Technical Memo 5

Trends in Alternative Technologies

Niagara Region // December, 2023

Executive Summary

This technical memorandum summaries key trends in the development of new and emerging technologies within the waste management industry. The focus of this memo is technologies specific to collection, processing and disposal operations and is intended to support development of the Regional Municipality of Niagara's (Niagara Region) upcoming Waste Management Strategic Plan (WMSP). Proven technologies in use across North America and Europe, applicable to the Niagara Region, were considered. Appendix A provides an overview of the technologies considered as part of this memo.

Key Take Aways

Technological change is occurring in all facets of life at an ever-increasing speed. Change within the waste management industry is no different and with that change will be challenges and opportunities to reduce operating costs and improve service delivery.

Fundamental change is expected in the area of waste collection in the near future. Automated cart-based collection is expected to become the norm for curbside collection of waste and source separated organics. Conversion of fleets to electric and/or hybrid vehicles will occur as fossil fuels are replaced by a growing range of available alternatives. Autonomous and semi autonomous collection will begin to be introduced in the next five to ten years. Real time data collection will become a standard for performance monitoring and management.

Incremental adoption of new and emerging technologies will continue to drive automation of waste processing operations. Optical and chemical resonance technologies for material identification combined with robotics and artificial intelligence systems for sortation systems are anticipated to continue to drive improved recovery and sortation efficiencies. Waste disposal is not expected to change dramatically albeit there will be incremental improvements in the efficiency of landfill operations through real time data access. Energy from Waste (EFW) and related technologies remain the most likely alternative for management of residue waste in the absence of available landfill capacity.

Birett & Associates

December, 2023

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List of Acronyms

ATR: Advanced Thermal Recycling

C&D: Construction and Demolition

CNG: Compressed Natural Gas

EFW: Energy from Waste

EPV: Electric Powered Vehicles

FCEV: Fuel Cell Electric Vehicles

GHG: Greenhouse Gas

LFG: Landfill Gas

LNG: Liquid Natural Gas

MRFs: Material Recycling Facilities

MWP: Mixed Waste Processing

RDF: Refuse Derived Fuels

RFID: Radio Frequency Identification Tags

RNG: Renewable Natural Gas

WMSP: Waste Management Strategic Plan

WtE: Waste-to-Energy

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1 Introduction

Technological development is occurring across society at an ever-increasing pace and the waste management industry is no different. Advancements in robotics and artificial intelligence are revolutionizing the way waste is collected, processed, recovered and disposed. While efficiency and cost reduction have been primary drivers of change in the industry, safety has also been at the forefront. In 2022, it was reported that 35,000 trash collectors are on the job each day across Canada and an average 44.3 per 100,000 workers die each year.[1] The most common cause of death on the job being workers struck by drivers who fail to slow down when passing garbage trucks. These workers are also at risk for infections such as tetanus and hepatitis due to the trash they are exposed to on the job. Changes in the types and complexity of waste and expectations of improved diversion have also been important drivers of technological investment by the industry.

2 Collection Fleet Innovation

Arguably, waste collection systems have seen some of the greatest transformative change in the industry. A mere thirty years ago, the typical waste collection vehicle would have been operated by a driver accompanied by a crew of two to four staff manually emptying steel garbage cans at the curb. Curbside Blue Box recycling was in its infancy and involved manual sortation of recyclables by the truck driver including physically colour sorting glass containers into different compartments on the truck.

Today's collection vehicles are sophisticated machines balancing operational efficiency with safety and environmental needs. The time spent in front of the average household has been reduced from approximately one minute down to about 10 seconds. In the coming years, due to advancements in technology, municipalities could potentially see significant changes in collection fleet.

2.1 Alternative Fuels

Waste collection vehicles are a major source of greenhouse gas (GHG) emissions. A traditional diesel powered truck burns over a litre of fuel per kilometer subject to driving conditions. Put in perspective, it has been widely reported that the average diesel powered collections vehicle can produce over 20 times more carbon emissions than the

[1] Canada's Most Dangerous Jobs of 2022 (https://www.wbwhite.com/blog/general-category/canadas-dangerous-jobs-2022/#:~:text=Trash%20and%20recycling%20collectors,100%2C000%20workers%20dying%20each%20year).

average US household.[2] At the same time, it will consume over $50,000 in fossil fuel per year.

With the rising cost of fuel and growing concerns about the environmental footprint of waste collection, waste haulers began exploring different types of alternative fuels and related systems to reduce fuel consumption and related emissions. Various approaches trialed over the past 15 years include options such as biodiesel, natural gas, hydrogen fuel cells, electric vehicles and various hybrids and variants of these systems.

Biodiesel is a term properly used to describe fuels produced from the transesterification of fats and oils. Glycerin is typically produced as a coproduct. Interest in biodiesel developed from the potential to use waste products like cooking oil and animal fats to displace fossil fuels. In addition to being a renewable fuel source, biodiesels are frequently reported to have lower emissions.[3] The term has also been used to describe equivalent products made from a broad range of organic waste ranging from yard waste through to unrecyclable paper fibre using a range of technologies. Production of these broader biofuels typically involves thermal and/or biochemical processes such as gasification or pyrolysis of waste.[4] The term biofuel can also include products like ethanol, produced from distillation of renewable sources such as corn and sugar cane, which is commonly blended with gasoline to reduce passenger vehicle emissions.

Biodiesel has been extensively trialed by various governments and private companies and is a viable alternative to diesel. It does, however, typically need to be blended with regular diesel to meet industry standards and accommodate colder climates. Some sources report higher vehicular maintenance costs but these issues are expected to be resolved as knowledge and development of reliable sources improves.[5]

Use of compressed natural gas (CNG) and liquid natural gas (LNG) has become a common option for waste haulers and other fleet operators. Natural gas vehicles emit up to 30 per cent less GHG emissions, 95 per cent less NOx and virtually no particulate

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[2] What is My Trucks Carbon Footprint (https://bigtruckrental.com/long-term-garbage-truck-rental-service/what-is-my-trucks-carbon-footprint/)

[3] Alternative Fuels Data Center Biodiesel Vehicle Emissions (https://afdc.energy.gov/vehicles/diesels_emissions.html)

[4] Alternative Fuels Data Center, Renewable Diesel (https://afdc.energy.gov/fuels/renewable_diesel.html)

[5] Evaluation of the Impact of Using Biodiesel and Renewable Diesel to Reduce Greenhouse Gas Emissions in City of Toronto’s Fleet Vehicles (https://www.toronto.ca/legdocs/mmis/2019/ie/bgrd/backgroundfile-130965.pdf)

matter.[6] Its penetration into the market as a diesel alternative is only limited by the development cost of the associated fueling infrastructure. Typical CNG fueling stations cost over $2 million (CAN). The federal government is, however, investing in this technology. The Department of Natural Resources Canada recently announced an investment of $6 million (CAN) into the installation of six CNG refuelling stations along the Trans-Canada Highway.[7] Private sector companies are also pursuing development of CNG infrastructure. Tourmaline Oil Corp. and Clean Energy Fuels Corp., for example, recently announced a $70 million (CAN) joint development agreement to build and operate a network of natural gas stations along key highway corridors across Western Canada.[8]

More recently, a number of municipalities have been exploring the feasibility of producing renewable natural gas (RNG) from sources such as landfill gas recovery systems and food waste anaerobic digestion systems to fuel their municipal fleets. Subject to local economic conditions and the availability of sufficient material to achieve economies of scale, RNG production can be a viable means of contributing to development of a circular economy.

Hydrogen fuel cells represent a variant on the development of electrical vehicles. Fuel cell electric vehicles (FCEV) have one or more tanks on board in which the hydrogen is stored. The hydrogen is introduced to oxygen from the air in a polymer electrolyte membrane fuel cell. The hydrogen and oxygen combine in an electrochemical reaction to produce water and electricity. Water vapour is the only emission making FCEVs ideal for reducing GHG emissions. Unlike electric vehicles, FCEVs can be refilled with hydrogen in less than four minutes and typically have comparable or better ranges than electric vehicles.[9] They are, however, still at the developmental stage making them more expensive and they lack the necessary supporting infrastructure to refill them.

Electric vehicles are, by comparison, becoming increasingly common in the waste hauling industry. Like the early days of electric passenger vehicles, there are challenges with the development of heavy-duty electric vehicles. Commonly reported issues include

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[6] Environmental Benefits of CNG, LNG and RNG-fuelled truck fleets (https://www.fortisbc.com/est/truck-fleets/environmental-benefits-of-lng-or-cng-fuelled-truck-fleets#)

[7] Canada funds 6 CNG stations along the Trans-Canada Highway (https://www.petrolplaza.com/news/26991#)

[8] Canada's largest natural gas producer invests in the development of CNG stations (https://altfuelscg.com/en/infrastructure-and-supply/canadas-largest-natural-gas-producer-invests-in-the-development-of-cng-stations/)

[9] Alternative Fuels Data Center Fuel Cell Electric Vehicles (https://afdc.energy.gov/vehicles/fuel_cell.html)

range limitations, battery weight and longevity, charging time, inadequate power (i.e., torque) in challenging terrain, performance challenges in cold climates and the cost of charging stations.[10,11] Still, trials in warmer climates have shown great promise and this technology is expected to evolve rapidly.

Just like with passenger vehicles, hybrid combinations of electric and fossil fuel or alternative fuel vehicles are possible to overcome some of the current challenges faced by electric vehicles.[12] These hybrid vehicles are understandably more expensive and, like electric vehicles, still under development but continue to show promise.

One of the key technologies supporting electric and hybrid vehicles is the development of regenerative braking technology and variants such as hydraulic hybrids. These systems transfer the kinetic energy that is otherwise lost when braking back to either the electric battery in the case of an electric vehicle or a hydraulic accumulator in the latter instance. Electromagnetic generators, flywheels and spring systems can all be used to convert braking power into electricity. A hydraulic pump uses the braking power of a vehicle to pressurize hydraulic fluid in the latter case.[13] This stored energy is typically used to assist with acceleration of the vehicle. These systems can extend the range of hybrid vehicles and also reduce wear and tear on the vehicle's braking system. Both types of systems are under development but evolving rapidly as a core component of electric and hybrid vehicles.

Niagara Region, through its procurement processes, has already been proactive in promoting the use of alternative fuels by its collection contractors. Continued monitoring of trends in the development of alternative fuel technology and prioritization of the adoption of proven low emissions options by contractors for collection vehicles is recommended. Niagara Region should also monitor advancements in the development of alternative fuels from landfill gas and other waste management sources to assess the feasibility of producing its own alternative fuels.

2.2 Autonomous Vehicles

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[10] NYC Says New Electric Garbage Trucks Are No Match for Wicked New England Weather (https://www.nysun.com/article/nyc-says-new-electric-garbage-trucks-are-no-match-for-wicked-new-england-weather)

[11] If electric trucks are the solution, what are the problems? https://www.sciencedirect.com/science/article/pii/S2214629622002262

[12] Meet HDT's 2022 Top Green Fleets (https://www.truckinginfo.com/10189034/meet-hdts-2022-top-green-fleets)

[13] Electric-hydraulic hybrid systems reduce emissions in refuse collection vehicles (https://www.mobilehydraulictips.com/electric-hydraulic-hybrid-systems-reduce-emissions-in-refuse-collection-vehicles/)

Autonomous vehicles, or vehicles that operate without the aid of a human, might seem like something out of science fiction but all expectations are that they are just a matter of years away from being commercially viable. Advancements in robotics and artificial intelligence are bringing this concept closer to reality every day. Companies like Volvo were already pursing the idea as early as 2016.[14] By 2021, TuSimple's autonomous trucking technology had successfully piloted a commercial delivery vehicle from Nogales, Arizona to Oklahoma City; a distance of almost 1,500 km. Since then, autonomous and semi autonomous vehicles have begun penetrating the passenger vehicle and commercial delivery vehicle industries. In 2020, Loblaws partnered with Gatik (a company specializing in middle mile autonomous logistics) to develop a fleet of autonomous delivery vehicles.[15] The fleet of five trucks began successful testing in the GTA in late 2022.

Understandably, it will be some time before an autonomous vehicle can be programed to adapt to, and overcome, the myriad of challenges human waste collectors deal with on a daily basis. However, if successful, the advancement of this technology would cut operating costs by at least 30 per cent and potentially reduce workplace injuries in the industry. Niagara Region should continue to monitor of trends in the development of autonomous vehicles and other applications applicable to the Waste Management Services Division and is recommended given the timeframe of the WMSP.

2.3 Automated Cart Based Collection

Automated cart based collection involves the use of lidded, wheeled plastic carts typically ranging from 75 to 360 litres in size. They are collected and dumped using a hydraulic articulated arm attached to the side of the waste collection vehicle. The arm is operated by the driver from within the vehicle cab using a joystick and sensor system. Automated cart based collection is a proven technology and has been in place throughout the United States and Europe for decades. It is also in use in a number of communities in Ontario including Peel Region. The cities of Toronto, Guelph, Timmins, and Temiskaming Shores and the Bluewater Recycling Association area along Lake Huron.[16] Communities such as the Region of Waterloo (Waterloo) are also moving

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[14] Volvo is working on an autonomous garbage truck (https://www.cnet.com/roadshow/news/volvo-is-working-on-an-autonomous-garbage-truck/)

[15] Gatik and Loblaw Make History with First Fully Driverless Deployment in Canada (https://www.loblaw.ca/en/gatik-and-loblaw-make-history-with-first-fully-driverless-deployment-in-canada/)

[16] Automated Cart Recycling: A Study of Municipal Collection and Operations in Ontario (https://thecif.ca/projects/documents/888-Autocarts_Study_FINALv2_Jun2016.pdf)

towards this collection system.[17]

Automated cart based collection offers significant savings in collection costs through reduced stop time at each household and reduced work related injuries. Productivity at the curb is typically improved by over 30 per cent compared to manual collection and can accommodate a more diverse workforce because of the reduced physical demands. It is not, however, without its own challenges. Cart based collection is known to result in significant contamination issues of source separated materials such as Blue Box recyclables and source separate organics (i.e., Green Bin). Initial capital costs are also significant. A typical set of garbage and Green Bin carts can cost between $150 to $200 per household (delivered to the property) depending on optional features. The additional features on the collection vehicles can also add an extra $75,000 or more to their initial purchase price. Implementation of automated cart based collection also requires significant planning. Residents may have issues related to cart size, storage and set out that need to be resolved as part of the planning process. Consequently, most municipalities recommend a two to three year planning cycle to obtain necessary budget approvals, negotiate collection contract impacts, procure new trucks and carts, prepare new routing, amend by-laws and plan an appropriate communications strategy. With municipalities across the province transitioning out of their Blue Box recycling programs, many are taking advantage of the opportunity to move to automated cart based collection for garbage and Green Bin collection.

Automated cart based collection is expected to become an industry norm in the coming years. Niagara Region should consider the option of planning to move towards adoption of this technology as part of its next collection contract and this WMSP.

2.4 Alternative Collection Systems

While curbside collection vehicles will continue to evolve, changes are also happening in commercial collection systems. Increasingly, municipalities and commercial plazas are moving to below ground storage systems such as Moloks, Earth Bins and The Cube to reduce the footprint of waste storage as downtown cores become increasingly constrained. These systems are a proven technology that has been in place for several decades. When coupled with front-end loader collection services, they can store larger volumes of waste within a smaller footprint, reduce odour, litter and rodent issues. They do, however, require careful consideration of the appropriateness and practicality of such options based on community needs and local environment.

[17] Big changes coming to garbage collection in Waterloo Region (https://www.therecord.com/news/waterloo-region/big-changes-coming-to-garbage-collection-in-waterloo-region/article_191f1c95-3bd5-5cab-aeb2-73daa896810d.html?)

An expansion on this theme is the Optibag system, which envisions development of underground vacuum conveyance of colour coded, bagged waste to central collection and processing sites. The system uses optical readers to sort the collected bags. In principle, there are a number of potential benefits to such a system including elimination of above ground storage and transportation but at a significant infrastructure cost. To date, Oslo, Norway has adopted the colour coded bag based program but the waste is collected using traditional collection vehicles.

The use of clear bags for waste collection has grown steadily in popularity amongst municipalities with well over a dozen municipalities having adopted this approach in Ontario.[18] The cities of Orillia and Peterborough are amongst the most recent municipalities opting to move towards this form of collection. The City of Markham is the only comparable municipality to Niagara that has adopted the clear bag system. Further, the use of clear bags may not be well paired to cart collection as noted in Technical Memo #5 – Trends in Alternative Technologies.

Clear bags are a proven tool used to support mandatory recycling and waste diversion policies provided they are coupled with sufficient enforcement resources. Niagara Region should consider adoption of a clear bag policy for waste set out to encourage participation in waste diversion programs operated locally by Niagara Region and other agencies. However, the use of clear bags should be considered by Niagara Region as part of its next collection contract for this WMSP.

2.5 Smart Collection Technologies

Arguably, some of the most important trends driving change in the industry are the application of smart technologies to collection and waste management activities. Over the past 15 years, the industry has invested heavily in a broad range of technologies to improve safety, operational performance and data management. Collection vehicles routinely now come with as many as six cameras mounted on them to allow drivers to see their surroundings, the materials being deposited in the vehicle and the set out of waste at the curb by residents. Coupled with on board Global Positioning System (GPS) technology, Radio Frequency Identification Tags (RFID) on containers, real time data upload capabilities and municipal Geographic Information System (GIS) mapping systems, the industry now has the potential to gather, monitor and evaluate collection performance at a household or per stop level. Data is now available on everything from missed collections through to contamination sources and routing issues. This big data is allowing municipalities and their waste haulers to make more informed decisions and

[18] Clear Bag Garbage Program Implementation Toolkit: A municipal step-by-step guide (https://thecif.ca/projects/documents/748-Clear-Bag-Toolkit.pdf)

seek cost-cutting opportunities. Route optimization, for example, is expected to be a key opportunity in the coming years.

Niagara Region's waste collection contractor already uses many of the currently available smart collection technologies as part of its contract requirements with Niagara Region. Niagara Region is should continue to encourage its contractors to adopt smart collection technologies where appropriate. Consideration should also be given to trialing their use for applications such as routing optimization, landfill site operations and container management in public settings at a minimum.

2.6 Public Communications

As described further in Technical Memo 3: Demographic Trends, it is recognized that the nature of communications is changing rapidly in response to the broad use of social media and smart devices by younger generations. Municipalities are already taking advantage of this potential to push tailored, real time information to residents about their waste management services and routinely provide information through notification services and cell phone applications such as the ReCollect Waste Wizard (used by Niagara Region).[19] Many are also allowing residents access to real time data about the location of their collection vehicle or snow plow services.[20,21]

Growth in the demand for real time data is expected to grow significantly in the next five years.[22] The growing use of RFID tags on householder or customer bins, for example, will allow municipalities to begin providing information to residents and customers about their set outs such as weights, contamination rates and issues (e.g., late set out).

This availability of big data is expected to drive a resurgence of user pay systems as municipalities face growing pressures on their waste management financial systems. Where practical, Niagara Region is encouraged to look for opportunities to share more program feedback and performance data (e.g., geolocated truck information, collection weights per household) with the public.

3 Innovations in Waste Diversion Technologies

[19] Route Education (https://recollect.net/waste-wizard/)
[20] Where's My Plow (https://www.aurora.ca/en/town-services/wheres-my-plow.aspx)
[21] How do I track my WM truck with the MyWM app? (https://www.wm.com/ca/en/support/faqs/how-do-i-track-my-service-estimated-pick-up-time-and-completion)
[22] Five Data Analytics Trends On Tap For 2023 (https://www.forbes.com/sites/forbestechcouncil/2023/01/11/five-data-analytics-trends-on-tap-for-2023/?sh=4e5b805c6cfd)

3.1 Processing of Organic Waste

Similarly, composting has evolved dramatically from the early municipal efforts to divert leaf and yard waste through open air or aerobic compost piles or windrows. Over the past two decades, as municipalities sought to divert a broader range of food and organic waste, facility operators developed a range of enclosed aerobic and anaerobic composting facilities. These technologies have reached a level of technological maturity that allows municipalities to select one or more options suitable to their available quantities and types of organic waste and local circumstances such as land availability. Aerobic composting systems still prevail as the most cost effective option for quantities of less than 35,000 tonnes per annum of organic waste provided there is a suitable location for a facility where odours will not impinge on neighbouring properties. Anaerobic digestion facilities tend to be the preferred option for materials like food waste or diapers where quantities of over 50,000 tonnes per annum are available and where space constraints are an issue.[23]

More recently, there have been concerted efforts to explore the feasibility of processing food waste through municipal wastewater treatment plants. Subject to any capacity or other operational constraints, this approach can be a viable solution for mid range quantities of organic waste. Costs are generally higher than for equivalent aerobic options subject to how the 'digestate' (i.e., the end product from the digestion process) is managed.[24] This approach does, however, provide the opportunity to support options like production of RNG or electricity which can reduce investment costs. Although there does not appear to be free digester capacity at Niagara Region's wastewater treatment plants at present, planning for future plants could include consideration for additional capacity, subject to capacity or other operational constraints.

There are a number of supplemental processes that are seeing a resurgence in popularity as a result of the introduction of the Food and Organic Waste Policy Statement in the province (as outlined in Technical Memo 1: Federal and Provincial Policy and Legislative Review). They include at home options for the multi residential sector such as vermicomposting and countertop food dehydrators like the FoodCycler.[25] Larger commercial versions of these systems and organic waste slurry systems are expected to be of interest to business and facilities affected by the provincial policy

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[23] City of Thunder Bay: Development of an Organics Diversion Program Implementation Plan (https://www.thunderbay.ca/en/city-services/resources/Documents/Garbage-and-Recycling/Thunder-Bay---Task-4---Program-Plan-Development---FINAL-jw.pdf)
[24] Ibid.
[25] City of Thunder Bay: Development of an Organics Diversion Program Implementation Plan (https://www.thunderbay.ca/en/city-services/resources/Documents/Garbage-and-Recycling/Thunder-Bay---Task-4---Program-Plan-Development---FINAL-jw.pdf)

statement. Municipalities should anticipate receiving calls from local businesses enquiring about the feasibility of receiving slurried organic waste at their local wastewater treatment operations as companies strive to meet the requirements of the policy statement.

Niagara Region already has a successful organic waste diversion program. Consideration, however, should be given to monitoring development of processing technologies that might offer lower emissions profiles (e.g., treatment of organic waste at Niagara Region's wastewater treatment plants). Options to improve capture in multi residential settings such as countertop dehydrators should also be explored.

3.1 Processing of Recyclables

While municipalities are no longer responsible for the recycling or processing of printed-paper and packaging from residential sources, there is still the potential for them to choose to manage this material from retail and commercial businesses in the community. Consequently, the evolution of technology in traditional Material Recycling Facilities (MRFs) remains relevant, on a peripheral level, and creates opportunities to observe potentially transferable technologies for managing other recyclables. Traditional MRFs were a simple series of conveyors, screens and magnets coupled with intensive manual sortation and quality control. Increasingly the human component of this work has been replaced by sophisticated systems involving optical readers combined with high-speed cameras and robotics controlled by complex computer systems. As this type of technology is refined and becomes less expensive, it is anticipated that opportunities may develop in the future to apply it to more challenging waste streams such as sortation and identification of batteries, textiles, and mixed waste processing from the multi residential housing sector.

Niagara Region is encouraged to continue monitoring trends in the development of new processing technologies that might aid in the diversion of recyclables and other priority wastes (e.g., household hazardous and special wastes) to support the development of local options.

3.3 Alternative Processing Options

Despite concerted promotion and educational efforts by municipalities, it is recognized that a significant portion of divertible waste continues to be discarded to landfill by residents and local businesses. This challenge is particularly true of the multi residential sector, which, as a whole, struggles with low accessibility, participation rates, and high contamination levels. Municipalities and service providers have therefore undertaken a number of studies and initiatives to consider alternative approaches such as mixed waste recovery and processing systems. These systems typically involve mechanical sortation of mixed waste to recover recyclable materials. The material is either composted before or after sortation to stabilize the balance of the waste prior to use either as low value compost or landfill and mine tailings cover.[26] Both types of systems have been extensively trialled over the past three decades and generally have challenges with material quality and lower diversion rates. Capital and operating costs can also be higher than traditional options.[27] Niagara Region is encouraged to continue working with other interested municipalities and other parties to pursue alternative processing technologies that might more effectively divert waste from key sectors such as multi residential families.

4 Innovations in Recovery and Disposal

Available waste disposal options have largely remained unchanged over the years with a few notable exceptions.

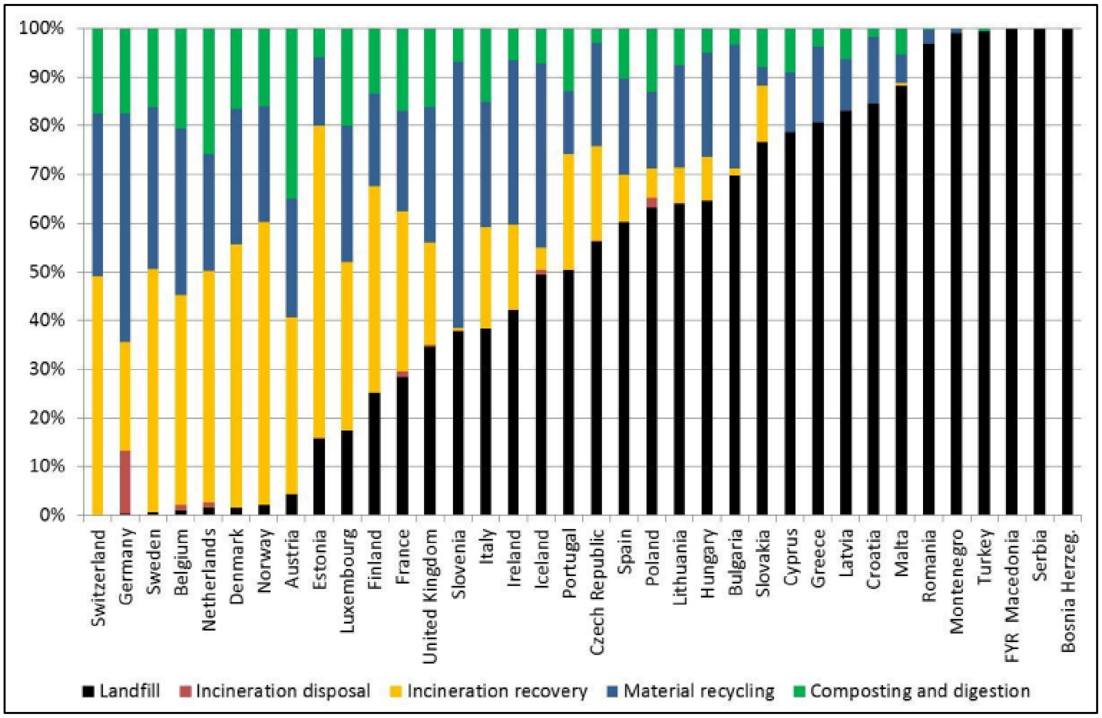
4.1 Energy from Waste

EFW and its common variants such as gasification, pyrolysis and hydrothermic treatment are all proven technologies that have advanced significantly since the early days of mass burn incinerators. Traditional EFW facilities, in particular, have a well established track record that has been recognized by countries across the world, as shown in Table 1, as a practical option to prioritize over landfill for the management of residual waste (i.e., waste that cannot be diverted). There are currently five large EFW facilities in Canada and approximately 800 worldwide.[28]

[26] 10 Points that Explain Mixed Waste Processing (https://www.waste360.com/mrfs/10-points-explain-mixed-waste-processing#)
[27] Mixed Waste Processing Study Update (https://www.toronto.ca/legdocs/mmis/2020/ie/bgrd/backgroundfile-146477.pdf)
[28] https://www.nswai.org/docs/State_Waste_Mgmt_in_Canada.pdf

Table 1: Waste Management Options in Europe (2013)

Source: IEA Bioenergy[29]



Technologies such as gasification and pyrolysis are scientifically proven but have not been commercialized to the extent of traditional EFW technology. They have typically been positioned as niche solutions for the production of syngas (i.e., synthetic gas) for use in development of biofuels and as a fossil fuel hydrocarbon substitute.

The greatest challenge with broad adoption of these technologies is their significant costs and capacity requirements as highlighted in Table 2. The Durham York EFW, for example, had a reported development cost of almost $300 million (CAN) when it was commissioned in 2011. Construction costs have escalated significantly since that time. In addition, like most waste management infrastructure, these facilities become exponentially more expensive at lower capacities.[30] At a global level, many are built with capacities exceeding 300,000 tonnes per annum. Recognizing the declining quantities of indivertible waste being generated locally and across the province, it becomes increasingly difficult to justify construction of such a facility unless it is part of a broader multi-jurisdictional initiative.

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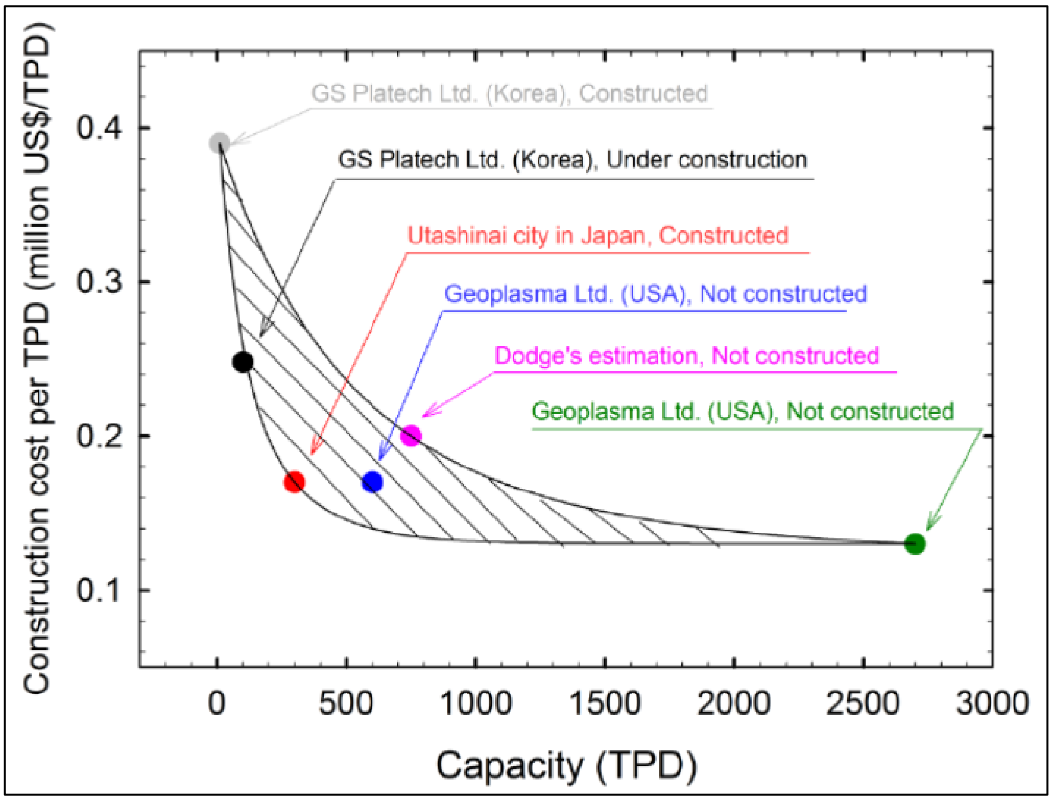
[29] Small Scale Energy-from-Waste (https://task36.ieabioenergy.com/wp-content/uploads/sites/4/2016/06/IEA-Bioenergy-Small-scale-EfW-Final.pdf)

[30] Thermal Plasma Gasification of Municipal Solid Waste (MSW) (https://www.intechopen.com/chapters/40402)

As part of its WMSP, Niagara Region is encouraged to consider the timing of when it should begin exploring alternatives to its current waste disposal option (i.e., landfilling of waste). Funds should be set aside to support examination and public consultation on the feasibility of developing scalable waste disposal options, potentially in partnership with neighbouring municipalities.

Table 2: Construction Cost vs Design Capacity of Thermal Plasma Plant

Source: Gasification for Practical Applications[31]



4.2 Refuse Derived Fuels

Production of refuse-derived fuels (RDF) is also a proven technology that has a long history of use on a global level. On a simplistic level, they normally involve grinding the incoming waste and forming it into uniform pellets with a predictable moisture level and energy level that can potentially be used as a replacement for brown coal in electricity and district heating facilities, greenhouses or cement kilns. Its primary benefit is the potential to be used for smaller quantities of residual waste. The challenge with this technology has been the relatively low success rate in commercial application. These

[31] Thermal Plasma Gasification of Municipal Solid Waste (MSW) (https://www.intechopen.com/chapters/40402)

technologies are very susceptible to unforeseen issues with the variability of the incoming waste stream, and many have gone bankrupt. The Dongara Pellet Plant in Vaughan, Ontario, for example, was commissioned in 2008 at a reported cost of

$50 million (CAN) to process up to 100,000 tonnes per year of residual waste for York Region. After several years of concerted effort, the contract with York Region was terminated due, in part, to regulatory approvals challenges.[32]

RDF can be a viable alternative to landfilling Niagara Region's waste. As noted in Section 4.1 Energy from Waste, Niagara Region should consider the timing of examining alternatives to its current disposal practices and production of RDF may warrant further investigation.

4.3 Landfill Optimization

Traditional landfill operations use the soil obtained from the development of the site to cover the refuse on a nightly and interim basis. These layers are referred to as daily cover and interim cover and serve to reduce the risk of fires, blowing litter and attraction of rodents. Application of daily and interim cover can often result in up to 30 per cent of the landfill capacity being lost. As a result, many municipalities such as Waterloo Region have begun exploring the use of alternative daily covers. These alternatives can range from the use of large reusable tarps that are dragged over the waste, through to machine applied spray foams and disposable plastic film covers. Many municipalities also use inert material such as shredded automotive wrecker waste, construction and demolition (C&D) waste, crushed Blue Box glass and shredded tires as a daily cover. It is also common for landfill operators to use crushed Blue Box glass and C&D rubble for road development on site to conserve use of virgin resources for this purpose.

Excavation and reclamation of landfill cells is also a proven practice commonly used in the United States to recover landfill capacity. The feasibility of this option tends to hinge on the ability to dispose of dirty recyclables, such as excavated old cardboard, newsprint and plastics, to one of the many EFW facilities in the country and reuse of the excavated soils for daily cover. The cost effectiveness of this practice is more challenging in Ontario because of the lack of EFW capacity and complicated and costly provincial approvals process.

There are other fundamentally different designs for landfill operations that have been trialed in the United States. Traditional landfill design tries to minimize the amount of

[32] York Region ends contract with company turning garbage into fuel pellets (https://www.thestar.com/news/gta/2014/11/03/york_region_ends_contract_with_company_turning_garbage_into_fuel_pellets.html?rf)

moisture that enters the waste. This practise is intended to reduce the potential for ground water contamination. Various proponents have built demonstration in situ bioreactors which effectively take the opposite approach and endeavour to accelerate the breakdown and stabilization of the waste through the circulation of nutrients and moisture throughout the waste within a lined and enclosed landfill cell. These systems, in theory, have a number of benefits such as improved landfill gas capture but they are still under development as a concept.

Niagara Region has already adopted and/or trialed many of these better practices and no further action is recommended at this time.

5 Conclusions

Continued investment and innovation within the waste management industry can be anticipated. Availability of real time, automated data collection systems combined with smart technologies is expected to provide significant gains in service delivery, safety and operational efficiency. These changes will have direct impacts on Niagara Region's operations and will need to be considered as part of the development of Niagara Region's new Waste Management Strategic Plan. Niagara Region has already adopted many of the known better practices utilized for collection and management of various waste streams. Niagara Regions should continue to monitor developments within the industry and continue to adopt proven practices when appropriate. Particular consideration should be given to the application of alternative fuels, automated cart based collection and associated smart technologies to minimize cost and environmental impacts of waste collection activities. The WMSP should also consider the appropriate timing of when to begin examining alternative options to replace or supplement Niagara Region's current practice of landfilling collected waste. Consideration should also be given to exploring alternative technologies to improve the capture of divertible waste from key sectors such as multi residential households.

Appendix A

Niagara Region

Collection, Processing and Disposal Alternative Technology Options Review

Collection Fleet Technologies - Alternative Options:

Technology	Description	Pros	Cons	Level of Technology Development
Autonomous (and semi-autonomous) Vehicles	• Uses sophisticated computer systems linked to cameras and sensors to pilot a vehicle without the need for a human driver (or partially without the need for a human operator). • For waste collection vehicles, there are many scenarios to design for automation including: pedestrians, safety, lining up to the garbage bin, oncoming traffic, and obstacles. • The vehicle would need to be able to manoeuvre within neighbourhoods and urban areas to collect garbage. • These vehicles would also need to determine where the garbage bin is and stop in front of it. • They would also be required to identify and pick up the correct waste stream	• Potential for efficient, cost effective waste collection service. • Improve working conditions for waste collectors and reduce occupational injuries (in the case of semi-autonomous vehicles). • Enhanced traffic safety in built-up areas and while reversing. • Potential to combine automated vehicles with electric or natural gas powered vehicles to reduce the generation of GHG emissions.	• Public concern that technology is still in its infancy and that the vehicle will not stop when it encounters an obstacle (e.g., a child). • Currently unknown how the technology will work during heavy snowfall, heavy rains and around snowbanks.	• Emerging (waste collection vehicles). • Trialed and tested in Europe and U.S.

Technology	Description	Pros	Cons	Level of Technology Development
Hybrid Vehicles	• Uses a combination of electricity and fuel (e.g., gasoline, diesel) to power it. • A hybrid vehicle uses more than one type of system to produce, store and deliver power such as electricity/gas and electricity/diesel.	• Increased fuel economy in stop-and-go traffic. • Reduces impacts from idling through the use of the electric motor during stationary activities. • Reduced noise emissions. • Fewer GHG's emitted compared to diesel-fueled vehicles. • Hybrid vehicles benefit the environment as they reduce the amount of GHG emitted compared to conventional diesel powered engines. The effects of this are more impactful if the electric charge is from a renewable energy source. • Minimal to no impacts of using hybrid vehicles. Minor positive health impacts due to fewer particulates in the air and reduced GHG emissions.	• Need to use hybrid vehicles for high operational uses (e.g., dense population) in order to achieve payback on the purchase price.	• Emerging (waste collection vehicles). • Implemented in Gothenburg, Sweden, Gatineau, PQ, New York City, Rotterdam, Netherlands

Technology	Description	Pros	Cons	Level of Technology Development
Electric Powered Vehicles (EPV)	• Run on electricity and use an electric motor powered by electricity from batteries or a fuel cell.	• Environmental benefits, especially if the electric charge is from a renewable energy source. • Potential to require less maintenance. • The electricity generated at these facilities can be used to fuel EPV that deliver organics to the facilities • Reduces GHG emissions (few GHG's emitted compared to diesel fueled vehicles). • Increased fuel economy in stop-and-go traffic. • Reduces impacts from idling through the use of the electric motor during stationary activities. • Reduced noise emissions. • Minor positive health impacts due to fewer particulates in the air and reduced GHG emissions.	• Low vehicle mileage range (reported to be about 60 kilometers). • Battery charging time (full recharge reported to be eight hours). • Batteries typically must be replaced every three to four years for large vehicles. • Cost of charging station infrastructure. • Electric vehicles may be more applicable for high operational uses (e.g., dense population, maximum distance range travelled) in order to justify the higher purchase price. • Need to use electric vehicles for high operational uses (e.g., dense population, maximum distance travelled) in order to achieve payback on the purchase price. • Existing collection system may need to be modified if electric vehicles are adopted which includes placement of charging stations and yard due to range. This may result in a reduced payload as the vehicle may take several hours to charge.	• Emerging (limited market viability and technology for waste collection vehicles is in pilot stage). • Truck manufacturers and waste facilities are evaluating the use of electric vehicles as an alternative to CNG and diesel powered vehicles. • Implemented in several major U.S. cities (i.e., Palo Alto, Los Angeles, Seattle, Chicago), as well as Rio de Janeiro, Brazil

Technology	Description	Pros	Cons	Level of Technology Development
Alternative Fuels for Collection Vehicles	• Compressed Natural Gas (CNG), biogas, biodiesel, or Liquefied Natural Gas (LNG), for waste management purposes, can replace the need for traditional petroleum-based fuels, such as diesel and gasoline. • Biodiesel and Hydrotreated Renewable Diesel (HRD) do not require a change to infrastructure or vehicles; however, biodiesel can only be used up to B20 (80per cent Petrodiesel and 20per cent Biodiesel) or both infrastructure and vehicles will fail.	• The use of CNG can create a closed-loop system by having a facility that generates CNG that can fuel collection vehicles to collect Green Bin organics and bring it back to the facility for processing. • CNG and LNG are typically less expensive and more environmentally friendly than extraction of fossil fuels such as diesel. • Natural gas fuel (CNG, LNG) can reduce GHG emissions from trucks by up to 30 per cent compared to petrodiesel and gasoline. • Minor positive health impacts due to fewer particulates in the air and reduced GHG emissions.	• CNG may not be available. • Cost to upfit existing garage and build infrastructure to accommodate CNG or LNG can be prohibitive (more than 10 years to pay off – and for 13per cent or so reduction.) • May be issues with biodiesel in cold months depending on the blend. • Alternate fuels not as readily available when compared to traditional fuels. • Biodiesel (depending on the blend) can be as expensive as diesel. • Biodiesel does produce some emissions but reduces air pollution emissions and carbon dioxide when used as a replacement to petrodiesel.	• Proven (biodiesel, RNG/CNG, renewable diesel) and emerging (LNG) depending on the fuel. • Implemented in several major Canadian cities (i.e., Toronto, London, Surrey and Victoria)

Collection Method Technologies - Alternative Options:

Technology	Description	Pros	Cons	Level of Technology Development
Automated Cart Collection	• Involves a specially designed truck that uses 'arms' to pick up carts, empty them and then return them to their original position as opposed to collection operators manually lifting and dumping carts or using semi-automated collection, whereby an operator places the cart on a lifter, which empties the cart. • Trucks can have "arms" to pick up carts at the side of the vehicle or an "arm" that empties carts into a container at the front of the truck, which is then emptied into the truck.	• Reduces the number of collection vehicles, which provides annual operating savings. • Allows for a more diverse workforce (e.g., physical ability, gender, age). • Curbside collection efficiency may be increased by eliminating the collection of multiple smaller containers (e.g., compared to using blue boxes or black boxes). The sizes of carts enable adequate space to accommodate collection needs from households. • Potential to provide residents with more capacity. • Potential to implement a cart-based pay as you throw system based on volume. • Improves customer satisfaction. Residents no longer need to purchase bags for collection. All materials can be placed loosely into carts thereby reducing the cost to the residents. • Carts also reduce the time and cost in dealing with issues related to bag collection on snow banks, as the automated arm has the ability to collect and return the carts to the top of a snow bank. • Being able to close lids on containers helps to contain material and minimize waste and recyclables blowing onto streets prior to service. • Operating efficiencies are gained by eliminating "thrower fatigue" as collection is mechanical. • Collection is at the front or the side of the collection vehicle, which is safer for the driver to observe the cart and surroundings. • Since the introduction of automated collection municipalities have reported a steady decrease in ergonomic related injuries. This validates the overall ergonomic injury risk reducing benefits of automated collection.	• Some municipalities report a significant increase in contamination, especially medical waste, by moving to a cart-based recycling program, since collection operators cannot see all the contents before dumping and therefore cannot enforce any by-law infractions. This reduces the value of the recyclable material, increasing the costs to sort the material at the MRF and reducing the revenue received for the material. • Delivering a new system of carts requires a significant onetime cost for carts, additional customer service staff, delivery and communications. • Bulky waste will need to be removed manually by collection staff and likely collected in another vehicle as the item may not be able to safely be placed into the collection vehicle. • Storage of the carts can be challenging in high-density areas and areas that do not have garages (or small garages that only fit a small vehicle). Additionally, some by-laws prohibit the storage of waste in front of a home. • Waste in carts may be difficult for rural households to bring to the end of the driveway as often garbage is driven in a vehicle. • A cart replacement system would need to be implemented and administered. • Support for bulky collection, enforcing potential organics/ material bans. • Infrastructure issues such as overhead wires can be an issue for collection. • Wind and snow can become a factor in either tipping the cart or making access difficult for the collection vehicle or uneven terrain.	• Proven (complies with best management practices as identified by Waste Diversion Ontario (WDO), Ontario Waste Management Association (OWMA) and Solid Waste Association of North America (SWANA). • Implemented in several major Canadian cities (i.e., Toronto, Peel, Guelph, and Gatineau)

Technology	Description	Pros	Cons	Level of Technology Development
Clear Bags	• In bag-based collection systems, clear bags can be regulated for garbage collection to encourage curbside waste diversion. • When clear garbage bags are required, items in the garbage that can be recycled or composted are visible which facilitates enforcement of the policy at the curb by the collector. • Rejected bags are left at the curb with a notification sticker educating the user about the diversion programs.	• Increases diversion. • Performance improvement in meeting diversion goals. • Potential to reduce contamination.	• Administrative requirements to administer program. • Enforcement requirements. • Potential increase in illegal dumping. • Initial public disapproval to change to clear bags.	• Proven • Implemented in several major Canadian municipalities (i.e., Halifax, Markham, Kawartha Lakes, Dufferin and West Grey)
Optibag Systems (i.e., Envac)	• Different coloured bags are used for the different waste streams. • Optibags are often used in conjunction with a vacuum/chute collection system. • The bags can be placed in one collection container and then sorted at an optical sorting processing facility. • The sorting facility is fully automated, requiring minimal labour. Every colour of bag is viewed as a “fraction” and the equipment can manage up to nine different “fractions”.	• Reduced impacts associated with co-collection of waste streams (e.g., financial, noise, GHG emissions) as fewer vehicles will collect from houses/buildings. • Greater convenience to users as all waste can go into plastic bags and be dropped off in one location which can lead to increased participation in diversion programs. • Reduction in number of collection vehicles will reduce GHG emissions from reduced transportation. • Increased convenience for separating waste streams can increase participation which will in turn, increase waste diverted from disposal. • Minimal to no health impacts from using multiple coloured bags.	• Potential for residents to contaminate the waste streams. • Extensive initial and ongoing promotion and education required for new and existing tenants, property managers/ superintendents and janitorial staff to reduce contamination. • Still requires residents to source separate their waste, which has been an ongoing challenge for multi-residential buildings. • Bagged recyclables would have to be opened before going through the waste diversion processing facilities. • Relies on residents consistently using specialized bags to maintain program. • Residents may not have space available to store multiple bags for the different streams. • More waste is created with each bag set out. • Bags that are required to be used would be for a single-use. May be issues with potential future bans on single-use plastics.	• Proven as this technology has been in place since 1990. • This technology is primarily located in Europe (i.e., Oslo, Norway). • There has been interest in North America; however, there are no optical sorting plants in Canada.

Technology	Description	Pros	Cons	Level of Technology Development
Radio Frequency Identification (RFID) Monitoring	• RFID chips are used for tracking waste performance, determining charges for waste management and improving waste collection services in the residential and Industrial, Commercial, and Institutional (IC&I) sectors. • This service requires collection vehicles outfitted with at least semi-automated collection technology, and wireless communication modules on both the vehicle and customer bins.	• Can be used with existing or new bins to optimize collection frequency thereby reducing the number of collection trips in a week. This reduces the number of trucks, fuel and labour as well as traffic congestion associated with standard waste collection routes and schedules. • Can provide data and statistics for each customer such as waste generation rates, weight of materials collected, waste densities and/or diversion rates. • Can increase transparency on billing since customer specific data is generated. • Allows municipalities to track which customers generate the most garbage and/or are not setting out expected quantities of recyclables and/or organics. This can allow municipalities to focus their educational efforts. • More efficient operations leads to improved service for customers. • Notifications that containers are full can lead to increased diversion efforts as customers may throw materials into undesired streams (contamination) if there is no space available in the correct stream.	• Installation / start-up costs can be high to implement the program and there may be on-going maintenance costs. Payback periods may be a few years depending on the technology used and capital expenses. • Reliance on external cloud-based platform to manage data and automatic collection routing. • Rate to maintain the utility may increase since the collection frequency and cost will decrease.	• Proven in many communities • Implemented in a few major Ontario cities (i.e., Peel, Markham)

Source Separated Organics Processing Technologies - Alternative Options:

Technology	Description	Pros	Cons	Level of Technology Development
Aerobic Composting (i.e., Aerated Static Pile, Enclosed Aerated Static Pile, Enclosed Channel)	• Naturally occurring process where organisms break down organic material in the presence of oxygen.	• Reduces GHG due to waste diversion. • Diverts organics from landfills and delays need to locate new landfill capacity. • Potential for material recovery. • Composting helps close the soil nutrient cycle if end product is land applied.	• Increased GHG to transfer materials to and from facility. • If facility not properly managed, potential for odour generation.	• Proven • Implemented in several major Canadian municipalities, (i.e., Durham, Waterloo, Calgary)
Anaerobic Digestion	• Biologically converts organic waste into biogas under anaerobic conditions (without oxygen). • Biogas can be used as fuel for boilers, be converted into electricity, and can be upgraded to Renewable Natural Gas (RNG).	• Significantly reduces GHG emissions. • Diverts organics from landfills and delays need to locate new landfill capacity. • Biogas is seen as a renewable energy, potential for material recovery. • Anaerobic digestion also helps close the soil nutrient cycle if end product (digestate) is land applied. • Renewable energy (RNG, electricity, heat) could displace some of the demand for fossil fuels currently being used in market.	• Time required to site and build a facility. • Maintenance requirements depending on the type of feedstock received. • Some feedstocks contain plastic contamination that needs to be removed prior to digestion. • Odour must be managed with odour control technologies. • Waste stream variability may create operational challenges. • Proximity to nearby users to utilize heat and biogas. • Ability to negotiate supply agreements for RNG with the gas utility. • Ability to supply electricity to the grid. Renewable electricity agreements are currently not an option in Ontario. • Energy pricing and volatility of energy markets. • Contribution to GHG's if biosolids disposed of in landfills.	• Proven • Implemented in several major Canadian municipalities, (i.e., Toronto, London, Ottawa, Surrey)

Technology	Description	Pros	Cons	Level of Technology Development
Mechanical/Chemical Processing	• Uses a combination of heat, alkali, and shear mixing to effectively breakdown biological material. • Recycling this product back into anaerobic digesters enhances the biogas production.	• Revenue from recovered resources (registered fertilizer). • Reduces GHG emissions by reducing requirement for fossil fuels. • Can be used to enhance digestion process and increase biogas production. • Completes the nutrient cycle in soil. • Creates a fertilizer from a waste product.	• If facility is not properly managed, potential for odour issues. • Process has been more commonly used with wastewater treatment facilities, which have a more uniform feedstock, when compared to household organics.	• Proven in wastewater treatment facilities and emerging in applications using food waste. • Implemented in a few Canadian municipalities (i.e., Guelph, Banff)
Biological Processing (i.e., vermicomposting)	• Uses insects or worms to decompose organic material into compost (fertilizer).	• Production of a valuable by-product which could be sold with appropriate approvals in place. • Potential option for on-site organics processing of institutions and commercial establishments (e.g., restaurants, schools). • Increased organics diversion reduces landfill airspace consumption rate and extends the life of landfill. • Reduces methane emissions from organics managed in landfills. • For on-site systems, reduces GHG emissions as no collection vehicle is required.	• If not properly managed, potential for odour issues. • Current applications require uniform organic waste feedstock such as manure or food waste. Process works for leaf waste but not wood wastes.	• Emerging. • Implemented in limited Canadian municipalities (i.e., North Rockies, BC)

Technology	Description	Pros	Cons	Level of Technology Development
Co-digestion of Sewage and Organics at Wastewater Treatment Plants	• Organic food waste from Green Bin program is mixed with municipal sewage sludge, which are then anaerobically digested to create biogas.	• Diverts organics from landfills and reduces GHG emissions. • Increase in diversion reduces landfill airspace consumption rate and extends life of landfill. • Process could generate additional renewable energy, with the addition of household organics. • Reduced energy costs for wastewater treatment operations if the biogas is used internally. • It may be more lucrative to export it as RNG. • Renewable energy displaces fossil fuels currently being used in market.	• Emerging technology for use with household organics. • Some feedstocks (from food industry or municipal programs that accept plastics for example) can contain plastic contamination that needs to be removed prior to digestion. • Odour must be managed with odour control technologies. • Energy pricing and volatility of energy markets. • Contribution to GHGs if biosolids disposed of in landfill.	• Proven technology for sewage. Emerging for managing sewage and household organics jointly. • Implemented in limited Canadian municipalities (i.e., Stratford)

Recovery Technologies - Alternative Options:

Technology	Description	Pros	Cons	Level of Technology Development
Mechanical and Biological Treatment with Refuse Derived Fuels (RDF)	• Uses processing equipment and labour to sort mixed waste to remove recyclable items for market and possibly recover organic material for processing, resulting in a residual waste stream that is then further processed into an RDF or landfilled. • Typical outputs and market uses are RDFs, biogas, plastics, metals, minerals and inert materials (e.g., stones, glass, etc.), process water and effluent. • RDFs are produced by shredding and/or pelletizing select waste and by-product materials with recoverable calorific value into a homogenous product which can be used as a fuel source.	• Captures organic waste and recyclables that would have otherwise been sent to landfill. • Benefits relate to higher waste capacity of the landfill and delayed need to locate new landfill capacity. • Produces a fuel and recovers recyclable material from residual waste. • Alternative to recover materials where source separation is not feasible or less successful (e.g., high density residential). • Reduction in GHG emissions by diversion from landfill. • Renewable resources could displace need for fossil fuels currently being used in market. • Significant reduction in CO_2 emissions.	• Potential for operational and maintenance issues associated with processing mixed waste. • As approach is more complex than typical waste management processing/transfer facilities, time for Ministry of the Environment, Conservation and Parks (MECP) Environmental Compliance Approval process may be longer than typical. • Availability of markets for RDF.	• Proven. • Implemented in limited Canadian municipalities (i.e., Halifax RM), as well as Korea, Spain, Eastern Europe and UK.

Technology	Description	Pros	Cons	Level of Technology Development
Mixed Waste Processing (MWP)	• MWP starts with unsorted and unseparated solid waste from residential and/or commercial collection vehicles being off-loaded onto a tipping floor. • Materials are first sorted on the floor using manual labour (if appropriate) and mobile equipment. • Materials are then processed through multi-stage screens to separate fibre, plastic, metal and glass containers, and small contaminants. • This is usually accomplished through the use of mechanical, optical or pneumatic screening equipment to separate materials into size classifications and/or light versus heavier materials. The remaining material is shipped to a local landfill or another appropriate waste processing/conversion facility.	• Reduces organic waste going to landfill. • Benefits relate to higher waste capacity of the landfill and delayed need to locate new landfill capacity. • Potential to produce a fuel and recover recyclable material from mixed waste. • Alternative to recover materials where source separation is not feasible or less successful (e.g., high density residential). • Reduction in GHG emissions with a reduction of organics disposed of in landfill. • Provides an opportunity to divert waste that would otherwise be disposed. • Reduction of landfill airspace used for disposal.	• Potential for operational and maintenance issues associated with processing mixed waste. • As approach is more complex than typical waste management processing/transfer facilities, time for approval process may be longer than typical. • Lower quality of recovered material compared to source separated recycling recovery. • Availability of markets for extracted materials may be limited given the 'dirty' nature of the process. • Greater contamination of materials can mean less marketable products, and result in material being disposed of instead of recycled anyways. • Increased organics management costs.	• Proven. • Implemented in a few United States (i.e., Alabama, California)

Technology	Description	Pros	Cons	Level of Technology Development
Mass Burn Incineration (e.g., Waste-to-Energy (WTE), Energy from Waste (EFW), Advanced Thermal Recycling (ATR))	• Uses traditional combustion methods to burn waste in order to generate energy in the form of electricity or heat. • The complete oxidation of a fuel at high temperatures is referred to as direct combustion (also referred to as waste-to-energy (WTE), energy from waste (EFW), or advanced thermal recycling (ATR)). • The mass incineration occurs under controlled conditions and yields a significant net energy production. • The end result of the combustion process also produces fly ash and bottom ash. • Ash can be disposed of at a regular landfill and fly ash, typically being hazardous due to concentrations of heavy metals and other pollutants, is usually disposed of at a hazardous waste landfill.	• Reduces landfill airspace consumption rate and extends the life of landfill. • Reduced land requirements compared to landfill. • Potential for net GHG emissions reductions due to avoided GHG emissions associated with the generation of electricity which offsets (avoids) emissions from electricity generation sources. • Recovery of energy and materials. • Renewable resource could displace fossil fuels currently being used in market.	• Must comply with stringent environmental monitoring and mitigation plans, regulations, standards and guidelines. • Reliability of technology, maintaining consistent facility operation. • Public opposition of incineration facilities is common. • Lengthy and uncertain approvals process. • Requires stable energy market. • Hazardous waste and fly ash disposal costs. • Typically requires a put or pay agreement with the municipality on the hook to meet these requirements.	• Proven. • Implemented worldwide, and in several Canadian municipalities (i.e., Durham-York, Emerald EFW, Brampton, Metro Vancouver WTE, Wainwright, AB EFW, Charlottetown, PEI, Quebec City).

Technology	Description	Pros	Cons	Level of Technology Development
Gasification	• Gasification involves converting solid or liquid carbon-based wastes into gas form (i.e., syngas) at high temperature without combustion. • Technology types include - updraft fixed bed; downdraft fixed bed; bubbling fluidized bed; circulating fluidized bed; entrained flow.	• Benefits relate to higher waste capacity of the landfill and delayed need to locate new landfill capacity. • Reduced land requirements/ airspace compared to landfill. • The process generates biofuels, displacing some need for fossil fuels.	• Must comply with stringent environmental monitoring and mitigation plans, regulations, standards and guidelines. • Reliability of technology, Plasma gasification had been piloted unsuccessfully by a private company in Ottawa. • Lengthy and uncertain approvals process. • Feedstock requirements including caloric value of the waste, moisture content, homogeneous nature, can be difficult to provide and maintain. • Process generates wastewater from the syngas clean-up and air pollution which need to be managed. • Air pollution control systems must be used to ensure gasification system complies with emission and environmental requirements.	• Emerging for municipal solid waste, proven for biomass (i.e., organic agricultural and industrial wastes, sewage sludge, vegetation waste). • Implemented in limited locations (i.e., Edmonton, Japan).
Pyrolysis	• Pyrolysis involves heating municipal solid waste in an oxygen-free environment to produce a combustible gaseous or liquid product and a carbon char residue. • Technology types include - auger-type; rotary kiln; updraft and downdraft fixed bed; bubbling and circulating fluidized bed.	• Benefits relate to higher waste capacity of the landfill and delayed need to locate new landfill capacity. • Reduced land requirements compared to landfill. • The process generates fuels, displacing some need for fossil fuels.	• Must comply with stringent environmental monitoring and mitigation plans, regulations, standards and guidelines. • Reliability of technology is still being tested, and is not yet commercially available. • Lengthy and uncertain approvals process. • Process generates wastewater from the syngas clean-up and air pollution which need to be managed. • Air pollution control systems must be used to ensure pyrolysis system complies with emission and environmental requirements.	• Pilot scale in some facilities in North America.

Technology	Description	Pros	Cons	Level of Technology Development
Waste to Liquid Fuels	• Generation of liquid fuels from biomass (carbon-rich wastes) and organic wastes by undergoing three stages of processing. • Non-recyclable waste can be processed into Refuse Derived Fuels (RDF). Using gasification, a thermal conversion process is used to generate syngas from the RDF. • One of four types of chemical catalyst processes can be used to synthesize the syngas into a liquid fuel. • These processes include Fischer-Tropsch synthesis; methanol synthesis; mixed alcohol synthesis; syngas fermentation.	• Benefits relate to extended waste capacity of the landfill and delayed need to locate new landfill capacity. • Reduced land requirements compared to landfill. • Less organic material disposed in landfills. • Renewed resource could displace fossil fuels currently being used in market.	• Must comply with stringent environmental monitoring and mitigation plans, regulations, standards and guidelines. • Reliability of technology is still being tested. • Lengthy and uncertain approvals process. • Odour management likely necessary.	• Pilot • Implemented in limited locations (i.e., Edmonton, and plans to build a biomenthanation plant in Montreal).
Hydrolysis	• Hydrolysis is a chemical reaction in which the organic fraction of the waste material is used to synthesize glucose and/or other simple sugars that can then be fermented or digested to manufacture other products (e.g., ethanol).	• Higher waste capacity of the landfill and delayed need to locate new landfill capacity. • Revenue opportunity from production of liquid fuels. • Generates biogas or RNG, displacing some need for fossil fuels.	• Reliability of technology for municipal solid waste is still being tested, and is not yet commercially available. • Lengthy and uncertain approvals process. • Odour management likely necessary.	• Pilot for MSW, emerging for modifying wood fibres. • Implemented in Oslo, Norway and Europe.

Technology	Description	Pros	Cons	Level of Technology Development
Landfill Mining	• Involves excavating previously landfilled waste to recover soils, gain landfill capacity, redevelop the property and/or mitigate environmental impacts. • Landfill reclamation can be used following landfill mining to re-engineer the landfill site with improved compaction and cover placement.	• Potential remediation of groundwater impacts (e.g., from unlined sites or sites with existing groundwater impacts). • Reduction of potential environmental liabilities as a risk management strategy, for example, improperly disposed of wastes or an unlined portion of a landfill. • Gain landfill capacity. • Opportunity to address soil shortages for future landfill operations. • Reclamation of other materials, such as tires for internal road construction. • Potential to improve environmental controls if landfill reclamation is sought.	• Health and safety concerns to workers from exposure to landfill gas, unknown waste materials and/or leachate. • Potential for increased nuisances (odour, litter, dust) for site neighbours during mining process. • Unknown waste conditions may result in a low rate of material recovery (i.e., mining cost exceeds value of recovered airspace or material). Recovery rates are dependent on a number of parameters (e.g., waste density, soil type, filling practices). • Presence of certain materials (e.g., wires and industrial fabrics) may slow down reclamation process. • Given the requirement to expose and handle previously buried waste, a short-term increase in release of GHG at the landfill mining area is likely. • A short-term increase in GHG emissions are also expected from more vehicular activity during the mining period. • Creates a risk of contaminants (e.g., fly plastics, leachate spill), escaping to the environment.	• Proven. • Implemented in limited Canadian municipalities (i.e., Barrie, Durham, Ottawa).

Landfill Disposal Technologies - Alternative Options:

Technology	Description	Pros	Cons	Level of Technology Development
Bioreactor	• Bioreactors are designed to enhance and accelerate the degradation of landfilled materials through biological processes (bacteria). Leachate is typically collected and recirculated back into the landfill. • Bioreactors can be designed as aerobic reactors (which rely on oxygen to sustain bacteria), anaerobic reactors (which rely on a low oxygen environment to sustain bacteria), and hybrid reactors which employ both types of bacteria.	• Decomposition and waste stabilization occurs in a shorter period of time compared to traditional landfills. • Large amount of organics can be processed at low cost. • For anaerobic bioreactors, landfill gas (LFG) is generated at a higher rate and at an earlier stage compared to traditional landfills. This increases the potential for gas utilization and minimizes risk and cost of maintaining and expanding system over a longer time period. • Recirculation stabilizes leachate faster, reducing treatment and disposal risks and costs. • Shorter contaminating lifespan has potential to reduce closure and post-closure care and costs. • For anaerobic bioreactors potential to generate energy if gas is collected. • Recovery of airspace due to a reduction in volume of the waste pile. • Revenue from recovered resources (compost or refuse derived fuel). • Reduces GHG emissions from rapid generation and collection of landfill gas for anaerobic bioreactors. • A potential increase or reduction in GHG if LFG for generating power, depending on the type of bioreactor used.	• Potential for higher odours compared to traditional landfills. • Physical instability of waste mass due to higher moisture content required in waste. • Potential for environmental impacts if pumping and collections systems fail, such as increased gas emissions and leachate management due to recirculation. • Environmental impacts associated with traditional landfills, such as seeps.	• Demonstration/pilot • Implemented in limited locations (i.e., Ottawa, North Carolina).

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Biocell	• Landfill biocell combines a number of technologies including anaerobic bioreactor, air injection, leachate recirculation system, LFG recovery and utilization system, air pumping equipment, computerized monitoring system, and base and surface liners. • Biocells differ from bioreactors in that there is always both anaerobic and aerobic phases, and air space is recovered through mining of residuals. • A biocell consists of the following components: composite liner, leachate collection and removal system, liquid injection system, gas collection and air injection system, intermediate covers and final cover.	• Decomposition and waste stabilization occurs in a shorter period of time than traditional landfills. • Large amount of organics can be processed at once. • LFG is generated at a higher rate and at an earlier stage. This increases the potential for gas utilization and minimizes risk and cost of maintaining and expanding system over a longer time period. • Recirculation stabilizes leachate faster, reducing treatment and disposal risks and costs. • Shorter contaminating lifespan has potential to reduce closure and post-closure care and costs. • Potential to generate energy if gas is collected during anaerobic stage. • Recovery of airspace. • Revenue from recovered resources (compost or refuse derived fuel).	• Requires municipal solid waste with high organic content. • Potential for adverse impacts if pumping and collections systems fail, such as increased odours and increased gas emissions. • Additional technologies needed to separate out residual materials recovered during final phase. • Physical instability of waste mass. • Relatively new technology; quality of final residual products unknown.	• Recommended for new sites in the design phase as specific infrastructure is more easily integrated during early stages of site development. Requires LFG systems that can accommodate high LFG generation rates and oxygen induced conditions. • Limited number of projects in North America (i.e., Calgary)
Landfill Optimization Approaches	• Landfill optimization consists of making changes to an existing landfill to enhance the operations of the landfill, review landfill equipment for optimizations and improvements, adjust to a changing climate, and to increase the volume of waste that can be deposited through changes in the configuration of the mound.	• Gain higher waste capacity of the landfill and delayed need to locate new landfill capacity. • Ability to improve operations to adapt to a changing climate.	• Healthy and safety concerns from exposure to landfill gas, unknown waste materials and/or leachate if old areas of the landfill are reopened and exposed. • Potential for marginal increased nuisances (odour, litter, dust) for site neighbours due to higher volume of waste landfilled. • EA process for landfill expansion is complex and takes many years until approval is received.	• Proven. • Implemented in limited Canadian municipalities (i.e., Halton, Fredericton).