Pathway Study on Solid Waste, Wastewater and Other Waste Sources in Ottawa

Presented to:
The City of Ottawa
110 Laurier Ave W
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In relation to:
The City of Ottawa's Energy Evolution Strategy (Phase 2)

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Executive Summary

There are significant opportunities to advance both energy and climate change objectives by integrating their consideration in strategic investment and policy choices in the waste management sector. Realizing these opportunities requires incorporating energy recovery and GHG minimization in capital investments and long term planning, as well as coordination and collaboration across public/private, urban/rural, and other subsector and jurisdictional boundaries that might otherwise impede the identification and implementation of the best strategies.

As is currently being demonstrated in Ottawa, solid and liquid wastes can be used to generate both fuel and electricity. The combustion of methane (biogas), for example, is now commonplace at a number of sites across the city, including various private and municipal landfills, the City's wastewater treatment plant, and from small biogas generators located on farming operations within the City boundary. Although the quantity of renewable energy produced from these operations is significant at the individual facility or site level, and the rationale for pursuing many of the projects noted above has often been an economic one due to the associated savings in energy and operational costs and/or the potential to generate revenue from the sale of renewable energy. As such, waste-based energy projects in Ottawa currently only represent or contribute a small fraction of the total amount of energy consumed in the city.

The analysis presented in this Pathway Study suggests there is potential for increasing the supply of waste-based energy. Depending on the extent to which efficiency gains reduce total energy consumption in the city, waste-based energy could provide five to ten percent of Ottawa's total energy needs in the long term. However, the financial and other benefits delivered by these energy technologies will continue to be of primary importance to policy makers and investors and are therefore identified as important considerations in the assessment of this pathway.

In the case of landfill gas (LFG) and methane from wastewater treatment, for example, these emissions can also represent a nuisance (e.g., odor) or a hazard subject to various regulations in addition to being a significant source of fugitive greenhouse gas emissions. Collecting and burning emissions from waste operations has the advantage of addressing these types of environmental, health and safety concerns as well as being a viable approach to generate renewable energy.

While flaring emissions from waste processes is typically sufficient as an approach to address nuisances and hazards (and historically was the dominant practice), the large biogas generating facilities in Ottawa (landfills and wastewater treatment plant) harness this this resource to produce electricity, thereby achieving additional financial and environmental benefits. The carbon content of wastewater, agricultural and the organic component of municipal solid waste is considered to be part of the natural carbon cycle (i.e. biogenic). The waste-based energy is therefore considered carbon-free, and to the extent it displaces fossil fuel consumption, it provides additional air quality benefits and greenhouse gas reductions.[1]

Waste and wastewater management are significant activities in Ottawa, and while energy and emission considerations are important to waste management strategies, there are a myriad of other economic, environmental and social factors that come into play in the formulation of waste

[1] Not all waste-based energy is carbon-free. Burning plastics, for example, releases fossil-based CO_2 to the atmosphere and displacing MSW from a landfill to an incinerator results in significant carbon emissions that would otherwise have been sequestered in the landfill.

management policies and business strategies. Energy recovery strategies that align with waste management priorities and that generate financial savings and revenues to offset waste management costs hold the greatest potential for contributing to Ottawa's energy future. This Pathway Study explores potential uptake scenarios for various waste-based energy projects in Ottawa and their estimated contribution towards the City's energy and emissions reduction targets, while identifying and assessing other, non-energy drivers, constraints and considerations where relevant[2].

Strategies for organics are a central issue in the consideration of the potential for GHG reductions from waste management. Organic wastes are the source of current greenhouse gas emissions from the waste sector, and these are the wastes that can be managed in ways that both eliminate those emissions and generate carbon-free and renewable biogas that can offset fossil fuel emissions. As the various stakeholders involved in the management of organic waste streams in Ottawa prepare for the next generation of climate policies and technological progress, it will be especially important to explore opportunities for collaboration and investment strategies that maximize flexibility and adaptability to a rapidly changing environment.

[2] Biogas opportunities related to ROPEC are being examined more thoroughly through a separate feasibility study and will therefore only be examined "at a high level" in this pathway. Any information, analyses and recommendations that emerge from the upcoming feasibility study will provide a more detailed guide for future decision making and project planning in this particular area of municipal operations

Section 1: Present Assessment of Waste Pathway

Pathway Description

The purpose of this paper is to identify and provide some preliminary analysis of the technologies, approaches, and opportunities for generating greater amounts of energy from municipal solid waste, wastewater, and other sources of waste in the community (e.g. agricultural, forestry, ICI waste, etc.).[3] This includes estimating their ability to generate renewable energy and/or reduce consumption of fossil fuels.

There are several thermal, chemical and biological pathways for extracting energy from waste, as illustrated in Figure 1.[4] However, variations in the heterogeneity and moisture content of the wastes, combined with the limitations of currently available technology, narrow the range of pathways of practical relevance to Ottawa's waste management planning to landfill gas recovery, anaerobic digestion (AD), combustion, and gasification.[5] These are the waste management practices and technology pathways that are examined in this Pathway Study.

From the perspective of energy recovery, it is important to distinguish between inorganic and organic waste (biomass). All municipal waste, including plastics and other inorganic synthetic materials, contains energy that can be recovered through combustion, but it is the organic portion of municipal wastes that has the potential to yield carbon-free energy.[6] Organic waste is waste from living systems -- food, paper products, yard and leaf waste, crop wastes, manure residues, wastewater and biosolids. Depending on how they are processed, these carbonaceous materials can be used to make gaseous or liquid fuels, as shown in Figure 2. Provided these materials are being generated with agricultural or forestry practices that are carbon-neutral, they are considered carbon-free substitutes for fossil fuels because their carbon is biogenic; the carbon dioxide they emit when burned would have been emitted when they died, through natural decomposition, albeit at a slower rate. As noted above, it is the combustion, anaerobic digestion and gasification pathways that are considered further in this report.

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[3] Consideration has also been given to the issue of snow removal in Ottawa, which is included in Appendix 1.

[4] For reviews of waste-to-energy technologies, see:
World Energy Council (2016). "Waste to Energy 2016", accessed at https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf.
DEFRA (2013). "Advanced Biological Treatment of Municipal Solid Waste", February 2013. UK Department of Food, Energy and Rural Affairs. Accessed at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/221037/pb13887-advanced-biological-treatment-waste.pdf
Abboud, S. et. al. (2010). "Potential Production of Methane from Canadian Wastes", Alberta Innovates, October 2010. Accessed at: https://www.researchgate.net/publication/268341359_Potential_Production_of_Methane_from_Canadian_Wastes
Environment Canada (2013). "Technical Document on Municipal Solid Waste Organics Processing". Accessed at https://www.ec.gc.ca/gdd-mw/3E8CF6C7-F214-4BA2-A1A3-163978EE9D6E/13-047-ID-458-PDF_accessible_ANG_R2-reduced%20size.pdf.

[5] Abboud S., Scorfield, B. 2011. "Potential Production of Renewable Natural Gas in Ontario", Alberta Innovates Technology Futures. Accessed via Ontario Energy Board at http://www.rds.oeb.ca/HPECMWebDrawer/Record?q=CaseNumber:EB-2011-0242&sortBy=recRegisteredOn-&pageSize=400. Filed on 2011-09-30, Case EB-2011-0242, 2011-0283, Exhibit B Tab 1 Appendix 1.

[6] Organic waste collected in the City's Green Bin program is managed by a private contractor at their private facility, while any residual residential organic waste is landfilled. Disposition of organic waste from the ICI sector is not the responsibility of the City; we assume it is landfilled.

Figure 1: Waste-to-energy pathways.[7]

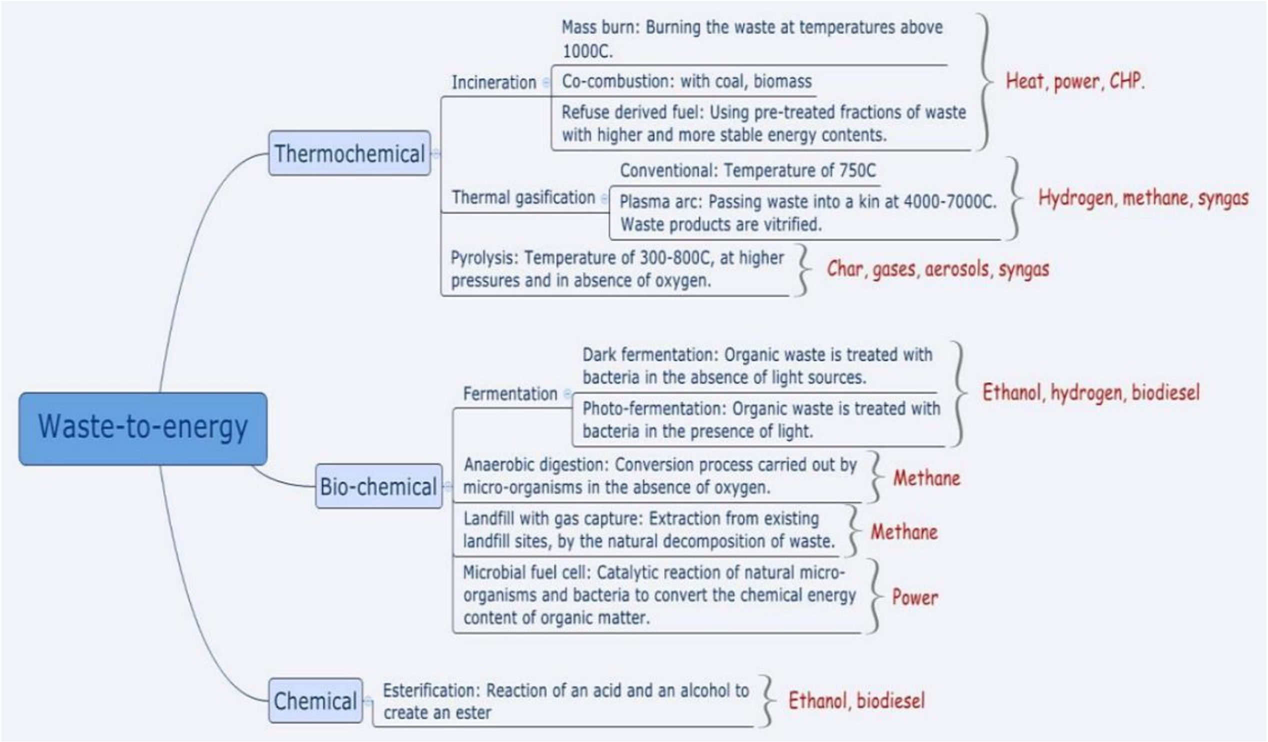
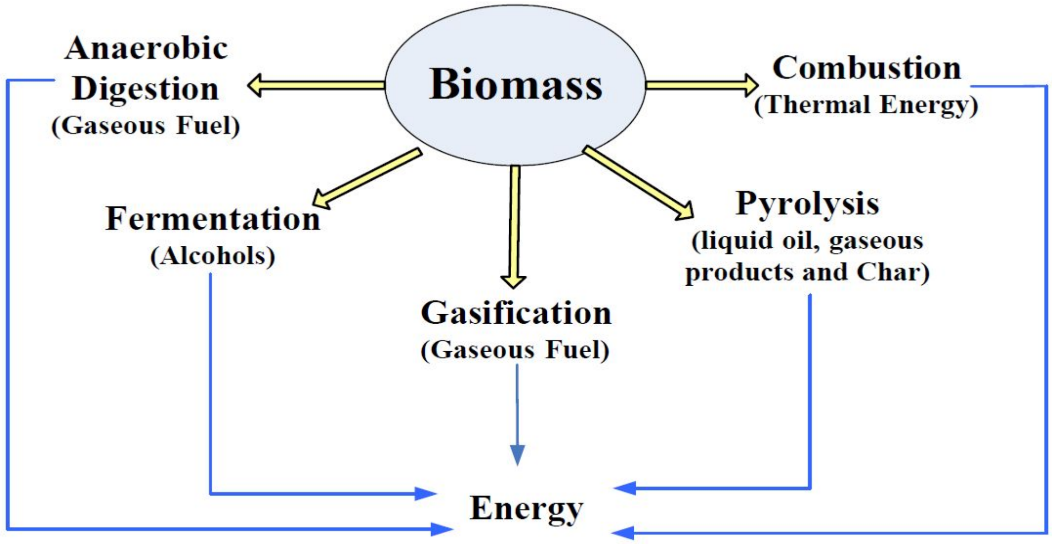


Figure 2: Biomass-energy conversion pathways.[8]



[7] World Energy Council (2016). "Waste to Energy 2016", accessed at https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Waste_to_Energy_2016.pdf

[8] Abboud, S. et. al. (2010). "Potential Production of Methane from Canadian Wastes", Alberta Innovates, October 2010. Accessed at: https://www.researchgate.net/publication/268341359_Potential_Production_of_Methane_from_Canadian_Wastes

Pathway Boundaries

This paper examines the potential of various waste management approaches to contribute to the City's short- and long-term energy and GHG reduction targets, including Ottawa's Council-approved target to reduce community-wide emissions by 80 percent below 2012 levels by 2050. The primary focus is on solid waste generated by households and firms in Ottawa[9], but consideration is also given to the potential role of agricultural and forestry wastes generated within the City of Ottawa.

In this report, the term Municipal Solid Waste includes waste from residential sources which is managed both on and off-site, and waste from IC&I (Industrial, Commercial and Institutional) sources which is managed off-site. In Ontario, the management of the residential portion of MSW is carried out by local authorities, whereas members of the IC&I sectors (Industrial, commercial and institutional) are individually responsible for complying with provincial regulations. While the term "municipal solid waste" is sometimes used to refer only to the waste for which the municipality is responsible, the broader definition used here is consistent with definitions used by Statistics Canada and provincial governments, including the Ontario Resource and Productivity Authority. This broader definition also ensures that all stakeholders are considered in the assessment of technologies and strategies for the future management of the city's waste streams.

As noted above, opportunities for waste-based energy projects at the City's Robert O. Pickard Environmental Centre will be examined more thoroughly in a separate and forthcoming feasibility study by the city, and so are considered only briefly in this report.

Background Information

Municipal Solid Waste (including Residential, ICI and C&D)[10]

For the residential component of MSW, including both residential and multi-family households, Table 1 provides an estimated breakdown of generation and disposition based on the database of the Ontario Resource Productivity and Recovery Authority (RPRA)[11] and a series of waste audits undertaken between 2014 and 2015.[12]

The RPRA database provides information on total residential waste generated and on disposition to landfills, diverted recyclables, and diverted organics. Separate RPRA tables provide the composition of the diverted waste by material categories: household organics, yard waste, various paper products, various plastics, aluminum, steel, scrap metal, glass, etc. For the composition of generated waste, the starting point was a provincial breakdown developed for the OWMA,[13] adjusted to make

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[9] Note that responsibility for waste management is split; the City manages residential waste, while ICI waste is regulated directly by the province.

[10] In Ontario, the management of the residential portion of MSW is carried out by local authorities, whereas members of the IC&I sectors (Industrial, commercial and institutional) are individually responsible for complying with provincial regulations. In addition to residential waste, the City of Ottawa waste management operations include the City's own waste as well as a very limited amount of waste from the ICI sector.

[11] Ontario Resource Productivity and Recovery Authority data call: https://rpra.ca/datacall/about-the-datacall/

[12] AET Group 2016. "2014/2015 Seasonal Multi-Family Waste Composition Study Summary Report" and "2014/2015 Seasonal Single Family Residential Curbside Waste Composition Study", prepared for the City of Ottawa, AET Group, August 2016.

[13] Torrie R. et. al., (2015). "Greenhouse Gas Emissions and the Ontario Waste Management Industry", report for Ontario Waste Management Association. Access at: https://www.researchgate.net/publication/300485656_Greenhouse_Gas_Emissions_and_the_Ontario_Waste_Management_Industry.

the material shares consistent with the AET audits for single and multi-family households. The per capita waste generation reflected in the AET audit data agrees well with the sum of the per capita data for disposal and diverted materials in the RPRA database and is consistent with the City of Ottawa data for single family households.

Using these sources, total residential MSW generated in 2015 was estimated to be 331,000 tonnes, of which 150,000 tonnes were diverted from landfill via the City's Blue Box, Black Box, and Green Bin curbside residential collection programs.[14]

The table shows the total potentially divertible material, as well as an estimate of the waste incorrectly put out in the wrong container according to the audit data. It bears emphasizing that there is no central, authoritative, internally consistent, and comprehensive database covering waste generation and management in Ottawa, or more generally in Ontario. The construction of the profile summarized in Table 1 is hampered by data gaps and inconsistencies that characterize the waste sector, and particularly the private sector segment. Nonetheless, Table 1 draws on the best information available and is sufficient for supporting an assessment of the "big picture" and for identifying strategic directions.

Table 1: Summary of residential waste generation and disposal in 2015 in Ottawa (tonnes).[15]

Put out as: → Waste type: ↓	Garbage	Blue Box	Black Box	Green Bin	Leaf/Yard	Total	Diverted
Glass, metal, plastic	8,852	**16,969**	410	-	-	**26,231**	16,969
Fibre (paper, cardboard)	11,435	847	42,327	1,019	-	**55,628**	43,346
Organics (food, yard)	64,877	642	496	**36,982**	**52,707**	**155,705**	89,690
Non-divertible	87,159	3,068	820	291	-	**91,338**	
Total	**172,324**	**21,611**	**44,198**	**38,438**	**52,707**	**330,772**	150,004

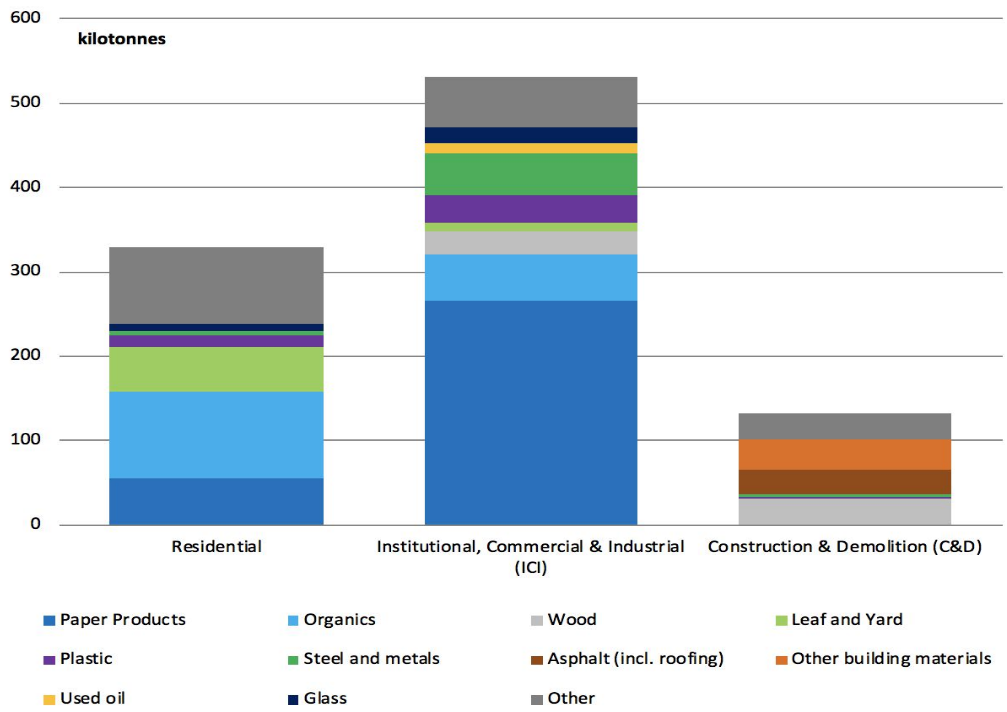
The residential waste stream accounts for less than half of the solid waste generated in Ottawa, with the balance generated by institutions, commercial and industrial establishments (the "ICI" sector) and by construction and demolition activities ("C&D" sector). Unlike the residential waste stream, the management of which is a City responsibility, ICI and C&D waste is provincially regulated and

[14] There are small inconsistencies between and within the databases used here, but none large enough to have any impact on the analysis and results of this pathway analysis. For example, the sum of the totals in the RPRA datacall tables for diverted materials is not in exact agreement with the total for diverted material in the waste diversion table. There are also small differences in per capita numbers due to differences in the population reported for the RPRA database and the Census population of Ottawa used for per capita calculations in this report.

[15] The column numbers in this table are the City of Ottawa from the RPRA database.

managed by the private sector[16], and data for this waste is less comprehensive or regularly published. A study completed for the City of Ottawa estimated total generation of ICI and C&D waste in 2005 as 730,000 tonnes, and also provided a detailed analysis of its sources and composition.[17] Statistics Canada data indicates that the absolute level of non-residential waste in Ontario declined at an average rate of 0.87% per year between 2006 and 2016.[18] This rate has been applied to the 2005-2015 period in order to arrive at an estimate of total ICI and C&D waste in Ottawa in 2015 of 660 kilotonnes.[19] Although it is likely that there has also been a shift in the relative shares of different types of ICI and C&D waste, the 2005 composition analysis has been applied in developing a profile of 2015 ICI and C&D waste generation. The consolidated inventory of residential, ICI and C&D waste is summarized in Table 2 and Figure 3.

Figure 3. Estimated waste generation in Ottawa for 2015, by source and type



[16] One consequence of this divided responsibility is that there are two, largely separate waste management industries, one that is municipally owned and operated and a second, private sector industry that collects and manages ICI and C&D waste. Most municipalities, including Ottawa, do not therefore manage or accept a significant amount of ICI waste, but the City of Markham has demonstrated the feasibility of greater municipal involvement in organics waste management from the ICI sector, and this is a direction that City of Ottawa may wish to explore.

[17] City of Ottawa, "IC&I Waste Characterization Report", IC&I 3Rs Strategy Project, prepared for Dept. of Public Works and Services by Genivar, Kelleher Environmental and Jacques Whitford, June 2007.

[18] Statistics Canada. Table 38-10-0032-01. Disposal of waste, by source.

[19] The generation of ICI waste includes estimates of ICI waste not captured by the Statistics Canada survey, which does not include or undercounts ICI waste by a large margin for some waste types, including recycled cardboard and mixed paper, ICI food waste, recycled and reused glass bottles, recycled motor oil, and tires. See Torrie et. al. (2015), op cit.

Table 2: Estimated municipal waste generated in Ottawa in 2015 (kilotonnes).

Waste Type	Residential	Institutional, Commercial & Industrial (ICI)	Construction & Demolition (C&D)	Total	Share of total
Organics	103	54	-	157	16%
Leaf and Yard	53	9	-	62	6%
Paper Products	56	266	-	321	32%
Wood	-	28	31	59	6%
Plastic	14	34	3	51	5%
Steel and metals	4	49	4	57	6%
Asphalt (incl. roofing)	-	-	29	29	3%
Other building materials	-	-	36	36	4%
Used oil	-	11	-	11	1%
Glass	9	20	0	29	3%
Other	91	60	31	182	18%
Totals	329	532	133	**993**	100%
Share of total	33%	54%	13%	100%	

Wastewater and Biosolids

The City's wastewater treatment plant, the Robert O. Pickard Environmental Centre, processes 470 million litres of wastewater per day (over 170 billion litres of wastewater per year), a highly diluted solution (99.99% water) containing suspended and dissolved organic waste and other contaminants that have been flushed and drained into sanitary and combined sewage collection systems. The multi-stage wastewater treatment process includes the anaerobic digestion of sludge that generates about 45,000 tonnes of dewatered sludge (biosolids) and 14 million m^3 of biogas containing about 60% methane. Most of the biogas is burned on site in boilers and cogeneration engines that together provide more than half the facility's fuel and electricity requirements. In 2016, the cogeneration units and boilers used 80% of the digester gas generated, and the remaining 20% was flared. Most of the biosolids, which are rich in nutrients, are applied to agricultural lands in Ottawa and Eastern Ontario.

The sludge output of the ROPEC facility is mostly human waste and its volume is directly correlated with the city's population. After exiting the digester, the dewatered, nutrient-rich, residual sludge is used as a fertilizer on farms throughout the region, thus creating an additional GHG benefit but offsetting the need for fossil fuel-intensive chemical fertilizers. Given projected population growth in

Ottawa, the volume is expected to grow by 25% or more by 2040, as will the methane generated in its treatment.

The City of Ottawa is in the early stages of a comprehensive review of the opportunities and the options for the future production and use of biogas from its wastewater treatment operations, including the implications to the quantity and quality (Class A vs. Class B) of biosolids. The review will include consideration of incorporating feedstocks from other organic waste streams in the community, including FOG wastes (fats, oils and greases from restaurants), source separated organics, and manure residues, and whether the potential supply of such feedstocks might justify the construction of new digester capacity. It will also consider the plant configuration and the potential for importing raw biogas from off site.

The energy recovered from wastewater treatment can and already does represent an important source of energy for the City's ROPEC facility; this energy is generated on-site, it reduces fossil fuel consumption (particularly in the boilers), and has enabled the facility to achieve considerable operational cost savings. At the individual site level, net energy self-sufficiency or near self-sufficiency for this facility might be possible with advanced technologies for efficiency and expanded biogas production. Relative to the total amount of fuel and electricity consumed in Ottawa, however, the potential energy contribution from wastewater and biosolids alone is relatively small. The co-processing and commingling of diverse organic waste streams is an emerging trend for increasing biogas generation while achieving other efficiencies and benefits.[20] As noted above, this is an area that will be explored more thoroughly in the forthcoming feasibility study.

Agricultural Wastes

The percent of the total provincial crop residue generated in Ottawa and in the Eastern Ontario Census Agricultural Region was estimated on the assumption that it would be equal to the corresponding share of total provincial crop production. Table 3 shows the Ottawa and Eastern Ontario[21] shares of total Ontario production for the three field grains that constitute most of the crop residue biomass feedstock identified in a study of Ontario's renewable natural gas (RNG) potential.[22] Ottawa's share of the provincial production of these grains is less than two percent; Eastern Ontario's share is 13.7%.

[20] See for example "Biogas Opportunities Roadmap: Voluntary Actions to Reduce Methane Emissions and Increase Energy Independence", U.S. Department of Agriculture, U.S. Environmental Protection Agency, and U.S. Department of Energy, August 2014. Also, "Biofuels and Bioproducts from Wet and Gaseous Waste Streams: Challenges and Opportunities", Bioenergy Technologies Office, U.S. Dept. of Energy, January 2017. Also, "Technical Document on Municipal Solid Wastes Organic Processing", Environment Canada, 2013.

[21] Eastern Ontario refers to the Eastern Ontario Census Agricultural Region and includes the United Counties of Stormont, Dundas and Glengarry, the United Counties of Prescott and Russell, the United Counties of Leeds and Grenville, the counties of Lanark, Frontenac, Lennox and Addington, Renfrew, and the Ottawa Census Division. Its area exceeds 35,000 square kilometres, with some Eastern Ontario farms located more than 250 km from Ottawa.

[22] Abboud S., Scorfield, B. 2011. "Potential Production of Renewable Natural Gas in Ontario", Alberta Innovates Technology Futures. Accessed via Ontario Energy Board at http://www.rds.oeb.ca/HPECMWebDrawer/Record?q=CaseNumber:EB-2011-0242&sortBy=recRegisteredOn-&pageSize=400. Filed on 2011-09-30, Case EB-2011-0242, 2011-0283, Exhibit B Tab 1 Appendix 1.

Table 3: Crop production in 2017, in kilotonnes.[23]

Crop Type	**Ottawa**	Eastern Ontario	Ontario	Ottawa as % of Ontario	Eastern Ontario as % of Ontario
Grain corn	**198**	1,411	8,738	2.3%	16.1%
Wheat	**21**	99	2,526	0.8%	3.9%
Soy	**70**	559	3,797	1.8%	14.7%
Totals	**290**	2,070	15,060	**1.9%**	**13.7%**

A similar method was applied in order to estimate the potential supply of manure residues. Most of the available manure residues in Ontario are those from cattle (45%), hogs (33%) and chickens (21%). Table 4 shows the populations for these animals for Ontario, Eastern Ontario and Ottawa in 2017, as well as the weighted share of the provincial manure residues generated in Ottawa (0.9%) and in Eastern Ontario (8.6%).

[23] Source: OMAFRA, http://www.omafra.gov.on.ca/english/stats/crops/index.html

Table 4: Livestock populations, by region.[24]

	Ottawa	Eastern Ontario	Ontario	Ottawa as % of Ontario	Eastern Ontario as % of Ontario
Cattle (2017)	28,652	252,854	1,622,500	1.8%	15.6%
Pigs (2017)	3,369	84,880	3,498,600	0.1%	2.4%
Chickens (2016)	2,529,856	17,527,596	485,771,829	0.5%	3.6%
Weighted share of manure residue as % of Ontario total:				**0.9%**	**8.6%**

In Table 5, these percent shares are applied to the provincial totals for available crop and manure residues[25] to generate estimates of the agricultural wastes that could be available to Ottawa. An estimate is also included that corresponds to 50% of the Eastern Ontario total, corresponding to Ottawa's 50% share of the Eastern Ontario population. The final column shows the estimate from the Pathway Study on Biogas developed for Phase 1 of the City's Energy Evolution Strategy in 2017.[26]

As the table illustrates, the annual crop residue within the City of Ottawa that could be available for energy is estimated to be 121 kilotonnes, without prejudging the feasibility of transporting it to energy conversion facilities. For manure residues, only 15 kilotonnes per year is available for energy within the City of Ottawa, again without prejudging the feasibility of transporting it to energy extraction facilities. To the extent the City of Ottawa could draw on feedstock from the broader Eastern Ontario region, greater quantities could be available, although still much less (on a mass basis) than the annual generation of residential, ICI and C&D waste identified in Table 2.

[24] OMAFRA,http://www.omafra.gov.on.ca/english/stats/livestock/index.html and Statistics Canada, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042601. Ottawa hog population for 2017 estimated using Ottawa share of Eastern Ontario hog population from 2011 Census. Poultry data from Statistics Canada: Table 32-10-0429-01 Poultry production in the year prior to the census. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210042901.

[25] The provincial totals for crop residues are based on 50% of the total residue being available for energy extraction. The provincial estimates for manure residues are based on the assumption that the availability of cattle manure was 25% of the total cattle manure produced with different availability indices for hogs (85%) and poultry (85%). As in Abboud and Scorfield 2011, op cit.

[26] Leidos 2017. "Pathway Study on Biogas Energy in Ottawa", prepared for the City of Ottawa Energy Evolution Program, October 2017.

Table 5: Agricultural waste availability (kilotonnes/year).

	Abboud and Scorfield 2011		This Study			Leidos 2017
	Ontario	Enbridge service territory only	Eastern Ontario (13.7% of crop, 8.6% of manure)	50% of Eastern Ontario	**Ottawa (1.9% of crop, 0.9% of manure)**	10% of Enbridge territory
Crop waste	6,299	1,151	866	433	**121**	115
Manure residues	1,707	356	147	73	**15**	36

Forestry Wastes

With regard to forestry industry residues, an independent estimate of the feedstock supply that might be available to Ottawa has not been developed. Urban forestry waste was not considered as it is being considered for use in the federal government's district energy system. Sawmill residues in Eastern Ontario are in the range of 500,000 m^3 per year. However, there are existing markets for virtually all the sawmill residue in Eastern Ontario, and so it is not waste in the same sense as other bioenergy feedstocks being considered here.[27,28]

The question of whether and how forest-based biomass may develop as an energy source for Ottawa merits independent consideration, but it is not a question about the combustion or gasification of waste products from the forest product industry. It is a question of the future utilization of the region's forest ecosystems, the marketability of round wood that is no longer in demand for pulp and paper (and which amounts to several times the volume of the sawmill residues), and the role of woody biomass in the value chains of the emerging bioeconomy.

Landfill Waste-in-Place

The methane being emitted from Ottawa landfills is being generated by the waste that has been placed in those landfills over the past 50 years, and this waste that is already in place will dominate the methane generation from these landfills for several years into the future. Total landfilled waste in Ottawa (including public and private landfills) has been a little over 600,000 tonnes annually in recent years, and exhibits little or no growth. A year-by-year estimate of the approximately 20 million tonnes of accumulated waste landfilled in Ottawa from 1971-2012 was provided by the City of Ottawa and is included as Appendix 3.

How much waste will be landfilled in Ottawa in future years, how much of it will be organic, and what the mix of different types of organic wastes will be, are all important questions when considering the links between Ottawa's future waste management strategies and both energy recovery and waste-related greenhouse gas emissions. The Province currently intends to ban

[27] Rachel Levin, Sally Krigstin, and Suzanne Wetzel, "Biomass availability in eastern Ontario for bioenergy and wood pellet initiatives", The Forestry Chronicle, Vol. 87, No. 1, January/February 2011.
[28] The situation in Western Quebec is different, where there may be a surplus of forestry waste that could be used for energy generation. While outside the scope of this study, it could be a topic for further investigation.

organics from landfills starting in 2022. This has significant long term implications for the potential to recover methane energy at the landfills, and raises the question of how the potential for energy recovery and greenhouse gas minimization will factor into the post-2022 organics management strategy.

Evaluation of the Current Pathway

Table 7 summarizes the estimates of the quantities of the various solid waste streams in Ottawa, including both residential and ICI generated waste. On a mass basis, solid waste constitutes 85% of all the waste generated in Ottawa. The availability of energy from these different streams varies both theoretically and in terms of what existing technology can extract. Typical net calorific values are 35-40 GJ/tonne for plastic, asphalt and other petroleum-based wastes, 15-20 GJ/tonne for wood and paper products, 3-6 GJ/tonne for food scraps and grass clippings, and zero or nearly zero for glass, steel, metals, concrete, brick, stone and other non-combustible materials. The weighted average calorific content of Ottawa's waste streams is about 10 GJ/tonne, and the total caloric content about 1,200 TJ per year. This is annual energy in the waste streams being generated in Ottawa. It does not include the energy embodied in the roughly 20,000 kilotonnes of landfill waste-in-place from previous years, which in 2015 emitted about 1,300 TJ of landfill gas.

Table 7: Municipal solid waste generation in Ottawa.

	Organic (kt)	Inorganic (kt)	Totals (kt)	% of all waste
MSW				
Food	157		157	13%
Leaf and Yard	62		62	5%
Paper and cardboard	321		321	27%
Wood	59		59	5%
Inorganic		394	394	34%
MSW[29] Subtotal	**600**	**394**	**994**	**85%**
Crop Wastes	121		121	10%
Manure Residues	15		15	1%
Biosolids	45		45	4%
Total	**781**	**394**	**1,175**	**100%**
Percent of Total	66%	34%		

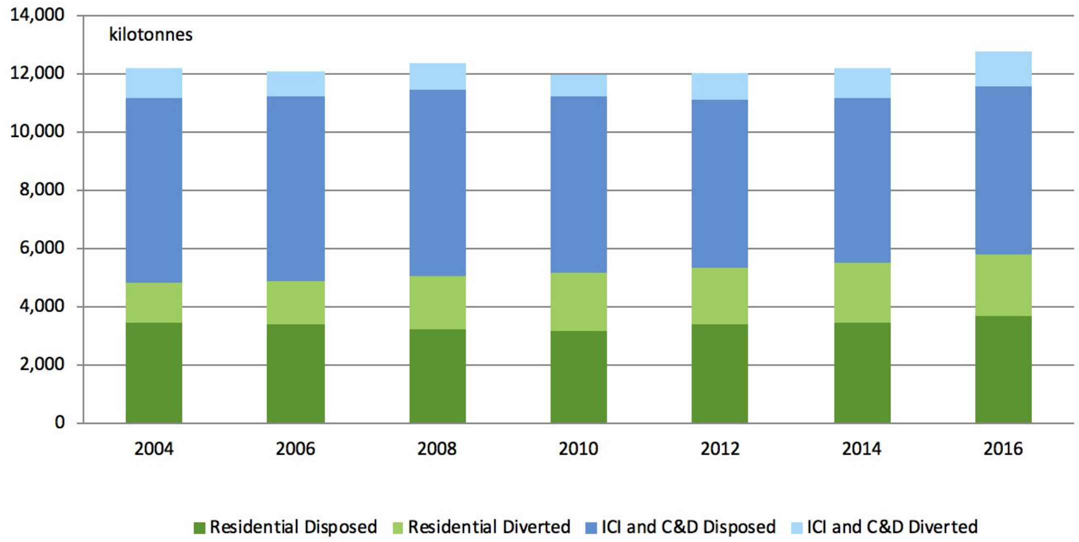
Trends in Ottawa Waste Generation

The above is a snapshot of the wastes generated in Ottawa in 2015 but estimates of energy recovery potential in the future must also consider how both the quantity and the composition of the waste may change, especially the MSW portion. There are a few databases with annual data on waste generated and diverted – the City of Ottawa Open Data on curbside collection,[30] the City of Ottawa data in the RPRA[31], and the provincial data collected by Statistics Canada.[32] They have different coverages and do not agree precisely on absolute quantities but do reveal some robust trends worth noting.

[29] As noted earlier, the definition of MSW -- Municipal Solid Waste – is consistent with usage by Statistics Canada and the Resources Productivity and Recovery Authority (RPRA) and includes all the solid waste generated in the city and not just the portion that is managed by the municipality.
[30] City of Ottawa Open Data website at: http://data.ottawa.ca/dataset/curbside-recycling-waste-tonnage.
[31] Ontario Resource Productivity and Recovery Authority data call website at https://rpra.ca/datacall/about-the-datacall/.
[32] Statistics Canada.
Table 38-10-0034-01 Materials diverted, by type:
https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810003401
Table 38-10-0033-01. Materials diverted, by source:
https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810003301
Table 38-10-0032-01 Disposal of waste, by source:
https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810003201

As shown in Figure 4, Statistics Canada indicates that the annual mass of MSW generation in Ontario has been fairly stable for the past ten years, although growing slowly in recent years. Per capita generation of residential waste is no longer growing at the rates that prevailed in previous planning cycles, and the Province is encouraging food waste reduction. For the ICI and C&D wastes covered by Statistics Canada's surveys, absolute tonnage has been slowly declining in spite of ongoing population and economic growth in the province. In 2016, the ICI and C&D waste covered by Statistics Canada was down three percent compared to 2006 levels, and seven percent compared to 2002 levels.

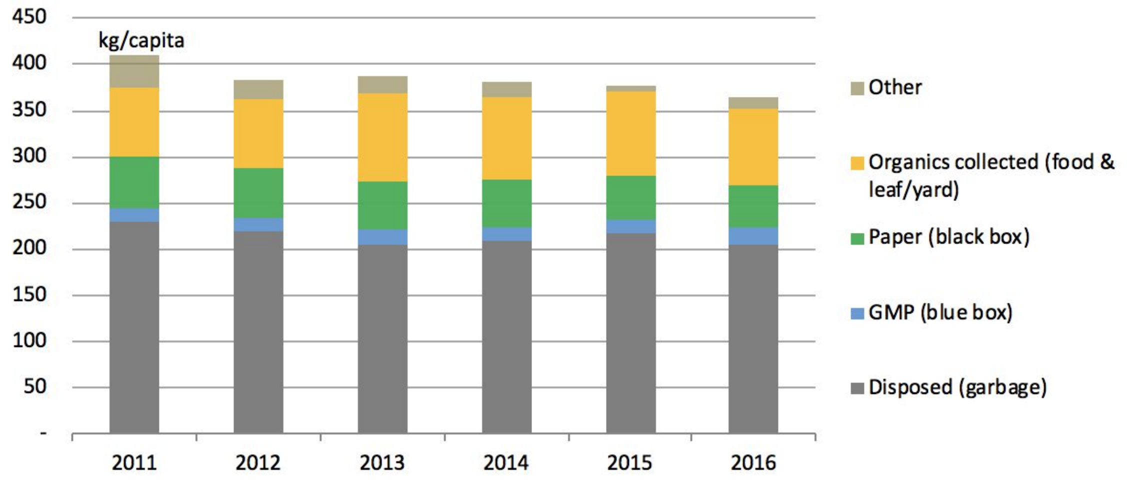
Figure 4: Ontario waste generation.



The RPRA data for Ottawa, which includes both single family and multi-residential households, indicates that per capita residential waste generation has declined 11% in the past five years and absolute levels of residential waste are down by six percent, as illustrated in Figure 5.

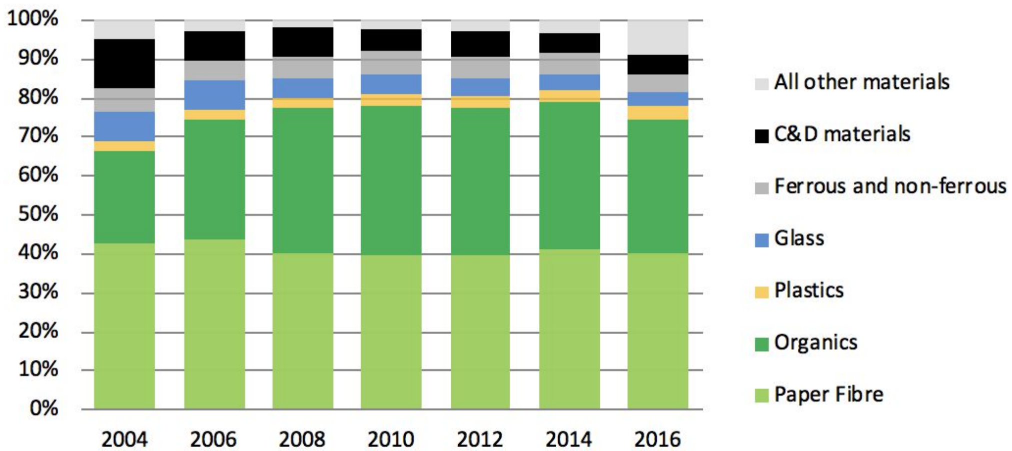
There are also changes taking place in the composition of the waste stream that have implications to both waste managers and the prospects for energy extraction. Paper waste, and especially newsprint, has dropped significantly and this may be the most important contributor to the moderation in the absolute tonnage of waste being generated. The absolute tonnage and percentage share of plastics in the waste stream has been growing steadily, although because the plastic wastes are so much bulkier than newsprint, this does not necessarily equate to a reduction in the volume of waste requiring collection and disposal.

Figure 5: Annual residential waste generation in Ottawa.



Using Statistics Canada data for the province, Figure 6 illustrates the shifting composition of diverted waste in Ontario. Diversion rates for recyclables and organics grew strongly up until 2010 but have levelled off since then. Diversion rates in the residential stream are higher than in the ICI and C&D streams, although the Statistics Canada surveys do not cover materials handled outside the waste management industry per se, and thereby omit large quantities of recycled ICI paper and cardboard. In Ottawa, the introduction of the Green Bin as part of the curbside collection program in 2010 has contributed to an increase in the overall diversion rate.

Figure 6: Breakdown of total Ontario MSW mass by waste type.



Current energy extraction from Ottawa waste

There are currently three active pathways for energy extraction from waste in Ottawa: electricity generation from landfill gas, heat and power generation from biogas generated from wastewater treatment, and biogas generation from manure residues by a few farming operations that are inside the city boundary.

Landfill gas utilization constitutes by far the largest of these three waste-based energy extractions. The landfill gas, which is about 50% methane, is generated by anaerobic digestion, but unlike engineered digesters, the waste in landfills is very heterogeneous, only some of it is methanogenic, and the digestion process proceeds slowly, over decades. As noted above, there is an estimated 20 million tonnes of accumulated landfilled waste in Ottawa landfills, and Figure 7 shows an estimate of the landfill gas being generated from that waste and how it will gradually decline. The total generation in 2016 from all the waste landfilled from 1971 was about 73 million m^3 of landfill gas of which 50% was methane, which equates to 1,300 TJ of potential energy.[33]

The decline in methane generation illustrated in Figure 7 is an approximation of what would happen if all landfilling of organic waste stopped immediately and as such, it provides some context for what can be expected when organics are banned from landfills. There is enough inertia in the system from the waste-in-place that it would take years for the methane generation to dissipate, but clearly the prospects of declining rates of landfill methane generation are an important consideration in the assessment the future potential for energy recovery at the landfills.

In 2016 the Trail Road Landfill generated 39 million m^3 of landfill gas (19 million m^3 of methane). This is about 50% of the total estimated in Figure 7, with most of the rest being generated at the Carp Road Landfill, which closed in 2011. Ottawa waste also ends up in Moose Creek, Navan and Seneca Falls, NY. At Trail Road, 70% of the gas or 27 million m^3 (about 500 TJ) was collected and burned in generators, producing 144 TJ of electricity. The Carp Road landfill has a similar sized facility and in 2016 generated 150 TJ of electricity. In summary, about 70-75% of the landfill gas generation at these two large operations is being captured and used to generate electricity with efficiency in the 30-35% range.

The Capital Regional Resource Recovery Centre on Boundary Road when fully built out will have the capacity to receive 450,000 tonnes of ICI and C&D waste annually, and is targeting a landfill diversion rate of 50% or higher (compared to current ICI and C&D rates in the range of 10-15%). In addition to a landfill, the private sector project will include recovery of paper, metals and plastics, as well as facilities for composting, contaminated soils recovery, anaerobic digestion of organic materials, and energy recovery from landfill gas and digester methane.[34]

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[33] The emissions shown in Figure 7 are calculated with the LANDGEM model, using the inputs from Table 6, a methane potential of 83 m^3/kg, and a time constant of .04 yr^{-1}. These are representative values and are not specific to any particular landfill. Also, the time constant and to an extent the methanogenic potential of the waste can be influenced by landfill operating practices. The main point being illustrated in Figure 7 is that the methane generation from historically placed waste decays over time and in 15 years will be about 50% of its current level. The actual future level of landfill gas generated will be sum of the emissions from the organic wastes (including paper and cardboard) that have been placed in the landfill in past years and the emissions of the organic wastes that are landfilled from this point forward, and this is an important issue in the context of energy extraction from waste. For example, when household organics are diverted to composting, the future potential to extract energy from those wastes is lost.

[34] See www.crrrc.ca for more details on the Capital Region Resource Recovery Centre.

Figure 7: Estimated methane emissions from waste-in-place by 2015 for Ottawa landfills.

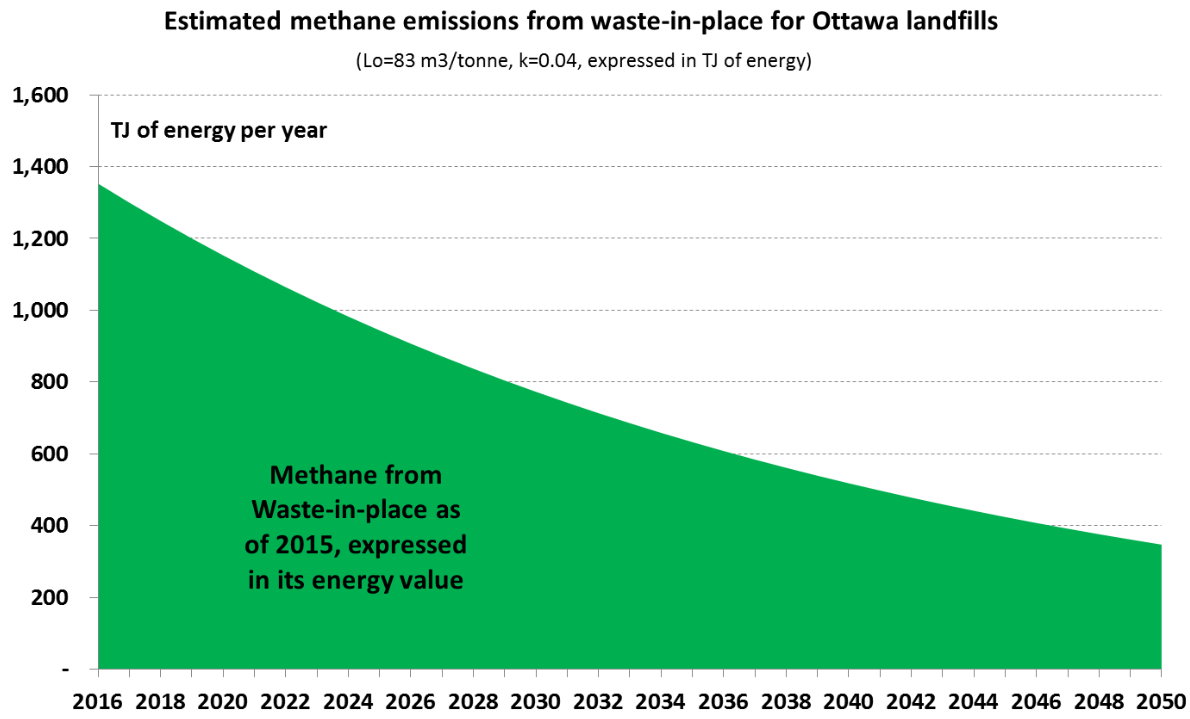


Table 8 summarizes the current energy recovery from landfills and waste streams in Ottawa. Landfill gas recovery from waste-in-place accounts for 70% of the biogas energy and 64% of the useful energy, with the ROPEC facility accounting for 22% and 28%, respectively. The utilization of heat and power at ROPEC yields an overall utilization of the biogas energy of 42%, as compared to 30% for the sites using the electrical output only.[35] Note that of the 1,410 TJ of biogas energy recovered, 430 PJ or 30% is being drawn from current waste streams (manure residues and wastewater sludge).

[35] As noted in the table, we have assumed that the heat produced in the generation of power from the farm biogas is not utilized for on-farm applications beyond the digester system itself.

Table 8: Current Energy Recovered from Waste in Ottawa.

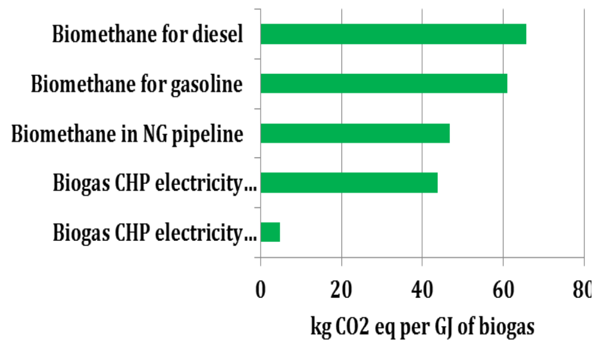
Facility	Waste Source	Methane energy recovered (est.) (TJ)	Electricity of CHP generated (TJ)
Jockvalley Farms*	Manure residues	40	12
Carleton Corner Farms*	Manure residues	40	12
Schouten Cornerview Farms*	Manure residues	40	12
ROPEC AD with CHP	Wastewater treatment sludge	310	Electricity 68 Heat 61
Trail Road Landfill	Landfill waste-in-place	500	150
Carp Road Landfill	Landfill waste-in-place	480	144
Total		**1,410**	**459**
* Only electricity output is included for the farm digesters, and methane energy has been estimated assuming a 30% conversion efficiency for biogas energy to electricity.			

Section 2: Growth Projections for the Waste Pathway

Methodology

The waste stream for the City of Ottawa was calibrated against waste production, diversion and disposal metrics for 2016. Future waste streams were generated out until 2050 based on population and employment projections according to the scenarios described in Table 9 for both residential and ICI sectors. The projections included assumptions with respect to waste generation, waste diversion and waste management for each major waste stream. Waste management strategies that reduced GHG emissions were prioritized, followed by an emphasis on energy generation. Agricultural and forestry waste streams were also included as potential feedstock for biogas/renewable natural gas.

Figure 8: GHG Offset Value of AD Biogas



A key factor in the GHG impact of organics processing options is how the biogas is utilized. If it is simply flared, then there are no additional GHG benefits beyond the combustion of the methane itself. If the biogas is used to offset fossil fuels, the net effect varies over a wide range, depending the utilization of the biogas. On average, grid electricity in Ontario has a very low GHG intensity, and so the GHG benefit of displacing electricity with biogas-generated electricity is small and expected to stay small. As illustrated in Figure 8, the GHG impact will be an order of magnitude greater if the biogas is cleaned up for injection into the pipeline network or refined for use as a diesel fuel substitute.

Note that even the Aggressive scenario in Table 9 falls short of the promulgated 100% diversion of organic waste by 2022. The organics landfill ban will require an acceleration of organics diversion in the residential sector, and this is especially true for the ICI organics; even the new Capital Region Resource Recovery Centre is designed on the assumption that there will be significant landfill of ICI organic wastes over the next 30 years.

Table 9: Actions and assumptions for each scenario.

Action	Conservative scenario	Moderate scenario	Aggressive scenario
Waste generation rates	Per capita waste generation rates are held constant across all scenarios.		
Residential diversion rates	Aligned with 2042 projections from the City of Ottawa (Appendix 2)	Aligned with 2042 projections from the City of Ottawa (Appendix 2) MURB green bin 90% by 2042	Paper: 100% by 2042 All other waste streams aligned with 2042 projections from the City of Ottawa (Appendix 2).
Non-residential diversion rates	By 2050: Paper: 75% Organics: 30% Plastic/metal/glass: 15%	By 2050: Paper: 95% Organics: 60% Plastic/metal/glass: 25%	By 2050: Paper: 100% Organics: 90% Plastic/metal/glass: 50%
Diversion routes	Maintain Business as Planned routing	Route half of organic waste to anaerobic digester and half to compost. All yard and leaf waste goes to compost. AD gas and LFG are used for electricity production.	Route all of organic waste to anaerobic digester. All yard and leaf waste goes to compost. AD gas and LFG are used as RNG and displace natural gas use.

Constraints

Placement within a city / neighbourhood feedback - Citizens generally do not like waste recovery plants in their neighbourhoods due to perceptions of pollution and potential reductions of property value. Thorough consultation is important, however placement of a plant may be limited due to lack of city owned land in industrial areas or due to the logistics of getting waste to a plant or delivering energy back to the community.

Reliability and cost of alternative technologies – While anaerobic digestion of organic waste is widely practiced in Europe, its application to municipal organic waste in North America is relatively recent. There is even less experience with gasification technologies, which can extract greater energy from the waste than anaerobic digestion but are more expensive than anaerobic digestion.

Existing contractual obligations and jurisdictional barriers present constraints to the practical availability of some waste-related energy options in Ottawa. Long term “put or pay” contracts for organic waste constrain consideration of alternatives in the short term. In addition, more than half the waste generated in Ottawa is in the ICI sector, outside the management responsibility of the City.

Cost of natural gas - The relatively low cost of natural gas is a disincentive to invest in renewable natural gas, which results in sunk investments in landfill gas utilization technologies that have low system efficiencies and low net GHG reductions due to the low GHG intensity of the Ontario grid.

Waste composition and generation rates -With the exception of wastewater treatment sludge, which will grow with population, it is not clear that waste generation is growing significantly in Ottawa, and it could decline. In assessing investment strategies for energy recovery from waste, it will be important to examine different scenarios for the future quantity and composition of the waste being generated.

Pathway Uptake Projections

Table 10 summarizes the results of the GHG impacts of the different pathways described in Table 9. The Aggressive scenario, with its high rate of organics diversion and biogas recovery and utilization as renewable natural gas, achieves nearly ten times more GHG reductions than the Conservative scenario. To put the emission reduction potential in context, the 459 kt of CO_2eq reduction in the Aggressive scenario is 11% of the reductions needed for Ottawa to achieve its target of an 80% reduction of GHG emissions as compared to the 2012 inventory. If Ottawa meets its 2050 target, GHG emissions from all sources in 2050 will be about 1,100 kt CO_2eq, illustrating the extent to which realizing the emission reduction potential from the waste sector is a large if not essential component of any effective strategy for achieving a low carbon future for the city.

Table 10: GHG emissions results of the waste scenarios.

Scenario	Measures Achieved	Cumulative emissions reductions 2018-2050 (kt CO2eq)	Emissions reductions 2050 (kt CO2eq)
Conservative	Achieve residential Ottawa waste diversion targets by 2042. Non-residential diversion targets by 2050: - paper: 75% - organics: 30% - plastic/metal/glass: 15% Maintain BAP routing of diverted waste.	1,132	99
Moderate	Achieve residential Ottawa waste diversion targets by 2042. Non-residential diversion targets by 2050: - paper: 95% - organics: 60% - plastic/metal/glass: 25% Route half of organic waste to anaerobic digester and half to compost. All yard and leaf waste goes to compost AD gas and LFG are used for electricity production.	5,155	339
Aggressive	Achieve residential Ottawa waste diversion targets by 2042, increase paper diversion to 100% Non-residential 2050 diversion targets: - paper: 100% - organics: 90% - plastic/metal/glass: 50% Route all of organic waste to AD. All yard and leaf waste goes to compost. AD gas and LFG are used as RNG and displace natural gas use.	10,202	459

Ways to Advance this Pathway

Energy Recovery and GHG Emissions from Ottawa Waste Streams

Greenhouse gas emissions from waste management in Ottawa consist almost entirely of the fugitive emissions from landfills that are not captured by the landfill gas and utilization systems. As noted above, it is estimated that the gas collected at the landfills comprises 75% of the total gas generated in the landfill with the balance emitted to the atmosphere. To maintain or improve on this will require additional gas capture capacity, especially if the rate of biogas generation continues to grow.

Alternatively, addition organic waste, and particularly ICI generated organics, could be diverted from the landfills, with the greenhouse gas implications depending on the type of organics and the method of disposition. Also, the carbon in some organics remains sequestered in landfills, particularly for newsprint and woody biomass, and the loss of this sequestration is an offsetting factor that should be considered when assessing the net GHG benefits of diversion options.

Waste reduction and recycling are the most effective diversion strategies for reducing greenhouse gas emissions because of the large energy savings and emissions reductions they cause in the resource extraction and manufacturing industries, albeit usually in locations remote from the community in which the waste recycling or reduction takes place.[36] For paper products, recycling not only eliminates the landfill emissions but also results in reduced emissions in the paper and forestry industries.

For food and yard wastes, diversion to composting eliminates the landfill emissions, but does not provide energy recovery. To capture both the direct emission reductions of landfill diversion and the added GHG benefits of producing carbon free energy, engineered anaerobic digestion (and eventually, gasification technology) is the preferred option. The engineered digester allows for faster and more complete digestion than occurs in the landfill, so the quantity and rate of methane generation is greater than for the same material in a landfill. Digesters can be designed and operated for single source or commingled organic waste streams.

Diversion to incineration provides energy recovery but results in a net increase in greenhouse gas emissions as compared to landfilling. Incineration of plastics and other petroleum-based waste materials results in GHG emissions that are comparable to fossil fuel combustion.

Landfill gas

The future levels of landfill gas emissions will depend on the amount and the composition of organic waste (primarily yard waste, food waste and paper products) landfilled in future years, and the efficiency with which those emissions are captured. In Figure 7, we illustrated the impact on methane generation of an immediate ban on organics landfilling, and Figure 9 illustrates a hypothetical case with a 50% reduction in the methanogenic potential of the waste being landfilled, starting in 2016. This could come about as the result of organic waste diversion, source reduction and recycling, or a reduction share of organics consisting of highly methanogenic materials (e.g. coated papers, food waste, grass clippings) as compared with low methanogenic wastes (e.g. woody biomass, organic textiles, newsprint).

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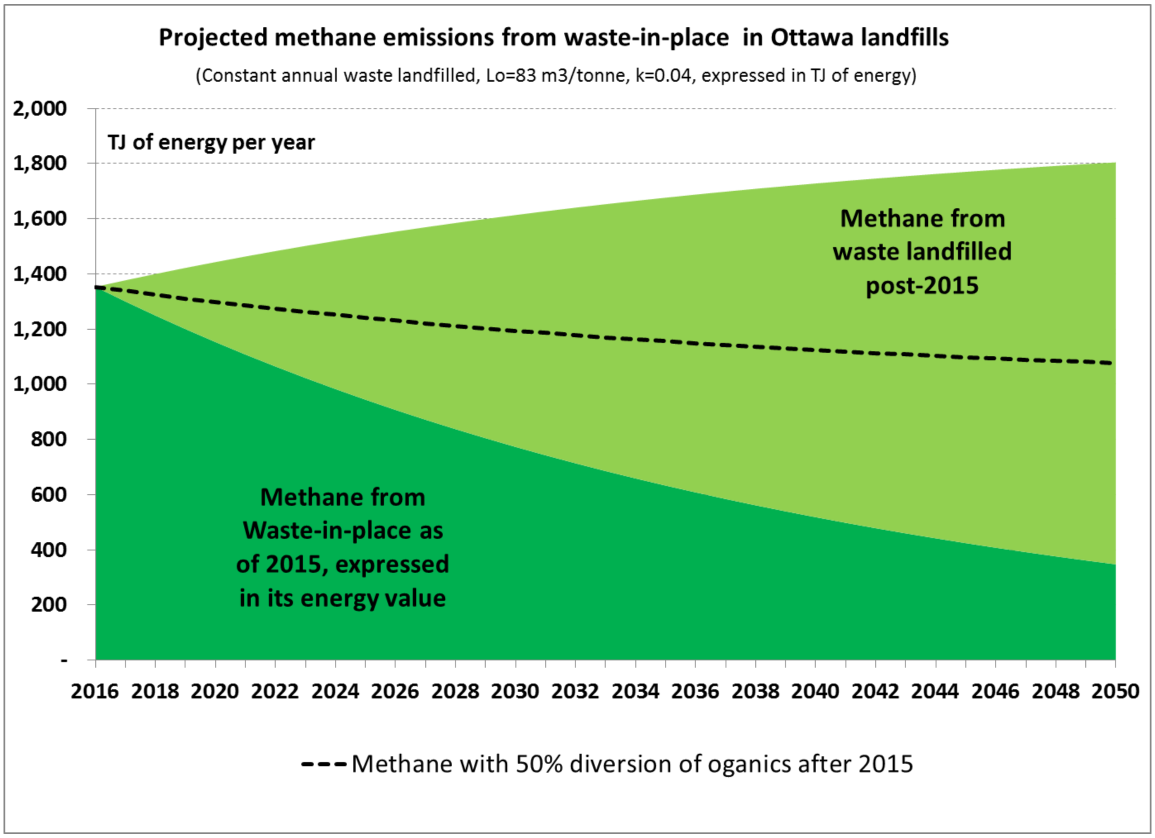
[36] Torrie R. et. al., (2015). "Greenhouse Gas Emissions and the Ontario Waste Management Industry", report for Ontario Waste Management Association. Access at: https://www.researchgate.net/publication/300485656_Greenhouse_Gas_Emissions_and_the_Ontario_Waste_Management_Industry.

Figure 9 illustrates how the constant addition of fresh organic material combined with the slow rate of decay, results in continued growth of landfill gas emissions throughout the period to 2050, even with no growth in the annual quantity or composition of landfilled organic waste. (It takes fifteen years before the emissions from freshly buried organic waste drop to half their initial level.)

The figure is a simplified illustration of a complex system, but it illustrates how a reduction in the amount or the composition of the organic waste being landfilled will change both the total emissions potential and the rate of emissions,[37] and it underscores the importance of a long term and integrated approach to organics management investment strategies, including detailed analysis of future level of landfill gas generation.

Figure 9: Projected methane emissions from waste-in-place in Ottawa landfills.



[37] De la Cruz, F. B. and M. A. Barlaz, 2010, "Estimation of Waste Component Specific Landfill Decay Rates Using Laboratory-Scale Decomposition Data," Env. Sci. Technol., 44, 4722 – 28. See also Morton Barlaz, "Effects of Organics Diversion on Landfill
Gas Generation and Comparison of Landfills and WTE. Access at: http://www.seas.columbia.edu/earth/wtert/meet2010/Proceedings/presentations/BARLAZ.pdf

Conclusions

In conclusion, there are significant opportunities to advance both energy and climate change objectives by integrating their consideration in strategic investment and policy choices in the waste management sector. Realizing these opportunities requires incorporating energy recovery and GHG minimization in capital investments and long term planning, as well as coordination and collaboration across public/private, urban/rural, and other subsector and jurisdictional boundaries that might otherwise impede the identification and implementation of the best strategies.

The central issue in considering the future of the energy and GHG reduction potential of Ottawa waste management policies and business strategies will be the approach that is taken to the organic portions of the waste stream. These are the wastes that are the source of current greenhouse gas emissions from the waste sector, and these are the wastes that can be managed in ways that both eliminate those emissions and generate carbon-free and renewable biogas that can offset fossil fuel emissions. As the various stakeholders involved in the management of organic waste streams in Ottawa prepare for the next generation of climate policies and technological progress, it will be especially important to explore opportunities for collaboration and investment strategies that maximize flexibility and adaptability to a rapidly changing environment.

Appendix 1: Consideration of snow melt

An analysis of melting snow in contrast to hauling snow was completed to see if there is a benefit from greenhouse gas emissions. Based on the assumptions applied, melting snow was assessed to have a greater GHG footprint than hauling the snow.

Table 11: GHG impact of hauling versus melting snow.

HAULING		
Fuel efficiency of truck	40	L/100 km
Idling fuel consumption	4	L/hour
Round trip distance	50	km
Idling time per round trip	20	minutes
Truck capacity	14	yards
converted to cubic metres	10.7	cubic metres
Assumed snow density	300	kg/cubic metre
therefore mass per trip	3.2	tonnes
Energy content of diesel	38.7	MJ/L
Truck energy consumption in motion	20.0	Litres
Truck diesel consumption, idling	1.3	Litres
Total diesel consumption per trip	21.3	Litres
in MJ	825.6	MJ/trip
GHG emission factor for diesel	73	grams per MJ
GHG emissions per trip	60.3	kg
GHG emissions per tonne of snow hauled	**18.8**	**kg CO2e/tonne of hauled snow**
THEORETICAL ENERGY AND EMISSIONS PER TONNE TO MELT SNOW		
Latent heat	334	kJ/kg
Heat to raise temperature	4.181	kJ/kg/degC
Temperature of meltwater	5	degrees Celsius
Theortical energy to convert snow to meltwater	354.9	kJ/kg
GHG emissions per tonne of melted snow	**25.9**	**kg CO2e/tonne of melted snow**

In addition to a high heat approach, associated with a mobile melting machine, an analysis of a "warm surfaces" approach was also completed. In energy terms, this approach was found to require energy inputs an order of magnitude higher than hauling.

Appendix 2: Projections of residential diversion rates

Municipal Capture Rates (%)	2010	2042
Residential Curbside Program [38]		
Paper & fibre	80	95
Metals	60	95
Glass	57	95
Recyclable Plastics	57	95
Green Bin Organics	28	90
Leaf & Yard Waste	99	99
Residential High-density Program [39]		
Paper & fibre	50	90
Metals	25	95
Glass	63	95
Recyclable Plastics	39	90

[38] Based on data in *City of Ottawa Residential Curbside Waste Characterization Study Green Bin Program Rollout 2010 Final Report*, Viridis Environmental Incorporated.
[39] 2010 capture rate for high density residential based on summary of data from audits completed in 2005 and 2006 per *City of Ottawa Solid Waste Services Division Multi-Unit Waste Characterization Study Quarterly Reports*, Integrated Environmental Waste Services.

Appendix 3: Landfilled Waste in Ottawa, 1971-2016.[40]

Year	kilotonnes	Year	kilotonnes	Year	kilotonnes	Year	kilotonnes
1971	139	1983	278	1995	491	2007	676
1972	149	1984	293	1996	505	2008	666
1973	160	1985	310	1997	521	2009	670
1974	172	1986	327	1998	539	2010	638
1975	183	1987	343	1999	560	2011	630
1976	195	1988	361	2000	586	2012	637
1977	206	1989	384	2001	613	2013*	630
1978	217	1990	403	2002	636	2014*	630
1979	227	1991	422	2003	659	2015*	630
1980	238	1992	440	2004	670	2016*	630
1981	250	1993	458	2005	681		
1982	263	1994	475	2006	668	* estimate	

[40] City of Ottawa landgem file <<landgem-v302_CityofOttawa_20140206.xlsm>> to 2012, 2013-2016 estimated by consultant.