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ORGANIC MATERIALS

Maximizing Resource Recovery from Waste Through Biogas and RNG Production

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A Spectra Energy Company

FCM
FEDERATION OF CANADIAN MUNICIPALITIES
FÉDÉRATION CANADIENNE DES MUNICIPALITÉS

Canadian Biogas Association

Contents

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1. Summary

1.1 OVERVIEW

This study assesses the economic feasibility and environmental benefits of producing biogas by anaerobically digesting the organic fraction of the City of London's (City) residential waste stream, and subsequently converting the biogas to renewable natural gas (RNG) for use in compressed natural gas (CNG) vehicles.

The City worked together with the Canadian Biogas Association (CBA) and Union Gas on this study. The Federation of Canadian Municipalities provided funds to assist the City in this study. The overall work is a contribution under the London Waste to Resources Innovation Centre, an initiative designed to maximize resource recovery and create value added products from waste feedstocks.

The City undertook this work as part of its investigation of options for the management of the organic fraction of its residential waste. In this report, two scenarios are considered: collecting and anaerobically digesting source-separated organic (SSO) materials or anaerobically digesting organic materials separated from a mixed waste stream at a processing facility (facility-separated organics (FSO)).

This study includes quantitative estimates of the costs of anaerobic digestion (AD) systems for the organic fraction of residential waste, of the quantities of biogas and RNG that can be generated, and of the net cost savings of replacing the City's waste collection fleet with CNG vehicles, fuelled by RNG. This report also estimates the annual greenhouse gas (GHG) emission reduction expected to result from the replacement of diesel with RNG as a fleet vehicle fuel. This information will assist the City in selecting the most appropriate solution for managing the organic fraction of London's residential waste stream.

1.2 RESEARCH PROCESS AND REPORTS

City of London, CBA and Union Gas worked together to characterize the data requirements and develop a research plan.

The research process used to generate this report, and related contributing documents, can be summarized as follows:

1. City of London, CBA and Union Gas gathered to discuss needs and requirements, City decision-making processes, and timelines.
2. The City, CBA and Union Gas drafted a detailed Request for Information (RFI) document for technology suppliers, which was sent to relevant companies in the biogas sector. The RFI included London's annual organic waste volumes and types, details related to the landfill site and current landfill gas production volumes, and asked companies for the following: products and services; cost estimates for full services and partial services; estimates of RNG production volumes; and operational considerations. This is included in ***Appendix A***.
3. Using data from the submissions, facility costs and RNG volumes were analyzed and compared. Findings from this analysis are summarized in sections 3.1 and 3.2 respectively.
4. Union Gas estimated London's potential CNG/RNG demand based on the London Transit Commission bus fleet (LTC was used as a theoretical example only as their current plans do not include CNG buses. Many municipalities are either directly or indirectly involved with public transit services) and City of London's waste collection fleet. Union Gas also calculated cost estimates for owning CNG fuelling stations, and also provided a qualitative discussion of alternative implementation strategies (using tube trailers to transport fuel to other stations) and privately owned fuelling station scenarios. These findings are summarized in Section 3.3. See the full report in ***Appendix B***.
5. CBA engaged the services of a consultant who calculated the lifecycle GHG emissions of switching from diesel fuelled trucks (the base case) to CNG trucks, using separate calculations to examine the impact of fuelling the vehicles with fossil CNG or RNG. Blending biodiesel into diesel fuel, and using conventional diesel fuelled trucks was examined in a separate analysis. These findings are summarized in Section 3.4. See the full GHG analysis in ***Appendix C***.
6. The CBA and the City consolidated all data inputs, and summarized them in this report.

It should be noted that municipalities have unique characteristics, such as population, available organic sources, and location and transportation factors. On this basis, it is strongly recommended that municipalities consider site-specific inputs when determining RNG cost estimates and volumes.

To maintain confidentially promised to technology suppliers, data is summarized, and data attributed to specific companies has been removed. Highlights of the technologies submissions received for this research are found in ***Appendix D***.

1.3 WASTE COLLECTION COST IMPACTS

The City of London has estimated that weekly collection of SSO from 120,000 single-family residences would generate approximately 14,000 tonnes per year of SSO. Based on the estimated cost of supplying SSO bins, purchasing additional collection vehicles, and operating the weekly SSO collection program, it is estimated there will be a net increase in annual garbage and organics collection costs of approximately $2,400,000 ($170 per tonne collected) compared to the existing garbage only collection costs.

1.4 FACILITY CAPITAL AND OPERATING COSTS

In response to a request for information, AD technology suppliers voluntarily supplied facility cost information as well as biogas and RNG generation information used in this report. The information provided to technology suppliers on which to base their estimates was limited and as a result a wide range of cost estimates were received. The cost estimates were adjusted by adding costs for missing information, and trimming the outlying high or low estimates.

1.5 SAVINGS

Both the SSO and FSO scenarios will result in a reduction in the disposal of waste in the W12A landfill. The City of London estimates that there will be avoided disposal savings of $20 per tonne of waste diverted from the W12A landfill. To account for processing residues, it is estimated that the SSO scenario avoided landfill disposal will be 90% of the processed material, and for the FSO scenario, 70% of the FSO separated from the garbage and processed by AD. The SSO scenario also includes processing of 11,000 tonnes per year of commercial organics, for which the SSO-AD facility will earn revenue from tipping fees.

1.6 BIOGAS AND RNG GENERATION

Biogas generation estimates provided by the technology suppliers ranged from 120-180 normalized cubic metres (Nm^3) per tonne SSO for the SSO scenarios, with an average of approximately 130 Nm^3 per tonne SSO at 60 percent methane. For FSO, the biogas generation estimates ranged from 110-140 Nm^3 per tonne FSO (55-70 Nm^3/tonne MSW), with an average of 125 Nm^3 per tonne FSO at 60 percent methane.

The biogas produced is processed to create usable RNG. It is assumed that about 90% of the methane can be recovered using biogas to RNG conversion technology. The pipeline quality RNG produced is 95% methane by volume.

The RNG quantities produced translate to approximately 2.8 gigajoules (GJ) of energy per tonne of separated organics either from SSO or from FSO processes.

1.7 ESTIMATING THE VALUE OF RNG AS A VEHICLE FUEL (RNG BENEFIT)

In order to provide a baseline estimate of the value of RNG to the City of London, Union Gas assessed the benefit of using RNG to fuel the City's waste collection fleet converted to CNG vehicles. Union Gas considered costs of converting the fleet to CNG, and establishing a CNG fueling station in the estimates.

The waste collection fleet would not consume all of the RNG produced by either the SSO or FSO scenarios, therefore a hypothetical conversion of the transit fleet was also considered. This study considered a hypothetical conversion of a fleet of buses operated through the London Transit Commission (LTC) as part of the analysis, in order to determine the cost of RNG as a vehicle fuel. It is important to note that as of 2016, the LTC has no plans to convert the bus fleet to CNG.

1.8 GHG EMISSION REDUCTION BENEFITS

A lifecycle analysis related to the GHG impact of using RNG as a vehicle fuel scenario was completed using the GHGenius model, which was designed specifically for transportation fuels by Natural Resources Canada. The lifecycle analysis also looked at the impact of carbon intensity of electricity in Ontario and Alberta to show a broader applicability to Canadian municipalities.

In Ontario, when 100 % RNG is used instead of fossil natural gas, the "well to wheel" emission reduction potential ranges from 87-91 %, depending on how organics are collected and separated. In Alberta, the emission reduction potential ranges are lower (41-56%) as a result of the higher carbon intensity of electricity in that province.

In addition to the GHG reductions from using RNG in place of diesel, there are also GHG reductions by diverting organics from the landfill. Harnessing the methane produced during decay reduces GHG emissions in both the SSO and FSO scenarios.

To get a better understanding of the scale of benefit provided by RNG as a vehicle fuel from these two sources, these emission factors were applied to the City of London's waste collection fleet and a hypothetical transit bus fleet based on LTC's current fleet and diesel use.

1.9 NET SCENARIO IMPLEMENTATION COSTS

Table 1 summarizes the estimated net cost to the City of implementing the SSO or FSO scenario, considering costs, savings, and revenues. There is a large range in the net cost. At the low end of the range, the cost for anaerobically digestion of SSO or FSO material is comparable to or even less than the cost expected to be offered by the local market for aerobic composting services in the vicinity of the City of London. These calculations and assumptions are further detailed within the body of this report. For the City of London, the analysis has demonstrated the importance of considering AD facilities and the potential of RNG as part of its future resource recovery solutions for the organic fraction of waste.

TABLE 1: SUMMARY OF COSTS, REVENUES AND SAVINGS BY SCENARIO

Component	SSO Scenario (25,000 tonnes/year)		FSO Scenario (90,000 tonnes/year)	
	Low	High	Low	High
	$/tonne processed waste			
Green Bin and Garbage Collection Costs	$170		-	
Facility Costs	$90	$160	$100	$120
Avoided Disposal Savings	$18		$7	
Offset Credit from Diversion	$24		$12	
Revenue from RNG as Fuel	$20		$10	
Revenue from RNG as Fuel (With Carbon Pricing)	$29		$15	
Net Cost[1]	$190	$260	$70	$90
Net Cost[1] (With Carbon Pricing)	$160	$230	$50	70

Notes

1. Costs rounded to the nearest $10.

This report will be used by the City of London as follows:

- As an outcome associated with the London Waste to Resources Innovation Centre;
- As input for the detailed feasibility study of using CNG as fuel for waste collection vehicles;
- As input into the ongoing options analysis for landfill gas recovery and energy creation (versus the current flaring);
- As input into a sensitivity analysis between aerobic composting and anaerobic digestion;
- To inform other public and private fleets in London and area on the potential that exist for CNG as a fuel;
- As input for City's Resource Recovery Strategy currently being developed; and
- As input into the Environmental Assessment process for long-term waste disposal.

1.10 INVESTIGATION OF RNG BY MUNICIPALITIES

The CBA is reaching out to municipalities across Canada to encourage them to investigate producing RNG from the biogas generated by existing landfills, wastewater treatment plants, and to consider producing biogas by anaerobically digesting the organic fraction of their residential and other waste streams.

Increasingly, RNG production is being investigated or implemented by municipalities across Canada. RNG can be used interchangeably with conventional or fossil natural gas. The following municipalities are in various stages of designing or building RNG facilities:

- Surrey and Nanaimo in British Columbia
- Edmonton, Alberta
- Niagara Region, Peel Region, Toronto, Durham Region in Ontario
- Saint Hyancinthe, Montreal, Quebec City, Rivière-du-Loup in Quebec

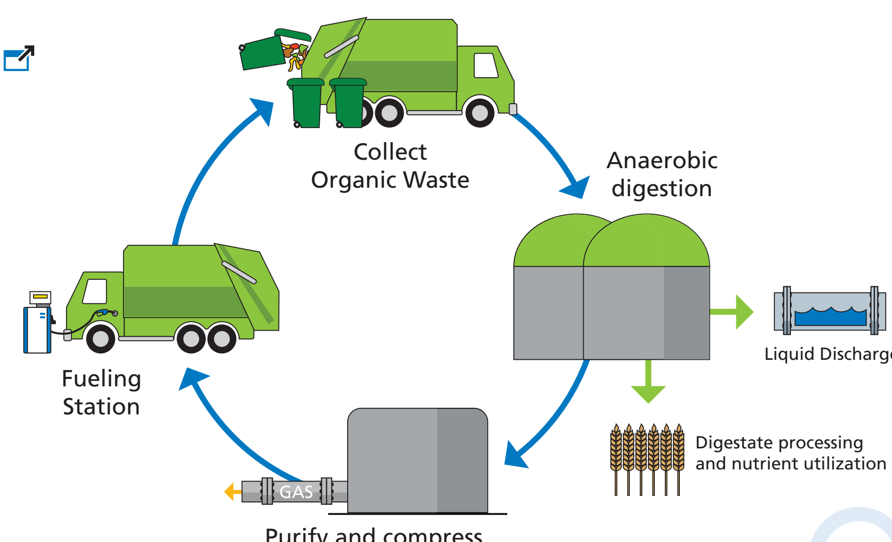
In addition, Hamilton is generating RNG, and using a portion of it as a vehicle fuel.

In Ontario, the CBA and Union Gas have been working together to develop the RNG market, providing support to potential producers, and advocating for supportive policies.

As climate change action plans and supportive RNG policies improve at all levels of government, there is potential to dramatically increase the volume of RNG production from municipalities. This report can provide assistance in assessing the feasibility and benefits of RNG to municipalities that are considering RNG production for the benefit of their own citizens, and for the global community.

Additional resources that may be of assistance include:

- Closing the Loop: Primer for Municipalities, Food Processors and Fleets on Fuelling Vehicles Using RNG
- Municipal Guide to Biogas
- Canadian Biogas Study
- Canadian Biogas Association website and resources
- RNG Technology Roadmap
- ReThink Organic Waste Report



2. Background: City of London, Ontario

The City of London is situated in the heart of Southwest Ontario and has a population of over 380,000. The City currently has a residential waste diversion rate of approximately 45% with a disposal rate of 225 kilograms per year per capita. London's waste diversion programs are similar to the programs in other large Ontario municipalities with one exception; London does not have a Green Bin program.

Curbside collection of garbage, recycling and yard waste is provided to approximately 120,000 single-family homes. Bulk collection of garbage and recycling is provided to approximately 50,000 multi-residential units.

The current waste collection system collects approximately 90,000 tonnes of garbage (which includes a small amount of commercial garbage) containing about 45,000 tonnes of organics (30,000 tonnes of food waste and 15,000 tonnes of other material such as non-recyclable paper products, diapers, etc.). The City also collects approximately 26,000 tonnes of blue box recyclables and 26,000 tonnes of yard materials (leaves, garden trimmings and brush) annually.

The City owns and operates the W12A Landfill located within the City. The landfill receives garbage from City programs (residential waste collection as well as City operations), as well as approximately 70,000 tonnes per year of commercial waste. The W12A Landfill has a gas collection and flaring system, which is expected to collect about 1,200 cfm of landfill gas at 50% methane over the next several years. It is estimated that the landfill gas collection system collects approximately 50% of the landfill gas generated.

3. Scenarios

3.1 RNG PRODUCTION SCENARIOS

Two RNG production scenarios were considered for this report, as summarized below.

3.1.1 Source-separated Organics Scenario

Under this scenario, the City of London would:

- implement program of weekly curbside collection of SSO from single-family residences,
- build and operate (under contract) a facility at the W12A Landfill to process and anaerobically digest 14,000 tonnes per year of SSO and 11,000 tonnes per year of commercial organics, for a total of 25,000 tonnes per year (the 'SSO-AD Facility'),
- manage any processing effluent or residue at the W12A site,
- manage the digested organic material as a fertilizer or soil conditioner through a beneficial use program,
- build and operate a biogas upgrading facility at W12A Landfill to refine the biogas to pipeline quality RNG supplied to Union Gas' distribution system, and
- use the RNG to replace diesel as a fuel for fleet vehicles.

3.1.2 Facility-separated Organics Scenario

Under this scenario, the City of London would:

- build and operate (under contract) a facility at the W12A Landfill to receive and process 90,000 tonnes per year of garbage, from which 45,000 tonnes per year of FSO would be anaerobically digested (the 'FSO-AD Facility'),
- manage any processing effluent or residue at the W12A site,
- manage the digested organic material as a fertilizer or soil conditioner through a beneficial use program,
- build and operate a biogas upgrading facility at W12A Landfill to refine the biogas to pipeline quality RNG supplied to Union Gas' distribution system, and
- use the RNG to replace diesel as a fuel for fleet vehicles.

The ability to produce a fertilizer or soil amendment meeting the quality requirements for beneficial use is proven in Ontario for SSO but not for FSO. The FSO scenario considered in this report assumes the beneficial use of the processed organic material, however further investigation outside of the scope of this report is required to confirm the assumption.

In addition, a facility processing garbage to separate FSO for anaerobic digestion may be capable of separating other materials, such as metals or plastics, for recycling, however this capability is not proven in Ontario. Since the proportion of the garbage stream that could be recovered for recycling is assumed to be small relative to the proportion separated as FSO, recovery of recyclables is not considered in the FSO scenario.

3.2 COSTS

3.2.1 Waste Collection Costs

The City of London has estimated that weekly collection of SSO from 120,000 single-family residences would generate approximately 14,000 tonnes per year of SSO (based on Ontario experience). The estimated cost of supplying SSO bins and purchasing additional collection vehicles required is estimated to be $12,000,000. Operating the weekly SSO collection program is estimated to result in a net increase in annual waste collection costs of approximately $2,400,000 (this is the net increase in annual garbage and organics collection costs compared to the existing garbage only collection costs) or $170 per tonne SSO collected. This cost includes annualized capital replacement costs.

3.2.2 Facility Capital and Operating Costs

A Request for Information (RFI) issued as part of this project asked technology suppliers to provide estimates of the capital and operating costs of the SSO-AD and FSO-AD Facilities, and also to estimate the quantity and methane content of the biogas that each Facility would produce. The RFI is included as ***Appendix A*** to this report.

RFI responses were received from five technology suppliers.

The RFI responses were used as the basis for the range of SSO-AD and FSO-AD facility capital and operating costs used in this report. However, some RFI responses did not include estimated costs for all components of a SSO-AD or FSO-AD Facility. Where necessary, assumed costs were added to complete the RFI responses as follows:

- where the costs of the biogas upgrading system were omitted, $7,000,000 in capital costs, and $500,000 in annual operating costs were added, and
- where the costs of managing digestate or digester solids through a beneficial use program were omitted, costs of $20-$35 per tonne of SSO processed, or $10-$18 per tonne of garbage received, were added for the SSO and FSO scenarios respectively.

One RFI response to each of the SSO and FSO scenarios provided costs significantly different from the costs provided by other submissions for the scenario. The high SSO-AD Facility and low FSO-AD Facility estimates were excluded from the range of SSO-AD and FSO-AD costs used in this report.

The ranges of the adjusted capital and operating cost estimates are presented in Tables 2 and 3.

TABLE 2: RANGE OF SSO-AD FACILITY COST ESTIMATES PROVIDED BY TECHNOLOGY SUPPLIERS (ADJUSTED)

SSO Scenario (25,000 tonnes/year)[6]				
	Units	**Range of Capital Costs[1,2,5]**	**Range of Operational Costs[3,4]**	**Range of Combined Costs[7,8]**
Low	Total	$17,000,000	$1,000,000	-
	$/tonne	$46	$40	$90
High	Total	$35,400,000	$2,625,000	-
	$/tonne	$95	$105	$160
Average	Total	$24,800,000	$1,750,000	-
	$/tonne	$65	$70	$140

Notes

1. Estimated capital costs include
   - SSO-AD facility and the biogas upgrading system
2. Estimated capital costs exclude:
   - land acquisition
   - site development and servicing
   - contingency budget
3. Estimated operational costs include:
   - operation and routine maintenance of the SSO-AD facility and the biogas upgrading system
   - management of solid process residue and liquid effluent at W12A Landfill site
   - management of digestate or digester solids through a beneficial use program
4. Estimated operational costs exclude:
   - contingency budget
5. Capital cost per tonne based on 20-year amortization and a real interest rate of 3%
6. Costs converted to 2016 $ Cdn
7. The combined costs do not represent the summation of the operational and capital costs, the high and low values were considered separately for each category.
8. Costs rounded to the nearest $10.

TABLE 3: RANGE OF FSO-AD FACILITY COST ESTIMATES PROVIDED BY TECHNOLOGY SUPPLIERS (ADJUSTED)

FSO Scenario (90,000 tonnes/year)[6]				
	Units	**Range of Capital Costs[1,2,5]**	**Range of Operational Costs[3,4]**	**Range of Combined Costs[7,8]**
Low	Total	$34,000,000	$4,950,000	-
	$/tonne	$25	$55	$100
High	Total	$89,700,000	$7,345,000	-
	$/tonne	$67	$82	$120
Average	Total	$57,900,000	$6,305,000	-
	$/tonne	$42	$70	$110

Notes

1. Estimated capital costs include
   - SSO-AD facility and the biogas upgrading system
2. Estimated capital costs exclude:
   - land acquisition
   - site development and servicing
   - contingency budget
3. Estimated operational costs include:
   - operation and routine maintenance of the SSO-AD facility and the biogas upgrading system
   - management of solid process residue and liquid effluent at W12A Landfill site
   - management of digestate or digester solids through a beneficial use program
4. Estimated operational costs exclude:
   - contingency budget
5. Capital cost per tonne based on 20-year amortization and a real interest rate of 3%
6. Costs converted to 2016 $ Cdn
7. The combined costs do not represent the summation of the operational and capital costs, the high and low values were considered separately for each category.
8. Costs rounded to the nearest $10.

The City of London has the opportunity to combine the upgrading of the biogas with landfill gas from the W12A Landfill. This would provide an 'economy of scale' by building a larger RNG upgrading facility and lower the unit upgrading costs for the biogas and landfill gas. The City estimates that if a combined biogas and landfill gas upgrading facility was constructed, the portion of the capital and operating costs attributable to the SSO-AD or FSO-AD facilities would be less than the costs for a stand-alone biogas upgrading system for either facility. The City estimates the savings to the SSO and FSO scenarios to be $3,000,000 in capital costs and $200,000 annually in operating costs.

3.2.3 Revenue and Savings

The SSO scenario includes processing of 11,000 tonnes per year of organics from the private sector or from another municipalities, for which the SSO-AD facility will earn revenue from tipping fees. For the purpose of this report, it is assumed the revenue from the 11,000 tonnes will cover the net cost of processing this material. In other words, this material would be charged the cost of facility (operating and annualized capital) less the RNG revenue. This is similar to how the City manages it Material Recovery Facility that receives recyclables from other municipalities. These municipalities are charged the combined capital/operating cost ($/tonne) of the facility less their portion of revenue from the sale of the recyclables.

In both the SSO and FSO scenarios, the tonnage of waste disposed of in the W12A Landfill will be reduced. For the SSO scenario, the avoided landfill disposal is estimated to be 90% of the tonnage of SSO processed at the SSO-AD Facility to account for processing residues. Similarly, for the FSO scenario the avoided landfill disposal is estimated to be 35% of the garbage processed at the FSO-AD facility (equivalent to 70% of the FSO separated from the garbage and processed by AD). The City has estimated the savings from avoided disposal to be approximately $15 to $20 per tonne. For the purpose of this study, it is assumed that avoided disposal savings will be $20 per tonne.

The avoided disposal savings attributed to each scenario are presented in Table 4.

TABLE 4: ESTIMATED AVOIDED DISPOSAL SAVINGS

Scenario	Avoided Disposal Savings		
	Tonnes Diverted/year	Annual Savings at $20/tonne diverted	Savings/tonne processed
SSO	12,600[1]	$252,000	$18
FSO	31,500[2]	$630,000	$7

Notes:

1. 90% of 14,000 tonnes per year of SSO
2. 70% of 45,000 tonnes per year of FSO

3.2.4 Summary of Collection and Facility Costs

The estimated additional waste collection and facility costs associated with the implementation of the SSO and FSO scenarios are presented in Table 5.

TABLE 5: ESTIMATED ADDITIONAL WASTE COLLECTION AND FACILITY COSTS BY SCENARIO

Component		SSO Scenario (25,000 tonne/ year SSO)		FSO Scenario (90,000 tonne/ year garbage)	
		Low	High	Low	High
SSO and Garbage Collection Costs[1]	$/tonne	$170		-	
Total Facility Costs[2]	$/tonne	$90	$160	$100	$120
Avoided Disposal Savings[3]	$/tonne	$18		$7	
Overall City Cost Excluding RNG Revenue	$/tonne[4] (processed)	$240	$310	$90	$110
	$/year[5]	$3,400,000	$4,300,000	$8,100,000	$9,900,000
	$/tonne (diverted)[6]	$270	$340	$260	$310

Notes:

1. Increase in annual garbage and organics collection costs compared to the existing garbage only collection costs. See Section 3.1.1 for details
2. SSO facility costs from Table 2 in Section 3.1.2. FSO facility costs from Table 3 in Section 3.1.2.
3. See Section 3.1.3 for details.
4. Costs rounded to the nearest $10.
5. Costs based on multiplying $/tonne (processed) by 14,000 (City) tonnes for SSO scenario and 90,000 (City) tonnes for FSO scenario.
6. Costs based on dividing $/year costs by 12,600 (City) tonnes diverted for SSO scenario and 31,500 (City) tonnes diverted for FSO scenario.

Based on the estimated costs and savings previously presented in this report, the estimated annual cost of implementing the SSO scenario ranges from $240 to $310 per tonne. For the FSO scenario, the estimated annual cost ranges from $90 to $110 per tonne.

The estimated costs of implementing the SSO or FSO scenarios presented in this report are based in part on limited information received from technology suppliers. There were a number of adjustments and assumptions made for the purpose of this report, which may not apply to municipalities with conditions dissimilar to those of the City of London. Any municipality considering either scenario presented in this report is strongly encouraged to develop their own cost estimates.

3.3 ESTIMATED BIOGAS AND RNG GENERATION

Table 6 summarizes the biogas and RNG generation estimates received from the technology suppliers.

TABLE 6: TECHNOLOGY SUPPLIER BIOGAS GENERATION AND RNG ESTIMATES BY SCENARIO

Factor	Units	SSO Facility	FSO Facility
Total Material Processed	tonnes/year	25,000	90,000
Total Organic Material to AD	tonnes/year	25,000	45,000
Range of Biogas Generation Rates	Nm^3/tonne (to AD)[1]	120 to 180	110 to 140
Average Biogas Generation Rate	Nm^3/tonne (to AD)	130	125
Total Estimated Annual Biogas Generated	Nm^3/year	3,300,000	5,600,000
Methane Concentration in Biogas	% (volume)	60	60
Total RNG Generated[2]	Nm^3/year	1,900,000	3,200,000
Energy Content of Generated RNG[3]	GJ	70,000	120,000
Energy Produced	GJ/tonne (to AD)	2.8	2.7
Energy Produced	GJ/tonne (Processed)	2.8	1.3

Notes

1. Nm^3 denotes Normal Cubic Metres which refers to the volume of gas at a pressure of 101.3 kPA and temperature of 15°C
2. Assumes that biogas to RNG conversion technology can achieve 90% recovery efficiency (90% of the biogas methane is recovered as RNG methane) and that RNG is 95% methane by volume, similar to pipeline quality natural gas therefore the quantity of RNG is calculated as biogas x 60% methane x 90% recovery x 1.05 $\frac{m^3 \text{ RNG}}{m^3 \text{ RNG methane}}$
3. Energy content of natural gas = 0.0373 GJ/Nm^3

3.4 DEMAND POTENTIAL AND FINANCIAL ASSESSMENT FOR CNG/RNG VEHICLES

Union Gas analyzed the financial implications of a hypothetical conversion of London's transit fleet and waste collection fleet from diesel fuelled to CNG fuelled vehicles, including the costs of establishing hypothetical fuelling station locations for those fleets. Union Gas based the analysis on a range of factors including distance traveled, travel patterns, and fuelling time requirements. This analysis is presented in ***Appendix B***.

3.4.1 CNG Vehicles

CNG is fast becoming the transportation fuel of choice in many applications. It is cleaner, greener and thanks to abundant and reliable supply, it can cut fleet fuel costs when compared to diesel by a significant amount. See the example for London below.

CNG is ideal for return-to-base fleets – vehicles that return to a central location for refuelling at the end of the day. Lower in both costs and emissions than other fuels, natural gas is the leading alternative fuel in North America for a growing number of heavy-duty, medium and light-vehicle applications including waste collection and transit fleets.

Several municipalities in Ontario such as the Region of Peel, the Cities of Hamilton, Ottawa and Quinte West, and the Counties of Dufferin and Simcoe have awarded contracts to service providers proposing the use of CNG collection vehicles. In addition, locations like the Bluewater Recycling Association (comprised of over 20 municipalities representing nearly 150,000 people) have switched to CNG powered packers.

In 2017, Hamilton's transit division is expanding its fleet of 85 CNG buses to 104 by the end of the year. Over the next couple of years, Hamilton plans to have roughly half of the bus fleet (125) operating on CNG. Hamilton is also using RNG from its wastewater treatment plant to help fuel this fleet.

A cleaner burning CNG is a logical fit to meet escalating environmental targets. CNG provides the following advantages over diesel vehicles:

- greenhouse gas emission reductions,
- lower emissions for nitrogen oxide (NOx) and volatile organic compound (VOCs),
- nearly zero fine particulate matter emissions, and
- quieter operation.

Burning RNG provides the same benefits above, in addition to nearly zero greenhouse gas emissions. Because the methane used to produce RNG is sourced from decaying organic materials, the carbon dioxide (CO_2) produced through combustion is considered biogenic CO_2. This means that the greenhouse gas effect of the CO_2 is neutralized, as it would have been released naturally as a part of the carbon cycle.

3.4.2 London's Fleets

The City of London is considering the use of CNG for its 37 curbside waste collection trucks as part of its Green Fleet Strategy. Within London, other vehicle fleets may have longer-term potential for CNG. CNG powered opportunities may exist with school buses, transport trucks, courier vehicles and other return-to-base vans, shuttles and utility vehicles.

It is important to note that the London Transit Commission (LTC) is currently investigating the use of battery electric vehicles (BEVs) for its transit fleet and currently does not have plans to investigate CNG as a fleet fuel. However, for the purposes of this report, this study looked at the hypothetical conversion of LTC's fleet of 206 diesel-fuelled transit buses, as well as the Corporation of the City of London's possible conversion of its 37 waste collection trucks. Union Gas conducted an analysis of converting these fleets, taking into account the following factors:

- fleet size,
- distance traveled (km/year),
- annual diesel consumption and equivalent natural gas consumption expressed in diesel litre equivalent (DLE), and normal cubic metres (Nm3),
- diesel cost,
- CNG fuelling infrastructure type and fill time required (i.e., slow fill vs fast fill stations), and
- capital and operating costs of CNG vehicles and fueling stations.

Union Gas's analysis can be found in ***Appendix B***. A summary of the fleet data is presented in Table 7.

TABLE 7: CITY OF LONDON FLEET DATA

	Units	Waste Collection Fleet	Transit Fleet
Fleet Size	# of vehicles	37	206
Distance Travelled	km/year	700,000	11,400,000
Diesel Consumption	L/year	600,000	7,170,000
Equivalent NG Consumption (DLE)	m^3/year	675,000	8,340,000
One litre of diesel = 1.032 m^3 of CNG/RNG.			

3.4.3 RNG Selling Price

For the purpose of this report it is assumed that the maximum price of RNG as a fuel for the City's fleets is the price at which the net cost of converting the fleets from diesel fuel to RNG is zero. Therefore, the maximum price for RNG is the cost of the diesel fuel supply minus the additional capital and operating costs of new CNG vehicles and fueling stations. ***Appendix B*** provides a detailed description of the maximum RNG price calculation. The maximum prices for RNG as a fuel for the waste collection and transit fleets are presented in Tables 8 and 9 respectively.

For a smaller fleet operator with relatively lower annual fuel consumption, the maximum potential price for RNG is lower since the costs of the CNG fuelling infrastructure are divided over a relatively smaller quantity of RNG.

TABLE 8: ESTIMATED MAXIMUM SELLING PRICE FOR RNG IN CITY WASTE COLLECTION FLEET

Item	**$/litre**	**$/GJ**
Diesel Price as of 2016	$0.85	$21
Estimated Cost for CNG in Equivalent Diesel		
CNG refuelling station capital cost (over 15 years)	$0.26	$6.50
Incremental CNG vehicle cost (over 10 years)	$0.32	$8.10
Annual maintenance cost	$0.04	$1.00
Annual electricity cost	$0.04	$0.90
Annual training cost	$0.01	$0.15
Union Gas delivery cost	$0.03	$0.70
sub-total for CNG capital and delivery costs	$0.69	$17
Ceiling Price for RNG	**$0.16**	**$4**

For a larger fleet operator with relatively higher annual consumption, such as a transit fleet, the maximum potential price for RNG is higher.

TABLE 9: ESTIMATED MAXIMUM SELLING PRICE FOR RNG IN TRANSIT FLEET

Item	**$/litre**	**$/GJ**
Diesel Price as of 2016	$0.85	$21
Estimated Cost for CNG in Equivalent Diesel		
CNG refuelling station capital cost (over 15 years)	$0.15	$3.70
Incremental CNG vehicle cost (over 10 years)	$0.14	$3.50
Annual personnel costs	$0.08	$2.00
Annual maintenance cost	$0.04	$0.90
Annual electricity cost	$0.03	$0.70
Union Gas delivery cost	$0.03	$0.70
sub-total for CNG capital and delivery costs	$0.47	$12
Ceiling Price for RNG	**$0.38**	**$10**

3.5 THE IMPACT OF CARBON PRICING

In principle, carbon pricing will make RNG more financially attractive, as the price of diesel fuel will increase. Diesel emits 2.73 kg CO_2 per L, totaling $0.027 for every $10/tonne carbon price increment. In 2018, the carbon price is expected to be $18/tonne, resulting in $0.049/L or $1.25/GJ. By 2022, it will be $0.14/L or $3.50/GJ.

If the carbon price is assumed to be $50 per tonne based on the proposed federal carbon price floor for 2022, the ceiling price for RNG will increase by $0.14 per L, or $3.50/GJ.

3.5.1 GHG Reduction Benefits

SSO and FSO scenarios reduce GHG emissions by diverting organics from landfill disposal and by producing biomethane, which can be used in place of fossil fuels. In this report, displacement of diesel fuel for RNG derived from biomethane was considered. GHG reductions may have an economic value in jurisdictions that have implemented a carbon pricing regime, such as a cap and trade system currently in place in Quebec and California and starting up in Ontario. It should be noted that cap and trade and other related policies in favour of renewable fuels are still in development in Ontario. Municipalities considering either scenario presented in this report are recommended to complete an analysis of GHG reductions specific to their situation and applicable policies.

3.5.2 GHG Emissions Reductions from Diversion

The introduction of greenhouse gas emissions cap and trade systems can provide an additional source of revenue for waste management systems that divert organic materials from landfills. Emissions offset protocols for the composting or anaerobic digestion of organic waste are in place in Alberta and Quebec, and are expected to be in place in Ontario in 2017. Using the Ontario Waste Management Association (OWMA) GHG Emissions Offset Calculation Tool, and an assumed offset price of $50 per tonne based on the proposed federal carbon floor price for 2022, the emission offset revenue that could be available in those jurisdictions with cap and trade is shown in Table 10.

TABLE 10: POTENTIAL GHG EMISSION REDUCTIONS AND OFFSET CREDIT REVENUE BY SCENARIO

Factor	Units	SSO Scenario	FSO Scenario
Total Material Processed	tonnes/year	25,000	90,000
Total Material to AD	tonnes/year	25,000	45,000
GHG offsets from diversion[1]	tonnes CO_2e/year	12,000	22,000
Offset revenue (at $50/tonne CO_2e)	$/year	$600,000	$1,100,000
	$/tonne processed	$24	$12

Notes

1. Calculated using the OWMA GHG Emissions Offset Calculation Tool

3.5.3 Lifecycle Analysis of RNG as a Vehicle Fuel

A lifecycle analysis, also known as a well-to-wheel analysis, related to the GHG impact of several scenarios was completed using the GHGenius model, which was designed specifically for transportation fuels by Natural Resources Canada.

For each of the scenarios, GHG reductions were calculated for both Ontario and Alberta for broader applicability to Canadian municipalities. The difference between Ontario and Alberta GHG reduction performance from RNG and CNG is based on the carbon intensity of the electricity supply within each province, since electricity is used to produce and upgrade biogas and provide power for compression. The scenarios are as follows, when applicable, use of the new Cummins CNG engine was assumed.

1. Diesel fuelled trucks
2. 5% biodiesel; 95% diesel fuelled trucks
3. CNG (fossil fuel) trucks
4. Renewable natural gas, or RNG, from landfill gas
5. RNG from anaerobic digestion (AD) from SSO material (two scenarios, a and b)
6. RNG from AD of FSO material

The use of fossil natural gas in a new medium or heavy duty truck compared to the same truck using diesel fuel provides an estimated 13% GHG emission reduction in Ontario, according to the analysis. When 100% RNG is used instead of fossil natural gas, the emission reduction potential ranges from 87-91%, depending on how the RNG is produced.

The following table summarizes the GHG emissions of the 12 scenarios expressed in grams of CO_2 equivalent per kilometre driven.

TABLE 11 – WELL TO WHEEL LIFECYCLE GHG EMISSIONS

Factor	Ontario	Alberta
	g CO_2eq/km	
1. Diesel Fuel	1,406	1,468
2. 5% biodiesel blend (2% in Alberta)	1,352	1,407
3. Fossil CNG	1,228	1,207
4. LFG RNG	128	407
5a. SSO RNG (no change to collection distance travelled)	156	639
5b. SSO RNG (additional collection distance travel required)	221	708
6. FSO RNG	185	872

See ***Appendix C*** for the full Lifecycle Analysis report: Greenhouse Gas Emission Reductions from using RNG as a Vehicle Fuel

3.5.4 Emission Reductions from Using RNG as a Vehicle Fuel

The previous section discussed the "well-to-wheel" greenhouse gas emission factors on a per-kilometre travelled basis for renewable natural gas from both source-separated organics and facility-separated organics in Ontario and Alberta. Similar "well-to-wheel" emission factors are also provided for diesel fuel, B5 (5% biodiesel) blends of diesel, and natural gas.

In the case of source-separated organics, two RNG emission factors are provided – one assuming no net increase in truck travel needed for collection, and one assuming additional trucks and truck travel are required due to operational aspects of curbside SSO collection with split-compartment collection trucks. For the purposes of this study, the City assumed that additional travel is required for SSO collection.

To get a better understanding of the scale of benefit provided by RNG as a vehicle fuel from these two sources, these emission factors were applied to the City of London's waste collection fleet and a hypothetical transit bus fleet based on LTC's current fleet and diesel use.

As noted earlier in the report, both RNG scenarios produce RNG quantities that are greater than could be consumed by the City of London even if all of the waste collection trucks were converted to CNG trucks. The current waste collection fleet's B5 biodiesel fuel use is equivalent to about 619,000 cubic metres per year of CNG. The production of RNG from SSO and FSO is estimated to be about 2,000,000 cubic metres and 3,400,000 cubic metres per year respectively.

For the purposes of this report, it was assumed that a transit fleet could hypothetically use the remaining RNG, based on the following:

- 100% of the City's waste collection fleet would be converted to CNG trucks, and that these trucks would use 100% RNG as a vehicle fuel; and
- only a portion of the transit fleet would be converted to CNG buses, based on the remaining amounts of RNG, and that these CNG buses would run on 100% RNG.

Based on these assumptions, the well-to-wheel greenhouse gas reductions for both fleets are outlined in the table below.

TABLE 12: WELL-TO-WHEEL GREENHOUSE GAS REDUCTIONS FOR BOTH FLEETS BY SCENARIO

Well-to-Wheel Greenhouse Gas Emission Reductions	**Scenario 1: SSO**	**Scenario 2: FSO**
Available RNG (m^3/year)	1,900,000	3,200,000
City Waste Collection Fleet		
Current B5 diesel fuel needs (L/year)	600,000	
GHG emissions from B5 diesel use (tonnes/year)	1,800	
Diesel as equivalent CNG volume (m^3)	675,000	
GHG emissions from RNG use (tonnes/year)	340	280
GHG reduction (tonnes/year)	1,700	1,770
GHG reduction	83%	86%
City Transit Fleet		
Current diesel fuel needs (L/year)	7,200,000	
GHG emissions from diesel use (tonnes/year)	25,500	
Diesel as equivalent CNG volume (m^3)	8,340,000	
Remaining RNG available (m^3)	1,230,000	2,530,000
RNG blend within CNG	15%	30%
GHG emissions from RNG use (tonnes/year)	22,300	18,800
GHG reduction (tonnes/year)	3,200	6,700
GHG reduction	13%	26%
Total GHG reduction (tonnes CO_2eq/year)	***4,900***	***8,500***

As mentioned earlier, the LTC does not have plans to convert their fleet to CNG buses, as it is currently studying the potential use of electric buses. Therefore, any local or regional use of RNG as a vehicle fuel in London and area would require significant private-sector adoption of CNG vehicles.

3.6 Summary of Costs

The following section summarizes the overall estimated costs of the facility, based on the sections in this report. Included in each estimation are: waste collection costs, revenue and savings, capital and operational costs, potential offset credit from diversion, and revenue from RNG as a fuel. Table 13 summarizes the net implementation costs for the SSO and FSO scenarios by category.

Selling RNG as a fuel will lower the cost of the SSO-AD or FSO-AD facility. Figures 1 through 4 summarize the impact of RNG selling price on the net implementation costs. The figures illustrate the ranges of annual costs, costs per tonne diverted, and costs per tonne processed based on the selling price of RNG for the FSO and SSO scenarios.

TABLE 13: SUMMARY OF COSTS, REVENUES AND SAVINGS BY SCENARIO

Component		Units	SSO Scenario		FSO Scenario	
			Low	High	Low	High
Costs and Savings	SSO and Garbage Collection Costs[1]	$/tonne	$170		-	
	Total Facility Costs[2]	$/tonne	$90	$160	$100	$120
	Avoided Disposal Savings[3]	$/tonne	$18		$7	
	Overall City Cost Excluding RNG Revenue & Offset Credit	$/tonne[4] (processed)	$240	$310	$90	$110
		$/year[5]	$3,400,000	$4,300,000	$8,100,000	$9,900,000
RNG Revenue & Offset Credits	Offset Credit from Diversion	$/tonne (processed)	$24		$12	
	Revenue from RNG as Fuel[6]	$/tonne (processed)	$20		$10	
	Revenue from RNG as Fuel[6] (With Carbon Pricing7)	$/tonne (processed)	$29		$15	
Net Cost for City	Net Cost for City (Without Diversion Offset Credit and Carbon Pricing)	$/tonne[4] (processed)	$220	$290	$80	$100
		$/year[5]	$3,100,000	$4,100,000	$7,200,000	$9,000,000
	Net Cost for City (With Diversion Offset Credit and Carbon Pricing)	$/tonne[4] (processed)	$190	$260	$60	$80
		$/year[5]	$2,700,000	$3,600,000	$5,400,000	$7,200,000

Notes:

1. Increase in annual garbage and organics collection costs compared to the existing garbage only collection costs. See Section 3.1.1 for details
2. SSO facility costs from Table 2 in Section 3.1.2. FSO facility costs from Table 3 in Section 3.1.2.
3. See Section 3.1.3 for details.
4. Costs rounded to the nearest $10.
5. Costs based on multiplying $/tonne (processed) by 14,000 (City) tonnes for SSO scenario and 90,000 (City) tonnes for FSO scenario.
6. RNG revenue based on supplying waste collection vehicles first at $0.16/L or $4/GJ (see Table 8) and selling excess RNG at $0.38/L or $10/GJ (see Table 9) to larger fleet (e.g., hypothetical LTC fleet)
7. Based on an assumed $50/tonne carbon tax by 2022, equal to $0.14/L

FIGURE 1: FSO IMPLEMENTATION ANNUAL AND PER TONNE PROCESSED COST BY RNG PRICE

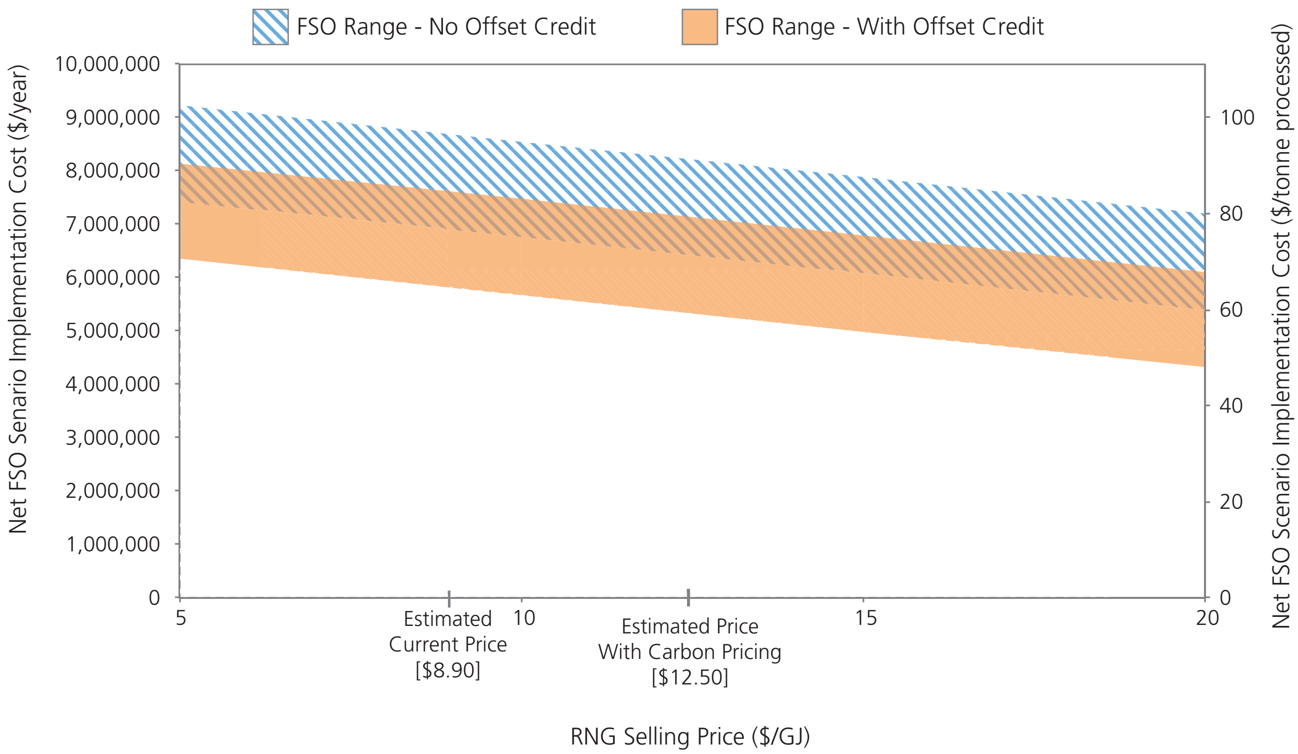


FIGURE 2: SSO IMPLEMENTATION ANNUAL AND PER TONNE PROCESSED COST BY RNG PRICE

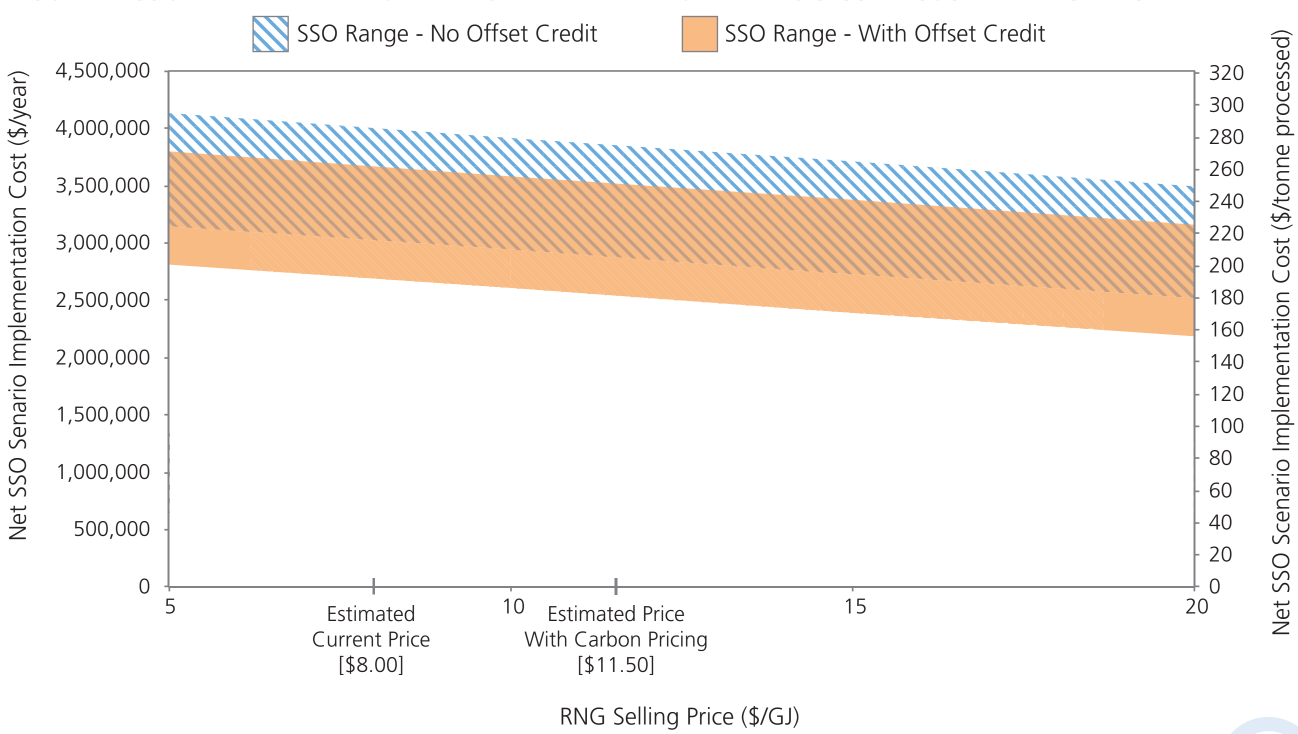
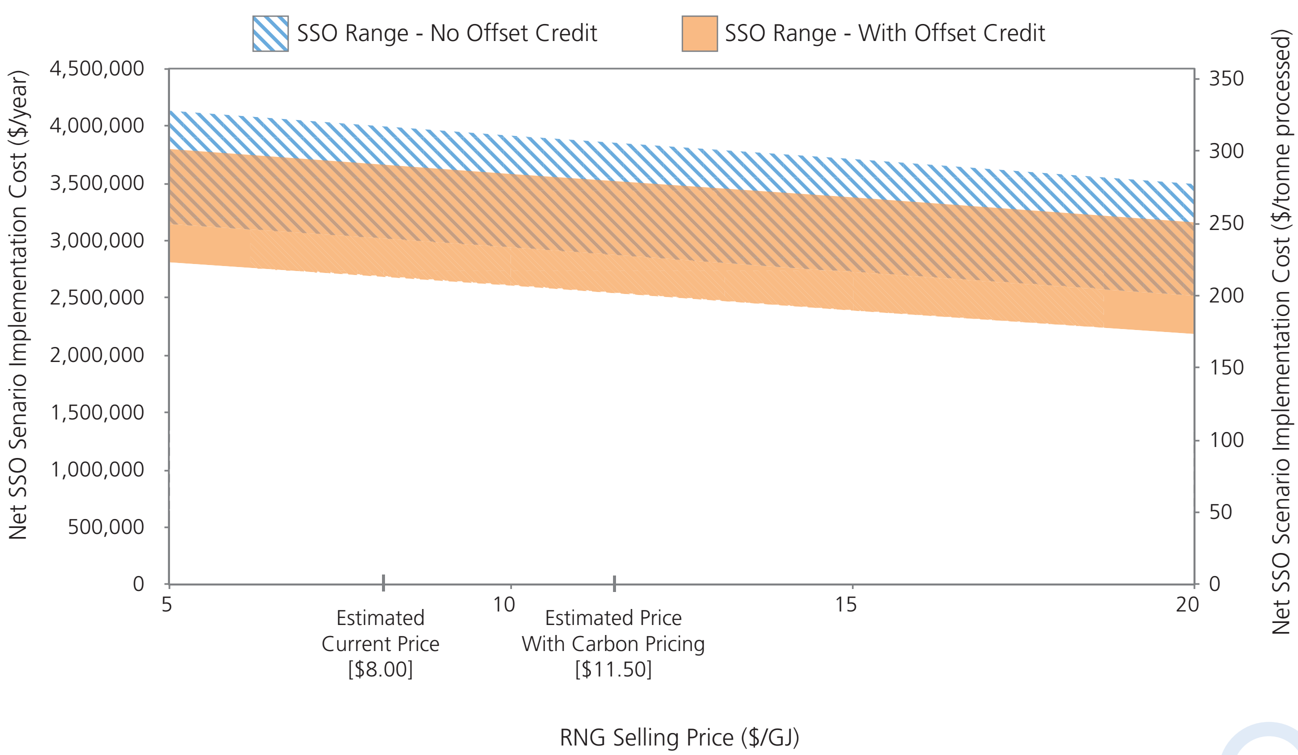


FIGURE 3: FSO IMPLEMENTATION ANNUAL AND PER TONNE DIVERTED COST BY RNG PRICE

FIGURE 4: SSO IMPLEMENTATION ANNUAL AND PER TONNE DIVERTED COST BY RNG PRICE



Notes (Figures 1 to 4):

1. Estimated RNG prices were calculated using a weighted average based on the quantity of fuel sold at the different price points for the transit and waste fleet.
2. Cost per tonne diverted based on annual cost divided by tonnes diverted by scenario in Table 4.

The annual cost range of the FSO scenario is much higher than the annual cost of the SSO scenario. The cost per tonne processed is lower than that of the SSO scenario; however, based on the quantity of material processed, the annual cost is greater. The net cost per tonne diverted from the W12A Landfill site is very similar in both scenarios.

It should be remembered that there are other considerations in addition to cost when deciding on the preferred method for organics management. For the City of London, this report has demonstrated the importance of considering AD facilities and the potential of RNG as part of future resource recovery solutions for the organic fraction of waste.

4. Operational considerations

Several firms included design and operational considerations for processing facilities for the City of London to take into account for planning purposes.

The design considerations relate to proprietary systems, and are oriented toward highlighting advantages of one system over another. These are summarized in the Highlights of Technology Submissions (***Appendix C***). Both wet and dry fermentation processes are viable system designs for SSO material.

In terms of operational considerations, technology providers offered guidance to the City of London, including the following:

- The organics market is very competitive, therefore any organics the City does not have complete control of (i.e. the 11,000 tonnes of industrial food waste required to reach the 25,000 tonne per year facility size), should be considered a competitive and risky source of feedstock. It is a very competitive market place to try to secure tonnes of material from the private sector. The vendors advised the City to do significant due diligence to understand what types of businesses are anticipated to generate that tonnage, and if it is already being processed elsewhere, or are new tonnes expected from other sources.
- Do not underestimate the difficulty and financial variability of managing digestate. The by-products (solids and liquids) will also require focus as they are cost centers for the project.
- It is advisable to assume that the marketing of digestate would not generate a revenue stream.

5. Next Steps for London

The work contained in this research report will be used by the City of London as follows:

- As an outcome associated with the London Waste to Resources Innovation Centre;
- As input for the detailed feasibility study of using CNG as fuel for waste collection vehicles;
- As input into the ongoing options analysis for landfill gas recovery and energy creation (versus the current flaring);
- As input into a sensitivity analysis between aerobic composting and anaerobic digestion;
- To inform other public and private fleets in London and area on the potential that exist for CNG as a fuel;
- As input for City's Resource Recovery Strategy currently being developed; and
- As input into the Environmental Assessment process for long-term waste disposal.

Appendix A: Request for Information Distributed to Vendors

Request for Information

Renewable Natural Gas (RNG) Production Potential from London Residential Waste

for the Canadian Biogas Association
on behalf of City of London

Closing Date: February 15, 2016

OVERVIEW

Background

The City of London (hereinafter referred to as the 'City') is working with the Canadian Biogas Association (CBA) and Union Gas to research the potential for using organic waste produced by London residents to produce renewable natural gas (RNG). The Federation of Canadian Municipalities (FCM) has provided funds to assist the City in this research.

In February 2015, London Municipal Council approved a concept referred to as the London Waste to Resources Innovation Centre. The primary goal of the Centre is to create a location(s) in or near London for the ongoing examination of innovative solutions to waste reduction, resource recovery, energy recovery and/or waste conversion. In the last year, a number of small projects have been initiated under this banner including significant discussion with Western University and a number of private companies.

Data collected as part of this Request for Information (RFI) will be used in three areas:

1. To inform a study that will assist the City of London, and other Canadian municipalities, in determining the role that using organic waste to produce RNG could play in their waste management and resource recovery systems in the future. The research will also examine diversion rates, treatment cost, greenhouse gas emissions, energy recovery, economic benefits, and other factors. The study seeks to quantify the amount of RNG that could be produced from London's residential organic material, supplemented with other sources of organics and the estimated costs associated with producing the RNG. The RNG may be used to help fuel the City's waste collection truck fleet, other vehicles, or sold to a third party.

2. A project undertaken as part of the development of the London Waste to Resources Innovation Centre.

3. To inform the City's Environmental Assessment (EA) for long term resource recovery and disposal plans. As the City consults with London residents about its waste management options as part of the EA process, data collected during this study will help raise awareness on the implications of different options for managing organic wastes. Data will also be used to help City staff and elected officials make informed waste management decisions.

Overview of Requested Estimates

Estimated prices, costs, and projected volumes submitted by technology suppliers should be provided at the conceptual level (ASPE Level 2 – Schematic/Conceptual Design scale or equivalent), and will be used for research purposes to determine the cost-effectiveness of producing RNG over other organic waste treatment options.

Estimated prices, or price ranges per tonne, should also be provided for capital costs and for tipping fees to cover operating costs for these organic waste treatment conceptual designs. The tipping fees should take in account the revenue from RNG sales offsetting operating costs along with any other revenue streams.

Cost estimates that are submitted will be made public; **however, company names will remain confidential.** Participating company names will be listed in an Appendix with complete contact details and website address.

The advantage to your company in submitting a response to this RFI is that the City and other jurisdictions will gain valuable information related to the costs and benefits of biogas for planning purposes, which will help grow the adoption of biogas in Canada.

It is understood that costs often decrease over time. This analysis is meant to be a snapshot in time. We also understand that costs are site specific. However, generalized information (such as price ranges) based on assumptions provided will be valuable to the City and other municipalities.

It must be emphasized that this is a research project with a host municipality, the City of London, providing the municipal context. As noted the City of London is starting an Environmental Assessment process prescribed by the Province of Ontario *Environmental Assessment Act*. The research will be used as part of the requirements of the EA.

Collection Options

The City is requesting Respondents provide data based on processing organics under one or both of the following organics separation scenarios:

1. Assumes weekly collection of source separated organics (SSO); and

2. Assumes 'facility separated organics' (FSO) where the proponent accepts garbage with organic materials included in the bag, and the organic material is separated by process equipment at a proponent's facility.

For the purposes of this research study, it will be assumed that the proposed organic processing facility site would be located at the City's Waste Management and Resource Recovery Area located beside the City's landfill site. Material separated from the organics and not treated through anaerobic digestion would be disposed of at the landfill at no cost.

RNG Gas Processing Options

In terms of **upgrading biogas to pipeline-quality RNG** from the organics separation scenarios above, proponents are requested to provide data based on one or both of the following two biogas scenarios:

1. RNG produced from anaerobic digester biogas only; and

2. Combining the RNG from biogas with the landfill gas captured at the nearby City landfill site.

WASTE MANAGEMENT DATA

For the purposes of this study, assume the following data.

<u>Residential Waste Profile</u>

1. Curbside collection of garbage, recycling and yard waste is provided to approximately 120,000 single family homes.

2. Bulk collection of garbage and recycling is provided to approximately 50,000 multi-residential units.

3. Curbside collection of garbage and recycling is provided to small businesses generating less than 12 containers of garbage per collection

4. The current waste collection system collects approximately 90,000 tonnes of garbage containing about 45,500 tonnes of organics.

5. Estimated composition of the collected garbage is provided in Table 1.

6. It is estimated that a SSO collection system for single family homes would collect approximately 12,000 to 14,500 tonnes per year of organic material. For the purposes of this study, assume 14,000 tonnes of SSO will be collected.

Table 1 – Composition of Collected Garbage

Material	Quantity (tonnes/year)	Comments
Food Waste	30,500	From Residential SSO and Small Business
Yard Materials	1,500	Brush, garden trimmings hidden with regular garbage
Non-Recyclable Paper	4,500	Tissue, paper towels, etc.
Recyclable Paper	4,500	Paper not placed in Blue Box for recycling
Diapers and Sanitary Products	4,500	
Subtotal Compostables	45,500	
Non-Compostables	44,500	Excludes bulk items (e.g., chairs, tables, etc.)
Total Residential/Small Business Garbage	90,000	

Additional Waste Profile

As noted in the Processing Scenarios section, there is a need to access about 11,000 tonnes of additional non-residential organic waste for Scenarios 1 and 2. For the purpose of this research study, assume the source separated organic sources are from typical businesses found within a municipality such as grocery stores, restaurants, large institutions, one or two medium-sized food processing industries, etc.

Landfill Gas

The landfill is currently equipped with a landfill gas collection and flaring system, operated by Comcor Environmental.

The landfill has approximately 10 years of approved waste disposal capacity remaining. For the purposes of this study, assume the landfill gas collection system would collect an average of 1,200 cubic feet per minute with 50% methane content over the next 10 years and would be operating 95% of the time. The usual decay of landfill gas generation rates should be assumed following closure.

Chemical characterization of landfill gas samples has been provided in Appendix A. For the purposes of this study, assume the City will deliver the landfill gas to the proponent's processing facility.

Processing Scenarios

Four processing scenarios, **designed to produce pipeline-grade RNG**, based on defined feedstocks, are identified below. Additional scenarios beyond these 4 can be introduced by the Respondents.

Scenario 1 and 2 identify clean organics from the residential sector with some additional organics from businesses/institutions a facility size of 25,000 tonnes.

Scenario 3 and 4 identify a larger overall facility size for processing garbage with limited quantities of large bulky items and metals; almost no white goods and almost no large electronics

Scenario	Summary Details
1. SSO and no landfill gas	Processing 25,000 tonnes (14,000 tonnes of Residential SSO and 11,000 tonnes of Additional SSO)
2. SSO and landfill gas	Processing 25,000 tonnes (14,000 tonnes of Residential SSO and 11,000 tonnes of Additional SSO) and 1,200 cfm of 50% methane landfill gas
3. FSO and no landfill gas	Processing 90,000 tonnes of garbage to create FSO for further processing

4. FSO and landfill gas	Processing 90,000 tonnes of garbage to create FSO for further processing and 1,200 cfm of 50% methane landfill gas

Location of Facility

For the purposes of this study, the facility will likely be located in an area known as the W12A Landfill Waste Management/Resource Recovery Area. This area, shown on Map 1, includes the W12A Landfill site and surrounding lands.

The City owns the most of this area so assume no costs related to site acquisition. Some site details include:

- Three-phase 27.6 kVA power line is available.
- Landfill has a leachate forcemain. Assume the City will provide a connection to the forcemain but include the cost of treating any wastewater generated by the facility. Consult the City's sewer use bylaw rates to price wastewater disposal.
- Weigh scales already exist at the site and can be used for the hypothetical AD facility.
- The geotechnical data for the area indicates nothing unusual in the soil conditions. No extraordinary foundation work is anticipated.

Digestate Management

Proponents should provide summary information on the proposed beneficial use for the digestate, the expected costs to manage the digestate, and the potential revenue that will be generated.

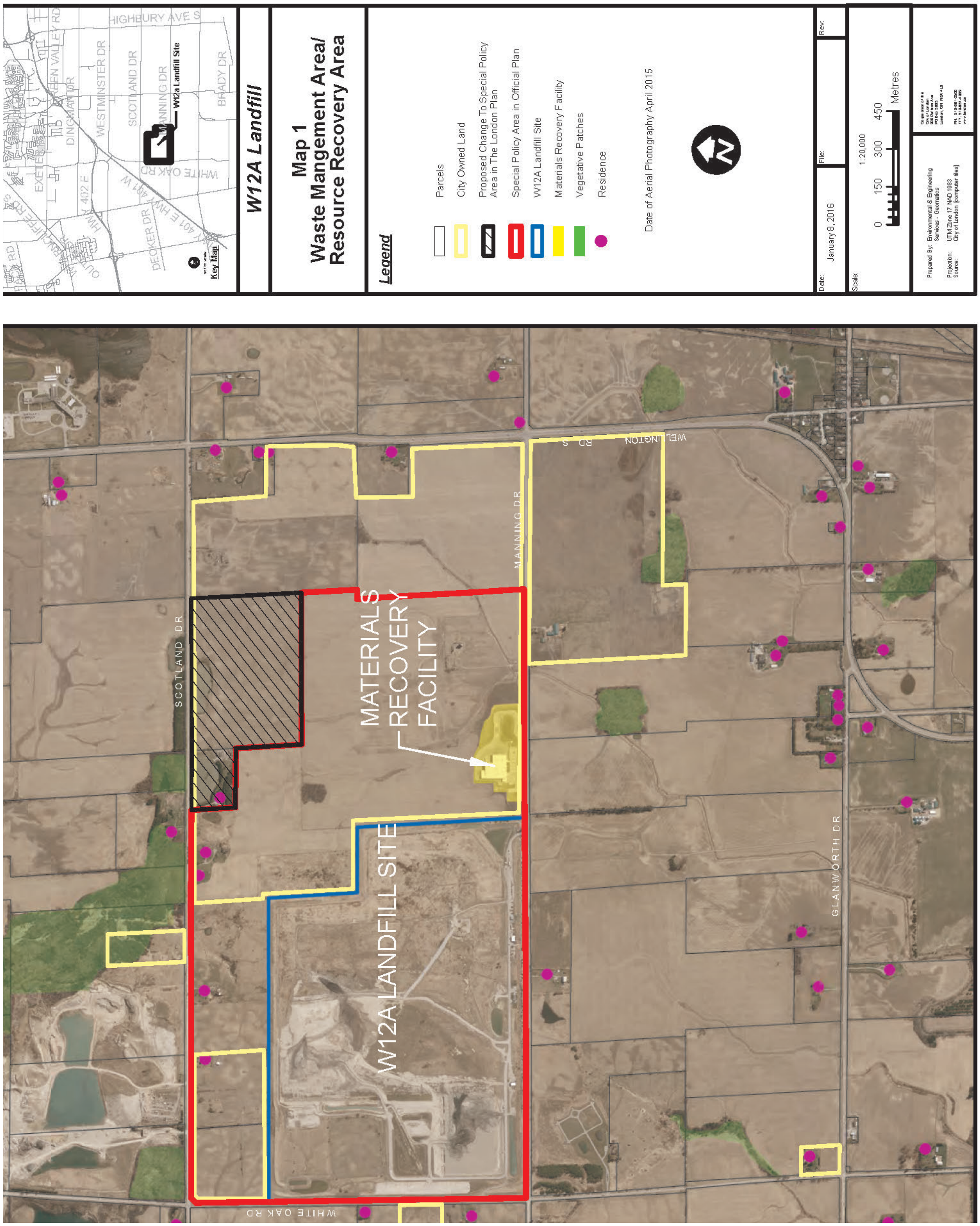
Alternatively, proponents can assume that the digestate can be composted off-site ($65 per tonne including transportation) if the level of contamination from plastic, sharps, etc. is at acceptable levels or landfilled (at $30 per tonne including transportation) if contamination levels are unacceptable for composting which may be the case for FSO.

Odour Control

Odour control equipment is essential to the operation of the biogas facility. Best available odour control technology must be considered in the cost estimates, and Ontario Ministry of Environment and Climate Change requirements will need to be met.

Connection to the Union Gas System

For design and cost estimation purposes (i.e., gas compression), assume the minimum pressure required to inject RNG into the natural gas system is 3585 kPa (520 psig). Actual operating pressure and ability to receive RNG into the Union Gas system may vary based on changing demands on the natural gas system. The Respondent is not required to provide an estimate of the cost to construct the RNG injection station or the associated piping.



W12A Landfill
Map 1
Waste Mangement Area/
Resource Recovery Area
Legend
Parcels
City Owned Land
Proposed Change To Special Policy Area in The London Plan
Special Policy Area in Official Plan
W12A Landfill Site
Materials Recovery Facility
Vegetative Patches
Residence
Date of Aerial Photography April 2015
Date: January 8, 2016
File:
Rev:
Scale: 1:20,000
0 150 300 450 Metres
Prepared By: Environmental & Engineering Services - Geomatics
Projection: UTM Zone 17 NAD 1983
Source: City of London [computer filed]
Key Map
W12a Landfill Site
HIGHBURY AVE S
WESTMINSTER DR
SCOTLAND DR
MANNING DR
BRADY DR
WHITE OAK RD
DINGMAN DR
DECKER DR
MATERIALS RECOVERY FACILITY
W12A LANDFILL SITE
SCOTLAND DR
MANNING DR
WELLINGTON RD S
GLANWORTH DR
WHITE OAK RD

Operation and Financing

The City requests that technology providers base their cost estimates on an assumption that the hypothetical facility would be built under a design/build/operate contract for 10 years. The proponent would keep all revenue from all RNG produced.

The City would pay the upfront capital costs and tipping fee ($/tonne) to cover ongoing operating and maintenance costs. The tipping fee would be paid on incoming tonnes.

After 10 years, the contract would be reviewed.

The City recognizes that there may be potential opportunities to sell Greenhouse Gas (GHG) emission credits generated by this facility in the future depending on the direction taken by the Provincial Government with respect to the proposed Cap and Trade system. For the purpose of this study assume no revenue from the selling of GHG emission credits.

Type of Project/Technology

The type of project and choice of technology to be used will be up to the Respondents. In the RFI submission, the Respondents will be required to provide supporting information for the type of project and technology selected.

Proponents are asked to provide information on the following:

- Proposed technology overview, and estimated price to process waste volumes outlined in Table 1.
- Potential partnerships with related technology suppliers that could assist in overall project delivery. For example, anaerobic digestion technology suppliers may partner with biogas to RNG upgrading technology providers.
- Estimates from individual technology types are also welcome.
- Separate information related to at-facility organics material sorting and processing technologies is encouraged. See Appendix B for information on Edmonton’s front-end system for managing garbage to extract organics, as an example.
- Any features or capabilities that separate your technology and its operation from others, such as maintenance considerations, should be clearly noted.

Inquiries

All inquiries and questions regarding this RFI are to be addressed to:

Stephanie Thorson
Canadian Biogas Association
sthorson@biogasassociation.ca
Office: 416-489-9388
Cell: 416-799-2221

SUMMARY – FORMAT OF YOUR SUBMISSION

Your submission should be sent electronically to the email address provided above on or before **February 15, 2016 at 5 pm**. Please use the following format:

1. **Introduction**.

2. **Your Products and Services**. Outline what your company, and potentially in conjunction with partners, offers in response to the needs outlined above.

3. **Cost Estimates for Full Service**. Clearly articulate your estimated price, at a conceptual level (ASPE Level 2 – Schematic/Conceptual Design scale or equivalent) to design, build and operate a facility for five years for one or more of the following scenarios. Note: Additional scenarios beyond these four can be introduced by the Respondents.

Scenario	Summary Details
1. SSO and no landfill gas	Processing 25,000 tonnes (14,000 tonnes of Residential SSO and 11,000 tonnes of Additional SSO)
2. SSO and landfill gas	Processing 25,000 tonnes (14,000 tonnes of Residential SSO and 11,000 tonnes of Additional SSO) and 1,200 cfm of 50% methane landfill gas
3. FSO and no landfill gas	Processing 90,000 tonnes of garbage to create FSO for further processing
4. FSO and landfill gas	Processing 90,000 tonnes of garbage to create FSO for further processing and 1,200 cfm of 50% methane landfill gas

The price estimate, or range of prices, should consist of a capital cost to construct the facility and a tipping fee (on an incoming per tonne waste basis) charged to process SSO and/or waste in a FSO facility. Outline assumptions used to estimate the price, and flag any uncertainties or explanations for price ranges.

4. **Cost Estimates for Partial Service**. Clearly articulate your price to provide a portion of the services outlined above. For example, AD companies and biogas/landfill gas to RNG upgrading companies may submit prices for their products and services only, based on the volumes and data provided in this RFI.

5. **Volume/quantity data:**
   Provide pertinent volume/quantity information on the process including:
   - Volume on RNG produced from organics
   - Total volume of RNG produced (if also processing landfill gas)
   - Quantity digestate produced
   - Quantity of material removed and sent to landfill (if processing the entire waste stream)

6. Considerations. Provide information that in your opinion decision makers should know when considering organic waste treatment technologies, processes, and service providers, based on your experience and expertise. This includes considerations related to cost-effectiveness, operational challenges, and other factors.

Appendix A

Chemical characterization of landfill gas

REPORT OF ANALYSIS: Comcor Environmental Ltd - Biogas Project 2877.1 - Selected Compounds in mg/m³					
REPORT: 08073 (Methods 1c, 3a, 5b, 6b, 7a, 7b)			V = 10.0 mL		
	DESCRIPTION		**29-Dec-08**	**29-Dec-08**	**29-Dec-08**
CAS #	**COMPOUND**	**Half Hour POI Regulatory Criteria (ug/m3)**	**mg/m3**	**µg/m³**	**µg/m³ with 98% destruction**
115-07-1/74-98-6	1-Propene/Propane		50.1	50100	1002
75-28-5	2-Methyl Propane/Isobutane		27.6	27600	552
115-11-7	Isobutene/2-Methyl-1-Propene		0.438	438	9
106-97-8/106-98-9	Butane/1-Butene		8.84	8840	177
78-78-4	2-Methyl Butane		5.67	5670	113
109-67-1/1191-96-4	1-Pentene/Ethyl Cyclopropane		0.254	254	5
109-66-0	Pentane		2.87	2870	57
60-29-7	Diethyl Ether/Ethyl Ether	7000	0.403	403	8
75-83-2	2,2-Dimethyl Butane	48000	0.776	776	16
67-64-1	Acetone		0.18	180	4
75-15-0	Carbon Disulphide	330	0.418	418	8
79-29-8	2,3-Dimethyl Butane		0.495	495	10
107-83-5	2-Methyl Pentane		2.52	2520	50
96-14-0	3-Methyl Pentane		2.36	2360	47
592-41-6/763-29-1	1-Hexene/2-Methyl-1-Pentene		0.155	155	3
110-54-3	Hexane	7500	5.67	5670	113
590-35-2	2,2-Dimethyl Pentane		0.225	225	5
108-08-7	2,4-Dimethyl Pentane		0.262	262	5
96-37-7	Methyl Cyclopentane		1.294	1294	26
78-93-3	MEK/2-Butanone	30000	0.998	998	20
141-78-6	Ethyl Acetate	19000	0.581	581	12
109-99-9	Tetrahydrofuran	93000	0.906	906	18
591-76-4	2-Methyl Hexane		6.42	6420	128
565-59-3	2,3-Dimethyl Pentane		1.218	1218	24
589-34-4	3-Methyl Hexane		5.39	5390	108
71-43-2	Benzene		0.86	860	17
142-82-5	Heptane	33000	5.97	5970	119
79-01-6	Trichloroethylene	33000	0.18	180	4
107-39-1	2,4,4-Trimethyl-1-Pentene	3500	0.105	105	2
108-87-2	Methyl Cyclohexane		7.21	7210	144
1640-89-7	Ethyl Cyclopentane		0.416	416	8
565-75-3	2,3,4-Trimethyl Pentane		1.76	1760	35
560-21-4	2,3,3-Trimethyl Pentane		2.13	2130	43
592-27-8	2-Methyl Heptane		1.78	1780	36
589-53-7	4-Methyl Heptane		0.627	627	13
589-81-1	3-Methyl Heptane		1.921	1921	38
108-88-3	Toluene	2000	6.16	6160	123
111-65-9	Octane	45400	3.73	3730	75
105-54-4	Ethyl Butyrate/Butanoic Acid Ethyl Ester		0.456	456	9
1678-91-7	Ethyl Cyclohexane		1.801	1801	36
100-41-4	Ethyl Benzene	3000	8.48	8480	170
108-38-3/106-42-3	m-Xylene/p-Xylene	2300 total	22.6	22600	452
95-47-6	o-Xylene	2300 total	5.56	5560	111
1678-92-8	Propyl Cyclohexane		14.25	14250	285
98-82-8	Cumene/Isopropyl Benzene	100	1.026	1026	21
79-92-5	Camphene		4.79	4790	96
103-65-1	Propyl Benzene		1.613	1613	32
620-14-4/622-96-8	m-Ethyl Toluene/p-Ethyl Toluene		2.6	2600	52
124-18-5	Decane		15.59	15590	312
95-63-6	1,2,4-Trimethyl Benzene	500	4.59	4590	92
13466-78-9	3-Carene		2.29	2290	46
1678-93-9	Butyl Cyclohexane		2.67	2670	53
99-87-6	p-Cymene		11.51	11510	230
493-02-7/91-17-8	Decalin(trans)/Decalin		1.918	1918	38
1120-21-4	Undecane		4.27	4270	85
4292-92-6/29949-27-7	Pentyl Cyclohexane/Amyl Cyclohexane		1.333	1333	27
-	Aromatics		1.619	1619	32
-	Alkanes		72	72000	1440
-	Cycloaliphatics		35	35000	700
-	Alkenes		3.28	3280	66
-	Oxygenates		10.06	10060	201
-	Complex		71.7	71700	1434
	TVOCs (Toluene)		353	353000	7060
	TVOCs (Quantified)		460	460000	9200
	Molhave-Clausen TVOCs (Toluene)		473	473000	9460

REPORT OF ANALYSIS: Comcor Environmental Ltd -Biogas Project 2877.1 - Target Organic Halide Compounds (TIVA) in mg/m³

REPORT: 08073halogen (Methods - 1c, 3a, 5b, 6b, 7b)

	DESCRIPTION		29-Dec-08	29-Dec-08	
CAS #	COMPOUND	Half Hour POI Regulatory Criteria (ug/m3)	ug/m3	µg/m³ with 98% destruction	
75-71-8	Dichlorodifluoromethane	1500000	6731	135	
75-45-6	Chlorodifluoromethane		12259	245	
2317-91-1	1-Chloro-1-Fluoroethylene		ND	ND	
76-14-2	1,2-Dichloro-1,1,2,2-Tetrafluoroetha	2100000	1037	21	
75-68-3	1-Chloro-1,1-Difluoroethane		1484	30	
74-87-3	Chloromethane	20000	ND	ND	
75-01-4	Vinyl Chloride	3	402	8	health
74-83-9	Bromomethane	4000	ND	ND	
1615-75-4	1-Chloro-1-Fluoroethane		3221	64	
75-00-3	Chloroethane		1413	28	
75-69-4	Trichlorofluoromethane	18000	227	5	
75-43-4	Dichlorofluoromethane		553	11	
1717-00-6	1,1-Dichloro-1-Fluoroethane		1132	23	
107-05-1	3-Chloroprene		ND	ND	
75-35-4	1,1-Dichloroethylene	30	203	4	health
76-13-1	1,1,2-Trichloro-1,2,2-Trifluoroethan	2400000	40	1	
75-09-2	Dichloromethane	5300	281	6	
156-60-5	1,2-Dichloroethene (trans)	315	4	0	
75-34-3	1,1-Dichloroethane	600	347	7	
126-99-8	b-Chloroprene		ND	ND	
156-59-2	1,2-Dichloroethene (cis)	315	219	4	
67-66-3	Chloroform		32	1	
71-55-6	1,1,1-Trichloroethane	3500000	378	8	
52-23-5	Carbon Tetrachloride		ND	ND	
107-06-2	1,2-Dichloroethane	6	ND	ND	
79-01-6	Trichloroethylene	35000	74	1	
78-87-5	1,2-Dichloropropane		ND	ND	
107-07-3	2-Chloroethanol		ND	ND	
75-27-4	Bromodichloromethane		ND	ND	
1107-75-8	2-Chloroethoxyethene		ND	ND	
4091-39-8	3-Chloro-2-Butanone		ND	ND	
10061-01-5	1,3-Dichloro-1-Propene (cis)		ND	ND	
10061-02-6	1,3-Dichloro-1-Propene (trans)		ND	ND	
79-00-5	1,1,2-Trichloroethane		ND	ND	
127-18-4	Tetrachloroethylene	10000	229	5	
124-48-1	Dibromochloromethane		ND	ND	
106-93-4	1,2-Dibromoethane		ND	ND	
108-90-7	Chlorobenzene	4200	318	6	
98-56-6	1-Chloro-4-(Trifluoromethyl)Benzene		80	2	
75-25-2	Bromoform	165	ND	ND	
79-34-5	1,1,2,2-Tetrachloroethane		ND	ND	
541-73-1	1,3-Dichlorobenzene		ND	ND	
106-46-7	1,4-Dichlorobenzene	285	199	4	
95-50-1	1,2-Dichlorobenzene		2	0	
120-82-1	1,2,4-Trichlorobenzene	100	ND	ND	
-	SUM		30866	617	

V = Volume of air sampled

< (ND) = Characteristic ions are not present therefore Not Detected

REPORT OF ANALYSIS: Comcor Environmental Ltd - Biogas Project 2877.1 - Selected Siloxanes (TIVA) in mg/m³

REPORT: 08073 (Method - 1c, 3a, 5b, 6b, 7b)

	DESCRIPTION	29-Dec-08	29-Dec-08	29-Dec-08
CAS #	COMPOUND	mg/m3	ug/m3	µg/m³ with 98% destruction
420-56-4	Trimethylsilyl Fluoride *	0.104	103.581	2.072
75-76-3	Tetramethylsilane	<0.001	1.000	0.020
1825-61-2	Methoxytrimethylsilane	<0.037	37.000	0.740
1825-62-3	Ethoxytrimethylsilane	0.035	35.184	0.704
1066-40-6	Trimethylsilanol *	0.276	275.777	5.516
1825-64-5	Isopropoxytrimethylsilane	0.015	14.853	0.297
1185-55-3	Trimethoxymethyl Silane #	ND	ND	#VALUE!
107-46-0	Hexamethyl Disiloxane - L2	0.146	146.035	2.921
1825-63-4	Propoxytrimethylsilane	0.040	40.255	0.805
1825-67-8	1-Methylbutoxytrimethylsilane *	ND	ND	#VALUE!
1825-65-6	Butoxytrimethylsilane *	ND	ND	#VALUE!
2768-02-7	Trimethoxyvinyl Silane #	ND	ND	#VALUE!
541-05-9	Hexamethyl Cyclotrisiloxane - D3	0.318	317.864	6.357
107-51-7	Octamethyl Trisiloxane - L3	0.008	8.351	0.167
78-08-0	Triethoxyvinyl Silane #	ND	ND	#VALUE!
78-07-9	Triethoxyethyl Silane #	ND	ND	#VALUE!
556-67-2	Octamethyl Cyclotetrasiloxane - D4	4.312	4311.847	86.237
141-62-8	Decamethyl Tetrasiloxane - L4	<0.003	3.000	0.060
78-10-4	Tetraethylsilicate #	ND	ND	#VALUE!
541-02-6	Decamethyl Cyclopentasiloxane - D5	2.780	2779.742	55.595
141-63-9	Dodecamethyl Pentasiloxane - L5	<0.034	34.000	0.680
540-97-6	Dodecamethyl Cyclohexasiloxane - D	<0.034	34.000	0.680
	SUM	8.143	8143.485	162.870

< (ND) = Characteristic ions are not present therefore Not Detected
V = Volume of air sampled
* = Semiquantitative (RF set at 5) commercial standards unavailable
# = Unstable, poor detectability, commercial standards tested

Appendix B:

City of Edmonton's Integrated Processing and Transfer Facility (IPTF)

The IPTF is where garbage arrives and is divided into three separate waste streams: composting, biofuels production and landfill. This facility can also capture the waste that can't be recycled or composted and turns it into feedstock for Enerkem's Waste to Biofuels and Chemicals Facility.

Facility features include:

- Two loading bays with hydraulic tampers to compact loads
- Two 120 ton rotating screens with bag breaking "spikes" to separate materials into different streams
- Manual pick stations, magnets and other equipment to remove unprocessable materials such as propane bottles
- A mechanical system to produce feedstock for Enerkem's Waste-to-Biofuels Facility from processed waste
- An overland conveyor to carry organic waste materials to the Edmonton Composting Facility and non-recyclable, non-compostable waste to the adjacent Waste-to-Biofuels Facility
- Bays to load material unsuitable for recycling, composting or gasification into trailers for transport to other landfills for disposal
- An overhead viewing gallery to allow tour groups to watch the facility in action

Note that the City of Edmonton announced in July, 2015 that it is building a new anaerobic digestion facility to treat organic waste collected in Edmonton.

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Appendix B: CNG Station & Delivered Fuel Prices

Report prepared by Union Gas

1. Introduction

Compressed natural gas (CNG) is fast becoming the transportation fuel of choice in many applications. It's cleaner, greener and thanks to abundant and reliable supply, the price for CNG on both a per gigajoule basis and on a per equivalent litre of diesel basis can cut fleet fuel costs when compared to diesel by a significant amount.

CNG is ideal for return-to-base fleets - vehicles that return to a central location for refueling at the end of the day. Lower in both costs and emissions than other fossil fuels, natural gas is the leading alternative fuel in North America for transit bus fleets and a growing number of heavy-duty, medium and light-vehicle applications including waste collection and transit fleets.

Several municipalities in Ontario such as the Region of Peel, the Cities of Hamilton, Ottawa and Quinte West, and the Counties of Dufferin and Simcoe have awarded contracts to service providers proposing the use of CNG collection vehicles. In addition, locations like the Bluewater Recycling Association (comprised of over 20 municipalities representing nearly 150,000 people) have switched to CNG powered packers.

In 2016, Hamilton's transit division is expanding its fleet of 35 CNG buses to 109 by the end of 2017. They will reach a total of 120 CNG buses by the end of 2019. Hamilton is also using Renewable Natural Gas (RNG) from its wastewater treatment plant to help fuel this fleet.

A cleaner burning, lower carbon fuel with almost zero particulate emissions, CNG is a logical fit to meet escalating environmental targets, including the following:

- Greenhouse gas emission reductions
- Lower emissions for nitrogen oxides (NO_x) and volatile organic compounds (VOCs)
- Nearly zero emissions of fine particulate matter
- Quieter operation

Burning RNG provides the same benefits as above in addition to the nearly zero greenhouse gas emissions.

In this appendix, Union Gas has provided estimated cost estimates for converting the City's waste collection fleet from diesel to CNG vehicles, including the costs of establishing a CNG fueling station. To create a larger pool of CNG powered vehicles, this research project included a theoretical example using the fleet of buses operated through the London Transit Commission as part of the analysis.

Below are cost estimates for owning fossil CNG Stations, blended R-CNG stations, alternative implementation strategies and other revenue earning opportunities if CNG was used as a fuel for the London Transit Commission bus fleet and the City of London's waste collection fleet.

2. CNG Station Costs – London Transit Commission

Below in Table 1 is a summary of the economic inputs and assumptions for London Transit Commission (LTC) that was provided through the 2014 CUTA Data Canadian Transit Fact Book, and used to create the cost estimates of two CNG fuelling stations for the 206 transit buses in the City of London's fleet:

Ultimate Fleet Size	206
Distance Traveled (km/yr)	11,400,000 km/year
Annual Diesel Consumption	7,170,000 L
Equivalent Annual m^3 Consumption (diesel litre equivalents - DLE)	8,340,000 m^3
Diesel Cost	$0.85 /L
Daily Operational Fleet	100%
CNG Refueling	Fast Fill
Fill Rate @ Highbury Ave	3 minutes per bus
Fill Rate @ Wonderland Rd	8 minutes per bus
Fuelling Window @ Highbury Ave	8 hrs
Fuelling Window @ Wonderland Rd	6 hrs

Table 1 – Inputs and Assumptions for LTC

Sections 2.1 and 2.2 provide costs of using fossil CNG fueling stations for each of the main Highbury Ave facility, and the Wonderland Rd S. satellite facility. In addition, the cost estimates provided in Table 2 and 3 are designed with a capital recovery approach for a one-time upfront Total Capital Cost. It is important to note that CNG station cost savings are also possible with other CNG fueling station configuration strategies, but with the absence of information about LTC bus routes, maintenance schedules, refueling and parking behaviours, assumption were made to provide an upset maximum cost approach:

2.1. 450 Highbury Avenue N. – Main Facility

London Transit Commission operates two bus facilities. The main site is located at 450 Highbury Avenue N., which is a 24,000 m^2 (260,000 ft^2) facility located on 6.8 hectares (16.8 acres) of land on the south-east corner of Highbury and Brydges. There was a Compressed Natural Gas (CNG) compressor fueling station that was constructed in 1993/94. The station had the capacity to fast fill 100 CNG buses per shift and was closed in 2008 paralleling the retirement of all CNG buses from LTC's fleet.

The Highbury Ave N. facility has a significantly lower CNG Station capital cost due to the higher suction pressure available from Union Gas at this site. Table 2 below outlines the total capital cost required to install an indoor CNG fueling station, along with a fuel comparison for 163 buses:

Capital			Fuel Comparison	
Total Station Cost	Total Initial Vehicle Premium (106 Buses)	Total Capital Cost	Diesel Cost	First Year CNG Cost (DLE)
$5,500,000	$6,200,000	$11,700,000	$0.85 /L	$0.35 /DLE

Table 2 – Costs and Fuel Comparison for 450 Highbury Avenue N

NOTE: All data presented in the above table is to an accuracy of +/- 25% and is intended as budgetary estimates

Simple Payback is estimated to be 3.8 years to recover the Total Capital Cost of $11,700,000.

2.2. 3508 Wonderland Road S. – Satellite Facility

In 2006, the LTC approved the construction of a second facility, operating as a satellite facility to accommodate fleet expansion by 110 buses. By 2010, London Transit completed the construction of the new 13,000 m^2 (140,000 ft^2) facility that accommodates up to 100, 40' buses for maintenance, servicing and storage. This facility can be expanded to house an additional 10, 40' buses in the future.

The total costs of an indoor CNG fueling station at the Wonderland Rd S. location would be higher than the Highbury Avenue N location due to lower suction pressure from Union Gas' 420 kPa distribution service at this site. The costs below are for 43 buses:

Capital			Fuel Comparison	
Total Station Cost	Total Initial Vehicle Premium	Total Capital Cost	Diesel Cost	First Year CNG Cost (DLE)
$5,500,000	$1,650,000	$7,150,000	$0.85 /L	$0.64 /DLE

Table 3 – Costs and Fuel Comparison for 3508 Wonderland Road S

NOTE: All data presented in the above table is to an accuracy of +/- 25% and is intended as budgetary estimates

Simple Payback is estimated to be 9.5 years to recover the Total Capital Cost of $7,150,000.

2.3. Operation and Maintenance

Cost estimates provided in Table 2 and Table 3 are all-in total costs that include capital recovery, maintenance, personnel, electricity and training. It should be noted that the DLE costs include capital recovery for the CNG fuelling infrastructure and associated equipment. Below is an estimated break-out of the annual operation and maintenance costs for each CNG station located at Wonderland Rd and Highbury Ave, which would be as ongoing costs even after the capital recovery period has been achieved:

Highbury Ave:

a) Personnel: $430,000 per year
   i. Note: Three Operating Engineers would be required at this site due to TSSA requirements
b) Maintenance: $215,000 per year
c) Electricity: $150,000 per year
d) Training: $3,500 per year

Wonderland Rd:

e) Personnel: $145,000 per year
   i. Note: One Operating Engineer would be required at this site due to TSSA requirements
f) Maintenance: $55,000 per year
g) Electricity: $60,000 per year
h) Training: $3,500 per year

2.4. Alternative CNG Station Implementation Strategies

If LTC were to consider the use of CNG, Union Gas would recommend to start with the Highbury Ave facility first, as high pressure gas is available at this location and a higher percentage of LTC's fleet refuels at this location.

In addition, another alternative that could avoid spending significant capital would be to sign a long-term agreement with a third-party retailer or the local gas utility that would provide a stable fuel price per DLE (diesel-litre-equivalent). The third party retailer or gas utility would essentially own the on-site CNG station and be accountable for all operation and maintenance. This would afford the LTC the ease of refueling their buses without the requirement to own and operate the CNG fuelling infrastructure. It would be important to note that the CNG prices (in DLE) listed in Sections 2.1 and 2.2 would be higher if a third-party retailer were to be the fuel provider.

Lastly, the prices listed in Sections 2.1 and 2.2 is based on the assumption that that all 206 transit buses would be converted to CNG in Year 1, along with installing, operating, maintaining and owning 2 CNG fueling stations. Costs can be deferred by gradually phasing-in CNG buses and fueling stations over a longer period of time.

3. CNG Station Costs – City of London Waste Collection

The W12A Landfill is located at 3502 Manning Drive in the City of London approximately 1.5 kilometres west of Wellington Road. The landfill is bounded by White Oak Road to the west, Manning Drive to the south and agricultural land to the north and east. All but one of the adjacent properties to the north and east of the landfill are owned by the City of London. The landfill accepts waste for landfilling within the City of London and the Municipality of Thames Centre.

Below in Table 4 is a summary of the economic inputs and assumptions for the City of London that was used to create the cost estimates of a fossil CNG Slow-Fill Station located at it waste collection fleet home base at 707 Exeter Road:

Waste collection fleet Size	37
Distance Traveled (km/yr)	700,000 km/year
Annual Diesel Consumption	600,000 L
Equivalent Annual m^3 Consumption (DLE)	675,000 m^3
Diesel Cost	$0.85 /L
Daily Operational Fleet	100%
CNG Refueling	Slow Fill
Fill Rate	10 hrs

Table 4 – Inputs and Assumptions for W12A CNG Station

From the above inputs and assumptions, the following costs listed below in Table 5 provides an upset maximum cost that can be used for budgetary purposes should an on-site 100% fossil CNG slow-fill fueling station be located at 707 Exeter Rd for the refueling of 37 curb-side collection waste collection trucks. It should be noted that the Station Cost below includes some ground storage for “fast-fill” capability of up to two waste collection trucks as a contingency plan should 2 trucks forget to refuel overnight:

Capital			Fuel Comparison	
Total Station Cost	Total Initial Vehicle Premium	Total Capital Cost	Diesel Cost	First Year CNG Cost (DLE)
$1,530,000	$1,560,000	$3,090,000	$0.85 /L	$0.45 /DLE

Table 5 – Costs and Fuel Comparison W12A Landfill CNG Station

NOTE: All data presented in the above table is to an accuracy of +/- 25% and is intended as budgetary estimates

Simple Payback is estimated to be 8.4 years to recover the Total Capital Cost of $3,090,000.

3.1. Operation and Maintenance

Cost estimates provided in Table 5 are all-in total costs that include capital recovery, maintenance, electricity and training. Please note that on-site personnel / operating engineers are not required by TSSA for slow-fill fuelling at this site. Below is a break-out of the annual operation and maintenance costs for a CNG station located at 707 Exeter Rd, which should be treated as ongoing costs even after the capital recovery period has been achieved:

a) Maintenance: $24,000 per year
b) Electricity: $21,000 per year
c) Training: $3,500 per year

3.2. Alternative CNG Station Implementation Strategies

Similarly to Section 2.4, if the LTC did pursue CNG, its Highbury Ave facility could act as a "mother station", with 707 Exeter could be designed as a "daughter station" where a CNG tube trailer could supply the CNG for this location. The tube trailer would be refueled during the day at the LTC Highbury facility, then returned to Exeter Rd to supply CNG for waste collection truck refueling in the evening. This scenario represents a significantly lower Station Cost because there is far less equipment and maintenance required.

In addition, another alternative to adopt CNG and avoid spending significant capital would be to sign a long-term agreement with a third-party retailer or the local gas utility that would provide a stable fuel price per DLE (diesel-litre-equivalent). The third party retailer or gas utility would essentially own the on-site CNG station and be accountable for all operation and maintenance. This affords the City of London the ease of refueling their waste collection trucks without the requirement to own and operate a CNG station. It would be important to note that DLE prices listed in Sections 2.1 and 2.2 would also be higher if a third-party retailer were to be the fuel provider.

Lastly, the prices listed in Section 3.0 assume that all 35 waste collection trucks are converted to CNG in Year 1, along with installing, operating, maintaining and owning 1 CNG fueling station. Costs can be deferred by gradually phasing-in the transition to CNG waste collection trucks over a longer period of time.

4. Various RNG / R-CNG Utilization Scenarios

This section will examine the incremental impact of hypothetical CNG pump prices at both LTC bus garages (Highbury Ave and Wonderland Rd), as well as pump prices for the City of London's 35 waste collection trucks that were previously discussed in Sections 2.0 and 3.0.
Heavy duty natural gas engine technology available today is more than 90 percent cleaner than the most stringent applicable U.S. EPA standards for oxides of nitrogen. With such low-emissions, this engine technology has a similar smog-precursor emission profile as that of a heavy duty battery electric truck plugged into the cleanest electrical grid in the United States.

These benefits, as well as significant reductions in GHG emissions, are achieved with HDVs fueled by conventional natural gas. When fueled with Renewable Natural Gas (RNG), lifecycle GHG emissions are reduced by more than 80 percent.

The combination of new near-zero-emission natural gas engine technology and RNG provides the an affordable opportunity for any municipal transit and/or waste collection fleet to achieve immediate and substantial NOx and GHG emission reductions in the on-road heavy duty transportation sectors.

Below are potential DLE (Diesel-Litre-Equivalent) pump price scenarios based on four blend scenarios at specific costs to produce Renewable Compressed Natural Gas (R-CNG) per Gigajoule (GJ) as referenced in Table 6:

Component	SSO Facility Cost		FSO Facility	
	low	high	low	high
Digester with Biogas Upgrading Facility	$0	$23	$12	$35
Digester with Biogas Sent to Landfill Upgrading Facility	($3)	$18	$9	$31

Table 6 – Estimated RNG Costs per GJ, Based on Fixed Tipping Fee

4.1. R-CNG Pump Price @ 450 Highbury Avenue N

RNG Blend	SSO ($/DLE)	SSO with LFG ($/DLE)	FSO ($/DLE)	FSO with LFG ($/DLE)
5%	$0.34	$0.33	$0.36	$0.36
25%	$0.32	$0.29	$0.43	$0.40
50%	$0.29	$0.24	$ 0.51	$0.46
100%	$0.24	$0.13	$0.68	$0.57

Table 7 - CNG Pump Price Comparison with RNG Blend - Low

RNG Blend	SSO ($/DLE)	SSO with LFG ($/DLE)	FSO ($/DLE)	FSO with LFG ($/DLE)
5%	$0.38	$0.37	$0.40	$0.40
25%	$0.53	$0.49	$0.64	$0.61
50%	$0.72	$0.63	$0.94	$0.87
100%	$1.09	$0.91	$1.54	$1.39

Table 8 - CNG Pump Price Comparison with RNG Blend - High

4.2. R-CNG Pump Price @ 3508 Wonderland Road S

RNG Blend	SSO ($/DLE)	SSO with LFG ($/DLE)	FSO ($/DLE)	FSO with LFG ($/DLE)
5%	$0.63	$0.62	$0.65	$0.65
25%	$0.61	$0.58	$0.72	$0.69
50%	$0.59	$0.53	$0.80	$0.75
100%	$0.53	$0.42	$ 0.97	$ 0.86

Table 9 - CNG Pump Price Comparison with RNG Blend - Low

RNG Blend	SSO ($/DLE)	SSO with LFG ($/DLE)	FSO ($/DLE)	FSO with LFG ($/DLE)
5%	$0.67	$0.67	$0.70	$0.70
25%	$0.83	$0.79	$0.94	$0.91
50%	$1.01	$0.92	$1.21	$1.17
100%	$1.39	$1.20	$1.84	$1.69

Table 10 - CNG Pump Price Comparison with RNG Blend - High

4.3. R-CNG Pump Price @ 707 Exeter Rd

RNG Blend	SSO ($/DLE)	SSO with LFG ($/DLE)	FSO ($/DLE)	FSO with LFG ($/DLE)
5%	$0.46	$0.45	$0.48	$0.47
25%	$0.43	$0.40	$0.54	$0.52
50%	$0.41	$0.35	$0.63	$0.57
100%	$0.35	$0.24	$0.80	$0.69

Table 11 - CNG Pump Price Comparison with RNG Blend - Low

RNG Blend	SSO ($/DLE)	SSO with LFG ($/DLE)	FSO ($/DLE)	FSO with LFG ($/DLE)
5%	$0.50	$0.49	$0.52	$0.51
25%	$0.65	$0.60	$0.76	$0.72
50%	$0.83	$0.74	$1.06	$0.98
100%	$1.21	$1.02	$1.65	$1.51

Table 12 - CNG Pump Price Comparison with RNG Blend - High

Appendix C: GHG Analysis – GHGenius Report

LIFECYCLE ANALYSIS OF BIOGAS

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EXECUTIVE SUMMARY

Biogas, resulting from the process of anaerobic digestion (AD), is a renewable energy source that can be used to create heat and power, used as a natural gas equivalent in the pipeline, or used as transportation grade fuel in vehicles.

The Canadian Biogas Association would like to understand the GHG emission benefits of biogas from landfill operations, from source separated organic (SSO) material, and facility sorted organics (FSO) when the produced gas is used for transportation applications.

This work utilizes an updated version of GHGenius 4.03a. The GHGenius model is based on the 1998 version of Dr. Mark Delucchi's Lifecycle Emissions Model (LEM). GHGenius has been developed over the past 17 years by $(S\&T)^2$ Consultants Inc. for Natural Resources Canada and other government and industrial clients. The model is continually updated as new data becomes available. This model has all of the pathways that are of interest to the Association. Lifecycle emissions include not only the emissions from the tailpipe of the vehicle (fuel use) but also all of the emissions associated with the fuel production.

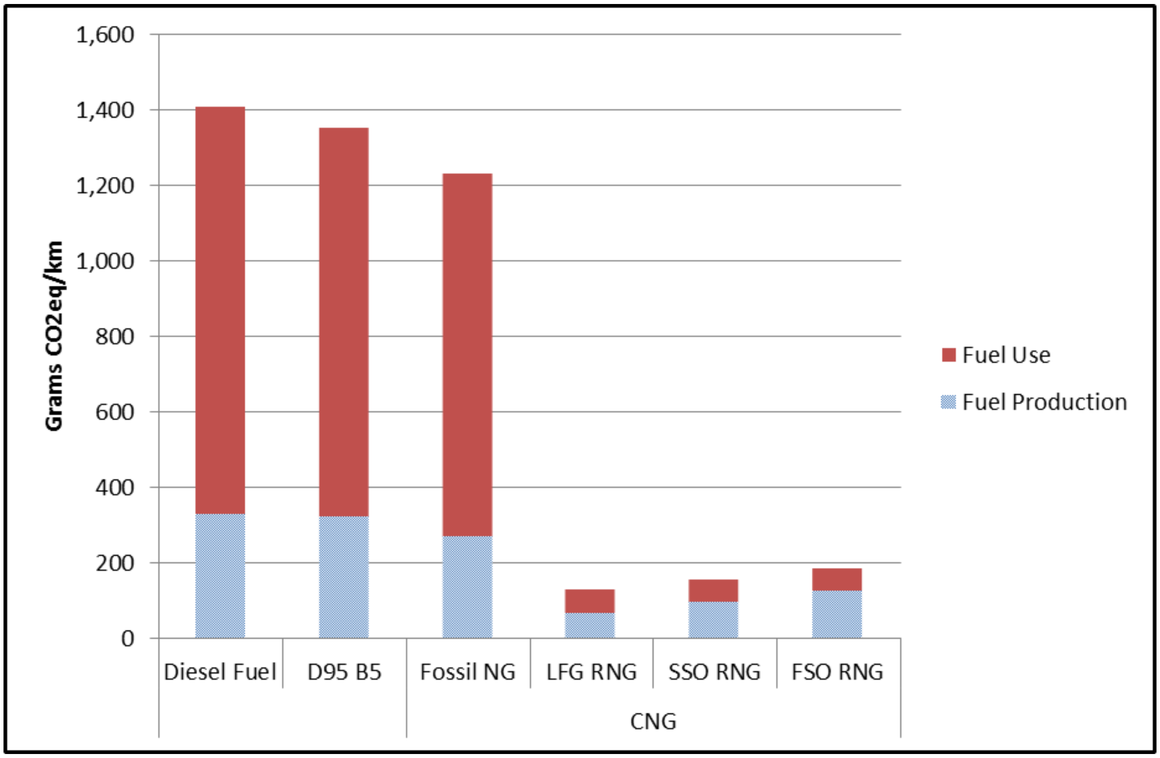
The report considers comparable trucks fueled by ultra low sulphur diesel fuel and using diesel emission fluid to meet emission standards, a 5% biodiesel blend, compressed natural gas, and three compressed biogases. The biogases have been modelled using two anaerobic digestion concepts (SSO and FSO) and landfill gas (LFG). The natural gas trucks all use the newly released CumminsWestport Near Zero NOx engine.

The fossil fuel and renewable natural gas production and use pathways have been modelled to determine the lifecycle GHG emissions and the potential GHG emission reductions that could be achieved with these systems. The systems have been modelled in Ontario (a relatively low carbon intensity power system) and in Alberta (a high carbon intensity power system). The fuel production and use pathways are:

- Diesel fuel
- A blend of 95% diesel and 5% biodiesel (D95 B5)
- Fossil CNG (compressed natural gas)
- Compressed landfill gas (LFG RNG)
- Source separated organics renewable natural gas (SSO RNG)
- Facility separated organics renewable natural gas (FSO RNG).

The GHG emission reductions available in Ontario are shown in the following figure. There are relatively small emission reductions available from the biodiesel blend and fossil CNG systems. The emission reductions are approximately 90% for the RNG systems and these systems have GHG reductions in both the fuel production and fuel use stages.

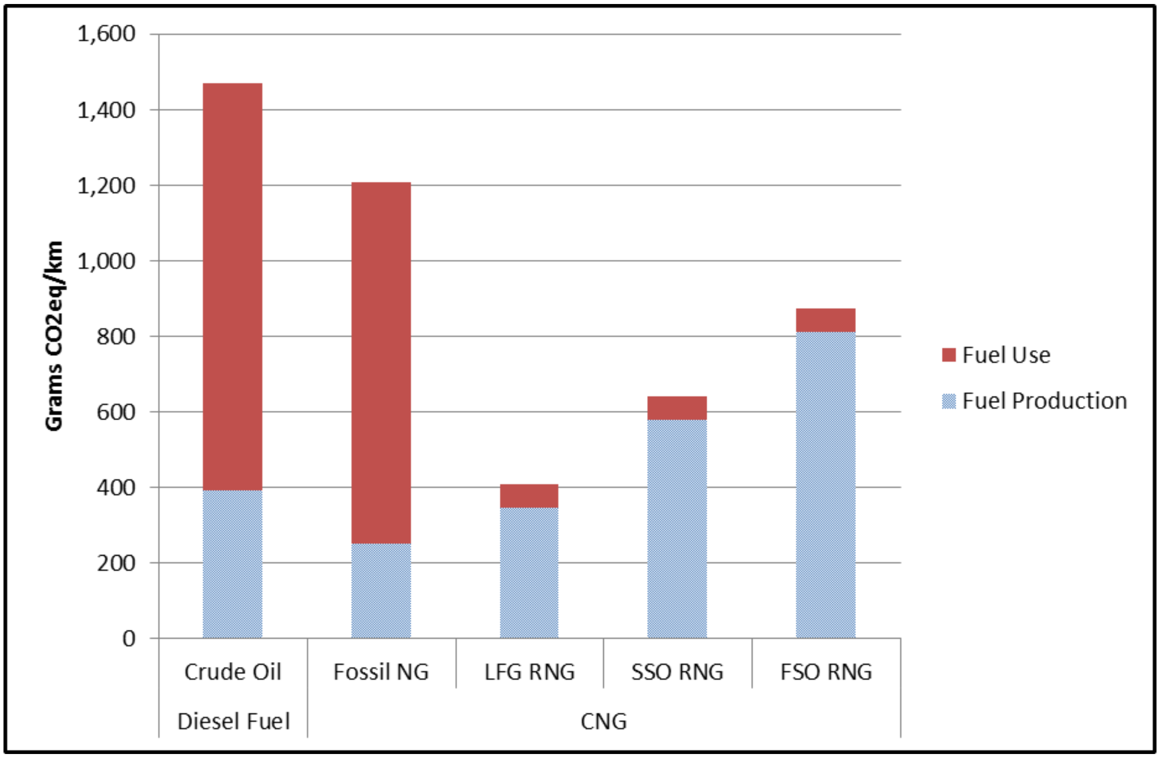
Figure ES- 1 Lifecycle GHG Emissions for Ontario Fuel Pathways



When renewable natural gas is burned the carbon dioxide emissions from combustion are not included in the analysis since the carbon in the fuel was extracted from the air when the original biomass was produced. It is the organic material that decomposes to produce RNG in the landfill or the anaerobic digester. There are still some fuel emissions from the use of RNG since unburned methane and nitrous oxide emissions are still counted in the bioenergy systems.

The RNG systems all consume electricity for production and clean-up the biogas so that it can be used in fuel systems. The emission reductions available from RNG systems therefore depend on the emission intensity of the power used. Ontario, Quebec, Manitoba, and British Columbia have low emission electric power. Other provinces have higher emissions associated with their power systems and the lifecycle emissions of RNG systems will be higher in these other provinces. For emissions for diesel fuel, fossil natural gas and the three RNG systems when they are located in Alberta are shown in the following figure.

Figure ES- 2 Lifecycle GHG Emissions for Alberta Fuel Pathways



The results for the Alberta pathways are quite different. The fossil NG system provides larger GHG emission reductions than it does in Ontario, but the RNG emission reductions are lower than they are in Ontario. The lower RNG emission reductions are due to the higher carbon intensity electric power.

The source of the electric power used in RNG systems can have a significant impact on the GHG emission performance of the systems. Care must be taken when designing systems in high power carbon intensity regions to ensure that the maximum GHG benefits are realized.

Summary

The use of fossil natural gas in a new medium or heavy duty truck compared to the same truck using diesel fuel provides a small reduction in GHG emissions. When renewable natural gas is used instead of fossil natural gas the emission reductions are very significant, although they will depend on where the RNG is produced. The following table summarizes the GHG emissions of the 12 scenarios.

Table ES- 1 GHG Emission Reductions

	Ontario	Alberta
	g CO_2eq/KM	
Diesel Fuel	1,406	1,468
5% biodiesel blend (2% in Alberta)	1,352	1,407
Fossil CNG	1,228	1,207
LFG RNG	128	407
SSO RNG	156	639
FCO RNG	185	872

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1. INTRODUCTION

Biogas, resulting from the process of anaerobic digestion (AD), is a renewable energy sources that can be used to create heat and power, used as a natural gas equivalent in the pipeline, or transportation grade fuel in vehicles.

The Canadian Biogas Association would like to understand the GHG emission benefits of biogas from landfill operations, from source separated organic material, and facility sorted organics when the produced gas is used for transportation applications.

The Association has collected some information on the production of renewable natural gas (RNG) for an Ontario application of the technology and would like to understand how the emission profile might change in other jurisdictions.

1.1 SCOPE OF WORK

This work utilizes an updated version of GHGenius 4.03a. This model has all of the pathways that are of interest to the Association.

The report considers comparable trucks fueled by ultra low sulphur diesel fuel and using diesel emission fluid to meet emission standards, a 5% biodiesel blend, compressed natural gas, and three compressed biogases. The biogases would be modelled using two anaerobic digestion concepts and landfill gas. The natural gas trucks use the newly released CumminsWestport Near Zero NOx engine.

The LCA results can also be influenced by the local systems, particularly pathways that consume significant quantities of electricity. Since the report may also be used by municipalities outside of Ontario we have also run the analysis for a high carbon intensity power system, such as Alberta. This way it is possible to determine the impact of the power system on the performance of biogas production and utilization systems.

The report only documents the key model assumptions and the key details of each of the pathways modelled. A total of 12 sets of results (2 provinces, diesel, 5% biodiesel blend, and the four natural gas systems have been produced. For each province the results include:

- Diesel fuel
- 5% biodiesel, 95% diesel fuel
- Fossil CNG – new engine
- R CNG - landfill gas CNG – new engine
- R CNG – AD from SSO material CNG – new engine
- R CNG – AD from FSO material CNG – new engine

1.2 GHGENIUS

The GHGenius model is based on the 1998 version of Dr. Mark Delucchi's Lifecycle Emissions Model (LEM). GHGenius has been developed over the past 17 years by $(S\&T)^2$ Consultants Inc. for Natural Resources Canada and other government and industrial clients. The model has been continually updated as new data has become available.

GHGenius is capable of estimating life cycle emissions of the primary greenhouse gases and the criteria pollutants from combustion and process sources. The specific gases that are included in the model include:

- Carbon dioxide (CO_2),
- Methane (CH_4),
- Nitrous oxide (N_2O),
- Chlorofluorocarbons (CFC-12),
- Hydro fluorocarbons (HFC-134a),
- The CO_2-equivalent of all of the contaminants above.
- Carbon monoxide (CO),
- Nitrogen oxides (NOx),
- Non-methane organic compounds (NMOCs), weighted by their ozone forming potential,
- Sulphur dioxide (SO_2),
- Total particulate matter.

The model is capable of analyzing the emissions from conventional and alternative fuelled internal combustion engines or fuel cells for light duty vehicles, for class 3-7 medium-duty trucks, for class 8 heavy-duty trucks, for urban buses and for a combination of buses and trucks, for light duty battery powered electric vehicles, and for marine vessels. There are over 200 vehicle and fuel combinations possible with the model.

GHGenius can predict emissions for past, present and future years through to 2050 using historical data or correlations for changes in energy and process parameters with time that are stored in the model. The fuel cycle segments considered in the model are as follows:

- Vehicle Operation
  Emissions associated with the use of the fuel in the vehicle. Includes all greenhouse gases.
- Fuel Dispensing at the Retail Level
  Emissions associated with the transfer of the fuel at a service station from storage into the vehicles. Includes electricity for pumping, fugitive emissions and spills.
- Fuel Storage and Distribution at all Stages
  Emissions associated with storage and handling of fuel products at terminals, bulk plants and service stations. Includes storage emissions, electricity for pumping, space heating and lighting.
- Fuel Production (as in production from raw materials)
  Direct and indirect emissions associated with conversion of the feedstock into a saleable fuel product. Includes process emissions, combustion emissions for process heat/steam, electricity generation, fugitive emissions and emissions from the life cycle of chemicals used for fuel production cycles.
- Feedstock Transport
  Direct and indirect emissions from transport of feedstock, including pumping, compression, leaks, fugitive emissions, and transportation from point of origin to the fuel refining plant. Import/export, transport distances and the modes of transport are considered. Includes energy and emissions associated with the transportation infrastructure construction and maintenance (trucks, trains, ships, pipelines, etc.)
- Feedstock Production and Recovery
  Direct and indirect emissions from recovery and processing of the raw feedstock, including fugitive emissions from storage, handling, upstream processing prior to transmission, and mining.
- Feedstock Upgrading

Direct and indirect emissions from the upgrading of bitumen to synthetic crude oil at a standalone facility, including fugitive emissions.

- Fertilizer Manufacture
  Direct and indirect life cycle emissions from fertilizers, and pesticides used for feedstock production, including raw material recovery, transport and manufacturing of chemicals. This is not included if there is no fertilizer associated with the fuel pathway.
- Land use changes and cultivation associated with biomass derived fuels
  Emissions associated with the change in the land use in cultivation of crops, including N_2O from application of fertilizer, changes in soil carbon and biomass, methane emissions from soil and energy used for land cultivation.
- Carbon in Fuel from Air
  Carbon dioxide emissions credit arising from use of a renewable carbon source that obtains carbon from the air.
- Leaks and flaring of greenhouse gases associated with production of oil and gas
  Fugitive hydrocarbon emissions and flaring emissions associated with oil and gas production.
- Emissions displaced by co-products of alternative fuels
  Emissions displaced by co-products of various pathways. System expansion is used to determine displacement ratios for co-products from biomass pathways.
- Vehicle assembly and transport
  Emissions associated with the manufacture and transport of the vehicle to the point of sale, amortized over the life of the vehicle.
- Materials used in the vehicles
  Emissions from the manufacture of the materials used to manufacture the vehicle, amortized over the life of the vehicle. Includes lube oil production and losses from air conditioning systems.

A modified version of GHGenius 4.03a is used for this work. The modifications include update data for much of the background information in the model including, the power generation mixes, natural gas sources and emissions, crude oil production. There are also new pathways in the model and in some cases improvements in the way that the model forecasts energy and materials use based on historical data.

GHGenius 4.03a is fully documented in two volumes of manual that are available on the GHGenius website www.ghgenius.ca.

1.3 Lifecycle Analysis

Lifecycle analysis is a relative analytical approach structured on the basis of a common function unit. The functional units used in this work are one GJ of energy (HHV) and one kilometer of travel in a heavy duty truck.

The relative aspect is that the systems studied are always compared to a similar system providing the same function. Not only is the relative approach applied to the outputs but also to the systems themselves. In our case, landfill gas used for transportation fuels is compared to diesel fuel and fossil natural gas. We assume that if the landfill gas was not used for this purpose, it would be flared at the landfill.

In the case of the anaerobic digestion of organic materials, it is assumed that the organic material would otherwise be collected and landfilled at a site with landfill gas capture and flaring. Using this relative approach simplifies the lifecycle analysis in that only differences in the two systems need to be considered in the modelling.

1.4 Global Warming Potentials

The model has been set to 2016 and it uses the 100 year GWPs from the 4th Assessment Report for the base case scenarios. It has been assumed that carbon monoxide (CO) and non-methane hydrocarbon (NMHC) emissions are ultimately oxidized to CO_2 and the CO_2 emissions are calculated using the carbon weighted emissions of CO and NMOC. Some sensitivity analyses will be undertaken using alternative GWPs, including those from the 5th Assessment Report. The GWP's are summarized in the following table.

Table 1-1 GWPs Used

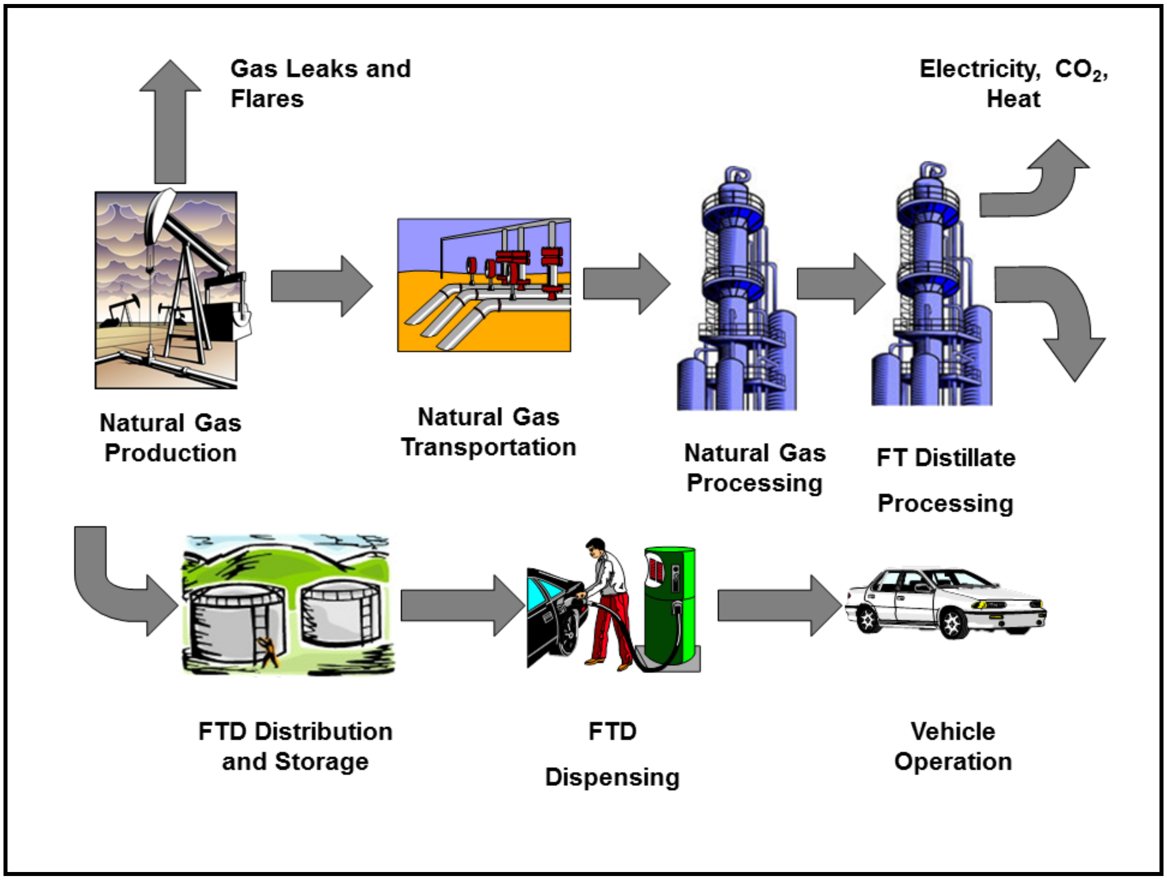
Contaminant	2007 IPCC GWP	2013 IPCC GWP
CO_2	1	1
CH_4	25	34
N_2O	298	298
CFC-12	10,900	10,200
HFC-134a	1,430	1,550
SF_6	22,800	23,500
CO	1.57	1.57
NMOC	2.99	2.99

2. FOSSIL NATURAL GAS SUPPLY CHAINS

Fossil natural gas is one of the fuels under study in this analysis. Canada is a major producer of natural gas but also imports natural gas from the United States in some regions of Canada. In Ontario about half of the natural gas is produced in Western Canada and transported by pipeline to Ontario and the other half of the gas is produced in the United States and transported to Ontario. Both producing regions are in GHGenius and there are some differences in the emission profile for the two regions.

The natural gas supply chain includes the energy and emissions associated with well drilling, production, gas processing, transmission, distribution and finally compression and use in a vehicle. The system boundary is shown in the following figure.

Figure 2-1 Natural Gas System Boundaries



2.1 WESTERN CANADA

The data on the energy use and emissions for the natural gas system in GHGenius comes from Statistics Canada (energy use), Environment Canada (solution gas CO_2 emissions), from the Alberta Energy Regulator (methane emissions for gas recovery and processing), and from the Canadian Energy Partnership for Environmental Innovation (methane emissions in gas transmission and distribution). The model uses time series of data so that the emissions in future years can be estimated from the historical trends in energy use and emissions. The Canadian data in the model covers the periods up to 2014 or 2015 depending on the data source.

The modelled emissions compare favourably to other sources such as the Clearstone Engineering report prepared for Environment Canada in 2014, even though the methodology and data sources for the two approaches are different.

2.2 United States

The data on the energy use and emissions for the US production of natural gas is derived from the US EPA 2016 National GHG Inventory report (2016) and from the US Energy Information Administration. The EPA report has a major revision of the methodology used for the emissions from the natural gas sector compared to earlier reports. The emissions from the natural gas recovery are significantly higher than previous estimates but the emissions from gas transmission and distribution are lower. Overall the GHG emissions are about 15% higher than in the 2015 GHG Inventory Report.

2.3 GHG Emissions

The emissions for Canadian gas delivered to Ontario and for US gas delivered to Ontario are shown in the following table. These emissions do not include the emissions associated with compressing the fuel for use in the transportation sector. These emissions will be included in the next section of the report. The blended supply will be used for the fossil natural gas in Ontario.

Table 2-1 Natural Gas Emissions in Ontario

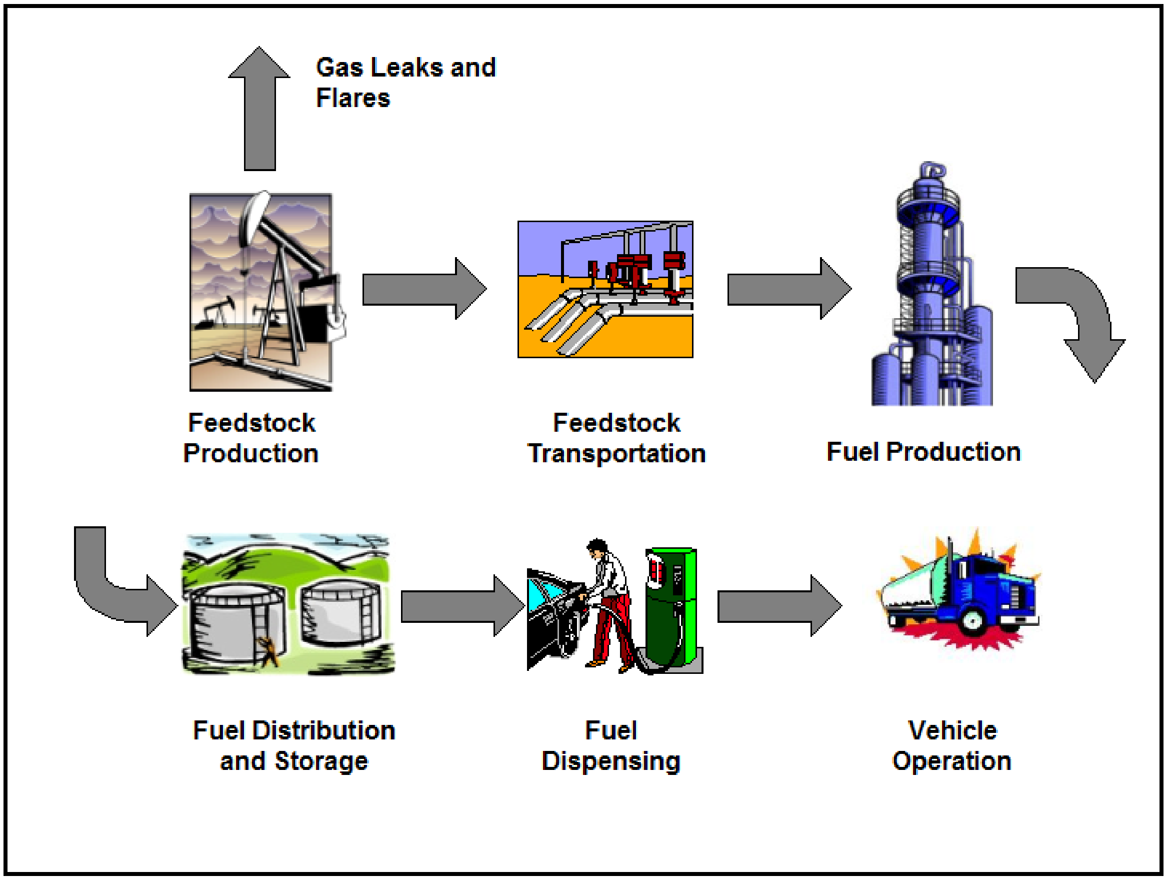
	W Canadian Gas	US Gas	Blended Supply
	g CO_2eq/GJ (HHV)		
Fuel dispensing	0	0	0
Fuel distribution and storage	658	658	658
Fuel production	2,347	1,994	2,205
Feedstock transmission	4,873	2,151	3,664
Feedstock recovery	3,609	8,406	5,888
Feedstock upgrading	0	0	0
Land-use changes, cultivation	0	0	0
Fertilizer manufacture	0	0	0
Gas leaks and flares	0	0	0
CO_2, H_2S removed from NG	552	748	642
Emissions displaced - co-products	0	0	0
Sub Total	12,039	13,957	13,057

3. REFERENCE FUELS

Lifecycle analyses should always compare the study system with a reference system. The RNG pathways can be compared to diesel fuel, diesel fuel blended with biodiesel, and fossil natural gas. All of these pathways are included in GHGenius.

Another important aspect of lifecycle analysis is ensuring that systems that are compared have the same system boundaries, the beginning and end of the analysis. The system boundaries for the liquid reference fuels are shown in the following figure.

Figure 3-1 Diesel Fuel System Boundaries



The GHG emissions for each of these reference fuels are discussed below.

3.1 DIESEL FUEL

Diesel fuel is the reference fuel for the RNG and the fossil NG systems. The diesel fuel GHG emissions are shown in the following table. We have included the emissions for the diesel emission fluid that must be used in new engines to meet the emission standards.

Table 3-1 GHG Emissions Diesel Fuel - Ontario

Fuel	Ultra Low Sulphur Diesel Fuel
Feedstock	Crude Oil
	g CO_2eq/GJ (HHV)
Fuel dispensing	59
Fuel distribution and storage	400
Fuel production	10,445
Feedstock transmission	355
Feedstock recovery	5,602
Feedstock upgrading	1,627
Land-use changes, cultivation	85
Fertilizer manufacture	0
Gas leaks and flares	3,089
CO_2, H_2S removed from NG	0
Emissions displaced - co-products	-62
Total	21,599
Diesel Combustion	70,326
Lifecycle Emissions	91,925

3.2 BIODIESEL

The Ontario Greener Diesel regulation required diesel fuel suppliers to blend biodiesel or renewable diesel with the petroleum diesel. The quantity blended and the carbon intensity of the greener diesel varies with the compliance period. In 2016, the diesel fuel should contain 3% greener diesel with a 50% reduction in GHG emissions. This increases to 4% and a 70% reduction in 2017. We have modelled a 5% blend with soy biodiesel which will meet the 70% reduction in GHG emissions target.

Table 3-2 GHG Emissions B5 - Ontario

Fuel	ULSD95/B5
Feedstock	Crude Oil
	g CO_2eq/GJ (HHV)
Fuel dispensing	59
Fuel distribution and storage	429
Fuel production	10,161
Feedstock transmission	430
Feedstock recovery	5,748
Feedstock upgrading	2,123
Land-use changes, cultivation	2,470
Fertilizer manufacture	278
Gas leaks and flares	2,947
CO_2, H_2S removed from NG	0
Emissions displaced - co-products	-3,469
Total	21,176
B5 Combustion	67,172
Lifecycle Emissions	88,348

3.3 Fossil Natural Gas

The GHG emissions for fossil CNG in Ontario are shown in the following table. These emissions are shown on the same basis as the previous tables, g CO_2eq/GJ of energy; however there is a difference in the efficiency of natural gas and diesel engines. When the lifecycle emissions are shown later in the report, the emissions will be presented as g CO_2eq/km travelled. That way the engine efficiency issue will be accounted for.

Table 3-3 GHG Emissions Fossil Natural Gas - Ontario

Fuel	Fossil CNG
Feedstock	Crude Oil
	g CO_2eq/GJ (HHV)
Fuel dispensing	1,929
Fuel distribution and storage	660
Fuel production	2,213
Feedstock transmission	3,676
Feedstock recovery	5,909
Feedstock upgrading	0
Land-use changes, cultivation	0
Fertilizer manufacture	0
Gas leaks and flares	0
CO_2, H_2S removed from NG	644
Emissions displaced - co-products	0
Total	15,030
Natural Gas Combustion	54,421
Lifecycle Emissions	69,451

4. BIOGAS SUPPLY

Three different RNG pathways have been modelled, a landfill gas (LFG), and two different feedstocks for anaerobic digestion systems. The systems are discussed below.

4.1 LANDFILL GAS

Organic waste in landfills is broken down by bacterial action in a series of stages that result in the formation of methane and carbon dioxide (termed biogas or landfill gas) and further bacterial biomass. In the initial phase of degradation, organic matter is broken down to small soluble molecules including a variety of sugars. These are broken down further to hydrogen, carbon dioxide, and a range of carboxylic acids. These acids are then converted to acetic acid, which, together with hydrogen and carbon dioxide, forms the major substrate for growth of methanogenic bacteria.

Landfill gas consists of approximately 50 per cent carbon dioxide and 50 per cent methane by volume. However, the percentage of carbon dioxide in landfill gas may be smaller because of decomposition of substrates with a high hydrogen/oxygen ratio (e.g., fats, hemicellulose) and because some of the carbon dioxide dissolves in water within the site.

The Association completed a Canadian Biogas Study in 2013. The findings of the landfill gas portion of the study were:

- 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.

Most LCA work on alternate use of LFG assumes that the gas is flared if it is not utilized and this is the case in London, Ontario. This assumption provides a very conservative emission profile for the reference system since it would appear from the Environment Canada data that about one third of the LFG in Canada is captured for flaring or utilization. The assumption also simplifies the issue of methane leaks and any flaring that would be present in the operation of the collection and upgrading systems, since these would generally also occur in the reference system. The combustion efficiency of flaring is generally assumed to be greater than 99.9%.

4.1.1 Landfill Gas Systems

Typical landfill gas collection systems have three central components: collection wells, a condensate collection and treatment system, and a compressor. Depending on the end application of the gas there may be a need to treat the gas to remove all trace contaminants typically found in landfill gas, particularly if the gas is used directly for vehicle fuel or further chemical processing. In addition, most landfills with energy recovery systems will have a flare for the combustion of excess gas and for use during equipment down times.

There are different technologies that can be used for the gas clean-up, scrubbers, membrane systems, and pressure swing absorption systems. All of the systems require electrical power to operate.

Xebec Inc. has sold a number of PSA systems for upgrading landfill gas. Detailed energy requirements for a system for a proposed landfill in British Columbia are publicly available (Sperling Hansen Associates). This system used 14 kWh/GJ of upgraded natural gas produced. That is the value used in GHGenius. The emissions for LFG production and purification are therefore the emissions associated with this power production.

The energy requirements for the compression of the gas for transportation use are calculated separately by the model.

If the landfill gas was produced at a landfill that is currently just venting the gas, then there would be a very large credit available for the avoided methane emissions from that landfill. This credit could range from 400,000 to 450,000 g CO_2eq/GJ depending on whether the ultimate oxidation of biogenic methane to biogenic CO_2 is considered.

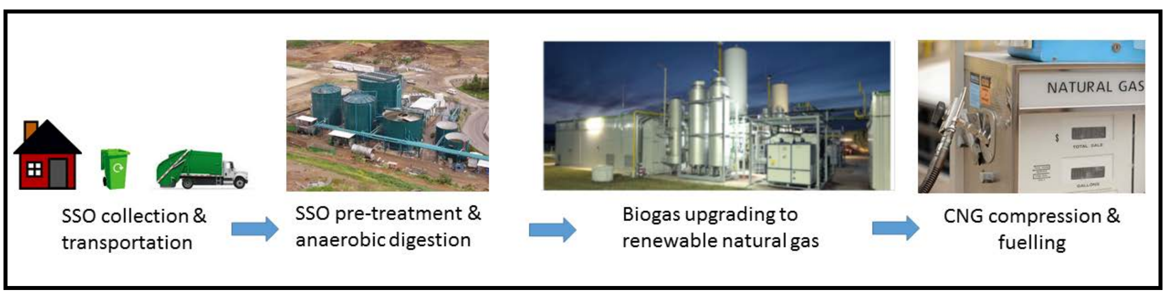
4.2 Anaerobic Digestion

Anaerobic digestion systems are conceptually similar to landfill gas except that the process is undertake in a man-made vessel instead of a landfill and thus there is more control over the process. There are many AD systems in operation around the world and there are variations on the process available from different suppliers. The systems do require electric power to operate and still require the produced gas to be cleaned up and the methane content concentrated in order to put the gas into a pipeline system.

4.2.1 Source Separated Organics

In the source separated organics (SSO) system, the waste is separated by the owner and the separated material is collected and trucked to the digester. If we assume that the AD system is located at the landfill then there will be little difference in the trucking energy use and emissions for landfilling this material or anaerobically digesting it. Since these emissions will happen in both the reference system and the study system they can be ignored. The basic system schematic is shown in the following figure.

Figure 4-1 SSO System



The City of London received responses from a Request for Information that it issued for AS systems. The gas production rates from the responders ranged from 120 to 180 NM^3 of biogas per tonne of SSO digested (2.6 to 4.6 GJ/tonne). The systems all produced some residue that would be landfill and produced some digestate that may have some undetermined beneficial use (such as fertilizer). It has been assumed that the digestate is a residue with no beneficial uses nor is it a burden in terms of GHG emissions for any disposal required.

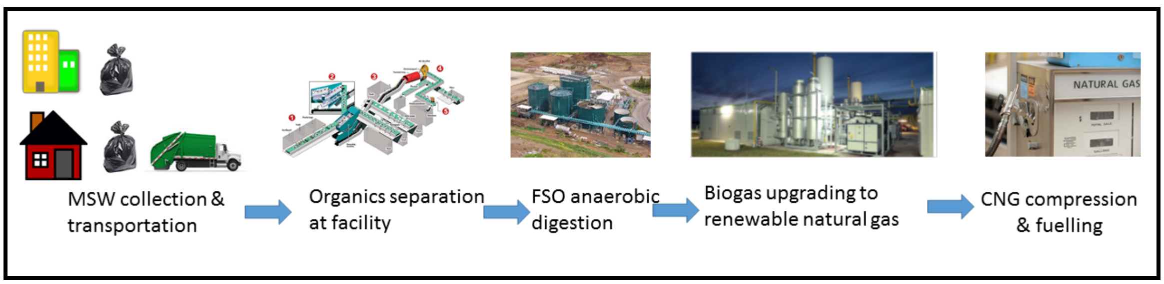
The AD systems all require some electricity to operate. The respondents suggested that the electrical load was 5 to 10% of the gas produced. For the SSO system we have assumed that the electrical load is at the low end of the range and that is 14 kwh/GJ of gas produced. There will still be gas cleanup required which will add an additional 14 kWh/GJ of pipeline quality gas produced.

There can also be fugitive methane emissions from AD systems. Losses of up to 3% were suggested by one respondent. The issue is whether these losses are any different from what would be experienced at a landfill. If they are different they are probably more likely to be less. We have assumed that they are the same.

4.2.2 Facility Separated Organics

The Facility separated organics system relies on a central sorting facility to separate the organics from recyclables and inorganics. The separation facility will have some electrical load that isn't present in the SSO facility. The operation of the AD and gas cleanup system is expected to be very similar to the SSO system. The basic system schematic is shown in the following figure.

Figure 4-2 FSO System



For modelling this system we have assumed that the total power load of the separation system and the AD is at the high end of the range provided by the respondents. We will model 28 kWh/GJ of gas plus the 14 kWh for the gas cleanup, for a total electrical load of 42 kWh.

The same assumptions concerning the digestate and the methane loss rate is applied to this system as the SSO system.

5. NATURAL GAS ENGINES

Information on the relative energy efficiency and the exhaust emissions of natural gas engines are presented below.

5.1 ENGINE EFFICIENCY

The natural gas engines are based on a diesel engine but they have been converted to spark ignition engines with a lower compression ratio. The result is that the thermal efficiency of the natural gas engine is lower than that of the equivalent diesel engine.

The relative engine efficiency in GHGenius considers not only the engine performance but also the impact of extra weight for the fuel tanks. The values in GHGenius are based on engine certification data supplied to the US EPA. These values have been checked against fuel consumption data supplied by Cummins Westport for the natural gas and diesel engines operating at governed speed, maximum power and at peak torque. This additional data is consistent with the emission certification data.

Argonne National Laboratory (ANL) (Gao, 2013) compared the fuel consumption of NG and diesel heavy-duty Class 8 trucks using Argonne's Autonomie model to simulate the vehicles on various drive cycles. The results of those simulations showed that the NG heavy-duty trucks had 6%–13% lower fuel economy relative to the diesel HDVs. However this is reported using the lower heating value of the fuels and GHGenius uses higher heating value and the equivalent range would be 11 to 18% lower fuel economy.

In GHGenius the relative engine efficiency is 86.9% and the relative vehicle efficiency is 84.5%. This is the middle of the ANL range.

5.2 EMISSIONS

Cummins Westport has announced a new Near Zero NOx version of their natural gas engines. The new Cummins Westport Near Zero NOx ISL G that will reduce NOx emissions by 90% from the current EPA limit of 0.2 g/bhp-hr to 0.02 g/bhp-hr NOx while also meeting the 2017 EPA greenhouse gas emission requirements.

The inputs for the GHGenius model for the near zero NOX heavy-duty natural gas engines are summarized in the following table.

Table 5-1 GHGenius Input Values – Near Zero NOx CNG Engines

	GHGenius Values
Exhaust Emissions	
NMOC exhaust ratio NGV to Diesel Vehicle	0.80
CH_4 exhaust ratio NGV to Diesel Vehicle	18
CO exhaust ratio NGV to Diesel Vehicle	3.0
N_2O exhaust ratio NGV to Diesel Vehicle	0.25
NOx as NO_2 exhaust ratio NGV to Diesel Vehicle	0.08
Particulate Matter from fuel ratio NGV to Diesel Vehicle	Calc.

The modelled emissions for diesel and natural gas engines on a g/kwh and a grams/kilometre basis are shown in the following table. These methane emissions include both the emissions from the tailpipe and from the crankcase.

Table 5-2 Near Zero NOx Engine Exhaust Emissions

	Diesel Engine		Natural Gas Engine	
	g/kwh	g/km	g/kwh	g/km
NMOC exhaust	0.127	0.25	0.102	0.20
CH_4 exhaust	0.041	0.08	0.650	1.29
CO exhaust	0.118	0.23	0.355	0.71
N_2O exhaust	0.030	0.06	0.007	0.01
NOx as NO_2 exhaust	0.258	0.50	0.020	0.04
PM exhaust	0.013	0.02	0.006	0.01

The fuel economy of the truck that is model is 41.0 litres of diesel fuel/100 km of distance travelled.

6. Lifecycle Emissions

The lifecycle emissions for the systems in Ontario and in Alberta are shown in the following sections.

6.1 Ontario

The RNG systems require electricity to operate but have little extra energy inputs into the systems. The electricity from the grid in Ontario is relatively low in Carbon intensity and so it is expected that the RNG systems will have relatively good emission performance. Diesel fuel is the primary reference fuel for all systems. The RNG pathways are also compared to the fossil natural gas systems and the 5% biodiesel blend.

6.1.1 Fossil Natural Gas

The lifecycle emissions for fossil natural gas, diesel and B5 fuels in Ontario are shown in the following table. The fossil CNG supply system reduces the lifecycle GHG emissions by 12.7% compared to the diesel fuel.

Table 6-1 Fossil NG and Diesel Fuel Lifecycle Emissions

Fuel	Diesel Fuel	D95 B5	CNG
Feedstock	Crude Oil	Crude oil/soybeans	Fossil NG
	g CO_2eq/km		
Vehicle operation	1,075.8	1,077.2	958.6
C in end-use fuel from CO_2 in air	0.0	-49.6	0.0
Net Vehicle Operation	1,075.8	1,027.7	958.6
Fuel dispensing	0.9	0.9	34.6
Fuel storage and distribution	6.1	6.6	11.8
Fuel production	159.8	155.4	39.7
Feedstock transport	5.4	6.6	66.0
Feedstock recovery	85.7	87.9	106.0
Feedstock upgrading	24.9	32.5	0.0
Land-use changes, cultivation	1.3	37.8	0.0
Fertilizer manufacture	0.0	4.2	0.0
Gas leaks and flares	47.2	45.1	0.0
CO_2, H_2S removed from NG	0.0	0.0	11.6
Emissions displaced by co-products	-1.0	-53.1	0.0
Subtotal (fuel cycle)	1,406.3	1,351.6	1,228.4
% changes (fuel cycle)	--	-3.9	-12.7

6.1.2 RNG – Landfill Gas

Renewable natural gas from landfills has much lower GHG emissions because the methane is produced from biogenic materials. The lifecycle emissions compared to diesel fuel are shown in the following table. The GHG emissions are reduced by 91% for this scenario. As stated previously, this assumes that the LFG is currently being collected and flared. If this is not the case and the LFG is being released to the atmosphere the emission benefit would be much larger.

Table 6-2 LFG RNG and Diesel Fuel Lifecycle Emissions

Fuel	Diesel Fuel	D95 B5	CNG
Feedstock	Crude Oil	Crude oil/soybeans	LFG NG
	g CO_2eq/km		
Vehicle operation	1,075.8	1,077.2	958.6
C in end-use fuel from CO_2 in air	0.0	-49.6	-897.7
Net Vehicle Operation	1,075.8	1,027.7	60.9
Fuel dispensing	0.9	0.9	34.6
Fuel storage and distribution	6.1	6.6	2.9
Fuel production	159.8	155.4	29.3
Feedstock transport	5.4	6.6	0.0
Feedstock recovery	85.7	87.9	0.0
Feedstock upgrading	24.9	32.5	0.0
Land-use changes, cultivation	1.3	37.8	0.0
Fertilizer manufacture	0.0	4.2	0.0
Gas leaks and flares	47.2	45.1	0.0
CO_2, H_2S removed from NG	0.0	0.0	0.0
Emissions displaced by co-products	-1.0	-53.1	0.0
Subtotal (fuel cycle)	1,406.3	1,351.6	127.7
% changes (fuel cycle)	--	-3.9	-90.9

6.1.3 RNG – SSO

The lifecycle emissions for the SSO pathway are shown in the following table. There is some uncertainty with respect to the feedstock transportation distance as the trucks may travel a longer distance when the material is sorted due to truck capacity challenges when there are multiple compartments so a case with an extra 25 km of feedstock transportation is included. The impact is relatively small.

Table 6-3 LFG RNG and Diesel Fuel Lifecycle Emissions

Fuel	Diesel Fuel	CNG	CNG
Feedstock	Crude Oil	SSO RNG	SSO RNG
Feedstock Transportation		None	25 km
	g CO_2eq/km		
Vehicle operation	1,075.8	958.6	958.6
C in end-use fuel from CO_2 in air	0.0	-897.7	-897.7
Net Vehicle Operation	1,075.8	60.9	60.9
Fuel dispensing	0.9	34.6	34.6
Fuel storage and distribution	6.1	1.3	1.3
Fuel production	159.8	59.0	59.0
Feedstock transport	5.4	0.0	65.1
Feedstock recovery	85.7	0.0	0.0
Feedstock upgrading	24.9	0.0	0.0
Land-use changes, cultivation	1.3	0.0	0.0
Fertilizer manufacture	0.0	0.0	0.0
Gas leaks and flares	47.2	0.0	0.0
CO_2, H_2S removed from NG	0.0	0.0	0.0
Emissions displaced by co-products	-1.0	0.0	0.0
Subtotal (fuel cycle)	1,406.3	155.7	220.8
% changes (fuel cycle)	--	-88.9	-84.3

6.1.4 RNG – FSO

The emissions for the AD system when the feedstock is sorted at the site of the AD system are shown in the following table. The only difference in terms of the energy inputs into the system is higher power use and the impact of this in a relatively low CI power system like Ontario is small.

Table 6-4 FSO RNG and Diesel Fuel Lifecycle Emissions

Fuel	Diesel Fuel	CNG
Feedstock	Crude Oil	FSO RNG
	g CO_2eq/km	
Vehicle operation	1,075.8	958.6
C in end-use fuel from CO_2 in air	0.0	-897.7
Net Vehicle Operation	1,075.8	60.9
Fuel dispensing	0.9	34.6
Fuel storage and distribution	6.1	1.3
Fuel production	159.8	88.4
Feedstock transport	5.4	0.0
Feedstock recovery	85.7	0.0
Feedstock upgrading	24.9	0.0
Land-use changes, cultivation	1.3	0.0
Fertilizer manufacture	0.0	0.0
Gas leaks and flares	47.2	0.0
CO_2, H_2S removed from NG	0.0	0.0
Emissions displaced by co-products	-1.0	0.0
Subtotal (fuel cycle)	1,406.3	185.2
% changes (fuel cycle)	--	-86.8

6.2 ALBERTA

All of the pathways have been redone using the same assumptions except the location is Alberta, which has a much higher carbon intensity power system than Ontario. There are also some differences in the fossil fuel reference systems as the Alberta refineries process different crude oils than the Ontario refineries and Alberta natural gas doesn't have the same transmission energy use and emissions that Ontario does, being closer to the source of the natural gas. All of these factors have an impact on the emission profiles.

6.2.1 Biodiesel Blend

Alberta has a regulation that requires an average of 2% biodiesel be blended and the biodiesel must demonstrate at least a 30% reduction in GHG emissions. The following table shows the typical impact of 5% canola biodiesel in Alberta.

Table 6-5 Biodiesel and Diesel Fuel Lifecycle Emissions - Alberta

Fuel	Diesel Fuel	5% Biodiesel
Feedstock	Crude Oil	Canola
	g CO_2eq/km	
Vehicle operation	1,075.8	1,077.2
C in end-use fuel from CO_2 in air	0.0	-49.6
Net Vehicle Operation	1,075.8	1,027.7
Fuel dispensing	7.1	7.2
Fuel storage and distribution	10.2	10.7
Fuel production	161.6	157.8
Feedstock transport	11.3	11.5
Feedstock recovery	90.0	88.4
Feedstock upgrading	74.8	75.8
Land-use changes, cultivation	3.2	3.7
Fertilizer manufacture	0.0	6.4
Gas leaks and flares	35.8	34.1
CO_2, H_2S removed from NG	0.0	0.0
Emissions displaced by co-products	-2.2	-16.6
Subtotal (fuel cycle)	1,467.7	1,406.7
% changes (fuel cycle)	-	-4.2

6.2.2 Fossil Natural Gas

The lifecycle emissions for fossil natural gas and diesel fuel in Alberta are shown in the following table. The fossil CNG supply system reduces the lifecycle GHG emissions by 17.7% compared to the diesel fuel. The emission reduction is larger than in Ontario because the diesel emissions are higher and the natural gas production emissions are lower.

Table 6-6 Fossil NG and Diesel Fuel Lifecycle Emissions - Alberta

Fuel	Diesel Fuel	CNG
Feedstock	Crude Oil	Fossil NG
	g CO_2eq/km	
Vehicle operation	1,075.8	958.6
C in end-use fuel from CO_2 in air	0.0	0.0
Net Vehicle Operation	1,075.8	958.6
Fuel dispensing	7.1	103.3
Fuel storage and distribution	10.2	11.8
Fuel production	161.6	43.2
Feedstock transport	11.3	15.5
Feedstock recovery	90.0	65.0
Feedstock upgrading	74.8	0.0
Land-use changes, cultivation	3.2	0.0
Fertilizer manufacture	0.0	0.0
Gas leaks and flares	35.8	0.0
CO_2, H_2S removed from NG	0.0	9.9
Emissions displaced by co-products	-2.2	0.0
Subtotal (fuel cycle)	1,467.7	1,207.3
% changes (fuel cycle)	-	-17.7

6.2.3 RNG – Landfill Gas

Renewable natural gas from landfills has much lower GHG emissions because the methane is produced from biogenic materials. The lifecycle emissions compared to diesel fuel are shown in the following table. The GHG emissions are reduced by 72% for this scenario as a result of the higher carbon intensity of the Alberta power grid. As stated previously, this assumes that the LFG is currently being collected and flared. If this is not the case, and there are landfills in Alberta without methane capture, the emission benefit would be much larger.

Table 6-7 LFG RNG and Diesel Fuel Lifecycle Emissions

Fuel	Diesel Fuel	CNG
Feedstock	Crude Oil	LFG RNG
	g CO_2eq/km	
Vehicle operation	1,075.8	958.6
C in end-use fuel from CO_2 in air	0.0	-897.7
Net Vehicle Operation	1,075.8	60.9
Fuel dispensing	7.1	103.3
Fuel storage and distribution	10.2	10.4
Fuel production	161.6	232.3
Feedstock transport	11.3	0.0
Feedstock recovery	90.0	0.0
Feedstock upgrading	74.8	0.0
Land-use changes, cultivation	3.2	0.0
Fertilizer manufacture	0.0	0.0
Gas leaks and flares	35.8	0.0
CO_2, H_2S removed from NG	0.0	0.0
Emissions displaced by co-products	-2.2	0.0
Subtotal (fuel cycle)	1,467.7	406.8
% changes (fuel cycle)	-	-72.3

6.2.4 RNG – SSO

The lifecycle emissions for the SSO pathway are shown in the following table. The emission reductions are lower than they were in Ontario due to the higher carbon intensity of the electric power. There is some uncertainty with respect to the feedstock transportation distance as the trucks may travel a longer distance when the material is sorted due to truck capacity challenges when there are multiple compartments so a case with an extra 25 km of feedstock transportation is included. The impact of the extra transportation is relatively small.

Table 6-8 LFG RNG and Diesel Fuel Lifecycle Emissions

Fuel	Diesel Fuel	CNG	CNG
Feedstock	Crude Oil	SSO RNG	SSO RNG
Feedstock Transportation		None	25 km
			g CO_2eq/km
Vehicle operation	1,075.8	958.6	958.6
C in end-use fuel from CO_2 in air	0.0	-897.7	-897.7
Net Vehicle Operation	1,075.8	60.9	60.9
Fuel dispensing	7.1	103.3	103.3
Fuel storage and distribution	10.2	10.4	10.4
Fuel production	161.6	464.8	464.8
Feedstock transport	11.3	0.0	68.5
Feedstock recovery	90.0	0.0	0.0
Feedstock upgrading	74.8	0.0	0.0
Land-use changes, cultivation	3.2	0.0	0.0
Fertilizer manufacture	0.0	0.0	0.0
Gas leaks and flares	35.8	0.0	0.0
CO_2, H_2S removed from NG	0.0	0.0	0.0
Emissions displaced by co-products	-2.2	0.0	0.0
Subtotal (fuel cycle)	1,467.7	639.4	707.8
% changes (fuel cycle)	-	-56.4	-51.8

6.2.5 RNG – FSO

The emissions for the AD system when the feedstock is sorted at the site of the AD system are shown in the following table. The only difference in terms of the energy inputs into the system is higher power use. In a high power CI environment like Alberta this is a significant impact.

Table 6-9 FSO RNG and Diesel Fuel Lifecycle Emissions

Fuel	Diesel Fuel	CNG
Feedstock	Crude Oil	FSO RNG
	g CO_2eq/km	
Vehicle operation	1,075.8	958.6
C in end-use fuel from CO_2 in air	0.0	-897.7
Net Vehicle Operation	1,075.8	60.9
Fuel dispensing	7.1	103.3
Fuel storage and distribution	10.2	10.4
Fuel production	161.6	697.2
Feedstock transport	11.3	0.0
Feedstock recovery	90.0	0.0
Feedstock upgrading	74.8	0.0
Land-use changes, cultivation	3.2	0.0
Fertilizer manufacture	0.0	0.0
Gas leaks and flares	35.8	0.0
CO_2, H_2S removed from NG	0.0	0.0
Emissions displaced by co-products	-2.2	0.0
Subtotal (fuel cycle)	1,467.7	871.8
% changes (fuel cycle)	-	-40.6

7. Discussion

A number of renewable natural gas production and use pathways have been modelled to determine the lifecycle GHG emissions and the potential GHG emission reductions that could be achieved with these systems. The systems have been modelled in Ontario (a relatively low carbon intensity power system) and in Alberta (a high carbon intensity power system).

The GHG emission reductions available in Ontario are approximately 90% for the RNG systems. There are emission reductions available from the fossil CNG system but they are much smaller.

Table 7-1 NG and Diesel Fuel Lifecycle Emissions - Ontario

Fuel	Diesel Fuel	D95 B5	CNG			
Feedstock	Crude Oil	Crude oil/soy	Fossil NG	LFG RNG	SSO RNG	FSO RNG
	g CO_2eq/km					
Vehicle operation	1,075.8	1,077.2	958.6	958.6	958.6	958.6
C in end-use fuel from CO_2 in air	0.0	-49.6	0.0	-897.7	-897.7	-897.7
Net Vehicle Operation	1,075.8	1,027.7	958.6	60.9	60.9	60.9
Fuel dispensing	0.9	0.9	34.6	34.6	34.6	34.6
Fuel storage and distribution	6.1	6.6	11.8	2.9	1.3	1.3
Fuel production	159.8	155.4	39.7	29.3	59.0	88.4
Feedstock transport	5.4	6.6	66.0	0.0	0.0	0.0
Feedstock recovery	85.7	87.9	106.0	0.0	0.0	0.0
Feedstock upgrading	24.9	32.5	0.0	0.0	0.0	0.0
Land-use changes, cultivation	1.3	37.8	0.0	0.0	0.0	0.0
Fertilizer manufacture	0.0	4.2	0.0	0.0	0.0	0.0
Gas leaks and flares	47.2	45.1	0.0	0.0	0.0	0.0
CO_2, H_2S removed from NG	0.0	0.0	11.6	0.0	0.0	0.0
Emissions displaced by co-products	-1.0	-53.1	0.0	0.0	0.0	0.0
Subtotal (fuel cycle)	1,406.3	1,351.6	1,228.4	127.7	155.7	185.2
% changes (fuel cycle)	--	-3.9	-12.7	-90.9	-88.9	-86.8

The results for the Alberta pathways are quite different. The fossil NG system provides larger GHG emission reductions than it does in Ontario, but the RNG emission reductions are lower than they are in Ontario. The lower RNG emission reductions are due to the higher carbon intensity electric power.

Table 7-2 NG and Diesel Fuel Lifecycle Emissions - Alberta

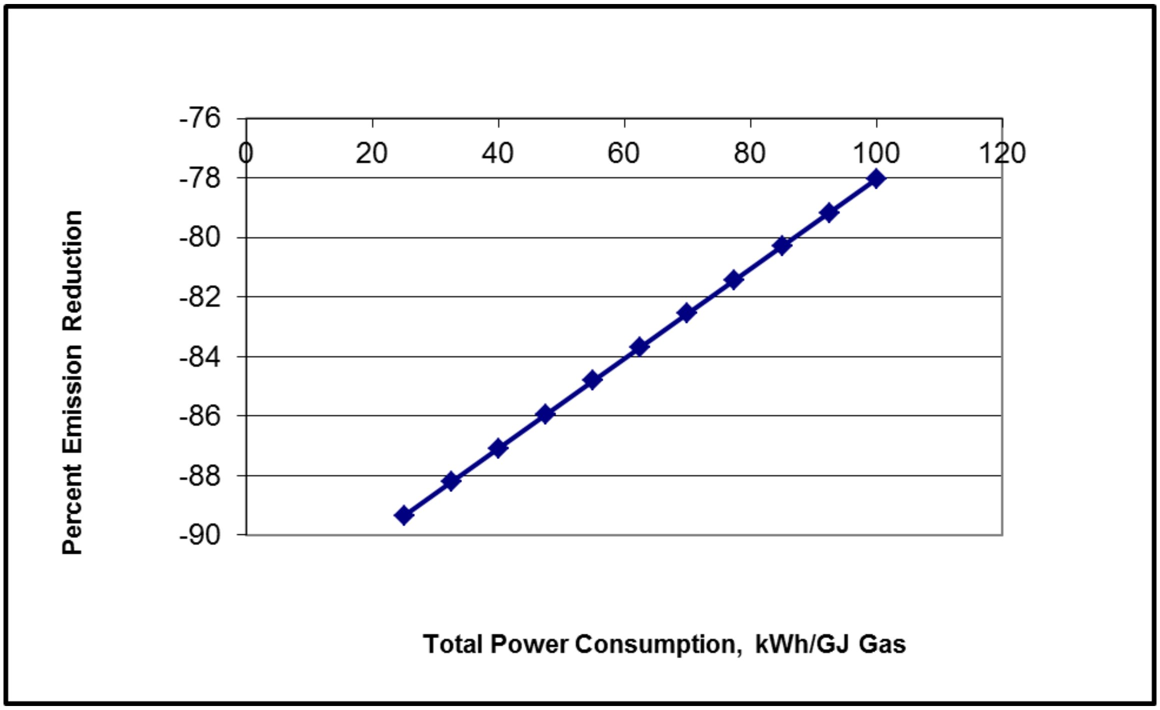
Fuel	Diesel Fuel	CNG			
Feedstock	Crude Oil	Fossil NG	LFG RNG	SSO RNG	FSO RNG
	g CO_2eq/km				
Vehicle operation	1,075.8	958.6	958.6	958.6	958.6
C in end-use fuel from CO_2 in air	0.0	0.0	-897.7	-897.7	-897.7
Net Vehicle Operation	1,075.8	958.6	60.9	60.9	60.9
Fuel dispensing	7.1	103.3	103.3	103.3	103.3
Fuel storage and distribution	10.2	11.8	10.4	10.4	10.4
Fuel production	161.6	43.2	232.3	464.8	697.2
Feedstock transport	11.3	15.5	0.0	0.0	0.0
Feedstock recovery	90.0	65.0	0.0	0.0	0.0
Feedstock upgrading	74.8	0.0	0.0	0.0	0.0
Land-use changes, cultivation	3.2	0.0	0.0	0.0	0.0
Fertilizer manufacture	0.0	0.0	0.0	0.0	0.0
Gas leaks and flares	35.8	0.0	0.0	0.0	0.0
CO_2, H_2S removed from NG	0.0	9.9	0.0	0.0	0.0
Emissions displaced by co-products	-2.2	0.0	0.0	0.0	0.0
Subtotal (fuel cycle)	1,467.7	1,207.3	406.8	639.4	871.8
% changes (fuel cycle)	--	-17.7	-72.3	-56.4	-40.6

7.1 Electric Power Sensitivity

The quality of the data on the power requirements for the SSO and FSO systems is not high as the respondents to the City of London RFI provided a wide range for the system power consumption and didn't really differentiate between the two types of facilities. To address this uncertainty we have run a sensitivity of the results to the electric load for both an Ontario and an Alberta location.

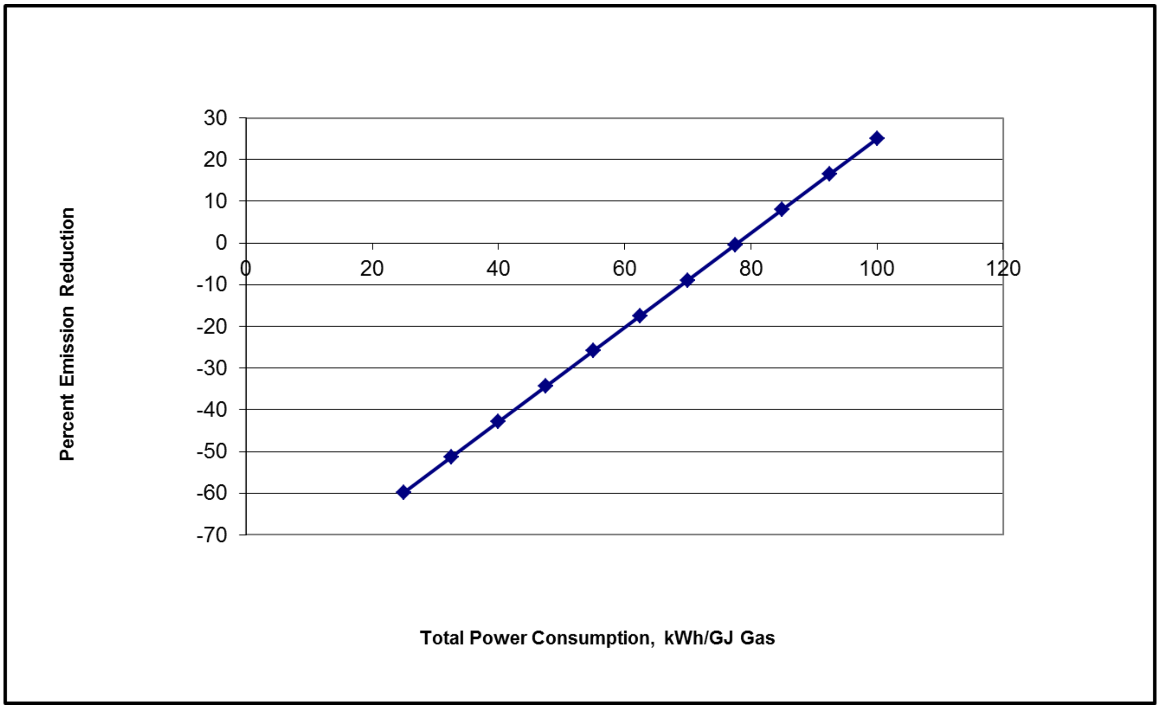
The Ontario results are shown below. Even with a power demand that is more than double the assumption for the base case modelling the GHG emission reductions are still significant.

Figure 7-1 Power Demand Sensitivity - Ontario



The sensitivity results for Alberta are shown below. Power demand is a much more significant issue in Alberta and power demand of more than 80 kWh/GJ of gas eliminates the GHG emissions, assuming the landfill gases are collected and flared presently.

Figure 7-2 Power Demand Sensitivity – Alberta



7.2 2013 IPCC GWP

The IPCC 5th Assessment report released late in 2013 increased the GWP for methane from 25 to 34. This impacts not only the natural gas systems but also the electric power and diesel fuel production. The summary table for Ontario is shown below when the 2013 GWPs are used in the model. The GHG emission reductions are lower but are still large for the RNG systems.

Table 7-3 NG and Diesel Fuel Lifecycle Emissions – Ontario 2013 GWP

Fuel	Diesel Fuel	CNG			
Feedstock	Crude Oil	Fossil NG	LFG RNG	SSO RNG	FSO RNG
	g CO_2eq/km				
Vehicle operation	1,076.4	977.5	977.5	977.5	977.5
C in end-use fuel from CO_2 in air	0.0	0.0	-897.7	-897.7	-897.7
Net Vehicle Operation	1,076.4	977.5	79.8	79.8	79.8
Fuel dispensing	0.9	43.8	43.8	43.8	43.8
Fuel storage and distribution	6.2	16.1	1.3	1.3	1.3
Fuel production	163.4	43.5	30.5	61.3	91.9
Feedstock transport	5.6	72.4	0.0	0.0	0.0
Feedstock recovery	87.1	125.2	0.0	0.0	0.0
Feedstock upgrading	25.9	0.0	0.0	0.0	0.0
Land-use changes, cultivation	1.3	0.0	0.0	0.0	0.0
Fertilizer manufacture	0.0	0.0	0.0	0.0	0.0
Gas leaks and flares	61.7	0.0	0.0	0.0	0.0
CO_2, H_2S removed from NG	0.0	11.6	0.0	0.0	0.0
Emissions displaced by co-products	-1.1	0.0	0.0	0.0	0.0
Subtotal (fuel cycle)	1,427.5	1,290.0	155.4	186.2	216.8
% changes (fuel cycle)	--	-9.6	-89.1	-87.0	-84.8

8. REFERENCES

Canadian Biogas Association. 2013. Canadian Biogas Study, Benefits to the Economy, Environment and Energy. Summary Document. http://www.biogasassociation.ca/bioExp/images/uploads/documents/2014/biogas_study/Canadian_Biogas_Study_Summary.pdf

Environment Canada. 2014. Technical Report on Canada's Upstream Oil and Gas Industry. Vols. 1 – 4. Prepared for Environment Canada. Calgary (AB): Clearstone Engineering Ltd.

Gao, Z., LaClair, T., Daw, C.S., Smith, D.E., 2013. Fuel Consumption and Cost Savings of Class 8 Heavy-Duty Trucks Powered by Natural Gas. Presented at the Transportation Research Board 92nd Annual Meeting.

GHGenius 4.03 Manual Volume 1. 2013. http://www.ghgenius.ca/reports/GHGenius403Volume1.pdf

GHGenius 4.03 Manual Volume 2. 2013. http://www.ghgenius.ca/reports/GHGenius403Volume2.pdf

US EPA. 2016. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2014. https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Main-Text.pdf

Sperling Hansen Associates. 2007. Highland Valley Centre for Sustainable Waste Management – Landfill Gas Utilization Options. http://a100.gov.bc.ca/appsdata/epic/documents/p263/1201720914359_73d30a11885846f686a89b24ffc4dc56.pdf

Appendix D: Highlights of Technology Submissions

Several technology suppliers provided information related to their technologies as part of the RFI process. The following are highlights related to their companies, technologies and processes, and relevant customers.

AIM Environmental Group

AIM Environmental Group is a division of Maple Reinders Inc, and has a specialty focus in organics processing operations, in which experienced and knowledgeable staff process municipal source separated organics and biosolids. The operations group along with its support partners have vast experience with the beneficial re-use and marketing of process derived products and energy generation derived from SSO processing. AIM's current operation experience includes the long term contracted operations of the 60,000-90,000 tonnes per year Hamilton Centralized Compost Facility (2006) and the 30,000 tonne per year Guelph Organics Composting Facility (2011). AIM has been selected as the operational provider for a design, build, finance and operate/maintain project (DBFOM) for the City of Calgary which includes the processing and composting of 100,000 tonnes of SSO material and 40,000 tonnes of dewatered biosolids. AIM's involvement in the Calgary project includes design process flow, technical support, pre and post processing systems selection and procurement, and the long term operational component under a fixed and a processing fee/tonne price arrangement.

A team consisting of Aim Environmental Group, Maple Reinders Inc., Komptech Ontario Inc., and Votorantim Cimentos has been assembled to respond to the Request for Information. Komptech Ontario Inc., is a direct distributor and servicing agent for Komptech GmbH of Austria, which provides highly engineered and efficient pre and post process technologies for the processing of all wastestreams. With nearly 10 years of experience in the Canadian market and 30 plus years in the waste industry Komptech Ontario Inc. and Komptech GmbH have successfullygrown to be the largest equipment provider for waste processing or organic waste in Canada through the supply of advanced size reduction, classification, sorting and screening technologies for both anaerobic and aerobic processes.

BIOFerm

Based on the information provided regarding the expected potential waste streams and their potential volumes, combined with London's interest in biogas upgrading to renewable natural gas ("RNG") and compost product (from digestate), BIOFermTM Energy Systems ("BIOFerm") recommends a series of pre-processing equipment steps, a high solids anaerobic digestion (HSAD) facility with aerated composting tunnels, and a gas upgrading pressure swing adsorption (PSA) skid for the conversion of biogas to RNG.

Composting (aerated) tunnels and biofilter design is provided by our partners at BioMRF. This in-vessel process can accelerate the composting by reducing ammonia, lowering moisture content, reducing pathogens and resulting in quality, nutrient-rich compost product which can be marketed and sold.

BIOFerm also offers expertise in gas upgrading via Carbotech Pressure Swing Adsorption (PSA) technology which can achieve >97% RNG conversion from biogas. The company's PSA skids are some of the most energy efficient and reliable systems on the market with some of the lowest methane losses; this PSA technology has been developed for over 35 years and includes over 900 installations.

BIOFerm was also selected as the anaerobic digestion (AD) technology provider for the City of Edmonton's high solids anaerobic digestion (HSAD) Facility, which has similarities in volume and characteristics to the facility the City of London is considering. The HSAD Facility in Edmonton will process 40,000 tonnes/year of SSO and MSW <2" fraction. This facility will feature, pre-processing equipment, an 8-fermenter HSAD, and composting aeration tunnels.

Orgaworld

Orgaworld's range of technologies are able to process either source separated organics (SSO) or separate and process organic material contained within a mixed residual waste stream, generating a range of valuable outputs, such compost, biofuels and RNG, while simultaneously diverting waste from landfill and reducing the environmental impact of municipal waste disposal.

Shanks Municipal Division's range of market-ready technologies have been critical in assisting municipalities to drive a step-change in recycling and recovery rates, achieving over 90% diversion in some cases. In Canada, Orgaworld Canada Ltd, has successfully designed, developed and operated a range of facilities to provide organic waste treatment solutions to cities and municipalities across the country.

Of particular interest as it relates to this RFI is Shanks Orgaworld's recent project for the City of Surrey, British Columbia. The company believes that an option wherein vehicle fuel is created from biogas can offer significant long-term economic advantages and offers the opportunity of implementing a 'closed loop' approach to waste management. This approach, whereby biogas derived via dry anaerobic digestion of organic waste is upgraded to a high quality RNG, will be delivered on the Shanks Orgaworld organic waste project recently signed for the City of Surrey.

Stormfisher

Since inception in 2007, StormFisher has led the development of two of the largest biogas facilities in North America: the StormFisher facility in London, and another facility in Orlando, Florida. Both Facilities have been operating for over two years. StormFisher is has been the lead developer on other large AD facilities in the US at both stand-alone locations as well as adjoining wastewater treatment plants The principals have over ten years of biogas development and operations experience with multiple forms of organics pre-processing equipment.

StormFisher provides a complete organics management solution – one that puts waste organics to the highest and best use. StormFisher's core business is in organics management; not only extracting the energy from the waste organics, but extracting the nutrient value in the form of a solid, organic based granular fertilizer, certified by the Canadian Food Inspection Agency (CFIA). No other biogas facility in North America makes a granular, certified fertilizer for sale to commercial markets.

Bio-En Power

Bio-En Power submitted some information through the RFI process, but did not include costs and indicated it would only design, build and operate such a facility, not turn over operations to the municipality.

Bio-En Power Inc. is an Ontario corporation, based in Elmira, Ontario. The company was established in 2005. It holds the North and Central American rights to develop and operate anaerobic digestion facilities for solid and other high-strength organic wastes, from Agrinz Technologies GmbH, of Austria.

As of February 2016, the company has successfully constructed three large anaerobic digestion (AD) facilities in Ontario, with the oldest commissioned in 2011. A fourth facility will be commissioned in the Spring of 2016, in Nicaragua. The three Ontario facilities have an aggregate capacity of 224,000 annual tonnes of organic waste.

It uses a two-stage digestion approach, in large part due to the proven ability of that this kind of system to recover more energy per input unit of waste than is possible with single-stage systems.

Appendix E: Glossary

Anaerobic Digestion (AD): A series of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. One of the end products is biogas, which is combusted to generate electricity and heat, or can be processed into renewable natural gas and transportation fuels.

Biogas: A gaseous emission from the anaerobic digestion of organic matter. Biogas is principally a mixture of methane (CH_4) and carbon dioxide (CO_2) along with other trace gases.

Biomethane: Biogas that has been compressed and purified. Biomethane is a renewable form of natural gas that is interchangeable with fossil fuel derived natural gas. Biomethane is referred to in this document as renewable natural gas (RNG). The two terms are used interchangeably.

Biosolids: Organic materials resulting from the treatment of sewage sludge.

Compressed Natural Gas (CNG): A readily available alternative to gasoline that is made by compressing natural gas to less than 1% of its volume at standard atmospheric pressure.

Facility-Sorted Organics (FSO): FSO refers to organic waste that is co-mingled and collected with garbage in the same bag, and is sorted at the treatment facility.

Greenhouse Gases (GHG): Gases that trap heat in the atmosphere and are the principal cause of climate change.

Landfill Gas (LFG): A form of biogas that is a by-product of the decomposition of organic waste buried in landfills.

Liquefied Natural Gas (LNG): Natural gas (predominantly methane, CH_4) that has been converted to liquid form for ease of storage or transport. It takes up about 1/600th the volume of natural gas in the gaseous state.

Normal Cubic Meters (NM^3): The conventional format for expressing natural gas volumes at normal temperature and pressure conditions.

Natural Gas Vehicle (NGV): A vehicle that uses compressed natural gas as an alternative to conventional fuels, such as gasoline and diesel. Natural gas vehicles can also be fuelled by renewable natural gas (RNG).

Renewable Natural Gas (RNG): Biogas that has been compressed and purified. A renewable form of natural gas that is interchangeable with fossil fuel derived natural gas.

Source-Separated Organics (SSO): Organic wastes, including food wastes from residential, commercial and industry sources. These organic wastes are separated from other landfill materials and can be used to generate biogas through anaerobic digestion.

Wastewater Treatment (WWT): The treatment of wastewater produces biosolids that can be processed through anaerobic digestion to produce biogas.