spin-Off ($ millions)	RNG Mm^3/year	Long Term Employees (11 per facility)
Canada	1,763,084	**38-40**	**54**	$ 1,322	$ 3,967	160	416
British Columbia	196,019	**4**	5.9	$ 147	$ 441	17.4	45
Alberta	338,913	**7**	10.2	$ 254	$ 763	30.1	78
Saskatchewan	75,157	**2**	2.3	$ 56	$ 169	6.7	17
Manitoba	64,737	**2**	1.9	$ 49	$ 146	5.8	15
Ontario	694,962	**15**	20.8	$ 521	$ 1,564	61.8	161
Quebec	338,390	**7**	10.2	$ 254	$ 761	30.1	78
New Brunswick	29,415	**1**	0.9	$ 22	$ 66	2.6	7
Nova Scotia	25,491	**1**	0.8	$ 19	$ 57	2.3	6
PEI and NL	n/a	n/a	n/a	n/a	n/a	n/a	n/a

6.4 Social and Environmental Benefits of Commercial Digesters

The social and community benefits of commercial digesters are similar to those discussed for residential digesters in Section 5 and relate to local community businesses being provided the opportunity to generate renewable energy from food waste. Digesters tend to have tighter odour control than composters, therefore for local communities, the odour generation is less. Digesters also have a much smaller footprint than composting, an advantage for facility siting in semi-urban areas.

6.5 Energy Impacts of Commercial Digesters

The analysis in this section shows that commercial digesters have the potential to produce 54MW or more and at least 160 Mm^3/year of RNG from commercial SSO generated by businesses across Canada which is currently disposed. This total does not include food residuals which are managed on-site or moved from business to business and are not captured in the current Statistics Canada WMIS survey. As discussed earlier in this section, a research study should be considered to quantify the existing situation with respect to management of high strength food waste in the industry sector across Canada, existing on-site energy recovery through AD and the potential for additional on-site energy recovery through AD.

6.6 Summary of Benefits of Digestion Of Commercial Source Separated Organics

The energy, environmental and economic benefits of landfill gas projects are summarized in Table 33.

Table 33: Energy, Environmental and Economic Benefits of Commercial SSO Projects in Canada

Energy	• 54MW or more and at least 160 Mm^3/year of RNG could be produced from commercial SSO across Canada which is currently disposed.
Environment	• About 23% of the solid waste generated in the industrial, commercial and institutional (IC&I) sector is food waste from businesses and institutions. • About 6 million tonnes of food waste is discarded in Canada each year. This food is a significant resource for digestion and renewable energy production. • Digesting half of the commercial organics currently disposed would save 2.2 million tonnes/year of eCO_2. This is equivalent to taking 490,000 cars off the road.
Economy	• Construction of 38 digesters in Canada to digest available commercial SSO could generate $1.5 billion in capital expenditures with a spin-off of $4.5 billion across Canada. • The construction of 38 digesters would result in 1,800 direct and 5,400 indirect jobs. • Operation of 38 digesters would produce 500 long term operating jobs across Canada.

6.7 Case Study: Harvest Power Fraser Richmond BC

On 11th September, 2013, Harvest Power, along with its partners, officially launched its Energy Garden in British Columbia, the largest commercial-scale high solids anaerobic digester in North America. The Energy Garden is located at Harvest's site in Richmond, B.C. and has the capacity to convert up to 40,000 tonnes of food and yard waste per year from area homes, businesses, restaurants and supermarkets into clean energy and compost.

"This facility represents the innovation, passion and commitment required to usher in the future of organics management," said Paul Sellew, Harvest Power founder and CEO. "We are excited to continue our partnership with the Metro Vancouver and the City of Richmond community to cost-effectively convert organic materials once destined for the landfill into clean energy and compost products."

Harvest's Energy Garden, which uses GICON's batch two-stage anaerobic digestion technology, is the largest of its kind in North America. The facility produces enough energy to power approximately 900 homes per year, and provides hundreds of thousands of cubic yards of top quality soil products to local farms, gardens and landscapes.

"Our Government is supporting innovative projects across the country and positioning Canada at the forefront of clean energy technology to help protect our environment and create high-quality jobs," said the Honourable Kerry-Lynne Findlay, Canada's Minister of National Revenue. "Projects like this not only support our local economy but also demonstrate how we can use clean technology to reduce greenhouse gas emissions."

"The City of Richmond is pleased to work with Harvest Power to manage and beneficially reuse our organic waste," said Malcolm Brodie, Richmond Mayor and Chair of the Zero Waste Committee for Metro Vancouver. "Together we are creating opportunities to reach our recycling targets while improving the soil for future generations and developing the increased use of renewable energy sources."

Harvest's services and products help reduce landfill-bound waste and greenhouse gas emissions associated with transportation while providing clean, local renewable energy and top quality soil products.

“We see an organic cycle of energy and nutrients: a pizza crust from last night’s dinner gets turned into power today, and soil that grows tomatoes in tomorrow’s garden,” continued Sellew.

Financing for the Energy Garden was supported by a $4 million contribution from Natural Resources Canada and a $1.5 million contribution from BC Bioenergy Network. Proud supporters of this effort include BC Hydro, Metro Vancouver and member municipalities, Port Metro Vancouver, haulers, landscapers and local residents. The energy is sold back onto the grid under a power purchase agreement with BC Hydro.

7Biogas From Wastewater Treatment Plants

In 2009, 82% of households in Canada lived in dwellings connected to municipal sewer systems.[67] All of these systems are connected to wastewater treatment plants. Wastewater is treated in primary or secondary wastewater treatment plants (WWTP's) or water pollution control plants (WPCP's). Each type of treatment produces wastewater treatment residuals or sludge. In some WWTP's the sludge is already processed through anaerobic digestion, with the production of biogas. The biogas is used for internal plant needs for heating, and the excess biogas is flared. In some facilities, the biogas is used to produce electricity or power for export outside of the facility. There are a number of co-generation facilities in place in wastewater treatment facilities across Canada but a large amount of biogas is flared with no energy recovery. This is a lost resource which should be utilized for energy production.

7.1 Existing Inventory of Municipal Wastewater Treatment Residuals in Canada

In 2006, municipalities across the country generated a daily average of 668 L of wastewater per person served by sanitary sewers[68]. Residential sources accounted for close to two-thirds of the flow into municipal sewer systems, while the industrial, commercial, and institutional sector produced 18% of municipal wastewater flows. Stormwater accounted for 9% of sewer flows and the remainder (8%) was the result of groundwater infiltration into sewer systems.

In Canada, about 660,000[69] dry metric tonnes of biosolids (2.5 million wet tonnes, assuming 25% total solids content) are produced annually by about 4,000 WWTPs. Biosolids from wastewater treatment facilities are currently either incinerated or land-spread.

In 2009, the CCME endorsed the *Canada-Wide Strategy for the Management of Municipal Wastewater Effluent*. The anticipated increased amounts of biosolids lead to the development of the CCME *Guidance Document for the Beneficial Use of Municipal Biosolids, Municipal Sludge and Treated Septage*. Land application of biosolids is favoured to enhance soil fertility, soil structure and plant growth. Nutrients such as nitrogen and phosphorous are wasted when biosolids are incinerated or landfilled. Land application of biosolids can supplement and may reduce fertilizer use, 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.

The potential RNG produced from the anaerobic digestion of wastewater presented in Table 34 was developed using data reported for many Ontario wastewater anaerobic digesters by Wheeldon et al. (2005), where the specific methane production was reported as 0.0336 m^3 CH_4/m^3 wastewater. The total Canadian potential RNG production from wastewaters is estimated to be ~ 184 Mm^3/year of RNG; provincial production correlates with population size.

[67] Statistics Canada, 2011, *Households and the Environment, 2009*, Catalogue no. 11-526-X.
[68] Environment Canada, 2010, *2010 Municipal Water Use Report: Municipal Water Use, 2006 Statistics*, Catalogue no. En11-2/2006E-PDF, *www.ec.gc.ca/Publications/default.asp?lang=En&xml=596A7EDF-471D- 44C-BCEC-2CB9E730FFF9* (accessed August 2, 2011).
[69] CCME 2012 Canada Wide Approach for Management of Wastewater Biosolids

Table 34: Annual Methane Production From Canadian Wastewaters (2006)

.	Population[1]	Wastewater Production		CH_4 Production		Biogas Production
	(persons)	(m^3/d)[2]	(M m^3/yr)[3]	(M m^3/yr)[4]	(kt/yr)[5]	(M m^3/yr)
NL	509,677	233,845	85.4	2.87	1.95	4.78
PE	138,519	63,554	23.2	0.779	0.53	1.30
NS	934,405	428,714	156	5.26	3.58	8.77
NB	749,168	343,726	125.5	4.22	2.87	7.03
QC	7,651,531	3,510,599	1281	43.05	29.28	71.75
ON	12,686,952	5,820,900	2125	71.39	48.54	118.98
MB	1,177,765	540,370	197	6.63	4.51	11.05
SK	985,386	452,105	165	5.54	3.77	9.23
AB	3,375,763	1,548,834	565	18.99	12.92	31.65
BC	4,310,452	1,977,678	722	24.25	16.49	40.42
NT	41,861	19206	7.01	0.236	0.16	0.39
NU	30,782	14123	5.15	0.173	0.12	0.29
YK	31,229	14328	5.23	0.176	0.12	0.29
Canada	32,623,490	14,967,983	5,463	184	124.83	**306.67**

1 Statistics Canada. 2007e.

2 Calculated as Column 2 (p) x 0.97 x 0.474 (m^3/d/p). (In 1999, 97% of Canadians used Wastewater treatment facilities that produced 14,400,000 m^3/day (population of 30,404,000) or 0.474 m3/person/day). (Environment Canada. 2001.)

3 Calculated as (Column 3 (m^3/d) x 365 d/yr)/(1,000,000 m^3/M m^3)

4 Calculated as Methane production (at 60% of biogas) = Column 4 (M m^3/yr) x 0.0336 (m^3 CH_4/m^3 wastewater) (Wheeldon et al, 2005)

5 Calculated as Column 5 (M m^3/yr) x CH_4 density (0.00068 t/m^3) x 1,000,000 (m^3/M m^3)

a Assumed to be processed by Anaerobic digestion, therefore the thermal production only is achieved by burning the biogas, which captures 17% of the energy in the biomass.

b Lower heat value expressed as Gigajoules (GJ) per tonne dry biomass. These values have been discounted to allow for the fact that the biomass typically has significant water content, which must be removed for thermal processing. These values assume about 45% water in forest biomass and 25% in crops and agricultural residues.

c Calculated as 3.6 GJ/MWhr at 35% efficiency for biomass combustion energy, or 52% efficiency for biogas combined cycle generation

Ontario Estimate[70]: Combined heat and power (CHP), also known as cogeneration, is a reliable, cost-effective option for wastewater treatment facilities that have or are planning to install, anaerobic digesters. Biogas from these digesters can be used to generate reliable electricity and power – some estimates equate this opportunity to an electricity generation potential of 50MW (1.3 GWh per day) across Ontario.[71] The total and recoverable amount of WWTP-biogas energy was estimated based on a survey of

[70] Brief on Water and Wastewater Treatment- Plant Operator Training.Background, Gap Analysis and Preliminary Recommendations. Prepared for the Ontario Power Authority, by Seeline group Ltd. January 2010

[71] "Utilization of Biogas Generated from Ontario Wastewater Treatment Plants in Solid Oxide Fuel Cell Systems: A Process Modeling Study" International Journal of Green Energy, Volume 4, Issue 2 March 2007 , pages 221 - 23

wastewater treatment plants in Ontario. The system assumed for the estimates included H_2S removal, reformation of the biogas and electrical and heat generation in a solid oxide fuel cell. If such biogas-SOFC systems were to be used at all the sites identified in the survey of Ontario WWTPs, a total of 1.3 GWh of electrical energy would be produced per day (about 50MW).

7.1.1 Current Biogas Generation From Digestion of WWTP Biosolids In Canada

Anaerobic digestion is the most widely used stabilization process in larger wastewater treatment plants across Canada with average flows greater than 23,000 m^3/year (5 MGD - million gallons per day)[72]. WWTPs that have influent rates more than 17 MGD (68,000 m^3/day), are at the threshold above which energy projects become viable (Takach, 2010). This is equivalent to a city of 140,000 people of which there are many across Canada.

CH2M Hill carried out a study of the 50 largest treatment plants in Canada for Environment Canada in 2000[73]. Based on a database that Environment Canada developed in 1996, and a survey carried out as part of the study, about 55% of the biosolids produced by the 50 largest plants in Canada are anaerobically digested. There does not appear to be any more recent data available on the topic, and this is considered a data gap which needs to be filled as part of a comprehensive biogas strategy. Based on the study results the following amounts of biosolids are currently digested or available for digestion:

- 55% of 660,000 dry tonnes = 363,000 dry tonnes via AD
- 45% of 660,000 dry tonnes = 297,000 dry tonnes potential AD or other

Current usage of the biogas from WWTP digesters varies from one wastewater treatment plant to another. Most plants burn the digester gas in boilers that heat digesters at the plant in winter and flare the excess gas in the summer. There are about a dozen or so plants that operate either gas engines or micro turbines to produce electricity and recovered heat is used for digester and plant heating. Table 35 presents available information on utilization of biogas at Ontario WWTPs. Equivalent information is not readily available for other provinces in Canada.

Table 35: Current Biogas Usage by WWTPs in Ontario

WPCP Location	Installed and Operating Capacity	Year Started
Atlantic Avenue WPCP, Thunder Bay	600kW	2009
R.O Pickard, Ottawa	2.4MW/2MW	1997
Barrie WPCC	500kW/250kW	1993
Humber STP Toronto	4.7MW/2MW	2005
Clarkson WPCP, Mississauga	810kW/250	1999
Guelph WPCC	500kW/250kW	1995
Woodward Avenue WWTP Hamilton	17,000 m^3/day digester gas - effectively displaces 1.6 MW of the water treatment facility's 8 MW load through a CHP facility. More recently, RNG is being injected into the natural gas pipeline, the first WWTP in Canada to do this.	
Proposed - Ashbridges Bay, Toronto	10MW	Approved 2009 status now known
Chatham Kent	250kW	2013

The digestate from WWTP digesters is dewatered to increase its solid content and is generally land applied as a Class B material on agricultural land, either as a liquid or a dewatered solid. In some

[72] Siemens, http://www.water.siemens.com/en/applications/sludge_biosolids_treatment/anerobic_digestion/Pages/default.aspx accessed. Jul 24, 2013
[73] Burrowes CH2M Hill Study of GHG Reduction Potential At Wastewater Treatment Facilities, 2000 Study for Environment Canada.

locations (e.g. Durham Ontario) where there is insufficient land to absorb all of the digested solids, the dewatered biosolids are incinerated.

There are many opportunities for utilization of the biogas from WWTP digesters- this was the subject of the report for Environment Canada (2000). There are also many opportunities to increase biogas from biosolids and some municipalities looking into co-digestion with fats, oils and grease (FOG) and source separated organics. An updated assessment is needed of the potential to increase energy recovery by utilizing biogas at wastewater treatment plants across Canada.

7.2 Environmental Impacts of Biogas From WWTP Biosolids

It has been estimated that in the US, a total of 2.3 million metric tons of carbon dioxide emission reductions can be achieved annually through increased use of CHP at WWTPs. These reductions are equivalent to planting approximately 640,000 acres of forest, or the emissions of approximately 430,000 cars[74]. A similar assessment should be carried out for Canada, updated to 2014.

There are many benefits associated with digestion of biosolids and capturing the biogas for energy production, compared to incinerating the biosolids. These include:

- beneficial use of biosolids to capitalize on nutrient and organic matter value and energy content of municipal biosolids (compared to the loss of these benefits if the biosolids are incinerated);
- energy production;
- Potential production of compost and soil products;
- Potential application of the stabilized biosolids to agricultural land, forestry lands or land reclamation projects as a fertilizer or soil conditioner.

7.3 Economic Impacts of Biogas From WWTP Biosolids

Capital Costs: Typical construction costs for digesters at WWTP varies by digester size and existing facilities at the plant. A recent project at an Ontario WWTP with a capacity to treat 64,000 m^3/d of wastewater has a capital budget for a project which included two digesters, each 2,440 m^3 capacity, a co-generation engine, boiler and electricity, as well as fuel production for vehicles, and cleaning of the biogas to sell to the natural gas grid.

Given the lack of firm information on the current status of biogas energy projects in WWTPs across Canada, for this project it was assumed that 50 AD projects could be established at WWTP's across Canada, each with a budget of $11 million, for a total investment of $550 million, with a spin-off of $1.7 billion. Should a provincial breakdown be required, national values should be pro-rated by relative provincial populations.

Jobs: An anaerobic digestion expert estimated that each digester project would involve 20 construction jobs for 52 weeks per project. Fifty AD projects would therefore produce 1,000 construction jobs for one year (not all the same year) with about 3,000 spin-off jobs. New digesters and energy recover projects are likely to generate 4 operations jobs (assuming an additional operator per shift) and 1 – 2 maintenance jobs to cover mechanical, electrical and instrumentation maintenance[75]. Therefore, assuming on average

[74] Case Study Primer for Participant Discussion; Biodigesters and Biogas, May 14th, 2012, USEPA
[75] Personal communication Peter Burrowes, CH2M Hill, September, 2013

5 new jobs per AD project, and 50 projects, about 250 on-going operation and maintenance jobs would be created over time

Revenues: For municipal plants, this biogas typically has a heating value of 600 BTU per cubic foot of gas produced. If this gas is converted to electricity, a municipal plant can expect to produce in the neighborhood of 2 watts of electricity per person served by the wastewater treatment plant. For a city of 50,000 people, that is equivalent to 100 kW or about $70,000 per year worth of electricity (assuming $0.08/kWh)[76].

7.4 Social and Community Benefits of AD at WPCPs

Social and community benefits of recovering energy from digesters which are already in place in many WWTP's across Canada are similar to those stated for other biogas sources. However, because WWTPs are generally owned by municipalities, the benefits generally accrue to the community. These include:

- More efficient use of energy;
- Long term savings in energy costs and
- Contribution to meeting community GHG reduction targets.

7.5 Energy Impacts of Biosolids Digesters

For each 20,000 m^3/day of wastewater processed by a WWTP using anaerobic digestion, the generated biogas can produce approximately 100 kilowatts (kW) of electricity[77].

The analysis in this section shows that biogas utilization at WWTPs across Canada has the potential to capture up to 180 Mm^3/year of RNG. This estimate should be refined to account for existing biogas utilization projects.

7.6 Barriers to WWTP Biogas Project Development

In 2011, the Water Environment Research Foundation (WERF) and New York State Energy Research and Development Authority (NYSERDA) posted an on line survey available to over 1,300 wastewater treatment facilities with AD located in the United States to determine the most significant barriers facing utilities in using biogas as a renewable energy source. Two types of uses were examined:

- Using biogas in the form of combined heat and power (CHP);
- Using biogas for non-CHP uses, such as injection into the gas pipeline as renewable natural gas (RNG) and conversion to compressed natural gas (CNG) for vehicle use.

Over 200 (209) respondents from wastewater treatment facility completed the survey. The survey research was augmented with a series of focus groups to enable the researchers to delve into the key barriers more deeply.

[76] http://www.water.siemens.com/en/products/sludge_biosolids_processing/digesters/Pages/getting-most-out-of-biosolids.aspx
[77] ibid

Among those respondents that generated an adequate supply of biogas for potential use , typically greater than 75 million gallons per day (MGD), the most prominent barriers, identified by the respondents, to using biogas for CHP were economic in nature involving:

- Inadequate payback/economics – The economics (perceived or real) do not justify the investment for beneficial use of biogas. "Evaluating project payback, which involves considering a variety of factors (e.g., capital costs, expected revenues, etc.) was identified as a major part of the decision-making process regarding whether to undertake an anaerobic digestion and/or CHP project. In utilities' decision making, it was found that many rely on simple payback, as opposed to more complex economic analyses"[78]. The lack of a standardized payback period for use in evaluating renewable energy options and low electricity rates also act as barriers.
- Lack of available capital – Renewable energy projects must compete with other funding demands and is often viewed as a discretionary project. The uncertainties and risks created when adding AD and/or CHP include the potential for increased operations and maintenance expenses. During one focus group, attendees agreed that decision makers (e.g. politicians) typically are focused on the economics of the project and avoid taking risks.

Other factors identified included a lack of support and cooperation for AD projects by partnering agencies, regulatory agencies and internally. During the focus groups, participants suggested that some of the lack of cooperation was a result of a lack of knowledge or understanding by decision makers and pre-conceptions about using biogas as renewable energy, for example "Many power companies are not willing to accept electricity produced from biogas due to concerns over whether the power is consistent or whether it might cause a problem for the grid."[79]

The lack of support is also related to the need to gain public support. Public support for CHP and biogas use can be uncertain. It can be time-consuming to achieve public awareness and support especially in the case of odour and noise concerns. It was identified in one focus group that where elected officials promoted biogas programs, good support and few obstacles occurred.

In some instances, air regulations, air permits, and air quality concerns have presented a high hurdle for CHP. Even air and greenhouse gas (GHG) regulations make it too difficult to get a CHP air permit.

The report identified some recommended next steps to increase biogas-generated renewable power at wastewater treatment plants in the United States. The recommended next steps were:

- Continue to quantify and define the energy generation potential from biogas at WWTFs (wastewater treatment facilities) throughout the United States;
- Develop databases, similar to that developed by U.S. EPA Region 9, of potential high strength waste (HSW) sources that could be used to increase biogas production at WWTFs as well as CHP installations and successful case studies;
- Develop a consolidated database or repository of grant funding opportunities for CHP and biogas production projects;
- Update the University of Alberta Flare Emissions Calculator to include nitrogen oxides (NOx) and carbon monoxide (CO). These emissions are often regulated by permitting agencies. The updated model would help to document the relative performance of non-recovery/fuel-wasting devices against CHP technologies;
- Develop an economic analysis tool that uses other financial evaluation methods in addition to simple payback;
- Develop an education and training course to assist in the understanding of the benefits of biogas, including a course specifically for decision makers and information exchanges targeting power companies and natural gas utilities;
- Identify how to pursue legislation to assist in financing CHP projects;

[78] Barriers to the Use of Biogas for Renewable Energy. 2012. Water Environment Research Foundation
[79] Ibid

- Promote research to identify less costly methods to achieve anaerobic digestion and biogas production so that it can become more widely applicable particularly to small WWTFs and industrial applications

7.8 Summary of Benefits of Digesting Wastewater Treatment Plant Residuals

Table 36 summarizes the energy, environmental and economic benefits of recovering energy from the digestion of wastewater treatment plant residuals.

Table 36: Energy, Environmental and Economic Benefits of Wastewater Treatment Biogas Projects in Canada

Energy	• Biogas utilization at wastewater treatment plants across Canada has the potential to capture up to 180 Mm^3/year or more of RNG. • This could produce 60MW of green electricity. • About 55% of the biosolids from the largest treatment facilities in Canada are processed in biogas systems. There is significant potential to recover more biogas at wastewater treatment plants across Canada.
Environment	• Capturing additional biogas in wastewater treatment plants across Canada could reduce GHG emissions by 2.8 million tonnes eCO^2/year or more. • This is equivalent to taking 560,000 cars off the road.
Economy	• Construction projects at wastewater treatment plants across Canada to increase energy production from biogas would generate $600 million in capital expenditures with a spin-off of $1.8 billion. • Digester construction projects would result in 1,000 direct and 3,000 indirect jobs • Digester construction projects create up to 30 construction jobs for 52 weeks per project. • Digesters create about 4 operations jobs and 1-2 maintenance jobs; development of additional digesters at wastewater treatment facilities in Canada would create 250 on-going operations jobs.

7.9 Case Study: Renewable Natural Gas Production at a Wastewater Treatment Plant Hamilton, Ontario

Overview

The City of Hamilton, Ontario, (population 520,000) has been using anaerobic digesters to process sludge from its Woodward Avenue Wastewater Treatment Plant for a half-century. In 2006, it stopped flaring off most of the biogas and began using it to fuel a combined heat and power (CHP) plant that generates electricity, provides space heating and warms the digesters. More recently, it began purifying the biogas into 98 percent methane – a product known as biomethane or renewable natural gas (RNG), and identical in performance to the conventional fossil fuel – that is injected into the local pipeline system operated by Union Gas Limited.

While commonplace for decades in parts of Europe, where it is supported by subsidies in Germany, France and Sweden, biomethane production is just beginning to grow in the United States, and lags even further behind in Canada. The country's first bio-methane facility is at an agricultural digester in

Abbotsford, BC. Hamilton's $4 million project is, so far, the only one in Canada based on digested solids from a municipal wastewater treatment plant.

The City was able to leverage several initiatives, including innovative planning and design as well as a shared municipal, provincial and federal government infrastructure funding to achieve environmental benefits, create revenue, validate new technology, and provide a full-scale demonstration facility for an emerging renewable biogas market in North America.

Features

- The CHP facility and the RNG purification plant are owned by the City and operated and maintained by a civic corporation known as Hamilton Renewable Power Inc.
- The City has a "wheeling" agreement with Union Gas. In this arrangement Union Gas does not pay for the biomethane; it charges the city a small fee to transport the gas on its behalf. The City then buys the remainder of its required supply by conventional means, less the amount of biomethane it has injected into the pipeline. The City also paid for the purification and injection facility, built to Union Gas' gas quality specifications, and covers its annual operating and maintenance cost.
- The CHP facility usually operates at maximum capacity, consuming 15,300 cubic meters (m^3)/day of biogas and accounting for most of the current daily biogas production of 17,150 m^3.
- As biogas production rises, more will flow to the Greenlane "Rimu" purification facility. The facility, with daily capacity of 10,000 m^3 of biomethane, was sized to handle the forecasted biogas supply until 2020, but the modular design enables expansion.
- The comparative economic benefits of CHP and RNG rise and fall with the market price of electricity and natural gas, and the availability of subsidies. The two uses are complementary, since outputs can be adjusted depending upon which offered the better return.

Future Plans and Opportunities

Hamilton is growing, and a formal master planning process identified the need to increase the treatment plant's daily capacity from 108 million to 132 million gallons/day. The expansion will generate additional sludge, so more digesters and dewatering centrifuges are also planned. These changes are expected to raise biogas production by 215 percent, to a daily average of about 37,000 m^3, within 20 years.

Biogas, CHP and RNG production are all part of the City's ambitious plan to make the Woodward Avenue Wastewater Treatment plant a zero-net-energy user'. Additional plans are in place to investigate co-digestion of fats, oils and greases from the restaurant industry as a supplemental fuel source for digesters.

8 A Comparison Of Biogas With Other Energy Sources

This section of the report provides some comparative metrics for biogas compared to other energy sources.

8.1 Carbon Intensity of Electricity By Province

The carbon intensity of electricity by province in Canada varies depending on the mix of nuclear, coal, natural gas and hydro electricity. The variation is shown in Table 37, which shows that the carbon intensity of the Canadian energy mix has decreased by almost 15% since 1990, with a significant decrease in Ontario as a result of the phase out of coal fired electricity. Increased use of biogas energy would reduce the carbon intensity of the Canadian energy mix even further.

Table 37: Carbon Intensity of Electricity Across Canada (tonnes/MWhr)

Region	1990	2000	2008	2009
Canada	0.210	0.230	0.200	0.180
Alberta	0.980	0.910	0.950	0.880
British Columbia	0.017	0.033	0.026	0.024
Saskatchewan	0.800	0.820	0.680	0.710
Manitoba	0.023	0.031	0.012	0.005
Ontario	0.190	0.280	0.170	0.100
Quebec	0.012	0.002	0.002	0.002
Other provinces, territories (weighted averages, weighted using 2009 production)	0.233	0.236	0.274	0.267

Source: Canada - National Inventory Report 1990-2009, Greenhouse Gas Sources and Sinks in Canada, Part 3

The carbon intensity data for Canada are compared to the data for Denmark and Germany in Figure 7.

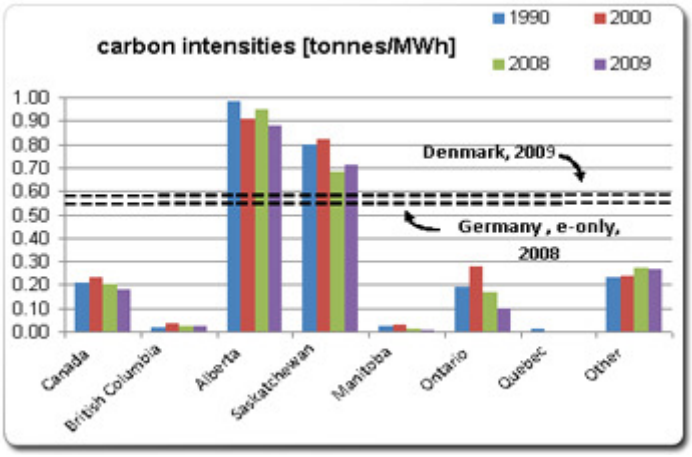


Figure 7: Carbon Intensity of Electricity Across Canada (tonnes carbon per MWhr)

Using actual and projected provincial electricity consumption values, Aegent has estimated that projected carbon intensities for Ontario's electricity mix will continue to decline as shown in Table 34. Again, increased use of biogas energy can contribute to lowering the carbon intensity of Ontario's electricity.

Table 38: Carbon Intensity of Ontario's Electricity[80]

year	CO_2 emissions [megatonnes]	Ontario consumption (generation less net exports) [TWh]	Carbon intensity [tonnes/MWh]
2008	25.6	148.4	0.17
2009	12.7	139.2	0.09
2010	21.4	142.0	0.15
2011	17.0	143.4	0.12
2012	11.8	144.9	0.08
2013	7.7	146.3	0.05
2014	7.0	147.8	0.05
2015	5.7	149.2	0.04

The coal phase-out, scheduled to be complete by the end of 2014, appears to be a clear driver behind Ontario's lessening carbon intensity. CO_2 emissions from natural gas were approximately 5 and 9 megatonnes in 2009 and 2010, respectively.

8.2 Air Emissions and GHG Compared To Other Energy Sources

Emission factors for different energy sources including biomass and natural gas (but not biogas specifically) are presented in Table 39. These factors are taken from a study by ICF International completed for Environment Canada in 2005, where AD was compared to landfilling and composting from a GHG reduction point of view. A research study is required to develop emission factors specific to biogas and RNG, compared to other fuels.

[80] http://www.aegent.ca/newsletters/OntarioCarbonIntensity.html viewed October, 2013

Table 39: Emission Factors For Different Energy Sources (ICF, 2005)

Fuel Type	Combustion kg CO_2/GJ	Combustion eCO_2 CH_4/GJ	Combustion eCO_2 $N2O$/GJ	Pre-combustion eCO_2/GJ	Total kg eCO_2/GJ
Coal	86.80	0.00	0.01	6.42	93.23
Natural Gas	49.65	0.27	0.40	9.89	60.20
Kerosene & Stove Oil	68.54	0.13	4.03	17.73	90.42
Diesel	71.28	0.05	1.24	17.73	90.30
LPG (Liquified Petroleum Gas)	60.61	0.02	-	17.73	78.37
Distillate (Light Fuel Oil)	72.94	0.13	4.03	17.73	94.82
Residual (Heavy Fuel Oil)	72.71	0.63	4.03	17.73	95.10
Gasoline	68.09	0.47	2.80	17.73	89.09
Oil/ Lubricants	47.93	-	0.19	17.73	65.85
Petroleum (Non- specified)	73.11	0.05	0.33	17.73	91.23
Biomass (**not biogas**)	-	0.96	-	17.73	0.96
Tires	75.00	-	-	-	75.00

GHG emission factors for end use electricity by province are presented in Table 40. These do not reflect Ontario's lower emissions following the closure of coal- fired plants in the last few years, as this work was completed in 2005.

Table 40: Emission Factors For End Use Electricity (2005)

	Electricity Coefficients (kg eCO2/kWh)			
	CO_2	eCO_2 N_2O	eCO_2 CH_4	eCO_2 Total
Newfoundland	0.186777	0.000237	0.000029	0.187044
Prince Edward Island	1.040882	0.001092	0.000170	1.042143
Nova Scotia	0.666402	0.003536	0.000094	0.670031
New Brunswick	0.530629	0.001659	0.000077	0.532366
Quebec	0.011436	0.000018	0.000002	0.011456
Ontario	0.315821	0.001939	0.000040	0.317800
Manitoba	0.036350	0.000048	0.000002	0.036400
Saskatchewan	0.889836	0.000562	0.000011	0.890410
Alberta	1.032736	0.007900	0.000167	1.040802
British Columbia	0.025418	0.000096	0.000002	0.025516
Yukon	0.045239	0.001645	0.000072	0.046956
Northwest Territories	0.474858	0.011377	0.000488	0.486722
Nunavut	0.000000	0.000000	0.000000	0.000000
Canada	**0.276270**	**0.001567**	**0.000036**	**0.277874**

The emission factors show the difference in GHG impacts of electricity generation per kWhr in provinces which use hydro power (with very low GHG emission factors) compared with provinces like Alberta and Nova Scotia which are heavily dependent on coal. Biogas emissions are considered "bio-genic" in GHG calculations, and would result in lower calculated GHG emissions

In its February 15, 2011 budget the Government of British Columbia identified RNG as a carbon neutral source of energy; however although BC considers RNG to produce biogenic emissions these only refer to CO_2 emissions. RNG also contains other greenhouse gas emissions including un-combusted methane (CH_4) and nitrous oxide (N_2O), which total 0.3034 kg CO_2 e/GJ.[81]

Approximate energy values in MJ/litre or MJ/m^3 for RNG and biogas compared to other energy sources are presented in Table 41.

Table 41: Comparative Energy Values for Biogas and RNG Compared to Other Energy Sources

Fuel	Approximate Energy Value	Approximate Energy Value
	MJ/unit	(BTU/unit)
Gasoline	32.6-34.6 MJ/L	(30,900-32,900 BTU/L)
No. 2 diesel	36.0-38 MJ/L	(34,000-36,000 BTU/L)
Propane (LPG)	23.4-26.9 MJ/L	(22,200-25,000 BTU/L)
Natural gas RNG or biomethane	35.3-40.6 MJ/m^3	(33,500-38,500 BTU/m^3)
CNG (at 3,600 psi)	10.6-12.2 GJ/m^3	(10,040,000-11,600,000 BTU/m^3)
LNG	20.4-23.6 MJ/L	(19,400-22,400 BTU/L)
Biogas	22-27 MJ/m^3	(20,800-26,000 BTU/m^3)

8.3 Comparison of RNG From Biogas As A Vehicle Fuel

Utilization of RNG as vehicle fuel to replace diesel and gasoline has been acknowledged by the US government as a beneficial way to:

- help reduce dependency on conventional fuels;
- reduce greenhouse gas emissions and
- result in a meaningful improvement of air quality.

A comparison conducted by Progressive Waste Solutions Inc. (BFI Canada Inc.) of CNG powered waste collection trucks compared to diesel trucks demonstrated that the CNG powered trucks saved 20 percent on an hourly basis when compared to an equivalent diesel truck.[82] The price of CNG in 2011 was approximately Cdn $0.58 per diesel litre equivalent. [83] Reasons for embracing CNG trucks include:

- The industry in general is moving to CNG vehicles;
- In the last five years a new engine designed to run on CNG (not converted from diesel) has come on the market. Five years of good operational performance data are available (for California) which prove good performance for CNG engines;
- A few cold climate issues remain to be resolved (e.g. Winnipeg);

[81] Biomethane Greenhouse Gas Emissions Review FortisBC May 30th, 2011
[82] Natural gas power - IESI turns to natural gas to fight back against the high cost of diesel. November 28, 2011. Recycling Product News
[83] Natural Gas: Looking Forward. March 23, 2011. GreenFleet Expo

- CNG trucks are significantly cheaper to operate than diesel equivalent (even if NG prices rise);
- Municipalities are asking for CNG trucks in their collection contracts (e.g. Surrey, BC; Simcoe Ontario), partly to meet GHG reduction targets. These contracts provide sufficient scale for fuelling station establishment

Integrated Biogas System in Vasteras, Sweden

The community of Vasteras in Sweden has fueled its bus fleet with upgraded RNG from digestion of biosolids, SSO and energy crops for a number of years:

- The anaerobic digester in Vasteras, Sweden, co-digests SSO from 144,000 households and energy crops grown by local farmers at the same facility. Through an upgrading facility and CNG (compressed natural gas) filling station, biogas from this facility as well as the local sewage treatment plant is upgraded to provide fuel for: 40 city buses, 10 refuse vehicles and 500 cars.
- Most of the biogas is upgraded to vehicle fuel. The remainder is used to produce electricity and heat. The biogas has an energy content of 15,000 MWh each year, equivalent to more than 1.6 million litres of gasoline. The upgrading plant also receives biogas from the sewage treatment plant with an energy content of 8000 MWh. The total amount of gas that can be used as vehicle fuel is therefore equivalent to 2.5 million litres of gasoline annually.
- The upgraded biogas is pressurized at the bus depot and stored. There is one filling station for buses and refuse collection vehicles and another public filling station for cars. A storage facility for liquid natural gas with a capacity 21 tonnes, or 50 m^3 guarantees a supply of fuel to the city buses.

Natural Resources Canada's GHGenius model has calculated that switching to 100% renewable natural gas for diesel in heavy-duty vehicles can result in an 85-90% carbon reduction.

A single transit bus operating on RNG and travelling 72,000 kilometers/year is estimated to have a carbon footprint that is 91 tonnes less than a 2010-compliant diesel transit bus.[84]

Most vehicles that run on CNG are heavy-duty vehicles such as trucks and buses. Waste collection trucks are a key focus for conversion from diesel fuel vehicles to CNG vehicles. For example, Waste Management Inc., the largest waste management company in North America, has converted 5% (1,000) of its waste and recycling collection vehicles to natural gas and has 17 natural gas fueling stations at its facilities throughout North America. The company has been replacing as many as 1,200 (6%) trucks each year with natural gas (NG) vehicles with the intent on using the RNG generated by the company's landfills as fuel for the NG vehicles.[85] Waste Management Inc is committed to converting LFG from their extensive network of landfills in Canada and the US to vehicle fuel for their truck fleets.

About 25% of biogas produced in Sweden was upgraded and used as a vehicle fuel, with over 60% of the vehicle fuel supplied by renewable natural gas (biomethane) and 40% supplied by natural gas.[86] Sweden has 36,000 vehicles fueled by natural gas representing about 1% of total vehicles and 13% of buses. Italy, on the other hand has 761,000 natural gas vehicles representing almost 2% of all vehicles.[87]

One estimate states that one gigajoule of 100% RNG will provide a savings of 50.3 $kgCO_2e$ when replacing conventional natural gas in BC.[88]

In Natural Resources Canada's GHGenius (http://www.ghgenius.ca/) RNG is defined as a low or ultralow carbon fuel with savings of 90% greenhouse gases compared with diesel (in heavy duty vehicles) and 80-97% when compared with gasoline, depending on the feedstock.[89] As discussed previously, even though the source of the RNG is bio-genic, some non CO_2 – greenhouse gases are generated in its production.

GHG Savings of Biogas and RNG Compared to Other Renewable Energy Sources

The German Energy Agency carried out a comparative study of GHG emissions for various fuels, including biogas and RNG. The results are presented in Figure 8 and clearly show the significant advantage of biomethane from all sources. The figure is produced by a German

[84] Canadian Natural Gas Vehicle Alliance at http://www.cngva.org/en/home/environment-safety/renewable-natural-gas.aspx
[85] Waste to Wheels: Building for Success. December 1, 2010. US Department of Energy, Clean Cities Program
[86] A biogas Road Map for Europe. October 2009. European Biomass Association
[87] Natural Gas and Vehicle Association Europe at http://www.ngvaeurope.eu
[88] Ibid
[89] The Addition of Biomethane to GHGenius," (S&T) Consultants Inc, March 2009.

Energy Agency, therefore terms are European: gasoline is referred to as petrol and Liquefied Petroleum Gas (LPG) is referred to as autogas in the figure. The figure shows that biomethane (from animal sources is used as an example in the chart) has a 97% lower GHG emission factor compared to gasoline (which is referred to as petrol in the figure).

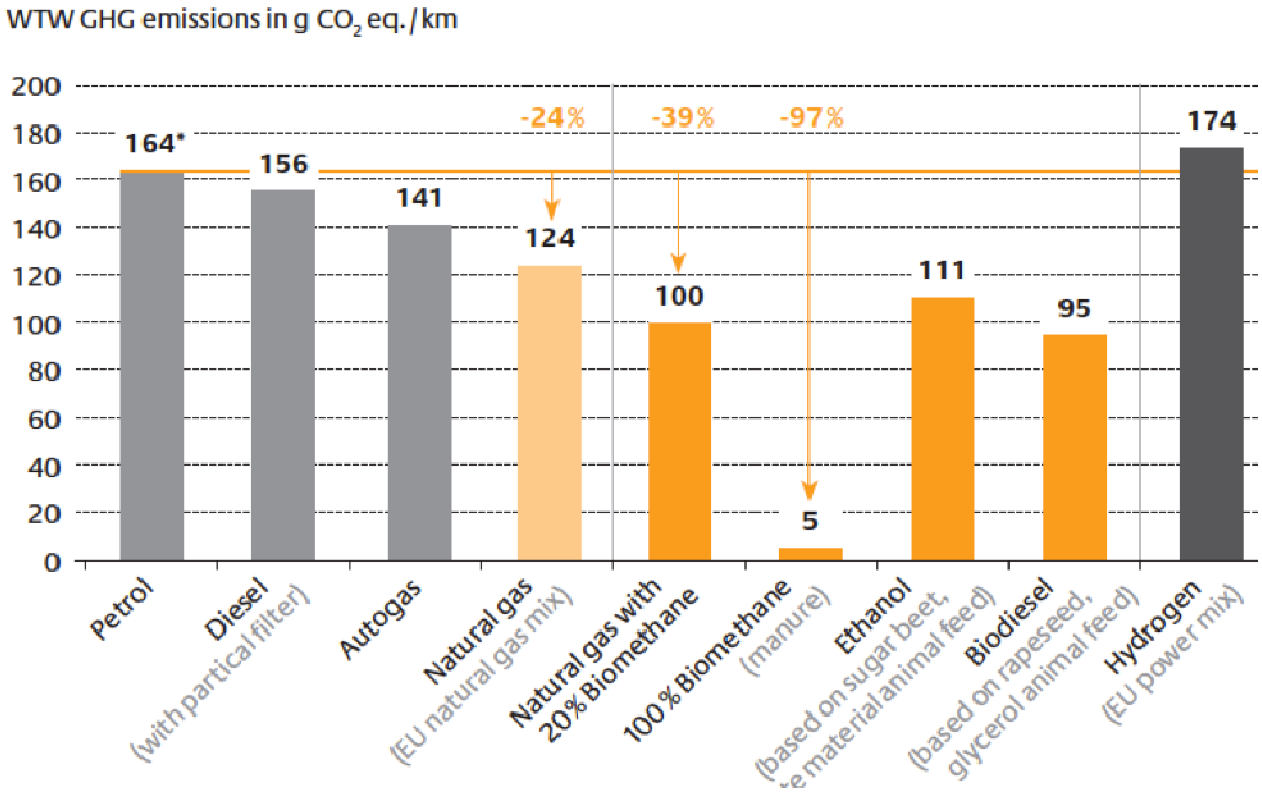


Figure 8: Greenhouse Gas Savings From The Use Of Alternative Fuels[90]

8.4 Comparison of Biogas With Other Energy Sources – Miscellaneous Metrics

Reliability of Biogas Compared to Solar and Wind

AD produces 24 hour energy, unlike other renewables such as solar and wind, which are dependent on climatic conditions. It is an excellent source of baseload power which is well suited to rural, distributed systems as well as larger urban systems. Yield Energy presented the following comparison of reliability and availability of biogas energy compared to other sources

- Wind -> 25%
- Solar -> 15%
- Biogas -> 85%

Anecdotally, experts interviewed for this study felt that biogas has a reliability factor higher than 85%, potentially above 90%. They considered biogas to be a source of energy second in reliability factor to

[90] Source: The role of natural gas and biomethane in the fuel mix of the future in Germany. June 2010. Germany Energy Agency

nuclear power.

A study carried out on the potential for biogas systems in Nova Scotia[91] concluded that compared to tidal and wind power, on-farm biogas energy production from livestock manure has potential in rural agricultural regions in Atlantic Canada, where farm operations are fairly distributed throughout the countryside and where power utility companies have difficulty adequately fulfilling electrical power needs.

AD in urban settings can be located near large energy demand areas. This precludes the need to build new, expensive transmission facilities required by other renewable energy sources (i.e. wind, solar, hydro). Furthermore, biogas energy production does not suffer from the generation intermittency of solar and wind facilities. Biogas energy generation is effectively 7x24 and can be utilized as a stable, reliable, on demand source of base-load power generation[92].

Relative Employment of Biogas Compared to Other Energy Sources: Table 42 presents findings from a UK study on relative employment of biogas systems compared to other energy sources.

Table 42: Relative Employment From Biogas Systems Compared To Other Energy Sources

Technology	Total Job-Years per GWh
Biomass	0.22
Geothermal	0.25
Solar PV	0.91
Solar Thermal	0.27
Wind	0.17
Carbon Capture and Storage	0.18
Nuclear	0.15
Coal	0.11
Natural Gas	0.11
Energy Efficiency	0.38

[91] Impact of single versus multiple policy options on the economic feasibility of biogas energy production: Swine and dairy operations in Nova Scotia (academic article) dairy operations in Nova Scotia (academic article) feasibility of biogas energy production: Swine and dairy operations in Nova Scotia

[92] Pearson Eco-Business Zone (PEBZ)Biogas Feasibility Study. No Date. Yield Energy.

9 Policies Which Support Biogas Projects

9.1 Existing Supportive Policies In Canada

9.1.1 Federal Policies Supporting Biogas Projects

In Canada, both the federal and provincial governments jointly share responsibility regarding political jurisdiction and decision-making on issues affecting the energy sector. In practice, although energy policy formulation and implementation primarily rests with individual provinces, the federal government has important regulatory roles in energy matters, especially regarding inter-provincial and international matters. Individual provinces also design their energy policies within a national framework. Consequently, policy instruments and incentive programs need to be considered within this shared responsibility framework.

Several federal government incentives have been in place over time for renewable energy projects.

- •Canadian Renewable and Conservation Expenses (CRCE) Allowance
- •Federal Government Green Electricity Purchase
- •Market Incentive Program for Distributors of Emerging Renewable Electricity Sources
- •Renewable Energy Deployment Initiative
- •Green Municipal Funds
- •Pilot Emission Removals, Reductions, and Learnings (PERRL) Initiative
- •Energy Innovators Initiative
- •Canadian Agricultural Rural Communities Initiative
- •Sustainable Development Technology Canada
- •Technology Early Action Measures (TEAM)
- •Transformative Technologies Program (previously, the TPC program)[93]

9.1.2 Provincial Policies Supporting Development of Biogas Facilities

Existing provincial and federal policies targeting bioenergy in general are summarized in Table 43.

[93] The Elorin Bioenergy Feasibility Study Anaerobic Digestion for Bioelectricity Production. March 2007. Goodfellow Agricola Consultants.

Table 43: Bioenergy Policies and Incentives in Canada

Jurisdiction	Bioenergy Policies and Incentives
BC	• In Feb 2008, BC announced North America's first carbon tax on all fossil fuels, starting at $10/tCO$_2$e or 2.41¢/l) at the pump, and increasing at $5 per year for four years. The tax hit $20/tCO$_2$e in 2010. • BC also set a target of 33% emission reductions from 2007 to 2020 • On Jan 2010, BC set a 5% ethanol, 5% biodiesel with a 14.5¢/l for ethanol and 0.09¢/l for biodiesel, tax exemption, BC fuel only • BC Carbon tax to be implemented July 1 2008 will be paid by consumers [1]. $10/tonne CO_2 equivalent ($0.4988/GJ natural gas) in 2008 to 30$ ($1.4964/GJ natural gas) in 2012. • In Feb 2008, BC announced North America's first carbon tax on all fossil fuels, starting at $10/tCO$_2$e (6.7€), or 2.41¢/l (1.6€) at the pump, and increasing at $5 (3.3€) per year for four years. The tax hit $20/tCO$_2$e in 2010. • Fortis BC offers consumers RNG option at extra levy • Standard Offer Program (SOP) for 10 cents/kWhr
Ontario	• A cap-and-trade system may be considered to reduce GHGs • Set GHG reduction targets of 6% below 1990 levels by 2014, 15% below by 2020 • 5% of generating capacity from renewable sources by 2007 (1350 MW), 10% by 2010 (2700 MW). • 5% ethanol in gas 2007 & 10% ethanol in gas 2010 - 20¢/l producer incentive • Ontario Power Authority Feed In Tariff Program (2009) was cancelled in late 2013 and replaced with a micro-FIT program and a procurement program for projects > 500kW • Biogas rates vary by size of facility with highest rates for < 100kW • Long Term Energy Plan (LTEP) released in November, 2013
Quebec	• In Oct of 2007, Quebec instituted a carbon tax on energy companies of 0.8¢/l gasoline and 0.9¢/l diesel • In 2009 Quebec committed to a 20% reduction in GHGs 1990 to 2020 • Quebec adopted the same standard as California for GHG emissions from transportation vehicles • Landfill ban on organics by 2020 • Policy to "de-carbonize" fleet and use biogas to produce fuel • Funding has been provided to 2017 to support the construction of digesters (see

	Section 5) • As of January, 2013, Quebec is a member of the Western Climate Initiative cap and trade system (with California). Trading will start Jan 2014
Alberta	• implemented a carbon emission trading system in June 2007 that required companies with large GHG emissions to reduce emissions by 12% from July 1 to Dec 31 of 2007 • 5% ethanol. 2% biodiesel-Apr, 2011 - 9¢/l tax exemption, producer incentive, Alberta fuel only • $15/t penalty for large emitters who exceed cap – can be offset by local Alberta emission reductions, including LFG
Saskatchewan	• 7.5% ethanol in Gas 10¢/l for ethanol and20¢/l for biodiesel, tax exemption. Saskatchewan fuel only
Manitoba	• 10% in ethanol 15¢/l producer credit 2010-12, Manitoba only2% in Biodiesel-Nov 1, 2009 10¢/l 2013-15, Man only
Nova Scotia	• COMFIT 17 cents/kwhr for biogas projects • incentive 15¢/l for biodiesel produced in N.S. • Renewable Energy Standards came into effect in 2007 to produce 18.5% of the provinces electricity from renewable sources by 2013 - NS aims to generate 25% renewable electricity by 2015 and 40% by 2020 • Ban on landfilling organics since 1998
New Brunswick	• would like to increase renewable power by 10% by 2016 • Distributed generation program

Interviews carried out for this study indicated that the Ontario FIT program was considered a leader in Canada for the stimulation of biogas facility development. This program was cancelled in summer, 2013 and replaced with a procurement program for renewable electricity projects with a capacity of 500kW or greater. A micro-FIT program supports projects which are 500kW or less. The OPA micro-FIT and procurement programs only support electricity generation from biogas.

Ontario requires LFG capture (but not utilization) in landfills with capacities greater than 1.5 million tonnes. BC is a leader with supportive policies which stem from a requirement to capture and utilize landfill gas (LFG) as well as some encouragement for the addition of RNG to the gas grid. Alberta allows credits from LFG projects to be used to offset emission requirements for Specified Emitters. Various provinces have GHG reduction requirements and plans which help to rationalize the development of biogas facilities.

9.2 Policies in The United States

The US offers many examples of policies which are supportive of biogas and other renewable energy sources. A few states, including California, are leaders in supporting biogas projects. .

US[94] Government Biogas Incentives over time have included:

- 30% of project cost
- US Treasury grant (through 2010)
- Tax credit •US Dept. of Agriculture
- Up to $500,000 or 25% of project costs
- Loan Guarantee up to $25 million

The Regional Greenhouse Gas Initiative (RGGI) in a US cap and trade system in operation in ten states in the northeast and mid-Atlantic The U.S. does not explicitly include biogas-to-pipeline gas in its criteria for offsets[95].

The tax classification and permitting processes for biomethane production now varies by state. When combined with regulatory hurdles, access to gas pipelines, a crucial component of more widespread adoption of biomethane as a vehicle fuel, can be difficult and/or prohibitively expensive.

Under the Renewable Fuel Standard (RFS)[96], 40 CFR 80.1426, biogas from landfills, sewage waste treatment plants, or manure digesters that is converted to CNG and then used as a transportation fuel qualifies for RINs (credits known as Renewable Identification Numbers, or RINs). The RIN credit is a special serial number given to batches of biofuels before they are sold to refiners and gasoline importers looking to comply with a federal mandate to use a certain amount of ethanol. The credit was created by Congress. Instead of blending ethanol, the refiner can choose to purchase RINs to comply with the mandate. There has been concern that the credits, originally seen as a way for refiners and others tied to ethanol to comply with the mandate, have been used as an investment tool, helping to inflate the cost of the RINs. The fear is that the higher RIN prices have made it more expensive to produce motor fuel with ethanol[97]. Most fuel in the US today contains 10 percent ethanol.

California has passed a statewide cap-and-trade program, and North Carolina's renewable portfolio standard has a specific provision for renewable power from on-farm biogas production.

Ohio passed House Bill 276, which confirms that a farm that uses technology (like a digester) will not lose its agricultural treatment for zoning or current agricultural use value (CAUV) as long as the energy produced is secondary to the farm's operations and at least 50 percent of the feedstock was from that farm.

Vermont Cow Power Utility Pricing (now Green Mountain Power owned by Gaz Metro): Few models exist in the U.S. for utility green pricing programs focused on electricity generated from biogas projects. Central Vermont Public Service (CVPS) operates one of the most successful green pricing programs for biogas electricity in the US. CVPS serves approximately 18,000 retail customers across the state of Vermont and created a program known as *CVPS Cow Power*. The program was the first manure-based, farm-to-consumer green power-purchasing program in the U.S. CVPS customers who sign up to participate receive all, half or a quarter of their energy through the program, which supports renewable energy development and Vermont dairy farms. Utility customers who opt into the program pay a four-cent premium per kWh. One hundred percent is paid to cow power-producing farms. The program has six participating farms that receive a premium price for their electricity.

California: California is cited as a leader in most interviews carried out for this study. California's Low Carbon Fuel Standard requires the carbon intensity of gasoline, diesel and substitute fuels to be reduced 10% by 2020. The reduction is gradual at first, starting in 2011 at 0.25%, but it becomes steeper in each

[94] The Biogas Opportunity In Wisconsin 2011 Strategic Plan. 2011. Wisconsin Agricultural Secretariat
[95] What is Renewable Natural Gas, Fortis BC website And Renewable natural gas (RNG): the solution to a major transportation challenge And Renewable Natural Gas – The Ontario Opportunity. October 2011. Prepared for: QUEST (Quality Urban Energy Systems of Tomorrow)
[96] Landfill gas energy: fueling the economy and a sustainable energy future while improving the environment. December 2010. USEPA
[97] Grassley concerned about ethanol credits, Sep. 25, 2013 DesMoinesRegister.com

subsequent year, reaching 10% by 2020.[98] Forty percent of the state's fossil carbon emissions derive from the combustion of transportation fuels.

California's Renewables Portfolio Standard (RPS) requires that utilities increase the ratio of renewable electricity purchased to total electricity sold to a minimum of 20 percent per year from January 1, 2011 to December 31, 2013; 25 percent by December 31, 2016, and 33 percent by December 31, 2020. Four types of bioenergy are identified as eligible for the RPS:

- Biomass – Technologies that convert eligible biomass to electricity.
- Digester gas – biogas and biomethane produced through anaerobic digestion.
- Landfill gas – biogas produced in landfills from natural decomposition of organic waste.
- Municipal Solid Waste (MSW), subject to the fuel-specific requirements described

Governor Jerry Brown's Clean Energy Jobs Plan calls for the state to increase renewable capacity by 20,000 MW by 2020, including 12,000 MW of energy located on-site or close to where energy is consumed (distributed generation) and 8,000 MW of new large-scale renewable energy.

A recommendation was made to allocate a significant portion of the Electric Program Investment Charge to fund research, development, and deployment of new and emerging technologies that:

- Produce biomethane or biogas from biomass residues and
- Upgrade biogas to biomethane (meeting utility gas quality standards).

While no RES (Renewable Energy Standard) has specific carve-outs for biogas, Arizona's RES requires a small percentage of renewable energy to come from distributed resources located at a customer's premises, including biogas. RES and RFS (Renewable Fuel Standard) policies miss important attributes of biogas, and there are few large-scale policy examples that encourage renewable natural gas, heat, or cogeneration from biogas. In general, however, the lowest cost forms of readily available renewable electricity are utility-scale wind turbines (e.g., 1.5 MW and larger) and utility-scale biomass. Solar and biogas projects are not typically used to meet RES requirements[99]

9.3 Biogas Policies in the EU and Selected European Countries

The European Commission[100] has developed sustainability criteria for renewable electricity, recommending that the use of biogas for electricity generation should reduce life cycle GHG by at least 35% compared to the European Union's fossil electricity mix. For AD, five rates were established based on the type of system (on-farm, off-farm) and generation capacity (e.g., 100−250 kW, 0.5−10 MW).

The EU Landfill Directive requires biodegradable waste going to landfill to be reduced to 35 per cent of 1995 levels by 2020. This has been a significant factor in development of AD facilities in Europe. All waste must be "stabilized" prior to landfilling through either incineration, composting or AD. Because of high FIT rates in Europe, and very high tipping fees (around $200/tonne in some countries) AD is cost competitive with the other technology options.

The Waste Framework Directive requires 50 per cent of household waste to be recycled by 2020 – AD outputs are counted towards these targets if they meet end of waste criteria[101]. This is an issue raised in Ontario recently with Bill 91 – the Waste Reduction Act and the Waste Reduction Strategy. As currently written in the strategy, AD outputs would not count towards diversion targets. The Biogas Association lobbied that this provision in the Strategy be re-considered.

[98] National Market Value of Anaerobic Digester Products. February 2013. Prepared for the Innovation Center for US Dairy
[99] Biogas: Rethinking the Midwest's Potential. June 2010. Clean Wisconsin
[100] Electricity Production from Anaerobic Digestion of Household Organic Waste in Ontario: Techno-Economic and GHG Emission Analyses. 2012. Environmental Science and Technology
[101] Hit the gas: How to get the anaerobic digestion sector moving. 2012. Centre Forum

Under EU[102] mandates (as part of the "20/20" Directive), nearly 10% of all natural gas will be replaced with RNG. Renewable Energy Directive (2009/28/EC) on the share of RES in overall final energy consumption - aims to achieve a 20 % renewables share of overall final energy consumption by 2020. and calls for a 10 % share of energy from renewable resources in each member state's transportation energy consumption. Renewable gases such as biomethane are to be granted "non-discriminatory access" to the gas grid.

Fuel Quality Directive (2009/30/EC)- aims to reduce the emissions from production and usage of fuels. The Directive states from 1st of January 2011 onwards fuel suppliers must annually report a gradual reduction in GHG emission intensity by at least 6 % of average European GHG value of fossil based fuels for 2010.[103]

Switzerland, Sweden, and Germany have eliminated the fossil fuel tax on biogas that is fed into the natural gas grid. In 2011 biogas plant operators reportedly received the most support in Switzerland, Italy and Germany. Four countries have introduced separate pricing for biomethane injection:

- UK (RHI Incentive);
- France (FIT);
- The Netherlands (SDE+) and
- Poland (brown certificates).

Although biomethane is still treated as a niche market, there are already five biomethane registries in the EU, which are issuing guarantees of origin and thus enable cross-border trade through natural gas grids.[104]The IEA reports that the principal policy tools that have been used to stimulate demand for biofuels are blending mandates, coupled with fuel duty rebates. Mandates are now in place in nearly 50 countries.[105]

The European Union introduced the Renewable Energy Directive (RED) in December 2010. The RED mandates that by 2020, 19% of the renewable electricity and 77% of the renewable heat will come from bioenergy. In addition, the EU Biofuels Directive sets a target for the biofuel market share (by volume) in the transportation sector to 10% by 2020. Lignocellulosic-biofuels (made from wood), as well as biofuels made from wastes and residues, count twice towards the target. [106]

Both Germany and Ireland have targeted municipal organic waste as a viable resource for generating renewable energy (methane). A report prepared by An Bord Gais, the Irish national NG utility states that "Biomethane produced from municipal solid waste could contribute significantly to Ireland's renewable heat or transport targets while at the same time diverting organic waste away from landfills".[107]

Sweden: In Sweden, government support for municipally owned biogas plants and incentives includes

- Zero fuel tax on biomethane;
- Low fuel tax on CNG;
- Reduction of personal income tax (40% reduction of income tax) payable on the free personal use of a company car;
- Free parking for 'environmental cars' in many cities;

[102] What is Renewable Natural Gas, Fortis BC website And Renewable natural gas (RNG): the solution to a major transportation challenge And Renewable Natural Gas – The Ontario Opportunity. October 2011. Prepared for: QUEST (Quality Urban Energy Systems of Tomorrow)
[103] Swiss lawmakers make biogas for transport tax-free http://news.mongabay.com/bioenergy/2007/03/swiss-lawmakers-make-biogas-for.html Sunday, March 25, 2007 and Biomethane guide for decision-makers - a policy guide on biogas injection into the natural gas grid. April 2013. Intelligent Energy - Europe programme.And Biogas report 2012. December 2012. European Biogas Association
[104] Biogas report 2012. December 2012. European Biogas Association
[105] Renewable Energy: Markets and Prospects by Technology. November 2011. OECD/International Energy Agency (IEA)
[106] Technology Roadmaps: Biofuels for Transport. 2011. International Energy Agency (IEA)
[107] The Future of Renewable Gas in Ireland. April 2010. Bord Gais

- Financial support (normally up to 30 % of total investment) for CNG stations, and for some types of biomethane production units;
- Priority lanes at airports, railway stations and ferry terminals for CNG taxi cabs;
- Five years exemption from vehicle tax for environmentally friendly cars and
- All types of biomethane utilisation are exempt of both carbon dioxide tax and energy tax.

The Natural Gas and Vehicle Association of Europe claims that Sweden's income tax benefit advantage is, "without question, the most significant support scheme".[108]

Denmark: In Denmark[109] a task force for biogas was established for the period 2012-2015, to evaluate and support new biogas projects. It has set targets (for instance 50% of the manure must be supplied to biogas plants by 2020), and promoted the integration of biogas into the energy system through technical and organizational support as well as supporting analysis of market opportunities/opportunities to promote biogas investment.

Netherlands : Biofuel tickets -The obligatory quota for biofuel increases every year by 10 %. Biomethane is eligible to fulfil this quota and generate bio tickets ,which are traded at the biofuel market. The scheme provids support for investments in energy-conservation equipment and renewable energy.

Germany: To ensure that small farms stay competitive in the green energy marketplace, the German Renewable Energy Sources Act provides a higher base rate for small-scale producers (currently 11.67 cents/kWh) than for larger producers (currently 8.25 cents/kWh for the largest producers)[110]. Despite the incentives for smaller systems, producers were quick to note that the high capital costs associated with biogas production – which have increased due to recent cost increases in raw materials like cement and steel – have led the current industry trend toward larger systems.

The National Biomass Action Plan for Germany set targets for RNG supply as a percentage of gas demand of 6% by 2020 and 10% by 2030.[111] Germany has encouraged the development of the biogas industry through the use of a carbon tax, carbon cap and trade system and a favourable renewable energy feed in tariff. The *Renewable Energy Source Act and the Renewable Energies Heat Act 16*, offers tariffs (in Eurocents) for biogas based on a number of criteria including:

- 7 eurocents per kWh if energy crops, such as grass, are used as a feedstock for biogas production;
- 2 eurocents per kWh for biogas upgrading to RNG;
- 11.67eurocents per kWh for combined heat and power (CHP) production using RNG sourced from the gas network.[112]

In Germany[113], more than five million homes were supplied with electricity from biogas in 2011 - about 18 billion kilowatt-hours (kWh) of electricity are generated from biogas. This is equal to a little less than 18 per cent of the electricity obtained from renewable sources and about 3.5 per cent of the total electricity consumption in Germany. The German government has set the target of feeding six billion cubic metres of biomethane into the gas grid every year by 2020. The target for 2030 is ten billion cubic metres. Under the Renewable Energies Heat Act (EEWärmeG) adopted in 2009, builders are obliged to include a certain amount of the heat for new buildings from renewable energy. Alternatively, the external envelope can be insulated more efficiently than prescribed by the Energy Saving Ordinance (EnEV). By making purchase

[108] Natural Gas and Vehicle Association Europe at http://www.ngvaeurope.eu
[109] Anaerobic Digestion: A Market Profile. March 2013. UK Cogent Skills Sector Council
[110] Got gas? An analysis of Wisconsin's Biogas Opportunity. March 2011. University of Wisconsin-Madison. And Got Gas? An Evaluation of the German Biogas Experience and Lessons for Wisconsin. September 2010. Great Plains Institute.
[111] National Biomass Action Plan for Germany. April 2009. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU)
[112] feed in tariff provided in Eurocents - The Future of Renewable Gas in Ireland. April 2010. Bord Gais
[113] Biogas Can Do It - facts, arguments and potential. December 2011. www.biogas.org

obligatory and establishing good revenues for biogas, the Renewable Gas Feeding and Storage Act (EEGasG) provided investors with the safety they need to invest in biogas feeding projects.

"Maschinenringe"–loosely translated as "machinery syndicate" are cooperatives that help farmers to buy their machinery. In recent years, these coops have increasingly expanded their business from standard farm machinery to renewable energy.

The most important policy to promote electricity production from renewable sources in Germany is the Renewable Energy Sources Act (EEG) under which renewable energy producers have guaranteed access to feed-in their electricity to the grid. The Act is reviewed every two years. The main recommendations of the 2011 draft review were: rates for producing biogas form manure, and food and biomass residuals should be increased. In combination with the 20-year-long fixed rates, this provides very high investment certainty. To compensate for the higher costs of small-scale installations, rates for small scale installations are higher. Similarly, systems that utilize agricultural waste receive a bonus payment in order to encourage farm participation.

An incentive law giving biomethane suppliers priority to the grid came into force in February 2008. The law also transfers responsibility for a major part of the associated costs to the grid operators instead of being borne by the biomethane suppliers. A loan program by the "Kreditanstalt für Wiederaufbau" (Credit Institute for Reconstruction) has assisted with 1,239 biogas plants,[114]

Germany set the target of getting 30 percent of total electricity production from renewables by 2020. The target was matched by an incentive of a higher utility buy-back rate that better reflected the cost to purchase equipment such as anaerobic digesters on farms. Other policy incentives were added such as sustainable biomass harvesting practices and matching biogas plants (anaerobic digesters) with CHP to increase the buy-back rate. The basic energy buy-back for biogas rate was 11.6 EUR cents for systems less than 150 kW, 9.1 EUR cents for less than 500 kW and 8.2 EUR cents for less than 5 MW systems. The added bonus incentives could result in almost doubling those buy-back rates.

United Kingdom[115]: The FIT for electricity from biogas or biomethane is paid on top of the electricity price, grandfathered for 20 years. The UK Feed in Tariff (FiT)[116] rates are : ≤ 250 kW = 14.0p/kWh; ≤500kW= 13.0p/kWh**,** and >500kW = 9.4p/kWh**.** The Renewable Heat Incentive (RHI)is 6.8p/kWh A major barrier confronting AD operators in the UK who wish to connect to the gas grid is that capital costs of grid connection are often very high, with quotes ranging from £ hundreds of thousands to over £1 million. Through the UK Green Investment Bank proposal to provide equity funding for AD – equity funding is available for suitable AD projects, under the management of a commercial fund manager. UK Renewable Heat Incentive (RHI) The UK provides investment support to directly facilitate the construction of new AD plants (fund £10 million). The AD Loan Fund provides loans for a minimum of £50,000 and a maximum of £1 million for a maximum term of five years

9.4 Barriers to Biogas Project Development

A number of barriers to biogas development were identified through the literature review as well as interviews undertaken during the Canadian Biogas Study. These included:

- High costs of projects;
- Lack of confidence in the technology by the financial services sector who loan capital to developers – AD is generally still considered an emerging technology in Canada. Interviewees

[114] Harvesting Clean Energy on Ontario Farms. June 2011. Heinrich Böll Stiftung, Washington DC
[115] Hit the gas: How to get the anaerobic digestion sector moving. 2012. Centre Forum
[116] A Detailed Economic Assessment Of Anaerobic Digestion Technology And Its Suitability To UK Farming And Waste Systems 2nd Edition. March 2010. The Anderson Centre And United Kingdom Anaerobic Digestion and Biogas Association

noted that dairy farmers are able to get capital financing because they have valuable land to use as collateral for loans;

- Low prices of natural gas (shown in Figure 9 below);
- FITs not high enough to justify biogas projects economically;
- Project approval takes too long and takes too much staff time;
- Uncertainty regarding municipal contracts and
- Financing and interconnection to utilities;
- Examples of regulatory barriers and challenges identified in BC include[117]:,extremely long approval process (estimated to be 2+ years); a lack of a clearly defined, linear regulatory process; a lack of a singular, provincially-recognized regulation and/or approval; lack of lateral communication between regulating bodies; and a requirement for up front information, which is impossible to provide (i.e. feedstock recipe)

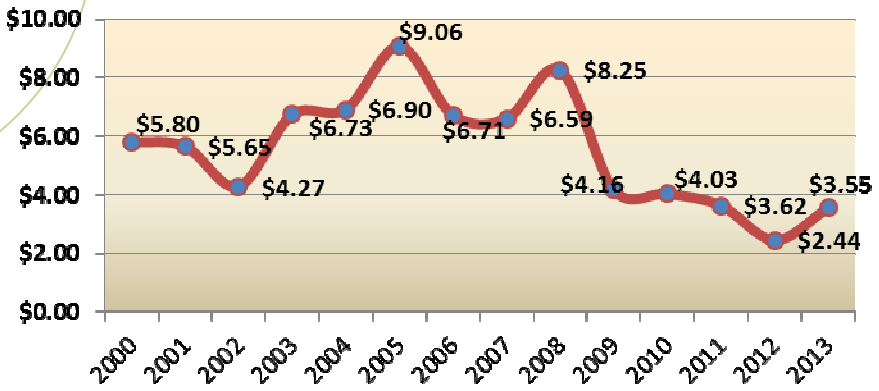


Figure 9: Price of Natural Gas in Canada, 2001 to 2013($/MMBTU)

[117] British Columbia on-farm anaerobic digestion benchmark study. No date. B.C. Agricultural Research and Development Corporation

10 Summary

This section summarizes information for biogas generally for Canada. Specific environmental, energy economic benefits of biogas from the five sources studied (agriculture; landfill gas; SSO from residential and commercial sources and wastewater treatment plants) are summarized in Sections 3-7 of the report.

10.1 Potential Biogas Opportunity in Canada

The previous sections of the report have shown that biogas can be produced from five different sources in Canada: agricultural wastes; municipal solid waste landfill gas; SSO from residential and commercial sources and wastewater treatment residuals. Many biogas projects integrate one or more of these sources: SSO material can be processed at wastewater treatment plants or at agricultural digesters using co-digestion. This approach has been implemented in the US but not in Canada to date.

Some recovery of energy is already underway in all of these sectors, but the potential for more recovery of biogas and production of green energy is significant.

Together all of these sources could produce an estimated 2,420 Mm^3/year of RNG or up to 810MW across Canada. This equates 3% of the national natural gas demand, or 1.3% of the national electricity demand.

Of this total, in theory about 68% is from agricultural sources; 12% is from landfill gas; about 6% to 7% could be from each of residential SSO digestion, commercial SSO digestion and wastewater treatment residuals. However, in practice, the contribution of each source is limited by practical considerations. An assessment is needed of the practical considerations related to each source as a follow on to this study.

The federal government carried out studies of LFG and WWTP biogas potential in the late 1990's as part of their climate change research. The LFG inventory and opportunity has recently been updated (2012) but the data are not available as the report is not yet public. This is an excellent source of realistic LFG recovery values but is not available by Province. Therefore for the summary tables we used publicly available sources of available LFG by province. These estimates do not consider the practicality of recovering LFG in some locations (limited by geography and economics) which has been assessed in the Environment Canada study.

Wastewater treatment residuals have not been studied in detail since a study by Environment Canada in about year 2000, assessing the opportunity for biogas utilization for energy production at the 50 largest plants in Canada. A recent report identified the main barriers to more development of WWTP projects is related to the fact that the recovery of energy is not the core business. Energy recovery projects generally need an internal champion who pushes the project forward.

Table 44: Estimates of RNG Available By Source in Canada (Mm^3/year)

	AG		LFG		SSO Residential		SSO Commercial		WWTP		Total	
Region	**Mm^3/y**	**MW**	**Mm^3/y**	**MW**	**Mm^3/y**	**MW**	**Mm^3/y**	**MW**	**Mm^3/y**	**MW**	**Mm^3/y**	**MW**
ON	333	111	113	38	48	16	62	21	71	24	627	209
QC	232	77	67	22	43	14	30	10	42	14	415	138
BC	73	24	38	13	14	5	17	6	24	8	167	56
Prairies	969	323	50	17	25	8	43	14	32	11	1,118	373

Maritimes	35	12	20	7	5	2	5	2	13	4	77	26
TOTAL	1642	547	288	96	135	45	157	53	182	61	2404	802

The potential contribution of future biogas energy compared to the current biogas energy being utilized is presented in Figure 10. It should be noted that estimates of the current installed base are approximate as no reliable inventory is available of existing biogas projects on a national basis.

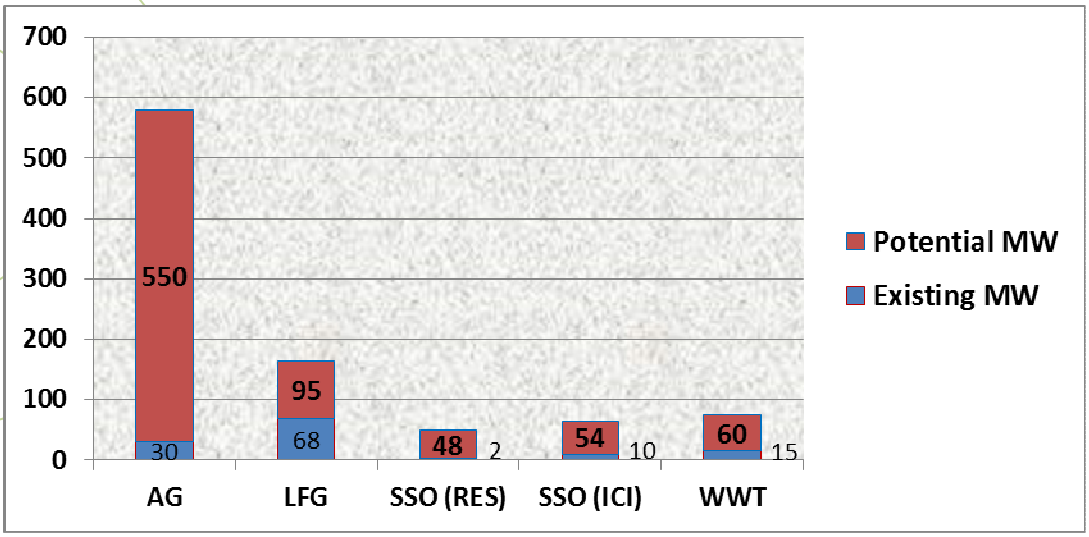


Figure 10: Future Biogas Potential in Canada Compared To Existing Biogas Energy By Source

The potential contribution of each source by region/province in Canada is shown in Figure 11. The relatively large contribution from agricultural sources in the Prairie provinces is related to the large agricultural base and availability of crop residues for digestion. The potential contribution from LFG and WWTP by province and region were not known, as only national totals were identified in the study. The totals were distributed to regions by pro-rating to population. The potential is shown as MW, assuming that 3Mm^3/year of RNG produces 1MW.

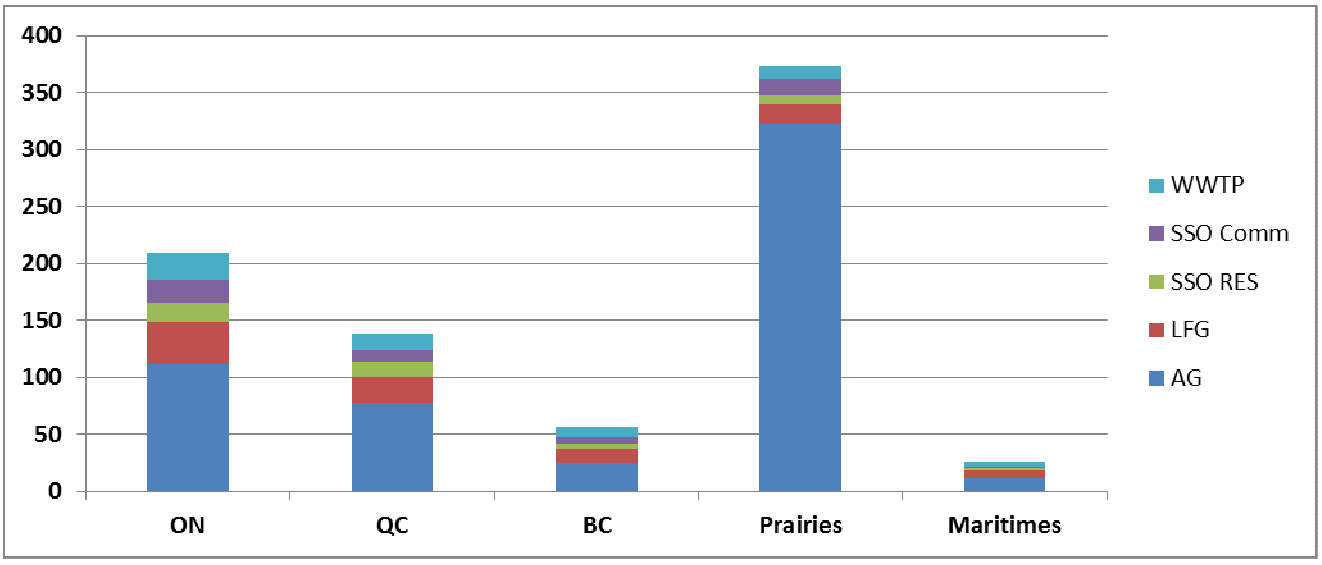


Figure 11: Potential Biogas Energy By Source and Region in Canada

10.2 General Benefits of Biogas

Biogas is a flexible energy source, suitable for different purposes:

- Generation of heat;
- Generation of electricity;
- Co-generation of heat and power;
- Production of RNG for injection into the natural gas network, or
- Creation of CNG for use as a vehicle fuel.

Biogas has a number of benefits compared to other sources of energy:

- It is a flexible energy source which can be converted to electricity, heat or vehicle fuel; other energy sources (e.g. solar, wind, geothermal) can only produce one type of energy;
- It is local and can contribute to a distributed electricity grid;
- It can be produced across Canada in a wide variety of settings (agricultural, municipal, commercial);
- It is an excellent baseload energy source as it is not dependent on climate factors for production.

10.3 Environmental, Economic, Social and Community Benefits of Biogas Energy

Biogas has a number of benefits across all sources and some specific benefits by source which were discussed in earlier sections of this report. General benefits (regardless of the source of the biogas) include:

- Recycling of nutrients through re-application of digestate on land;
- Preservation of carbon within the carbon cycle by landspreading digestate after digestion;
- Reduced emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from storage thereby reducing GHG emissions and contributions to climate change;
- Reduced odours;
- Pathogen destruction of up to 99% which contributes to cleaner, safer waterways, and
- GHG reductions from biogas projects can help local communities meet sustainability, community energy plan and GHG reduction targets.
-

10.4 Barriers To Developing Full Biogas Energy Potential

There are a number of barriers to realizing the full potential of biogas energy identified in this document. Some are common to all biogas projects and some are unique to specific waste streams:

- Financing of AD projects is challenging due to a reported lack of familiarity with the technology by financial institutions. Many more full scale facilities need to be constructed in Canada to address this barrier; financing institutions need to be able to “kick the tires” of existing facilities to have a comfort level that their investment is secure;

- Wastewater treatment plant biogas projects generally are not developed as energy generation is not the "core business" of wastewater treatment plant operating staff. When capital budgets are set, other capital projects generally receive more attention than biogas recovery projects;
- Receiving approvals for interconnections with the electricity system are slow and expensive. Some plants simply waste energy rather than trying to sell it into the electricity grid;
- Except for Ontario, feed in tariffs or revenues available for electricity from biogas facilities are not at a level which makes most biogas projects related to electricity generation economically viable;
- Biogas projects related to processing of SSO need to compete with composting which is generally less expensive, although the price gap between the two technologies narrows at capacities of above 60,000 tonnes/year (the amount typically produced by a Green Bin program in a city of 300,000 households, or a population of 1 million);
- Policies in provinces and municipalities across Canada are not sufficiently supportive of biogas projects. This could be changed through procurement specifications which require e.g. RNG fuelled trucks or other requirements to support production of more RNG.
- Low prices of natural gas present challenges for the RNG industry

10.5 Policies Which Support Biogas Project Development

The literature review identified a range of policies in place across Canada, the US and Europe which support biogas projects and encourage expansion of the biogas industry. Those which are considered most supportive often relate to renewable energy or GHG reduction targets. California is considered a leader in biogas supportive policies, with some other states (such as New York State) having some good policies. The EU and Europe in general are very supportive of renewable energy as they are more dependent on imported energy than other countries. Germany and Sweden are considered leaders, with interesting policies emerging from other countries also, but particularly in northern European countries such as Denmark and the Netherlands.

The Ontario FIT program is considered a leader in Canada and has led to the construction of a number of farm digesters and the development of a number of landfill gas and wastewater treatment plant biogas projects, and interest in AD of residential and IC&I SSO. Policies which have spurred interest in landfill gas projects in other provinces include an interest in GHG reduction by municipalities, and an active market for GHG reduction credits in Alberta related to large emitter caps, with a penalty of $15/tonne where the caps are exceeded. The shortfall can be purchased through GHG reductions achieved in Alberta. Purchase of RNG by Fortis BC has stimulated the market to some extent in BC.

The Quebec government planned landfill ban on organics by 2020 has stimulated activity in organics diversion projects, but the pace has slowed down, however, the Quebec cap and trade system which is being brokered through the Western Climate Initiative (with California) is likely to stimulate the market.

10.6 Conclusions

Biogas presents a significant opportunity to recover energy from resources which are currently wasted. This contributed to renewable energy and GHG reduction goals.

Various information gaps currently exist and need to be filled through a comprehensive workplan with a number of research elements.

Procurement specifications stipulating renewable energy content is a successful approach to developing a biogas market. The Biogas Association should develop a strategy on targeting procurement processes to support more biogas projects.

The financial community need certainty before they invest in technologies which are relatively newer to the Canadian market. Government policy provides the certainty that the financial markets need, and this helps investment in projects involving AD.

10.7 Next Steps and Research Needs

A number of research needs were identified through the technical research which could refine the practical estimates of the biogas opportunity in Canada even further. Suggested next steps to fill some of these information gaps are listed below:

- Partnerships should be explored with associations which represent wastewater treatment facility research and support to complete two areas of research related to biogas energy generation at wastewater treatment plants:
    - A study of the 50 largest WWTPs in Canada was carried out by Environment Canada in 2000. This assessment needs to be updated. A current inventory of all biogas projects at wastewater treatment plants across Canada should be developed; the potential for development of biogas energy projects at wastewater treatment plants across Canada should be explored and the most promising opportunities should be identified;
    - In the US, a total of 2.3 million metric tons of carbon dioxide emission reductions can be achieved annually through increased use of CHP at WWTPs. These reductions are equivalent to planting approximately 640,000 acres of forest, or the emissions of approximately 430,000 cars[118]. A similar assessment should be carried out for Canada, updated to 2014.
- The most recent detailed publication of LFG data by province in Canada is based on 2005 data. A recent Environment Canada study is not yet public. A current listing of all landfill gas projects in Canada should be developed.
- A research study should be considered to quantify the existing situation with respect to management of high strength food waste in the industry sector across Canada, including existing on-site energy recovery through AD and the potential for additional on-site energy recovery through AD.
- A methodology should be developed to accurately estimate the net GHG emission impacts of biogas energy use from different sources (agriculture vs LFG, etc) and in different applications (e.g. electricity vs transportation, etc)
- Emission factors for different energy sources including biomass and natural gas (but not biogas specifically) were found in various studies. Biogas specific emission factors need to be developed.
- This study identified significant potential for biogas project development. However, in practice, the contribution of each source is limited by practical considerations. An assessment is needed of the practical considerations related to each source as a follow on to this study.

[118] Case Study Primer for Participant Discussion: Biodigesters and Biogas; May 14th, 2012, USEPA

Appendix A – List Of Reports and Literature Sources Reviewed

Reports and Articles Reviewed

1. 2012 Bioenergy Action Plan. August 2012. Prepared by the Bioenergy Interagency Working Group, California Natural Resources Agency
2. A Canadian Biomass Inventory: Feedstocks for a Bio-based Economy. June 27, 2003. BIOCAP Canada
3. A Comparison Of Dairy Cattle Manure Management With And Without Anaerobic Digestion And Biogas Utilization. June 2004. AgSTAR ProgramU.S. Environmental Protection Agency - shows positive environmental and economic Impacts of anaerobic digestion compared without anaerobic digestion
4. A Detailed Economic Assessment Of Anaerobic Digestion Technology And Its Suitability To UK Farming And Waste Systems 2nd Edition. March 2010. The Anderson Centre
5. An Inventory of Landfill Gas Recovery and Utilization in Canada 2008 and 2009. Prepared by: The Greenhouse Gas Division of Environment Canada, January, 2011
6. A Review of Low-Carbon Energy for Canada. March 2013. Trottier Energy Futures Project
7. Anaerobic Digestion: A Market Profile. March 2013. UK Cogent Skills Sector Council –
8. An Economic Analysis of Three Operational Co-digestion Biogas Plants in Germany (academic article)
9. An evaluation of the policy and techno-economic factors affecting the potential for biogas upgrading for transport fuel use in the UK (academic article)
10. Assessment of Business Case for Purpose-Grown Biomass in Ontario. March 2012. Prepared for Ontario Federation of Agriculture Erie Innovation and Commercialization
11. Beyond Waste : A Regulatory and Market Report by Edgar & Associates, Inc. April 2013
12. Biogas Can Do It – facts, arguments and potential. December 2011. www.biogas.org
13. Biogas report 2012. December 2012. European Biogas Association
14. Biomass Inventory and Bioenergy Assessment: An Evaluation of Organic Material Resources for Bioenergy Production in Washington State. December 2005 (updated 2010). Washington State Department of Ecology
15. Biomethane Guide For Decision-Makers - A Policy Guide On Biogas Injection Into The Natural Gas Grid. April 2013. Intelligent Energy - Europe programme.
16. Biogas prediction and design of a food waste to energy system for the urban environment. October 2011. Nathan Curry, Pragasen Pillay. Renewable Energy
17. Biogas report 2012. December 2012. European Biogas Association
18. British Columbia on-farm anaerobic digestion benchmark study. December 2011. B.C. Agricultural Research and Development Corporation.
19. California Renewable Technology Market and Benefits Assessment. November 2001. Prepared by EPRI for the California Energy Commission
20. Canada Report on Bioenergy 2010. Sept 15, 2010. Prepared for Natural Resources Canada

21. Canada Wide Approach for the Management of Wastewater Biosolids, Canadian Council of Ministers of the Environment (CCME), 11th October, 2012

22. Carbon-Free Prosperity 2025: How the Northwest Can Create Green Jobs, Deliver Energy Security, And Thrive in the Global Clean-Tech Marketplace. October 2008. Clean Edge

23. Case Study Primer for Participant Discussion: Bio-digesters and Biogas. May 14, 2012. EPA

24. Cheap Enough? Making the Switch From Diesel Fuel to Natural Gas. The Conference Board of Canada Energy, Environment and Transportation Policy, 2012

25. City of Toronto Biogas Potential. October 2009. Yield Energy

26. CO_2 abatement costs of greenhouse gas (GHG) mitigation by different biogas conversion pathways (academic article)

27. Concepts and profitability of biogas production from landscape management grass (academic article)

28. Cost-effective biogas utilisation a: A modelling assessment of gas infrastructural options in a regional energy system (academic article)

29. Development of an investment decision tool for biogas production from agricultural waste (academic literature)

30. Direct marketing of electricity from biogas and biomethane: an economic analysis of several business models in Germany (academic article)

31. Economic and environmental assessment on the energetic valorization of organic material for a municipality in Quebec, Canada (academic literature)

32. Economic Feasibility of Anaerobic Digesters. June 2008. Alberta Agriculture and Rural Development.

33. Economic assessment of the integrated generation of solid fuel and biogas from biomass (IFBB) in comparison to different energy recovery, animal-based and non-refining management systems (academic literature)

34. Environmental and economic evaluations of centralized biogas plants running on cow manure in Hokkaido, Japan (academic literature)

35. Electricity Production from Anaerobic Digestion of Household Organic Waste in Ontario: Techno-Economic and GHG Emission Analyses. 2012. Environmental Science and Technology

36. Energy analysis of biogas production and electricity generation from small-scale agricultural digesters (academic article)

37. Exploring the potential for biomass power in Ontario. (February 2006). BIOCAP Canada Foundation

38. Farm to Fuel: Developers' Guide to Biomethane. July 2012. Viking Strategies for Biogas Association

39. Feasibility Study – Anaerobic Digester and Gas Processing Facility in the Fraser Valley, British Columbia. November 2007. Prepared by Electrigaz for the BC BioProducts Association

40. Feasibility Study – Biogas upgrading and grid injection in the Fraser Valley, British Columbia. June 2008. Prepared by Electrigaz for the BC Innovation Council

41. Final Report for the Study of Food-Based Inputs for Biogas Systems in Ontario. May 9, 2009. Ontario Ministry of Agriculture, Food and Rural Affairs

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