CLOSING THE LOOP

Primer for Municipalities, Food Processors and Fleets on Fueling Vehicles Using Renewable Natural Gas

Canadian Biogas Association

JUNE 2015

Acknowledgements

The Biogas Association thanks the following sponsors for their support of the Closing the Loop Primer:

This project was funded in part through Growing Forward 2 (GF2), a federal-provincial-territorial initiative. The Agricultural Adaptation Council assists in the delivery of GF2 in Ontario.

The views expressed in this report are the views of the Canadian Biogas Association and do not necessarily reflect those of the governments of Canada and Ontario.

The Closing the Loop Primer was authored by Viking Strategies. Special thanks to Margaret Girard of Algonquin College for her contributions to the research and writing of this Primer.

The Biogas Association wishes to thank the expert advisory committee that assisted in the development and review of this Closing the Loop Primer. The committee consists of staff from:

- Bio-en Power
- Change Energy
- Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA)
- Union Gas
- Integrated Gas Recovery Services (IGRS)

Canadian Biogas Association

Contents

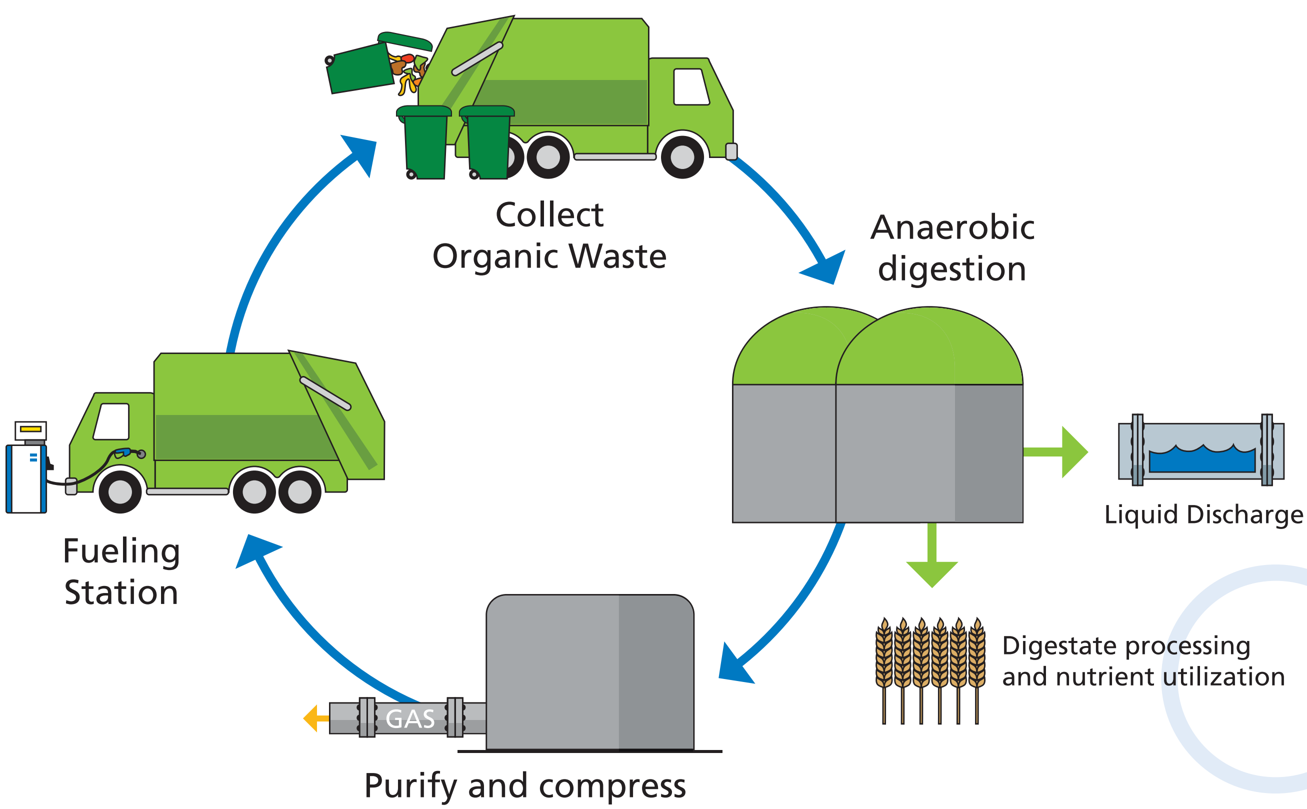
Canadian Biogas Association

Introduction

Renewable natural gas (RNG) from food waste and organic material is the next game-changer in vehicle fueling. RNG is cost-competitive with diesel fuel, and is carbon neutral.

RNG vehicle fueling is your organization's biggest opportunity for near-term, cost-neutral sustainability.

Not only can food waste be considered a resource, but it can be converted cost-effectively into a renewable vehicle fuel, significantly elevating its value.



YOU CAN CLOSE THE LOOP IN THREE WAYS:

1. Stop sending your organic materials to landfill, and instead harvest vehicle fuel
2. Fuel your fleet from local organic material
3. Use locally-produced RNG and keep your energy dollars in your community instead of purchasing fossil-fuel based diesel and gasoline produced outside your community.

By *Closing the Loop*, your organization can take a meaningful step toward reducing carbon emissions, make money, help your fleets and/or other fleets in your community be more green, and be effective leaders in energy sustainability.

This primer shows you how your organization can close the loop. It helps identify if compressed natural gas (CNG) and RNG are right for you, outlines how RNG fits with municipal planning and policy development, and highlights case studies and lessons learned. It is part of a larger *Closing the Loop* initiative, which includes workshops, tours, and networking to promote the adoption of RNG as a vehicle fuel.

Closing the Loop is a collaborative initiative of the Canadian Biogas Association, and involves working with municipalities, food processors, energy and waste management companies to divert organic materials from landfill, and use them to generate biogas and renewable natural gas (RNG). It is supported by Growing Forward 2, a federal-provincial-territorial initiative, Bio-En Power, Bullfrog Power, and Union Gas.

The chart below shows why CNG is being adopted by fleets – up to 40% lower operating costs than diesel or gasoline, based on five-year price averages:

Fuel	Price	GHG Impact
Gasoline and diesel	~$1.15/litre	Base case
Compressed natural gas	~$0.60/litre	25% lower than base case
Compressed RNG	~$1.15/litre	90% lower than base case
CNG/RNG blend (90%/10%)	~$0.65/litre	31% lower than base case

Note that the CNG and RNG numbers are expressed in diesel litre equivalents (DLE). One cubic metre of natural gas or RNG has the energy equivalent of one litre of diesel fuel.[1] This makes a CNG/RNG blend cost effective at about 60-65% of the price of diesel.

The chart also shows that switching to CNG results in emissions reductions of about 25% from diesel or gasoline. Fueling with RNG results in emissions reductions of about 90% from diesel or gasoline. A blend of CNG with 10% RNG results in emissions reductions of about 31%, and provides added benefits which are outlined in this document.

1 Go With Natural Gas

Early Adopters: Municipal Fleets

The Canadian Biogas Association's *Closing the Loop* initiative builds on the visionary work of leading municipalities that have a sustainability focus and are moving to reduce greenhouse gas emissions and transportation costs, while recycling organic material. Many municipalities are transitioning to CNG vehicles to save money and reduce GHG emissions. With secure organic material supply, return-to-base fleets, and strong public-interest priorities, municipalities are logical early adopters.

RNG is a logical fuel to integrate into CNG fleets, as it can be injected at its production source and vehicles can be fueled anywhere on the natural gas pipeline. In other words, the vehicles do not have to be fueled where the RNG is produced. Municipalities can generate RNG at their wastewater or SSO treatment facilities, or their landfills, or in purpose-built food waste biogas systems. In Canada alone, the following municipalities are planning or have implemented RNG as a vehicle fuel from the sources shown below:

City	Source	Status (in 2015)
Nanaimo	Landfill	Under construction
Surrey	SSO	Under construction
Hamilton	Wastewater treatment	Complete
Niagara	Wastewater treatment	Under study
London	SSO	Under study
Saint-Hyacinthe	Wastewater, SSO and industrial waste	Under construction
Rivière-du-Loup	SSO and landfill	Under construction

Many of these municipalities are showcased in more detail in this primer.

Food Processors and Waste Management Companies

Food processors and their waste management companies can close the loop by diverting their organic waste outputs to anaerobic digestion (AD) facilities, located either off-site or as part of on-site wastewater treatment, instead of sending them to landfill. They can also consider purchasing RNG as a vehicle fuel, or work with their waste haulers to make the switch, which closes the loop by using the outputs of food processing as an input or fuel to the waste vehicles.

First, sending material to biogas facilities is cost competitive with landfill for Ontario companies, and has a number of benefits, including:

- Significantly lower greenhouse gas emissions. Digesting half of the 6 million tonnes of food waste discarded in Canada each year would save 2.2 million tonnes/year of eCO_2. This is equivalent to taking 490,000 cars off the road.[2]
- Nutrients are returned to the soil. Recycling nutrients from municipal, industrial and commercial operations is an important ongoing source of soil health.
- Protecting water sources through pathogen destruction of organic material and mitigating risk of potential environmental impact.
- Contributes to renewable energy production, green job creation and local energy security.

2 Canadian Biogas Association, *Canadian Biogas Study Summary*, November 2013.

Second, food processors that have sustainability goals can consider using a blend of conventional compressed natural gas (CNG) and RNG for their trucking needs. Many fleets are making the switch to CNG from diesel because of the lower cost and lower greenhouse gas emissions as outlined in the chart above.

Exciting Industry Trends:

- At the City of Surrey, BC, organic material will be processed at a facility and converted to RNG to fuel 100% of the energy needed for the waste fleet. The business case was built comparing RNG to diesel prices and the facility will be a public-private partnership.
- In southwest Ontario, the *Rural Green Energy Project* is in development and will generate RNG, blend it with CNG, and sell it as a vehicle fuel to a fleet of milk trucks, local farms, and other businesses and customers.
- Progressive Waste Solutions has the largest fleet of CNG waste vehicles in Canada, and has opened a RNG injection facility at its Terrebone landfill site in Quebec, selling RNG to the US.
- Waste Management is using RNG from its landfill in Fairmont City, Illinois to fuel its waste trucks. "This innovative facility utilizes renewable landfill gas, and purifies it to a high-quality natural gas that in turn feeds into the adjacent pipeline to fuel our growing fleet of CNG trucks," says Jim Trevathan, executive vice president and chief operating officer for Waste Management.
- Entrepreneurs at Atlas Disposal teamed up with Clean Energy Fuels, and currently provide RNG to Atlas's own waste fleet, and to the City of Sacremento's waste fleet.
- "Redeem" is a branded RNG fuel by Clean Energy Fuels that is available across the U.S. to natural gas vehicle fleets including heavy-duty trucks, refuse trucks, airport shuttles, taxis, and buses.

Moving from Yesterday's Fleet to Tomorrow's Fleet

The transportation sector has been identified as a major contributor to greenhouse gas (GHG) and air pollutant emissions. In Ontario, over 34% of our greenhouse gas emissions come from transportation.[3] One in five trucks and buses in Canada is over 20 years old. Choosing natural gas vehicles (NGVs) to replace older fleet vehicles or to upgrade existing ones by modifying them to become NGV would result in long-term economic benefits and significant reductions for both air pollution and GHG emissions.[4]

Examine your fleet and your ability to benefit environmentally and economically by choosing to replace aging fleet vehicles, or upgrade existing fleet vehicles, with NGVs. Consider your fleet: what portion of vehicles do you renew every year? For vehicles less than five years old there are clear benefits to converting from diesel over to dual-fuel diesel/CNG. For older vehicles, consider a phased plan to purchase new CNG vehicles. It's only by converting to CNG vehicles that you can capitalize on the RNG opportunity.

Why Choose CNG over Diesel?

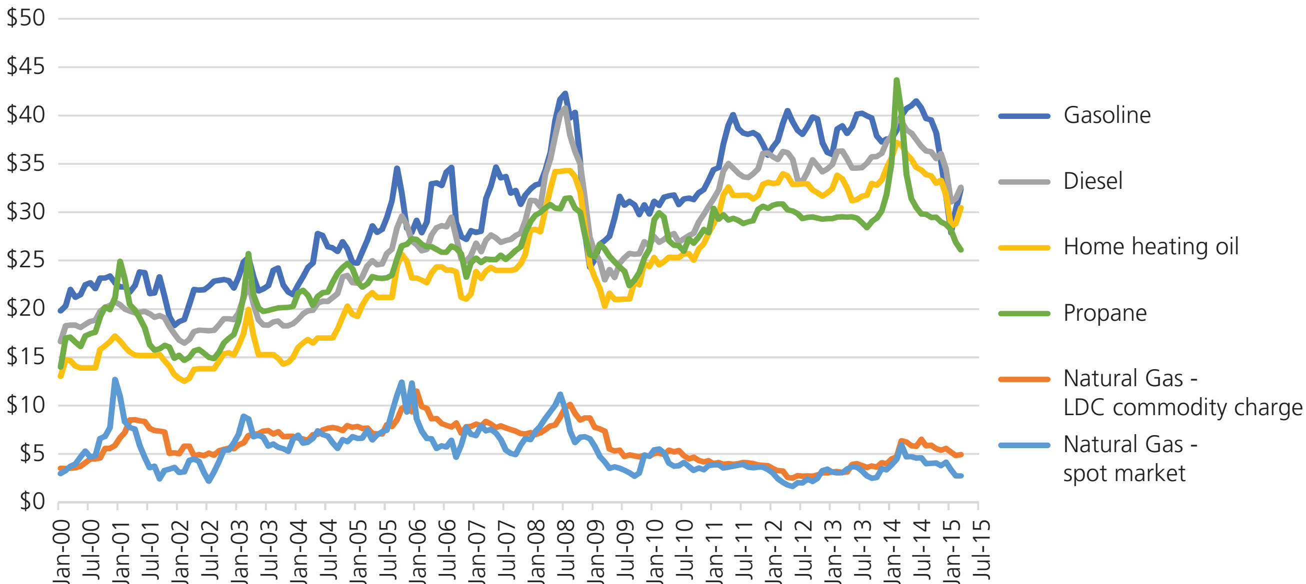
Compressed natural gas (CNG) is a competitively priced fuel that has historically sold at a significant discount to crude oil-based fuels. The recent advances in extraction techniques have resulted in an increase in the North American natural gas supply, which analysts predict will maintain the commodity price advantage for CNG vehicle fuel for the foreseeable future.[5]

Natural gas is no longer tied to oil price volatility. The pricing of natural gas became de-linked from world oil prices in late 2008. While approximately 60% of pump price for diesel is linked to fluctuating crude oil commodity prices, only about 30% of pump price for natural gas is tied to the historically more stable natural gas commodity price.[6]

3 Ontario Climate Change Discussion Paper, 2015, p. 30
4 Canadian Natural Gas Vehicle Alliance. (2015). Environment & Safety
5 Natural Gas Use in Transportation Roundtable. (2010). Natural Gas Use in the Canadian Transportation Sector-Deployment Roadmap
6 Union Gas Ltd. (2014). Natural Gas for Fleet Vehicles: The Answer to Rising Energy Prices and Lower Emissions Targets

On average, CNG fuel prices are 40% less than other vehicle fuels.[7] The chart below shows energy commodity prices in Canada over a 15-year period. Note that retail sale prices for CNG are different than natural gas, but retail data is not published.

ENERGY COMMODITY PRICES – CANADA
($/mmBtu)



Source: StatsCan 326-0009, Kent Group, CGA

When considering a switch to CNG vehicles, analysts[8] use models that assess a number of factors, including:

- If natural gas (CNG or LNG) is an appropriate fuel for the fleet
  - o Lifecycle cost over 10 year timeframe
  - o Refueling patterns and distance driven (e.g., return-to-base each night)
  - o Power requirements of the vehicles
- Value propositions
  - o Financial analysis including cost forecast
  - o GHG reductions and their importance to the operator
- The correct fueling station configuration/network for the operation
- Location, including site conditions
- Natural gas distribution infrastructure and cost to connect
- Proximity to other natural gas refueling stations
- Local transportation fuel demand characterization
- Supportive policies and programs
- Sensitivity analysis of risks

7 Union Gas Ltd. (2014). Natural Gas for Fleet Vehicles: The Answer to Rising Energy Prices and Lower Emissions Targets
8 Analysis in this section provided by Change Energy

Analysts examined a wide range of fleet cases to determine the relative sensitivity of the business case to a variety of factors. Here are some real-world examples:

- Fleet size and implementation rate: In one example, a fleet of 25 waste haulers, a quick adoption of all vehicles gave a payback of three years, whereas a staged adoption (five vehicles/year) gave a payback of five years, even with a phased-in installation of the refueling station.
- The amount of fuel used: In comparing two identical fleets of 25 waste haulers, a fleet with an annual mileage/vehicle/year of 40,000 km had a three-year payback, whereas the same fleet with an annual mileage of 20,000 km/vehicle/year had a six-year payback.

Other sensitivity analyses have been conducted looking at such factors as:

- Construction schedule
- Financing costs
- Fuel price differential
- Utility costs
- Maintenance costs

Currently, CNG is not subject to a fuel tax in Ontario. Historically, governments have favoured innovative fuels during adoption periods to incent new adoption. For instance, biodiesel first gained commercial momentum in the early 2000's, and was exempt from Ontario's Fuel Tax. Ontario's 14.3 c/L Fuel Tax was applied to biodiesel in 2014 only after a B2 mandate (a requirement for 2% of diesel sold be biodiesel) was implemented.[9]

Although NGVs cost typically 20-40% less to operate than gasoline-fueled vehicles, each fleet should conduct its own analysis based on its usage patterns.

Does RNG Blending Make Sense Economically?

While RNG is more expensive than CNG, it is about the same price as diesel or gasoline. It is also the greenest, cleanest way to go. By blending a portion of RNG fuel with your CNG you can be green and still save money. RNG can be integrated into CNG in a 10/90 blend in order to achieve the emissions reductions benefits associated with RNG. Since RNG is more expensive to produce than conventional natural gas, a 10% blend adds ~5 cents/litre to the price of CNG, which maintains the strong economic advantage of using CNG/RNG over crude oil-based fuels.

Clean Energy Fuels, a U.S. and Canadian fuel retailer, has successfully integrated RNG into its product offering. RNG under the Redeem brand made up 17% of total CNG sales for Clean Energy Fuels in the U.S. and Canada. Redeem-branded RNG sales in 2014 were over 74 million diesel litre equivalent.

9 Government of Ontario, http://www.fin.gov.on.ca/publication/fuel-biodiesel-exemption-revocation-en.pdf

According to Union Gas analysis, the following price scenarios for different RNG blends, based on different costs of RNG production, can be calculated.

Scenarios	100% CNG*	10% RNG @$6/GJ	100% RNG @$6/GJ	10% RNG @$15/GJ	10% RNG @$32/GJ
Cost component:	($/DLE)	($/DLE)	($/DLE)	($/DLE)	($/DLE)
Gas ($4/GJ) + delivery	0.18	0.20	0.26	0.23	0.30
O&M + Cap recover	0.36	0.36	0.36	0.36	0.36
Taxes	0.07	0.07	0.08	0.08	0.09
Total	0.62	0.63	0.70	0.67	0.74
Difference		$0.01/L	$0.07/L	$0.05/L	$0.12/L

** Note that this represents in-house CNG refueling (not retail) costs. O&M and capital recovery estimates represent a fleet of moderate size and utilization. Small fleets, with low utilization may results in higher CNG fueling costs, while large fleets with high utilization may achieve lower CNG fueling costs than the example provided.*

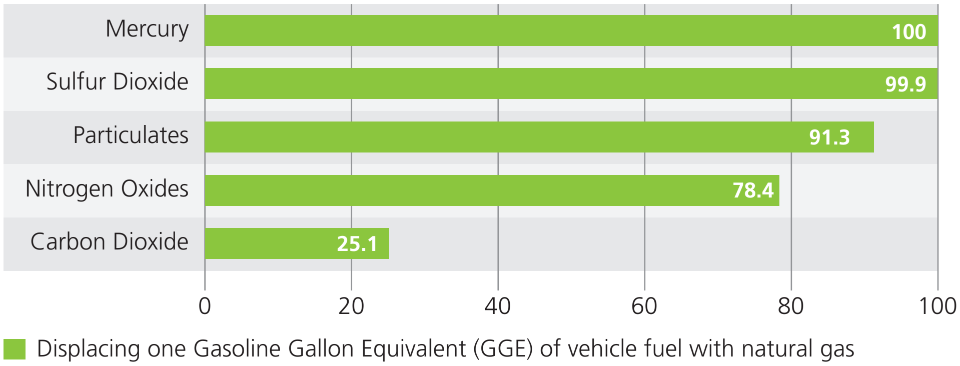
Environmental Benefits of Blending RNG

The transportation sector is the largest contributor of GHG in Canada (24%)[10] and about 34% of Ontario's greenhouse gas emissions come from transportation[11]. Natural gas can provide an advantage for companies striving for GHG emission reductions, as conventional natural gas vehicles emit up to 25% less carbon on a fuel lifecycle assessment (also described as well-to-wheel) basis compared with diesel or gasoline.[12] Lifecycle assessments take into account the carbon emissions from each step of a fuel's lifecycle – from production and distribution to combustion at the tailpipe. A fuel lifecycle assessment typically quantifies emissions across two stages: well-to-tank and tank-to-wheels.[13]

Using natural gas as a vehicle fuel generates fewer atmospheric pollutants than diesel as well. See the chart below:

NATURAL GAS VEHICLES CAN REDUCE CO_2 EMISSIONS BY 25%

Natural gas emission reductions versus gasoline (EIA 2010)



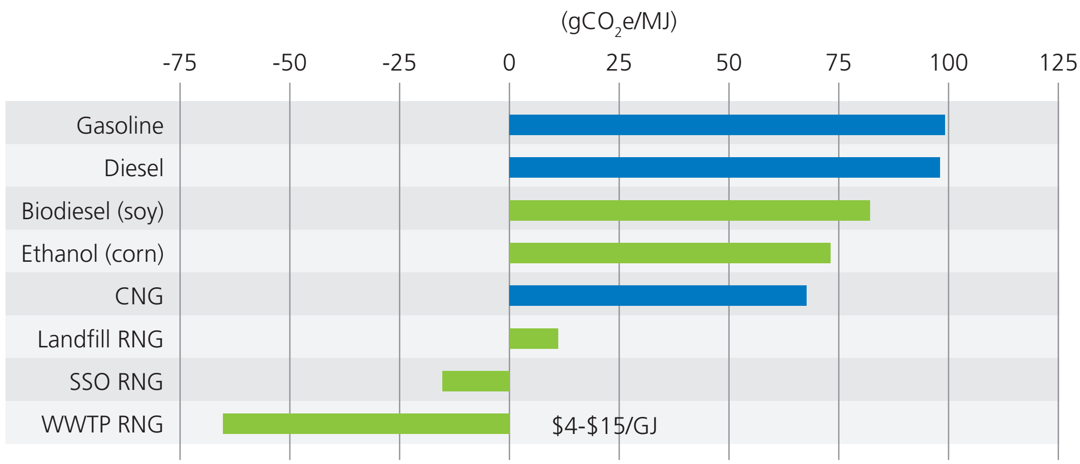
Source: https://www.iea.org/publications/freepublications/publication/natural_gas_vehicles.pdf

10 Environment Canada, Canada Emission Trends, 2013
11 Ontario Climate Change Discussion Paper, 2015, p. 30
12 Natural Gas Use in Transportation Roundtable. (2010). Natural Gas Use in the Canadian Transportation Sector-Deployment Roadmap
13 Electric Ride Colorado

Overall, blending 10% RNG with 90% CNG offers GHG emissions reductions over 31% in comparison with diesel.

When RNG is used to fuel natural gas fleet vehicles, lifecycle greenhouse gas emissions can be reduced by about 90%. This is an industry-accepted estimate, and reflects an average of sources of RNG, including agricultural operations. For municipalities, however, the following California data relates to municipal sources of RNG:

CARBON INTENSITY OF VARIOUS FUELS



Data Source: Carbon Intensity Lookup Table for Diesel and Fuels that Substitute for Diesel, California Air Resources Board, 2012

Why Does RNG Have Such a Big Greenhouse Gas (GHG) Benefit?

RNG is a renewable fuel that provides significant GHG reduction benefits. The displacement of a carbon-positive fuel, such as natural gas, through the use of this fuel results in a net reduction of GHG emissions.[14] Capturing biogas from organic wastes reduces GHG emissions by preventing methane from directly entering the atmosphere. The carbon dioxide that is generated during the production and combustion of RNG is used in the regeneration of new biomass, representing a closed-loop cycle for carbon dioxide that is released. For these reasons, RNG is considered to be a carbon neutral fuel and energy source since no net GHGs are released into the atmosphere through either the combustion or lifecycle emissions of RNG.[15]

Carbon Pricing

Provincial carbon pricing schemes assist in RNG development. Carbon policies translate to financial support as demonstrated in BC and Quebec of about $1.50/GJ and 50 cents/GJ, respectively. The carbon pricing benefit expressed in DLE is 5 cents/DLE in BC, and 1.5 cents in Quebec. Ontario's cap and trade system designers are encouraged to include carbon pricing for RNG.

With total costs to produce and compress RNG of about $1.00/ diesel litre equivalent (DLE), comprised of $0.65/DLE (or $18/GJ) to produce, plus $0.40/DLE to compress, carbon pricing has a minor influence on the business case. Additional government support will be required to build the market. U.S. policy, for example, has been successful.

14 Natural Gas Use in Transportation Roundtable. (2010). Natural Gas Use in the Canadian Transportation Sector-Deployment Roadmap
15 Quest. (2012). Renewable Natural Gas: The Ontario Opportunity

CNG Vehicle Technology

There are an estimated 11 million NGV in use in over 30 countries globally. Canada has used natural gas as a transportation fuel for more than 25 years. The Canadian natural gas vehicle industry has engaged with the Canadian government to establish codes, standards and regulations in order to ensure that CNG vehicles are safe and that CNG refueling stations have been installed according to industry standards. Canada played a formative role in the development of internationally recognized standards for CNG fuel storage tanks that are used in Canada and abroad. There is a strong safety record for NGV and the industry works closely with local authorities to ensure that CNG continues to be a safe and reliable transportation fuel.[16]

New NGVs for fleets typically cost between $15,000 and $35,000 more than conventional diesel fleet vehicles. The higher initial investment for CNG fleet vehicles is offset by the substantial fuel savings from using CNG over diesel.[17] A waste truck that uses 35,000 litres of diesel per year would achieve economic payback for the price differential within three years.[18] With the recent increase in interest for CNG-fuelled fleet vehicles, the relative cost of purchasing these vehicles has begun to decline due to economies of scale.

In Canada, Cummins Westport supplies two natural gas engines, ISL G 8.9L and ISX12 G 11.9L, which are suitable for municipal return-to-base fleet operations. These engines are comparable to diesel engines in both performance and warranty coverage.[19] Both engines meet 2014 U.S. Environmental Protection Agency (EPA) and California Air Resource Board (ARB) emission standards as well as the 2014 EPA and U.S. Department of Transportation fuel economy and greenhouse gases regulations.[20] To date, Environment Canada has matched all regulations which the EPA has created, and therefore both engines are compliant with Environment Canada's requirements.

A variety of factory-built CNG light duty trucks and cars are available for fleet users as well. Generally fuel costs make up a smaller proportion of total ownership cost on smaller vehicles, meaning the business case is not as clear as for larger vehicles. However there are still clear greenhouse gas and air quality benefits to be had from any CNG vehicle.

Dual-fuel vehicle conversions can also make sense, particularly to alleviate "range anxiety" and to provide a power boost for certain applications. In a dual-fuel conversion, the vehicle maintains its capacity to run on diesel fuel, while often achieving fuel switching rates of 50-65%. In Ontario, a fleet of milk trucks is currently converting existing vehicles and find high fuel switching rates, while maintaining the significant power demands required to haul large volume milk trailers.

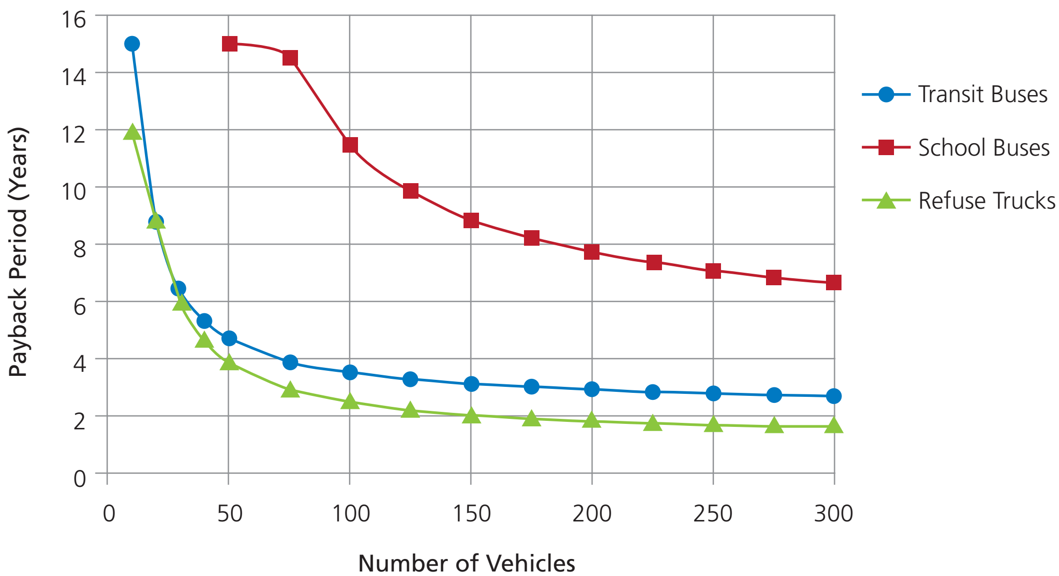
16 CNGVA. (2015). Renewable Natural Gas
17 Crittenden, G. (2014). Natural Gas Vehicles for the Waste and Recycling Industry
18 Milner, A. (2013). Compressed Natural Gas
19 Milner, A. (2014). Factory-Built Natural Gas Trucks
20 Cummins Westport. (2015). Heavy-Duty Natural Gas Engines

The following data tables may assist fleet managers in understanding the economics behind fleet conversion.

Truck Procurement and Fuel Cost				
Change only cells highlighted in Yellow, i.e., # of trucks added annually, $/liter, and # litres consumed annually				
Truck Procurement	**# of Trucks**	**Cost Per Diesel Truck**	**Cost Per CNG Truck**	**CNG Savings vs Diesel**
Cost Per Truck		$250,000	$285,000	$(35,000)
Initial Truck Purchase	15	$3,750,000	$4,275,000	$(525,000)
Next Truck Purchase	15	$3,750,000	$4,275,000	$(525,000)
Next Truck Purchase	15	$3,750,000	$4,275,000	$(525,000)
Next Truck Purchase	15	$3,750,000	$4,275,000	$(525,000)
Total Trucks	60	$15,000,000	$17,100,000	$(2,100,000)
Fuel Costs (Flat Line)		**Diesel**	**CNG**	
Estimated Fuel Cost Per Litre		$1.20	$0.60	$ –
Estimated Litres Consumed Per Truck Per Year		35,000	38,500	
Annual Fuel Cost Per Truck		$42,000	$23,100	$18,900
Year 1	15	$630,000	$346,500	$283,500
Year 2	30	$1,260,000	$693,000	$567,000
Year 3	45	$1,890,000	$1,039,500	$850,500
Year 4	60	$2,520,000	$1,386,000	$I,134,000
Year 5	60	$2,520,000	$1,386,000	$I,134,000
Year 6	60	$2,520,000	$1,386,000	$I,134,000
Year 7	60	$2,520,000	$1,386,000	$I,134,000
Year 8	60	$2,520,000	$1,386,000	$I,134,000
Year 9	60	$2,520,000	$1,386,000	$I,134,000
Year 10	60	$2,520,000	$1,386,000	$I,134,000
10 Year Total Fuel		$21,420,000	$11,781,000	$9,639,000
Total Truck Cost		$15,000,000	$17,100,000	$(2,100,000)
10 Year Truck Purchase & Fuel		**$36,420,000**	**$28,881,000**	**$7,539,000**
Average Savings Per Truck				**$125,650.00**

Source: Clean Energy Fuels, Natural gas vehicles supplement in Solid Waste and Recycling Magazine, 2014, P.26

PAYBACK PERIOD BY FLEET SIZE



Source: National Renewable Energy Laboratory, Fueling Change, p.3

Fleet Refueling

The cost for a typical CNG refueling station ranges from approximately $600,000 for 15 trucks to $1.3 million for 50 trucks, and up to $1.8 million for 100 trucks, depending on site-specific requirements and conditions. The costs associated with modifications to vehicle maintenance facilities and the purchase of equipment for vehicle maintenance must also be factored into budgets. The costs for these vehicle maintenance facilities range from approximately $70,000 for a two-bay shop to upwards of $175,000 for larger operations.[21]

There are three options for refueling: Fast fill, slow or time fill, and combination systems.

SLOW OR TIME FILL

Return-to-base fleet vehicles most commonly use "slow fill" CNG refueling stations. At these refueling stations, all vehicles are plugged in at filling posts and refuelled simultaneously overnight. The complete refueling process takes approximately eight hours. There are several advantages of slow fill. The primary advantage is lower capital expenditure by using a smaller compressor and little or no storage. There can also be benefits from off-peak electricity for compression if time-of-use rates are available. In addition, the heat of compression dissipates over time, making it easier to achieve a true full fill.

21 Crittenden, G. (2014). Natural Gas Vehicles for the Waste and Recycling Industry

FAST FILL

Fast fill refueling is best suited for relatively small volumes (less than 50 litres at a time), and in cases where fueling is intermittent and a fast turn-around time is desired (e.g., six minutes or less). A retail facility that services vehicles that arrive through the day might consider fast-fill capacity.

Fast fill station design: www.angienergy.com

COMBINATION FILL

Combination fast and slow fill systems are typically employed by facilities that can take advantage of the benefits that slow fill fueling provides, but that also provide fueling services to external fleets, or to vehicles of their own that may routinely require quick fueling.

Partnering with other organizations that operate fleets to share fueling infrastructure can be highly beneficial for fast fill facilities, as it allows the infrastructure to be used regularly.

Local Economic Benefits

Part of the goods and services procurement decisions for some organizations, particularly municipalities, relate to the impact on the local economy. Some local economic advantages of using a CNG/RNG blend for vehicles include:

- Revenue generated from the production and use of RNG is kept local. This revenue is sometimes referred to as "sticky dollars"
- Waste is treated locally, keeping jobs and associated revenue in the local economy
- Diverting organic wastes generates revenue while extending the life span of local landfills
- Local economies benefit from the energy resilience associated with producing energy locally rather than relying on imported energy, and being subject to price volatility
- Revenue opportunities for sharing CNG fueling infrastructure with other users

Steps to Success – RNG Production

The production of RNG offers an attractive waste management solution for closing the loop between organic waste and fuel. Converting organic materials to RNG captures energy from waste, diverts waste from landfill, reduces odour, and can fuel return-to-base fleet vehicles. RNG can be injected at its production source and piped to any vehicle fueling location.

This section addresses RNG sources, the business case for RNG generation, a brief technology overview, connection requirements, regulations and approvals, and where to go for more information.

Suggested steps to follow when considering producing RNG include:

1. Examine objectives in relation to RNG production, including sustainability objectives and GHG reduction, local economic benefits, and cost recovery from organic waste processing.
2. Contact companies and municipalities that have experience in planning or implementing RNG projects, and ask for lessons learned. Refer to the case studies in this primer.
3. Consult with experts, including technology suppliers, your natural gas supplier, and engineering and technology firms to help understand the business case, resources and level of effort required, and timeframes to expect.
4. Socialize the concept internally, including with your internal and contracted fleet operators. Winning support for these undertakings requires educating, consulting and collaborating with colleagues.

Municipalities can generate RNG from their landfills, residential source separated organic material, and wastewater treatment. These sources of RNG are briefly described below. (See the Canadian Biogas Association's *Municipal Guide to Biogas* if you are interested in generating electricity, not RNG, from these sources.)

LANDFILLS

Landfills are relatively large producers of biogas concentrated at a relatively small number of sites across Canada. While some sites generate electricity and sell it to the grid, several landfills are not able to connect. Many of these sites offer sufficient economies of scale to produce RNG fuel for fleet vehicles used for waste management and other services, creating local closed-loop energy systems.

Landfills that are located close to natural gas pipelines can inject into the pipeline.

See the Nanaimo case study below.

Convince Your Colleagues to *Close the Loop*

- **Refer to what has been done.** List the Canadian projects (page 3) and case studies (page 19).
- **Visuals help.** Use graphics and charts from this primer to illustrate the opportunity.
- **Be bold.** Cultures are shifting toward climate action. Use the momentum!

SOURCE SEPARATED ORGANICS (SSO)

Residential SSOs represent a substantial and relatively undeveloped new source of material for renewable fuel production. Many municipalities have implemented green bin programs to collect household organic wastes, and this SSO represents another opportunity for creating local closed-loop energy systems by fueling fleet vehicles used for SSOs collection, particularly if SSO-fueled biogas systems are built on natural gas pipelines that have capacity to accept fuel.

Note that trucks can be fueled anywhere, since RNG is injected to the natural gas pipeline where it is produced, and "wheeled" to other locations.

What is wheeling? It's when you produce the gas in one location, and use it somewhere else. Dad's Oatmeal Cookies in Toronto uses RNG supplied by Bullfrog Power from the Terrebonne landfill near Montreal through an audited accounting process of RNG injection and usage. While the cookie plant doesn't use the actual molecule of RNG produced in Quebec, this "wheeling" of the gas is considered a legitimate approach to production and consumption of RNG. In the case of a municipality or food company, the wheeled gas might still be produced locally, but rely on a few kilometres of the natural gas pipe grid to wheel the gas to the end use location.

See the Surrey and London case studies below.

WASTEWATER TREATMENT (WWT)

Some wastewater treatment plants process biosolids through anaerobic digestion (AD), which produces biogas that can be upgraded to RNG. Most WWT plants in Ontario flare the biogas that is produced instead of capturing it for energy recovery. This large source of biogas represents a significant opportunity to increase the production of RNG from biogas which is already being produced.

See the Hamilton and Niagara case studies below.

INTEGRATED SOURCES

Landfills owned by municipalities or waste management companies provide opportunities to integrate LFG processing with the anaerobic digestion of other municipal organic wastes.

For example, biogas from a municipal landfill site could be expanded to accommodate biogas systems for SSOs. The two sources of biogas, LFG and SSO, could share infrastructure needed to upgrade biogas to RNG and connect to the natural gas grid.

Similarly, wastewater treatment and SSO treatment can be combined to share infrastructure and improve efficiencies. See the Saint-Hyacinthe case study below for details.

Business Case Considerations

When studying the business case for producing RNG, consider the gas volumes the material can produce, and the cost to do so. Then consider what costs this production is replacing to make a decision.

Consider the following volumes and outputs gathered from existing and proposed municipal systems:

- Generally, one tonne of SSO generates 110 cubic metres of biogas. Depending on the methane content of the biogas, which can range from 50-65% methane, depending on the material being processed, one tonne of SSO can produce about 70 cubic metres of RNG.

- For wastewater treatment, for each 250 m^3/day of sludge treated, an anaerobic digester will produce 1,900 m^3/day of biogas.[22]

- At Hamilton's WWT, biogas generation rates were based on 0.9 m^3 of biogas generated for each 1.0 kg of volatile solids (VS) destroyed in digestion. In 2014, it injected 536,062 m^3, or 20,290 GJ into the Union Gas grid at a rate of 750 Nm^3/hr or 500 SCFM. Volumes varied significantly from month to month. Revenue was over $116,000 in 2014. The business case in future will be strengthened as they shift to displacing gasoline and diesel for transit vehicles that will be CNG and RNG fueled.

- Niagara Region's wastewater treatment plant is expected to produce 84,000 gasoline gallon equivalent (GGE) per year of RNG and would reduce the municipality's annual GHG emissions by 1,000 tonnes. The RNG generated would fuel 60 fleet vehicles that would be converted to run on CNG/RNG.[23] The total capital cost of the pilot project is estimated at $1.1 million for the first year and an additional $200,000 annually for the subsequent 4 years. Payback is anticipated at 9.5 years.[24]

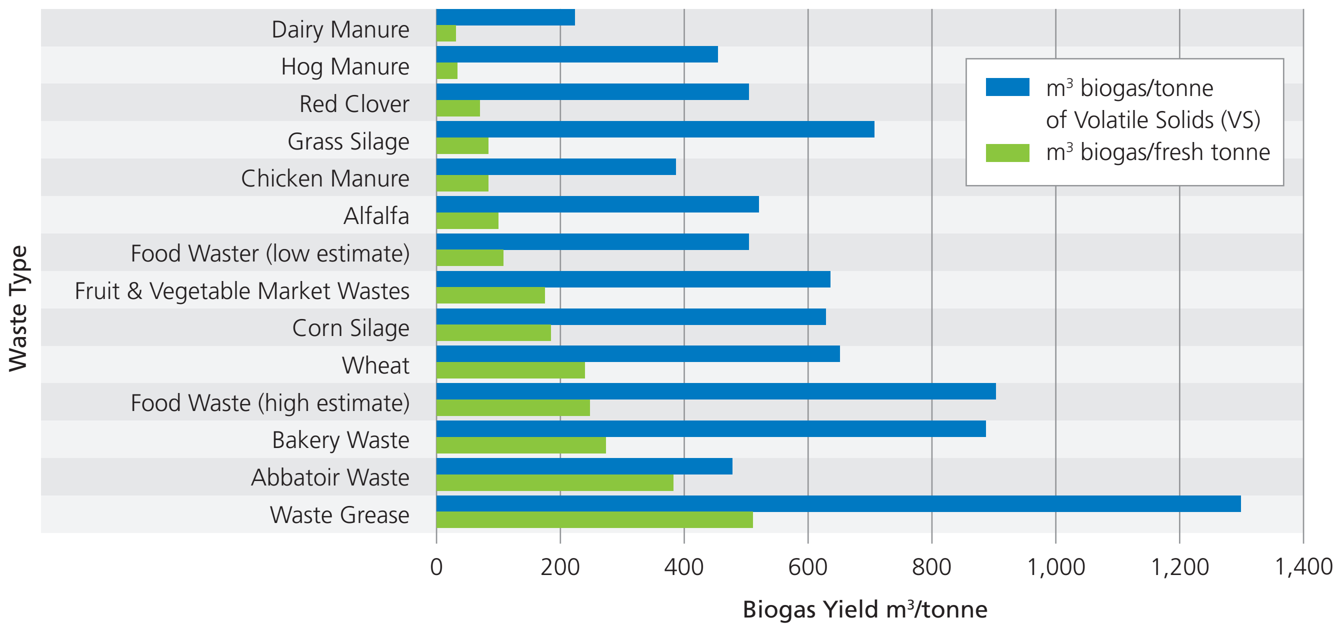
- Progressive Waste Solution's Terrebonne landfill near Montreal is processing approximately 10,000 cubic feet per minute (SCFM) of incoming landfill gas. The energy generated is sufficient to keep the equivalent of 1,500 trucks on the road for 20 years, or the equivalent of a reduction in fossil-fuel dependence of 350,000 barrels of oil per year. The new plant will also result in avoidance of greenhouse gas emissions of as much as 1.2 million tonnes of carbon dioxide (CO_2) over a 10-year period.

There are many variables with RNG production which limit generalizations that can be made about the business case. When investigating the business case for your organization, it is recommended that you connect with consultants, technology suppliers, and representatives from municipalities or industrial biogas operations that have direct experience with these systems. A list can be supplied by the Canadian Biogas Association upon request.

22 Data provided by CEM Engineering
23, 24 The Regional Municipality of Niagara (2014).
Request for Proposal - Design of Biogas to Biomethane to Compressed Natural Gas Project: Port Dalhousie Wastewater Treatment Plant

In addition to the outputs related to SSO and WWT above, the chart below may be useful as well. A cubic metre of biogas will produce about 0.65 cubic metres of RNG.

BIOGAS YIELDS OF DIFFERENT WASTES



Source: Regenerate Biogas

Biogas Purification Technology Overview

Biogas generated through anaerobic digestion or in landfills includes gases and moisture which need to be removed in order to inject it into the pipeline or used in a vehicle engine. These include carbon dioxide, water, hydrogen sulfide, oxygen, nitrogen, ammonia, siloxanes, and particulate matter. Concentrations depend on the compositions of the organic materials used to create the biogas.

The most widely used technologies for biogas upgrading are the following:

1. **Pressure swing adsorption.** This technology purifies the gas by way of adsorption of impurities on active coal or zeolites.
2. **Water scrubbing.** Water (or another liquid such as alcohol) is used to bind carbon dioxide. This is a form of physical absorption, and is also called pressurized water wash.
3. **Chemical absorption.** Chemical absorption is comparable to water absorption. A liquid such as amine is chemically bonded to the carbon dioxide. In order to recycle the solution, a heat treatment is applied.
4. **Membrane separation.** Methane can be separated from carbon dioxide using semi-permeable membranes. The force can be a pressure difference, a concentration gradient, or an electrical potential difference.
5. **Cryogenic separation.** Trace gases and carbon dioxide are removed by cooling down the gas in various temperature steps.

The International Energy Agency's *Biogas upgrading technologies – developments and innovations* document is also a useful resource.

Connection Charges and Quality Expectations

If you are planning to use the natural gas pipeline to store or transport your RNG, you will need to enter into an agreement with the local distribution utility. For a listing of gas utilities across the country, visit the Canadian Gas Association website. You will be expected to pay all of the costs of connecting your facilities to the natural gas distribution system. Typically, the utility will be able to define the physical connection requirements necessary to inject RNG into its system. Typically, the utility will require the installation of a producer station which includes components for billing measurement, pressure regulation, odourization, and gas quality monitoring, as well as a length of interconnecting pipe necessary to tie into the nearby distribution system.

The charge is dependent on the site-specific facilities requirements and can vary based on the length of piping required to connect to the system, outlet delivery pressure, and flow rate from the supplier into the system.

The natural gas utility also regulates the quality of all gas entering its distribution system. Producers need to follow guidelines laid out by the utility. The Canadian Gas Association has published a *Biomethane Guideline* highlighting a general consensus of gas quality expectations for RNG by the utilities across Canada.

Permits, Approvals and Safety

Government permits and approvals required for biogas and upgrading systems vary from province to province.

British Columbia Ministry of Environment requires three permits for biogas systems: effluent; air; and solids. Permits are issued by the regional offices, and are site-specific.

In Ontario, an *Environmental Compliance Approval* from the Ministry of the Environment and Climate Change is required for RNG production facilities. If electricity is not being generated for connection to the electricity grid, a *Renewable Energy Approval* is not required.

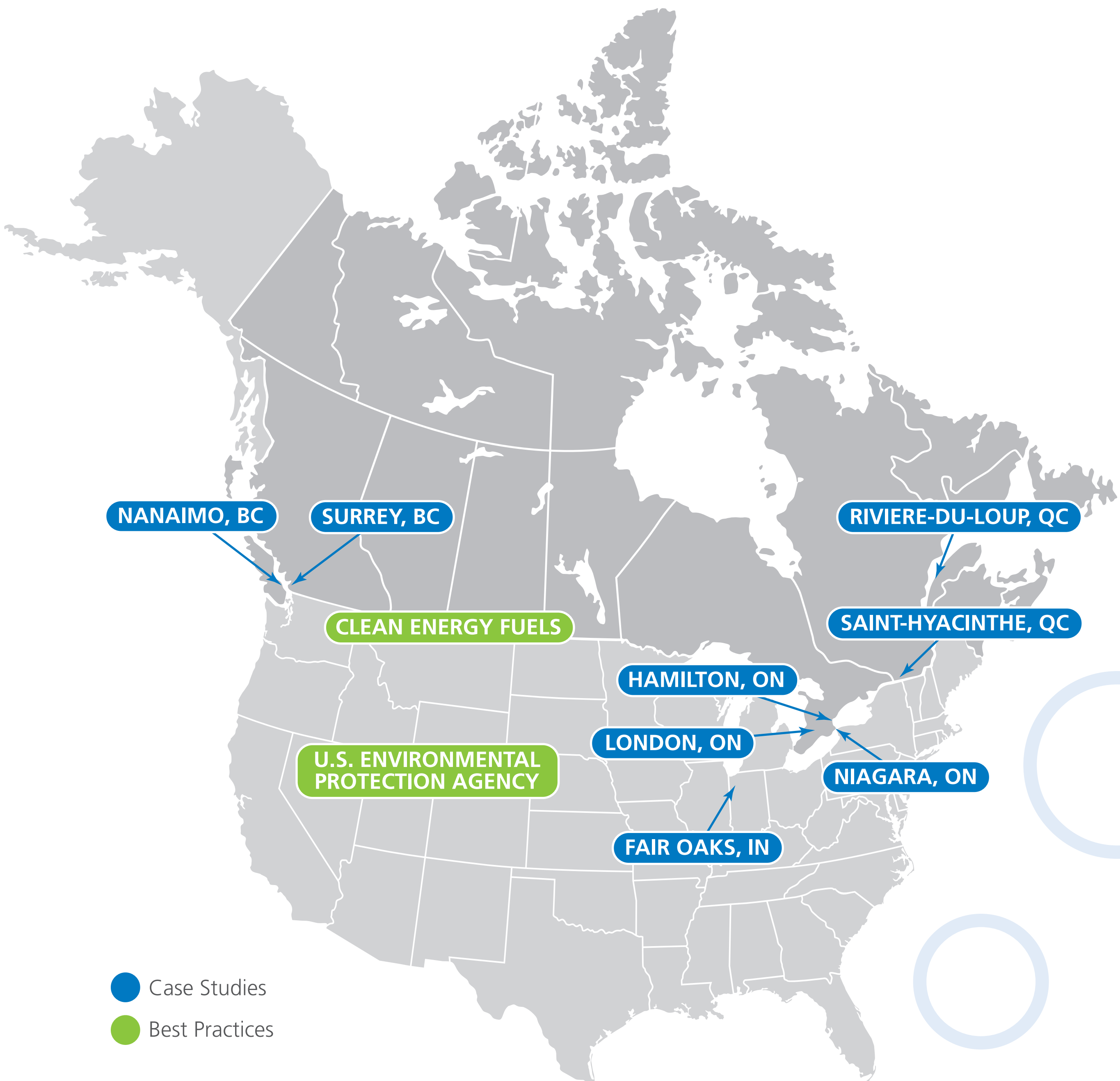
Within Ontario, RNG production facilities also require approval from the Technical Standards and Safety Authority (TSSA). The TSSA enforces Ontario's *Technical Standards and Safety Act, 2000* which covers industry sectors such as boilers and pressure vessels, propane and other fuels and equipment, including RNG. Operators need to consult the *Compressed Gas Regulation (O. Reg. 214/01)* and *Gaseous Fuels Regulation (O. Reg. 212/01)* to understand the certification and operational requirements, registration processes and other pertinent safety information. The TSSA has published a number of relevant code adoption documents for these sectors, which updates the standards and requirements. Of special note is that the TSSA plans on adopting a new ANSI/CSA code that will be published in late 2015: *ANSI/CSA B149.6-15: Code for Digester Gas, Landfill Gas and Biogas Generation and Utilization*. For further information on TSSA requirements for RNG, go to the TSSA website.

In other provinces, consult with your Ministry of Environment and provincial safety authority regarding permits and approvals required.

Municipal building permits are also required. Developers report these are not difficult to obtain.

Case Studies and Best Practices

Case studies from Ontario, British Columbia and the United States demonstrate the feasibility of biogas generation from organic waste sources. These examples illustrate the various applications for biogas and how these projects have been implemented by municipalities and private sector entities. These case studies highlight the potential for biogas projects to generate revenue, provide cost savings, and reduce greenhouse gas (GHG) emissions.



HAMILTON, ONTARIO: CANADA'S FIRST WASTEWATER PLANT INJECTING RNG

The City of Hamilton completed a biogas cogeneration plant at the Woodward Avenue Wastewater Treatment Plant in 2006. The project was undertaken to: generate revenue, reduce costs and increase environmental benefits. Establishing the facility allowed Hamilton to lower its energy consumption, increase its energy efficiency, reduce GHG emissions, minimize external energy requirements for the wastewater plant and increase the amount of renewable energy that is locally produced in Hamilton.[25]

When a series of process upgrades were undertaken at the plant in 2012, additional biogas was produced and a biogas purification unit was installed to purify the biogas to renewable natural gas (RNG). The purifier is based on a water scrubbing technology rated at a capacity of 750 Nm3/hr (500SCFM). This RNG is injected directly into the regional Union Gas distribution system and complements the cogeneration unit as a diversified source of revenue for the City.[26]

Currently, Hamilton is in the process of upgrading its wastewater treatment facility again through a *Biosolids Management Project*. The proposed $111 million dollar project is being undertaken in the form of a public private partnership with support from P3 Canada. As part of this project, Hamilton will be seeking innovation from industry experts to further maximize their energy recovery and utilization from their biosolids treatment system to bring a long term sustainable *Biosolids Management Program* to their community. In addition, the City of Hamilton will be replacing many of its transit system buses, to CNG and will blend in RNG produced at the wastewater treatment plant.[27]

25 Environment Canada (2008). Hamilton Renewable Power Incorporated
26, 27 Water Tap Ontario (2013). Moving From "Cost Centre" to "Profit Centre": Hamilton Water

NANAIMO, BRITISH COLUMBIA: PROVINCE'S FIRST LANDFILL FUELING WASTE TRUCKS

The Nanaimo Bioenergy Centre, located in the Regional District of Nanaimo, uses its landfill gas (LFG) in a range of ways.

Cedar Road Bioenergy Ltd., a member of the Sun Current group, owns and operates the gas utilization facility at the Nanaimo Landfill under a private public partnership agreement with the Regional District of Nanaimo and the BC Bioenergy Network.[28]

The facility became operational in March 2009, producing 1.4 MW of electricity from LFG collected at the Nanaimo Landfill. In 2012, the facility reduced GHG emissions by 28,113 tonnes.[29] The small-scale LFG conversion facility was constructed over two phases. The actual installed cost for Phase 1 was $4.8 million. Operation and maintenance costs are $600,000 per year and include debt interest payments.[30]

The project received funding from the BC Government Innovative Clean Energy Fund, the Federation of Canadian Municipalities, and the BC Bioenergy Network.[31]

Phase 2 started in 2012 and involved a $2.3 million expansion and upgrade of the facility, including a double membrane biogas storage system.[32] Phase 2 has increase net output efficiency by 30%. A new biogas cleaning system has also been installed, which will enable the facility to expand to other LFG uses, such as RNG transportation fuel.[33] The partners anticipate operation of this third phase in 2016.

The improvements and expansion of the Nanaimo Bioenergy Centre are expected to increase annual revenue by $238,000.[34]

SURREY, BRITISH COLUMBIA: CANADA'S FIRST MUNICIPALITY TO CLOSE THE LOOP

The City of Surrey is building an *Organic Waste Biofuel Processing Facility*, which will be a sustainable closed loop system. Organic waste will be used to produce RNG, which will power Surrey's waste collection vehicles, thus creating the closed loop system. The *Organic Waste Biofuel Processing Facility* is expected to be operational in 2016-2017.[35]

The facility will be developed as a *Public Private Partnership*.[36] The City of Surrey has entered a $9 million waste contract with Progressive Waste Solutions for organic waste collection using CNG trucks that will be powered by the RNG generated at the facility.[37] The Government of Canada, through the *P3 Canada Fund*, will contribute up to 25% of the capital costs.[38]

The plan will cut operating costs, reduce air pollution and GHG emissions, and serve as an integrated model for organic waste management for communities across North America. Additional information on the Surrey, BC waste management plan is available in the *Canadian Biogas Study Summary* document.

28, 29, 30 Global Methane Initiative. (2012). Nanaimo Bioenergy Centre LFG Utilization Facility
31 BC Ministry of Community and Rural Development. (2010).
Integrated Resource Recovery Case Study: Regional District of Nanaimo Landfill Gas Recovery and Utilization
32 Global Methane Initiative. (2012). Nanaimo Bioenergy Centre LFG Utilization Facility
33 Chan, K. (2013). A New Kind of Angel: A Private-Public Partnership Examined
34 Global Methane Initiative. (2012). Nanaimo Bioenergy Centre LFG Utilization Facility
35, 36 City of Surrey (2015). Organic Biofuel Facility
37 Sinoski, K. (2011). Surrey Signs 'Sustainable' Garbage Contract
38 City of Surrey (2015). Organic Biofuel Facility

SAINT-HYACINTHE, QUEBEC: PRODUCING RNG FROM MULTIPLE WASTE STREAMS

The City of Saint-Hyacinthe and Gaz Métro reached an agreement in 2014 for the purchase and injection of renewable natural gas produced in the city's biogas facility. Under the agreement, Gaz Métro will purchase up to 13 million cubic metres of RNG per year for a 20-year period from Saint-Hyacinthe. Saint-Hyacinthe implemented the collection of organic waste in 2007, and is installing new anaerobic digesters at the City's wastewater treatment plant. The existing digesters, which were used to treat sewage sludge, are being upgraded to be able to accept multiple waste streams.

The city is expanding organic waste collection to in the communities of Les Maskoutains and Acton. The bin contents will also be processed at the anaerobic digestion plant in Saint-Hyacinthe, thus avoiding transport to external composting sites.

Saint-Hyacinthe has begun recycling organic matter from local agri-food businesses at the facility, which can now dispose of their organic waste in an environmentally friendly manner and at a lower cost.

For the city of Saint-Hyacinthe, the project's total cost is over $48 million, provided in equal parts by the city and subsidies from the federal and provincial governments. In a few years, the city will amortize and then self-finance the cost of constructing its organic waste reclamation and biogas plants.

"In 2016-2017, once our facility is fully operational, the city will make a significant annual profit [from the sale of the RNG to Gaz Metro], including savings of a half-million dollars in lower fuel and heating costs for our municipal buildings and vehicles," said Saint-Hyacinthe Mayor Claude Corbeil. "By maximizing the reclamation of organic waste from brown bins, residents and agri-food businesses are taking a positive step for the environment and generating a source of income that the city will be able to use to improve services. Saint-Hyacinthe is proud to innovate with such green, profitable and sustainable practices."

RIVIERE-DU-LOUP, QUEBEC: PRODUCING RENEWABLE LNG FROM RESIDENTIAL SSO

Gaz Metro is building a public liquified renewable natural gas fueling station in Riviere-du-Loup, Quebec. The agreement with the municipality covers the purchase of liquefied RNG produced by the anaerobic digestion plant of SSO at Riviere-du-Loup, approximately 200 kilometres northeast of Quebec City, and the operation of a new liquefied natural gas (LNG) fueling station, intended for the heavy transport market.

The project marks a new stage in the 'Blue Road' project, which supplies liquefied natural gas in the corridor between regions of Quebec and the Greater Toronto Area (GTA) that sees high volumes of heavy trucks.

According to Gaz Metro, the annual production of liquefied RNG at the Riviere-du-Loup plant is estimated at three-million cubic metres (m^3).

LONDON, ONTARIO: STUDYING OPTIONS FOR RESIDENTIAL SSO TO PRODUCE RNG

The City of London has established a *Community Energy Action Plan* for 2014 to 2018. The goal of the plan is to increase the local economic benefit of sustainable energy use, while reducing waste and GHG emissions, consistent with Ontario's GHG emissions reductions targets.

One of the key strategies outlined in the London *Action Plan* is to work with Union Gas to promote the use of CNG and RNG as a substitute for diesel fuel in trucks and transit vehicles.[39]

The City of London is currently studying the feasibility of collecting SSO, and processing it in a biogas system to use as a vehicle fuel.

NIAGARA, ONTARIO: FUELING TRUCKS FROM WASTEWATER

The Regional Municipality of Niagara is planning a RNG pilot project at its Port Dalhousie Wastewater Treatment Plant. The RNG will be used to fuel the division's fleet vehicles and any surplus will be injected into the natural gas grid.[40]

The project is expected to: produce 84,000 gasoline gallon equivalent (GGE) per year and would reduce the municipality's annual GHG emissions by 1,000 tonnes. The RNG generated would fuel 60 fleet vehicles that would be converted to run on CNG/RNG.[41]

The total capital cost of the pilot project is estimated at $1.1 million for the first year and an additional $200,000 annually for the subsequent 4 years. Payback is anticipated at 9.5 years.[42]

RNG FUELS MILK TRUCK FLEET FROM FAIR OAKS DAIRY, INDIANA

Fair Oaks Dairy produces biogas from manure through anaerobic digestion. The biogas that is produced on site generates enough electricity for the farm. The remaining biogas is upgraded to RNG for use as transportation fuel. The manure from 11,000 dairy cows is anaerobically digested to produce biogas that is approximately 60% methane. The biogas is purified, compressed and upgraded to 98% methane.[43] The gas is further compressed to 4,000 psi at the Fair Oaks fueling station, at which point it can be used to fuel CNG vehicles or be added to the natural gas pipeline.[44]

39 City of London (2014). Community Energy Action Plan
40, 41, 42 The Regional Municipality of Niagara (2014).
Request for Proposal - Design of Biogas to Biomethane to Compressed Natural Gas Project: Port Dalhousie Wastewater Treatment Plant
43 Anaergia (2013). Anaergia Provides Renewable Fuel for Milk Tanker Fleet from Manure Biogas
44 United States Environmental Protection Agency (2012). Fair Oaks Dairy: Digester 1

A fueling station supplies the RNG to fuel a fleet of 42 milk trucks operated by Fair Oaks Farms and AMP Americas, which is a transportation company that focuses on displacing liquid fuels with CNG. The renewable fuel avoids the consumption of diesel fuel for their daily milk deliveries. The deliveries cover more than 32,000 km per day across the Midwest United States. The project is saving $10,000 per day in fuel costs,[45] and is expected to reduce fleet GHG emissions by 40,000 tonnes per year, which is the equivalent of removing 7,000 passenger cars from the road.[46]

The project received government grants to convert trucks to natural gas, which reduced the payback period. Grants and loan guarantees came from the U.S. Department of Energy, U.S. Rural Development, and the Clean Cities Coalition of Greater Indiana.[47]

BEST PRACTICE: RNG AT PRICE PARITY THROUGH CLEAN ENERGY FUELS

Clean Energy Fuels produces the first commercially available RNG vehicle fuel. Clean Energy Fuels has named its product 'Redeem'. Clean Energy Fuels is North America's largest provider of natural gas fuel for transportation, fueling over 30,000 vehicles each day at over 350 fueling stations throughout Canada and the United States.

Clean Energy Fuels produces Redeem from methane gas that is collected from organic waste sources, such as landfills and farm-based biogas systems. The gas is then purified and compressed to pipeline specifications. The RNG enters the interstate fuel pipeline and is distributed across the country. The RNG produced by Redeem is available at fueling stations for use by CNG and liquefied natural gas (LNG) vehicles. Clean Energy Fuels offers the CNG and LNG Redeem fuel at the same price as conventional natural gas.[48]

BEST PRACTICE: UNITED STATES ENVIRONMENTAL PROTECTION AGENCY RENEWABLE FUEL STANDARD

The Environmental Protection Agency (EPA) is responsible for developing and implementing regulations concerning minimum renewable fuel volumes for transportation fuel sold in the United States. The *Renewable Fuel Standard* (RFS) is a renewable fuel volume mandate that requires that 36 billion gallons of renewable fuel is blended into transportation fuel by 2022.[49]

RNG is recognized as a renewable fuel under the EPA's *Renewable Fuel Standard* (RFS). Under the RFS, RNG can be generated from landfills, municipal waste-water treatment facility digesters, agricultural digesters, and other organic wastes.[50]

45 Biogas Association (2013). Farm to Fuel: Developers' Guide to Biomethane as a Vehicle Fuel
46 Anaergia (2013). Anaergia Provides Renewable Fuel for Milk Tanker Fleet from Manure Biogas
47 Biogas Association (2013). Farm to Fuel: Developers' Guide to Biomethane as a Vehicle Fuel
48 Clean Energy (2013). Redeem: Fueling a Renewable Future
49 United States Environmental Protection Agency (2014). Renewable Fuel Standard
50 Dodge, E. (2014). New Biogas Rules in the RFS

RNG Technology Roadmap

The Canadian Gas Association has published a *RNG Technology Roadmap*, which was written by CanmetENERGY with participation from leading RNG experts from across Canada, including representatives from Canada's natural gas utilities, biogas producers, technology supplies, academic and research groups, and federal and provincial governments. The roadmap identifies market barriers, technologies, research and development, and marketing and investment decisions needed to support the development of a RNG sector in Canada by 2020. It recommends exploring the use of RNG for vehicles.

Natural Gas & Energy Conversions

Convert from	Convert to	Multiply by
cubic foot	cubic metre	0.028328
cubic metre	cubic foot	35.314667
gigajoule	cubic metre	26.8
million cubic feet	1,000 cubic metres	28.328
1,000 cubic metres	million cubic feet	0.0353
BTUs	Joule	1054.615
Joule	BTUs	0.0009482
million BTUs	Gigajoule	1.054615
gigajoule	million BTUs	0.948213

Source: www.energy.gov.ab.ca/about_us/1132.asp

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.

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.

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

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 (SSOs): 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 which can be processed through anaerobic digestion to produce biogas.

Well-to-tank, and well-to-wheels: Well-to-wheel is the specific lifecycle analysis used for transport fuels and vehicles. The analysis is often broken down into stages entitled "well-to-station", or "well-to-tank", and "station-to-wheel" or "tank-to-wheel", or "plug-to-wheel". The first stage, which incorporates the feedstock or fuel production and processing and fuel delivery or energy transmission, is called the "upstream" stage; while the stage that deals with vehicle operation itself is sometimes called the "downstream" stage. The well-to-wheel analysis is commonly used to assess total energy consumption, or the energy conversion efficiency and emissions impact of marine vessels, aircraft and motor vehicles, including their carbon footprint, and the fuels used in each of these transport modes.

Resources

Biogas Association (2014). Organic Materials Primer

The Primer provides a brief historic overview of anaerobic digestion (AD), and an outline of the AD process; challenges faced by the AD sector, and opportunities related to capitalizing on the food waste opportunity and creating jobs; regulations that govern the AD sector, and testing and certification requirements; pathways that organic material can follow, depending on which type of AD system accepts the material; and what is being done differently in other jurisdictions, including Quebec, NS, the U.S. and Europe, where restrictions are in place on how organic material can be treated and disposed.

Biogas Association (2012 and 2013). Farm to Fuel: Developers' Guide to Biomethane; and Farm to Fuel: Developers' Guide to Biomethane as a Vehicle Fuel

The guides were created to build the production of biomethane in Canada. The Guide helps farmers determine if biomethane production is a good fit for their farm and operations. For those farmers considering developing biogas systems, and upgrading the biogas to biomethane, the Guide walks them through the planning process, offering a check-list of questions to ask relevant technology and service providers. It also alerts farmers to important considerations, such as feedstock, financing, permits and safety.

Biogas Association (2014). Progressive Waste Solutions

Clarke S. and J. DeBruyn (2012). Vehicle Conversion to Natural Gas or Biogas

Union Gas Ltd. (2014). Natural Gas for Fleet Vehicles: The Answer to Rising Energy Prices and Lower Emissions Targets

Explores the use of compressed natural gas for fleet vehicles and explains the economic and environmental benefits.

Natural Resources Canada (2010). Natural Gas Use in the Canadian Transportation Sector-Deployment Roadmap

Explains the market for natural gas vehicles in Canada, the outlook for natural gas, business case modelling, and identifies challenges and opportunities for the use of natural gas in the transportation sector.

Quest (2012). Renewable Natural Gas: The Ontario Opportunity

This business case study examines the potential growth of renewable natural gas (RNG). The case study demonstrates that the creation of an RNG industry in Ontario could bring significant benefits to the province and contribute to meeting the Government of Ontario's greenhouse gas, energy efficiency and clean air targets.

Crittenden, G. (2014). Natural Gas Vehicles for the Waste and Recycling Industry;
Milner, A. (2014). Factory-Built Natural Gas Trucks

These articles are from the February/March (2014) issue of Solid Waste and Recycling Magazine, which featured a natural gas vehicles supplement section. The specific focus of the articles is the use of natural gas vehicles for the waste and recycling industry. The articles featured include an analysis of economic payback as well as information on the Cummins Westport engines for natural gas trucks.

Milner, A. (2013). Compressed Natural Gas

Alicia Milner is president of the Natural Gas Vehicle Alliance. In this article, she discusses the use of compressed natural gas for the waste and recycling industry.

Cummins Westport (2015). **Heavy-Duty Natural Gas Engines**

Cummins Westport supplies two natural gas engines, ISL G and ISX12 G, which are suitable for municipal return-to-base fleet operations.

Canadian Natural Gas Vehicle Alliance (2015). **Renewable Natural Gas**

The Canadian Natural Gas Vehicle Alliance website contains information on: commercial vehicle and station technologies, environmental benefits, Canada's natural gas vehicle industry, as well as links to other useful resources.

United States Environmental Protection Agency (2014). **Renewable Fuel Standard**

Environment Canada (2008). **Hamilton Renewable Power Incorporated**

United States Environmental Protection Agency (2014). **Greenhouse Gas Equivalencies Calculator**

Water Tap Ontario (2013). **Moving From "Cost Centre" to "Profit Centre": Hamilton Water**

City of London (2014). **Community Energy Action Plan**

Pollution Solutions (2014). **Organic Waste-to-Energy Project Illustrates Global Potential of Biogas to Provide Green Power**

De Bono, N. (2011). **Biogas Project Revived**

The Regional Municipality of Niagara (2014). **Request for Proposal – Design of Biogas to Biomethane to Compressed Natural Gas Project: Port Dalhousie Wastewater Treatment Plant**

Global Methane Initiative. (2012). **Nanaimo Bioenergy Centre LFG Utilization Facility**

BC Ministry of Community and Rural Development (2010). **Integrated Resource Recovery Case Study: Regional District of Nanaimo Landfill Gas Recovery and Utilization**

City of Surrey (2015). **Organic Biofuel Facility**

Progressive Waste Solutions (2014). **Leading the Conversion to Natural Gas for Waste and Recycling Fleets in Canada**

Progressive Waste Solutions (2014). **We are Revving up our CNG Fleet Conversion Program**

Anaergia (2013). **Anaergia Provides Renewable Fuel for Milk Tanker Fleet from Manure Biogas**

United States Environmental Protection Agency (2012). **Fair Oaks Dairy: Digester 1**

Clean Energy (2013). **Redeem: Fueling a Renewable Future**

Canadian Biogas Association

275 Slater Street, Suite 900, Ottawa, Ontario K1P 5H9
www.biogasassociation.ca